CAN A MODIFIED, LOW-RISK FORM OF BOXING ACHIEVE SIGNIFICANT COMMUNITY UPTAKE?

A thesis by published works submitted for the degree of Doctor of Philosophy

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Abstract

Boxing has long been surrounded by debate. It has been subject to criticism on medical, legal, ethical and sociological grounds. Conversely, supporters argue that it is an excellent sport for physical fitness development, embodies egalitarianism, builds character, offers hope to depressed population sectors, has inherent aesthetic qualities and provides a cathartic outlet for emotions that otherwise could lead to anti-social activities. Recent years have seen small-scale emergence of modified versions of boxing aimed at retaining positive aspects of the sport but eliminating negative aspects. The research reported in this thesis was directed at determining whether such a version could attract substantial community uptake.

A scoping review of current literature was undertaken to objectively evaluate arguments for and against conventional boxing and to assess the need for a modified form of the sport. A modified boxing program based on an existing model was established at a community club in Canberra, Australia, with the author of this thesis as its coach. It rapidly grew to include more than 100 regular participants. Design methodology underpinned by an epistemological constructivist approach to investigation was employed to progressively adjust program characteristics over an almost 5-year period, based on continual participant feedback. After ~2 years, several participants who had been present almost from the outset underwent in-depth, semi-structured interviews. Interpretative phenomenological analysis of interview transcripts revealed that their sustained involvement in the program was motivated primarily by a sense of belonging to a special community and by perceptions that coach-athlete relationships were strong, the training was purposeful, and there was a focus on safety. A follow-up study showed that the most valued coaching practices were an holistic approach to participant development, treatment of the participants as serious athletes, use of constrained games to promote skill acquisition, and an emphasis on athlete improvement rather than competition. These findings were instrumental in shaping ongoing program refinement.
At the start of the program, previously developed automated scoring technology was employed. This technology was then progressively adapted through repeated cycles of evaluation, reflection, planning and action. It proved effective in attracting public attention to the modified boxing concept but there were issues associated with its cost and the logistics of its regular use. In addition, several technical problems affecting system accuracy and predisposing to occasional system failure were identified. The technology was found to influence the style of boxing favoured by contestants and to reward all-out attack over skilled performance. Solutions to all these problems were conceived and partially implemented, but

it was eventually decided that in the program setting that provided the basis for the research, use of the technology to judge contests between individuals was inconsistent with the shift of the program emphasis away from traditional notions of competition.

Throughout the duration of the program, specialised boxing gloves capable of markedly reducing peak impact forces were iteratively developed and refined to enhance participant safety and enjoyment. In laboratory trials, pneumatic gloves with capacity for air release and reuptake afforded protective effects superior to those provided by conventional boxing gloves or by pneumatic gloves with sealed bladders. This remained true when target conditions in the laboratory were altered so that measured peak impact forces more closely resembled those reported to occur during boxing matches. Further research showed that the pneumatic gloves with capacity for air exchange were robust when subjected to a long series of consecutive impacts, with drift in various impact parameters less than that observed for conventional gloves. The development of the pneumatic gloves and their use in constrained games that formed part of the modified boxing program was highly regarded by the program participants.

When the Canberra modified boxing program eventually closed, the participants completed a written survey in which they recorded their impressions of it. Thematic content analysis of the feedback from 38 participants who had been involved in the program for three or more years revealed four major themes relating to the program environment, the underlying concept, the timetable and the training itself. The environment was seen as friendly, welcoming and supportive. The concept was perceived as entailing the development of a community, not just a sport program. The timetable was considered flexible and accommodating and the training itself was regarded as safe, fun and beneficial in multiple respects. These findings complemented and extended those obtained through interviewing a much smaller number of program participants earlier in the research process.

The Canberra modified boxing program underwent considerable dynamic change over its duration and this apparently allowed it to become highly effective in meeting the needs of its participants. The research surrounding the program demonstrated that a modified, low-risk form of boxing can achieve substantial uptake if tailored to the interests of a target population. Although there can be no guarantee that the Canberra program in its final form would be equally popular in other settings, it is likely that at least some of the knowledge acquired through the research that produced it is transferable. There may be a future for a form of modified boxing focused on safety, fitness improvement, learning of skills through constrained games, building of a sense of community among participants, and cooperation between participants instead of competition. Judicious use of advancing technologies could enhance the potential.

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I would like to thank the Canberra Police Community Youth Club for allowing me to undertake the majority of this work while in their employment and wish to thank all the wonderful participants from the program for their passion and commitment over its duration, and for the support and friendship they gave me during my time as coach/researcher of the program.

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Last but by no means least, I am extremely thankful for the support of my beautiful wife Sharan, whose love sustained me at my most vulnerable times and encouraged me when I needed it most. Sharan, this dissertation is for you as much as it is for me.

Dedication

This thesis is dedicated to my beautiful grandchildren, Myesha, Kiana, Charlise and Cecil.

"Always remember, you have within you the strength, the patience, and the passion to reach for the stars to change the world" – Harriet Tubman.

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PhD candidate's modified boxing an international success. University of Canberra Monitor Magazine https://www.canberra.edu.au/about-uc/media/monitor/2017/march/phd-candidates-modified-boxing-an-international-successh

Coach education and accreditation resources developed as a part of this project

The ModBox Information Guide: A reference tool to assist with the planning, implementation and delivery of community-focussed modified, boxing programs.
https://issuu.com/modbox8/docs/the_modbox_information_guide_

The ModBox Community Coach Presenters Kit: A guide for the effective and efficient delivery of the ModBox training course.
https://issuu.com/modbox8/docs/the_modbox

Presentation of project

2016: Boxing Australia Board Meeting. Canberra, Australia.

2017: Media conference for the launch of ModBox as part of the Australian Government's Asian Sports Partnership Program. Dehradun, India.

2017: Oceania Boxing Championships. Gold Coast, Australia. (Presentation of project to Executives of the International Boxing Association, AIBA).

2017: The International Development Women in News and Sport Conference. New Delhi, India.

2017: University of Canberra Research Institute for Sport and Exercise Research Seminar Series. Canberra, Australia.

2018: The University of Canberra Aboriginal and Torres Strait Islander Leadership and Strategy Workshop. Canberra, Australia.

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Chapter 1. Introduction

"The insider's account will provide, sometimes inadvertently, the minutiae and emotional resonance of what is being examined; the outsider's account is likely to provide a more detached view but may be distorted as a result of bias, such as class or gender bias, or a lack of detailed knowledge" - Maguire & Young [1].

1.1. Background to and motivation for the project

In January 2013, the University of Canberra admitted me to its Masters by Research program. I was enrolled part-time, with a scheduled completion date of 31 December 2018, and obtained approval to pursue a research project titled: 'Can a modified, low-risk form of boxing achieve significant community uptake?'.

The project was aimed at identifying barriers and facilitators that could affect acceptance of a new, modified and much less dangerous form of boxing, then using that information as a foundation for the design and implementation of a series of interventions. By the end of 2014 the project had evolved to such an extent that it had become more consistent with the requirements of PhD as opposed to Masters research. Its focus on the progressive design and implementation of a new modified sport was necessitating an holistic approach that demanded development of knowledge across multiple academic disciplines.

The design challenges extended to conceptualisation and development of new, specialised protective equipment for use in the modified sport and the creation of purpose-specific training programs. Attention at the time was also being given to optimising methods for program delivery in community sport settings where individual coaches could be required to deal simultaneously with very large numbers of athletes. Novel competition protocols supported by customised software were being explored, as was the feasibility of using a boxing-related activity as a vehicle for effective social outreach, with a particular focus on assisting with the education and personal development of its adherents.

After extensive discussions with my supervisory panel, I decided to 'take the plunge' and apply for an upgrade to Doctoral candidacy – a process that required me to prepare a revised research proposal and present an upgrade seminar, with both these works evaluated by two expert assessors. The application was successful and in May 2015 the project was formally upgraded to PhD level, with a mandated completion date of 31 December 2020.

My background was well suited to the project. I have been involved with boxing for almost my entire life – an involvement that began in 1978 when my Father, who was an ex-boxer and keen for me to learn the 'noble art', introduced to me to the sport. I was then 10 years old and growing up in Wiradjuri country (the traditional name for a vast area of land that covers approximately 127,000 km^2 of central New South Wales) [2]. It was an area where in those days displays of toughness and technical superiority inside a boxing ring were not only highly regarded but would often help to elevate a person's status within their local community. For example, the region's most successful boxer, who in addition to winning multiple national championships was also an Olympian and a Commonwealth Games medallist, was often described as a *"role model for our kids"* and *"an example of what can be achieved through hard work and dedication"*, with these descriptions coming not just from people associated with boxing but from leading members of the broader community. In fact, I still remember when I first met him. I had only been training for about 2 weeks and was still quite nervous whenever I entered the gym. On this day one of the coaches, perhaps sensing my anxiety, called me over as I was putting my bag down and said something like: *"Pauly boy, I'd like you to meet Brian. He started out just like you and look what he has gone on to achieve"*. After I had shaken Brian's hand and introduced myself, the coach went on to say something like: *"If you turn out to be half as good as him, you'll not only be very hard to beat, but you'll be a great man too"*. Over the following years I observed that the coaches, probably due to their admiration for Brian's sporting achievements, performed similar introductions and used similar words whenever welcoming a *'newcomer'* to the gym. It was against this backdrop that I initially engaged with the sport and spent most of my youth either at the gym developing and enhancing my technical skills and physical qualities or traveling to local tournaments to put my skills to the test.

Back then, most boxing participants were from low-socio economic background and, like today, there was wide belief that the sport could be used to assist with the positive growth and development of young people. I know this was one of the main reasons why my Father was such an advocate for boxing and was keen for me to be involved. He believed whole-heartedly that such desirable personal traits as determination, confidence, self-discipline and respect for others could all be developed through taking part in the sport, and he was quite eager to get me to the gym and into training.

The gym was run by a small team of dedicated volunteers (all ex-boxers) and operated out of a sparse upstairs room at the local Police and Citizens Boys Club. Training was held from 17:00-18:30 daily and consisted mostly of sport-specific drills such as skipping, shadow boxing, punch bag exercises and sparring. These were performed for set periods separated by short intervals of rest. Body-weighted exercises such as push-ups, dips, mountain climbers, burpee jumps and a variety of abdominal exercises were used at the end of most sessions, with Coach 'Bomber' considering them necessary *"just to make sure we're fitter and faster than the other blokes"*. Although the sessions were very challenging, I was able to complete almost all of them - a feat that quickly earnt the respect of the older, more established boxers and the coaches. This led to my Father being told that I was *"good enough and fit enough"* to start competing and after ~ 4 months of training I began traveling to the other towns throughout the region as a member of the Dubbo Police and Citizens Boys Club Boxing Team (Figure 1).

Dubbo boxers win bouts at Bourke

Three young boxers from the Dubbo Police and Citizens Boys Club won bouts at a recent Bourke tournament.

Paul Perkins had his bout stopped in the first round while Steve McDonald won on points.

However the most impressive performance on the night was put up by 14-year-old Gary Macfarlane.

Macfarlane had a tough bout on his hands but was able to beat Gilgandra's Anthony Towney on points. It was Macfarlane's performance in this bout that earned him a trophy for the "best boxer on the night."

Macfarlane last year reached the finals of the State PBC 57-60 kilograms division but suffered a back injury while playing rugby league and was out of action for 10 months.

Since coming back this year he has had three fights beating Dave Smith at Gilgandra on points before going down to Wayne Langlow in a very close points decision at the big Narromine tournament several weeks ago.

Four Dubbo boxers fought at Brewarrina last weekend.

Steven McDonald won his 66 kilogram bout after the referee intervened during the first round but Paul Perkins was beaten on points.

Lindsay Guihot and Darren Kelly both fought exhibition bouts.

The boxing scene will shift to the 1983 State PBC titles in Sydney this weekend.

Garry Macfarlane will fight in the 63 kilogram division, Lindsay Guihot (60kg), Paul Perkins (51kg), Darren Kelly (44.5kg) and John Gaydon (32kg) will be accompanied by "Bomber" Kearney to the titles which will be held at the St George Sailing Club.

—Barry Hildebrandt

Figure 1: Newspaper clipping from 1983 and a photo of the author (without shirt) taken at that time and just prior to the NSW State Titles. Also present are my Father, older Brother (and sometime sparring partner), my Mother and two sisters.

Tournaments in those days were usually held in small halls or on outdoor sporting courts and were a far cry from the glitz and glamour of the multimillion-dollar events staged at Caesar's Palace or Madison Square Garden during the same period. Nevertheless, they were important events that brought communities together, raised much needed funds for the host clubs and provided opportunities for young boxers like me to experience the thrill and excitement of competition.

Initially, I was one of the youngest boxers, so generally boxed in the earlier bouts and usually against someone who was similar in weight and had the same level of experience. This of course changed as I grew older and by the time I was fifteen years old I was mostly boxing at the end of shows. Because of my small size, I was often matched against opponents who were somewhat bigger and stronger than me, but the size disparity was never an issue and in many cases it actually resulted in very good bouts with high levels of skill being displayed. Normally, my opponents would try to use their size and strength to overpower me, while I would try to outmanoeuvre and outbox them by using my footwork and defensive skills to disrupt their attacks and launch my own counter-attacks. Such displays tended to appeal to the boxing purists, who in those days were almost exclusively men, and they would show their appreciation by tossing coins into the ring at the end of a bout. Although amounting to only a few dollars, the coins were always divvied up between competitors and usually spent on soft drinks and sausage sandwiches that were generally enjoyed together.

Performing in the ring, however, was only a small part of what made the trips so special and over the years I had many experiences that not only gave me a sense of significance but also a great deal of satisfaction. For example, along with two of the other younger boxers I was responsible for setting up the official weigh-in area – a task that involved unfolding a small square table and putting out enough chairs so that all the officials had one and *"could look important"*. Perhaps most importantly, we had to make sure that there were always a couple of pots of fresh tea on hand. Once those tasks were completed, we were expected to help with some of the other *"vital jobs"* and would often assist with putting up the ring, preparing the backstage and gloving areas, and on special occasions taste test some of the food that was to be sold by the host club throughout the night. As I got older, I was given greater responsibility and in addition to the above, I was required to *"help out with the younger blokes"* by *"showing them the ropes".* This usually involved sport-specific tasks such as introducing and familiarising the younger boxers to the pre-bout routines of weighing-in and seeing the doctor (a medical examination), and sometimes extended to assisting with warm-up activities, walking the boxers to the ring and assisting in the corner during bouts. Other more general tasks such as making sure the younger boxers had something to eat and remained hydrated throughout the day were also performed. But perhaps the most important job of all was trying to ensure that the younger athletes enjoyed themselves and had a positive and rewarding experience.

My own experience during those early days had a substantial impact on my life. Although I was never able to emulate the feats of some of the other boxers from my home town, I developed a deep love of boxing and after retiring as an athlete I became a boxing coach. My coaching philosophy and style, and my ideas about sport in general, have been greatly influenced by my initial embedment in a regional boxing community.

My concept of sport and approach to coaching were further enhanced during 15 years in the Australian Army, which I joined shortly after retiring from boxing, and through a subsequent 5 years of service to the United Nations after my discharge from the Army. Working for these organisations required me to operate in some very challenging locations across Africa, South-East Asia, the Middle East and the South Pacific, and in these locations I saw at first-hand how sport could be used as a powerful mechanism to assist with the achievement of broader social outcomes (Figure 2).

Figure 2: My time with the Australian Army and United Nations greatly influenced my ideas about sport and helped shape my approach to coaching.

My time in the Army and United Nations also assisted with the building of skills that greatly enhanced my coaching. For example, when I first transitioned into coaching, I was simply mirroring what I had experienced during my time as an athlete. However, because my roles with the Army and the United Nations required me to manage complex situations, plan thoroughly, provide leadership and communicate effectively, I developed a wide range of new competencies that I was able to progressively adapt and apply to my work as a boxing coach.

As a coach, I have had the opportunity and privilege to work at all levels of the sport (Figure 3) and have received the highest level of coaching accreditation offered by the International Boxing Association (AIBA), the organisation which oversees world amateur boxing.

Figure 3: Images A and B show me working at the community level. Coaching at this level required performance of a wide range of roles, including technical advisor, strength and conditioning coach, nutritionist, fundraiser, policy-maker, cleaner, bus driver and mentor. Working at the pre-elite level (Image C) entailed helping athletes develop the skill sets required to successfully transition to the elite pathway. A real highlight for me while working at the elite level was coaching the Australian Team in Cuba (image D) as part of the team’s preparation for the 2010 New Delhi Commonwealth Games, and meeting 3-time Olympic Gold Medallist and 6-time Amateur World Champion, Felix Savon (image E).

My elder son, Dylan, took up boxing under my tutelage. He went on to win several Australian amateur championships, and in the process became one of the youngest ever boxers to attain an open national title. He also won medals at prominent international tournaments, and was well-known for his technical proficiency. My younger son, Daniel, often trained with Dylan and me, and while he never engaged in formal competition (preferring to concentrate on other sports), he too developed excellent boxing skills (Figure 4). Along with two other Australian Amateur Boxing Champions, my sons eventually became great advocates for the concept of modified boxing.

Figure 4: Image A: My elder son with his Cuban counterpart shortly after their bout in one of the oldest gyms in Havana. Although my younger son didn’t compete in boxing due to medical advice following an injury to his nose (sustained in other circumstances), both of my sons developed exceptional boxing skills and a real passion for training (Image B).

In 2009, after many years of coaching at club and state level, I was appointed to a position of boxing coach at the Australian Institute of Sport (AIS) where I was afforded the opportunity to assist with the development of some of Australia’s most talented boxers under the supervision and guidance of one of the world’s best boxing coaches, Mr Bodo Andreass. It was while working at the AIS that I first became aware of a new, modified and much safer form of boxing called Box’Tag – a low-risk variant of the sport that precludes impacts to the head and uses automated scoring technology as a way of enhancing participant enjoyment. The concept immediately resonated with me, since this was something that Coach Bodo had often spoken about during our time together in boxing powerhouse countries like Cuba, Germany and Russia, where high-performance success is underpinned by large participation rates and wide acceptance of the sport. Coach Bodo believed that a modified version of boxing could be used to develop the critical mass of participation required for sustained high-performance results, and that such a form could be used to great effect as an entry-point program for the sport, similar to the way in which AusKick is used by the Australian Football League (AFL) to increase participation rates and to provide more social engagement opportunities for families and friends.

Toward the end of 2010, the AIS Boxing program was closed and I subsequently took on a new role as Head of Boxing for the Canberra Police Community Youth Club (PCYC) – a not-for-profit, community-based organisation that uses sport and other recreational activities as part of crime reduction and diversion strategies. This organisation was very similar to the one in which my own boxing journey began.

A key requirement of the new role was to substantially increase participation in PCYC Boxing. I therefore introduced a range of new initiatives aimed at addressing and meeting this challenge. These included restructuring of the existing program so that it ran 5 nights per week and was available to everyone from beginner to elite, the introduction of a junior development program, the addition of boxing-for-fitness (non-contact) training sessions, establishment of a clear athlete pathway to high-performance, and the provision of greater opportunities for competition and travel. The new measures proved to be only partly successful and resulted in only a small increase in the participation rate. Undeterred, I then tried to attract new members by targeting some of the nearby high schools. This entailed providing a short overview of the program to students and staff during morning assemblies. Again, there was little effect, with the school presentations yielding only a few initial inquires and almost no new memberships. By this stage, I had concluded that conventional boxing would probably only ever be a niche sport in Australia and that any attempt to broaden participation in it would be likely to fail. Subsequent discussions with members involved in other programs at the Canberra PCYC supported that conclusion and revealed that they considered boxing to be a dangerous sport and one in which they thought that neither they nor their children should take part. A chance meeting with Coach Bodo, however, was about to change my perspective and set me on a course that would eventually lead to the writing of this thesis.

During the meeting, Coach Bodo revealed that Professor Allan Hahn (who had been Head of Performance Research and the Chief Scientist at the AIS and would later become my primary supervisor) had recently left the AIS and was looking for a suitable venue to continue his work on the automated scoring technology employed in Box'Tag. When I mentioned the difficulties I was experiencing, Coach Bodo suggested talking with Allan about the possibility of introducing a Box'Tag program at the Canberra PCYC. The idea soon gained momentum and after a series of meetings between interested parties, the Canberra PCYC Box'Tag program was launched. Initially running only two nights per week (Tuesday and Thursday), Box'Tag quickly became more popular than conventional boxing.

Encouraged by the increased participation rates and amount of community interest in Box'Tag, I decided to draft a letter to the CEO and Board outlining a proposal for the Canberra PCYC to break with tradition and formally adopt Box'Tag as its new boxing program. The aim was to replace the conventional boxing program with a form of boxing that would offer a safer and more enjoyable experience, thereby providing potential to significantly further increase participation rates for the organisation. The Board and CEO subsequently approved the proposal, resulting in the official launch of the Canberra PCYC Box'Tag Program in January 2012. Not long after the launch, there was a realisation that the program could support the ongoing refinement of Box'Tag through research and development (R&D) activities that had previously been undertaken at the AIS and at a Sydney boxing and fitness club where the Box'Tag concept originated. After successful completion of several small projects, a series of discussions between University of Canberra (UC) personnel and PCYC management resulted in the club formally becoming a joint Field R&D Centre of the Canberra PCYC and UC. It was envisaged that R&D efforts concentrated on Box'Tag could eventually provide an avenue to conduct projects surrounding a whole range of other PCYC programs. As the person in charge of the Box'Tag program, I soon became engaged in various R&D endeavours. My enjoyment of these endeavours provided the impetus for me to seek acceptance as a UC Masters by Research candidate, which in turn led to PhD candidature and eventually the submission of this thesis.

While the above is intended to demonstrate my suitability for undertaking this project, it also highlights how my background and experiences have helped shape my theoretical, philosophical and cultural views about sport, coaching and life, which in turn has inevitably influenced the research perspective that I have brought to the work presented in this thesis.

That work has incorporated both quantitative and qualitative aspects, and my research perspective has undoubtedly been of particular relevance to the latter. This, however, should not be confused with potential for bias - a term drawn from the quantitative research paradigm [3] and one which is incompatible with the philosophical underpinnings of qualitative inquiries [4]. Attention should instead be focussed on concepts such as credibility, transferability, dependability, and confirmability [5,6], and the degree to which these were addressed, since a qualitative researcher's perspective will be fully embedded within the research process rather than detached from it due to the subjective nature of the work [7-9]. Regarding the qualitative research presented in this thesis, a host of strategies were employed throughout the project to ensure these concepts were addressed as is evident from the table below.

Table 1: Strategies employed to ensure concepts such as credibility, transferability, dependability and confirmability were integrated, adhered to and maintained throughout the project.

Credibility	Transferability	Dependability	Confirmability
Credibility refers to the level of confidence that can be placed in the truth of the research findings [5]. Credibility was achieved in the present case through prolonged engagement within the research setting, daily observations and interactions with program participants over an almost 5-year period, and by using different sources of data and methods for their collection (triangulation). Adopting this approach enabled me to identify and continuously refine areas of focus through the direct involvement of program participants.	Transferability is the degree to which qualitative research results can be transferred to other settings with other respondents [5]. In the present context, transferability was established through detailed description of the research context so that similarity to other environments could be assessed. It should be noted, however, that the research was primarily focused on answering questions that emerged in a specific context.	Dependability is concerned with the consistency and repeatability of qualitative research findings [5]. Steps taken to ensure the findings presented in this thesis are dependable included: Participation in internal and external audits so that participants involved with the study and researchers outside of project could examine the data collection and analysis process and provide their own interpretations and recommendations. Use of peer-reviewed publications to provide detailed description of the research methods underpinning the findings.	Confirmability deals with the degree to which findings of a qualitative study could be confirmed by other researchers and includes the aspect of consistency [5]. Confirmability of the evidence presented in this thesis was achieved through the publication of findings in a series of peer-reviewed publications. This approach helps to demonstrate how the reported conclusions were not based on personal viewpoints but were interpreted from the data, thereby providing the research with an additional level of transparency.

1.2. Research strategies and philosophical assumptions

Due to the exploratory nature of the project, a "real-world", multidisciplinary, co-operative approach to investigation was employed. This approach was applied to the various technological, social, cultural and pedagogical aspects of the project. It was framed by a constructivist ontological understanding that individuals could construct different versions of reality, and was guided by an epistemological orientation that the researcher and participants are linked and will construct knowledge together [10-13]. It involved the direct participation of Canberra PCYC modified boxing program participants in the research process, along with inputs from sport and exercise scientists, bio-engineers, sport management personnel and industrial designers.

The research described throughout this thesis is therefore presented through the interpretive lens of a practitioner/researcher who had an extensive boxing background, was highly motivated to explore the potential for a much safer form of boxing to achieve significant community uptake, and was progressively influenced by the insights gained from long-term engagement as coach/researcher of the Canberra PCYC modified boxing program.

For example, by occupying the dual role of coach/researcher I gained first-hand experience of the demands, frustrations, joys and challenges associated with the planning, delivery and evaluation of ~2,000 modified boxing training sessions conducted within a community setting. I was able to develop strong and meaningful relationships with many of the participants, thereby giving me greater insights into the emotional and psychological reasons for their participation. In addition, the coach/researcher role assisted the generation of new knowledge and the development of new hypotheses by providing opportunities for daily observations and interactions with participants in a "real world" training and competition environment.

The use of the above approach, however, required high levels of reflexivity (i.e., awareness of the influence that a researcher has on the people or topic being studied, and of the ways in which the experience is affecting the researcher [14]). This reflexivity was pursued through repeated cycles of introspective self-analysis that were used to explore and critically interrogate the possible influences my role as coach/researcher was having on my relationship with the program participants, the social structure of the setting and the generation of new data. Offering an opportunity to consciously step away from the situation in order to theorise and make sense of what was happening, these self-analysis sessions became an integral part of my work. The aim was to thoroughly document the processes through which the knowledge was being generated in an attempt to ensure the credibility, transferability, dependability and confirmability of the research findings by taking into account the effects of my own evolving preconceptions, assumptions, attitudes and beliefs. As a mechanism for achievement of the aim, I maintained a reflective journal over the entire period of my PhD project. I used the journal to record not only project activities and outcomes but also the ways in which they affected and influenced me. The reflective journal therefore became a vital instrument of my research. The iterative nature of the practice of introspective self-analysis is summarised in Figure 5.

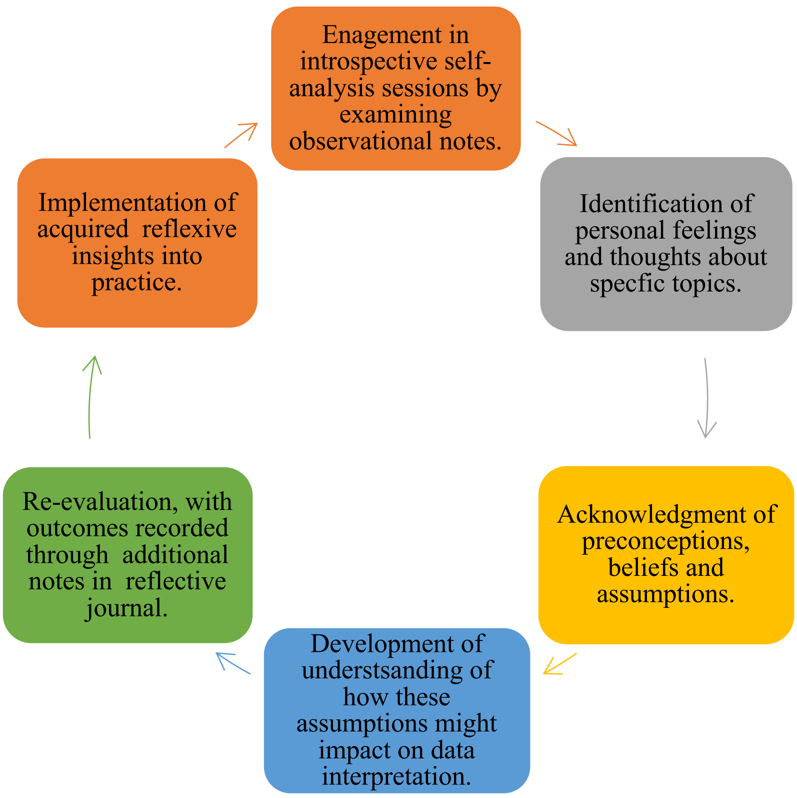

Figure 5: Schematic illustration of the cyclical introspective self-analysis process that was used throughout the project to constantly identify the influence that my presence as a coach/researcher was having on the participants and research setting while also recognising how the experience was affecting me.

1.3. Research aims and areas of focus

The current project sought to determine whether a modified, low-risk form of boxing could be developed in a way that would lead to sustainable large-scale community participation. In summary, the primary aims of the project were:

1. To develop a comprehensive understanding of the medical, legal, social and moral objections to boxing, and of how these might influence uptake of a modified form of boxing.

2. To develop a comprehensive understanding of the physical, psychological, social and community benefits of boxing, and of how these might influence uptake of a modified form of boxing.

3. To investigate the need and want for a modified and safer form of boxing.

4. To implement a modified boxing program in a community setting and liaise with participants through everyday conversation, formal interviews and written surveys, thereby developing deep understanding of their perceptions of the program and enabling informed program refinement.

5. To explore and iterate specific technologies seen as having potential to enhance the experience of the modified boxing participants, particularly in terms of safety and program enjoyment.

6. To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

I began with the hope that my research findings might provide a foundation for development of a nationally accredited coach education program that would prepare coaches to effectively oversee the delivery of community-based modified boxing programs able to meet the specific needs of their participants.

1.4. Structure of the thesis

After being upgraded to PhD candidature, I arranged to complete my PhD commitments through a series of academic publications. Over the course of my candidature, I published 9 papers, and they form the bulk of this thesis. All the papers were published in peer-reviewed open-access journals. I targeted open-access journals because I wanted to ensure that my work could be easily accessed by people currently or potentially interested in the modified boxing concept. Additionally, word limits for papers submitted to those journals were generally higher than those imposed by more traditional journals, providing me with opportunity to more fully describe my research and include details that I thought might be helpful to individuals or groups wanting to apply or build upon my findings.

For the purposes of the thesis, the papers are presented in the order in which they were published, since I believe that this demonstrates not only the progression of my thoughts but also the fact that the diverse elements of my research were pursued concurrently, rather than in a linear sequence. I trust the structure of the thesis will highlight the fact that at all points of my candidature I was focused on informed iteration of an effective modified boxing program and of special equipment to support it.

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Chapter 2: The Boxing Conundrum: Is there a place for a new variant of the sport?

2.1. Declaration for chapter 2

Declaration by candidate

In the case of Chapter 2, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Summarised, interpreted and critically evaluated information retrieved from an extensive review of the current literature. Preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC ? Y/N
Allan Hahn	Assisted with literature review and manuscript preparation.	No
Richard Keegan	Contributed to manuscript preparation.	No
Richard Lucas	Assisted with literature review.	No

Candidate's Signature [signature] **Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1: Allan Hahn	25/3/2019
Signature 2: [signature]	26/3/2019
Signature 3: Richard Lucas	5/4/2019

2.2. Prologue

To determine whether a case exists for development and promotion of a modified form of boxing, it seemed that a logical starting point would be to document contemporary perceptions concerning both problems and benefits associated with the conventional form of the sport, and to examine the evidence base for those perceptions. After almost 40 years of involvement in boxing, I was aware of a diversity of public opinion, with some people believing that the sport should be universally banned and others regarding it as not only acceptable, but even virtuous and a force for public good. To some extent, I was also cognisant of the grounds upon which the different opinions were based. This enabled me to identify key words for use in searching available scientific and other literature. Google Scholar and PubMed were the primary search engines that I employed, but in addition I conducted some standard Google searches, particularly to access information regarding the backdrop against which the scientific papers were prepared. Where materials identified as relevant were not readily available on-line, I used University of Canberra Library Services to obtain them. Reading of the various materials led to progressive widening of the literature search as it alerted me to new considerations. With support from expert colleagues with whom I was able to discuss some of the more nuanced issues that emerged, I eventually produced and published a quite comprehensive scoping review of the literature, and this appears below.

The review facilitated realisation of two of the six research aims identified in Chapter 1, as follows:

- **Aim 1:** To develop a comprehensive understanding of the medical, legal, social and moral objections to boxing, and of how these might influence the uptake of a modified form of boxing.
- **Aim 2:** To develop a comprehensive understanding of the physical, psychological, social and community benefits of boxing, and of how these might influence uptake of a modified form of boxing.

2.3. Published paper 1 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

The Boxing Conundrum: Is there a place for a new variant of the sport?

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2.3.1. Abstract

The purpose of this review is to establish current knowledge in regard to the legal, medical, ethical and moral concerns of boxing. The review also presents a case for boxing by highlighting the social and physical benefits associated with participation. It summarises, interprets, and critically evaluates the existing literature and introduces a safer alternative, Box'Tag.

Keywords: Boxing, Box'Tag, Community participation, Low-risk modified boxing, Modified sports, Sport for development.

2.3.2. Introduction

Boxing is a controversial sport. It has equally passionate proponents and opponents. Since the late 19th century, it has evolved into two different forms – professional and amateur boxing [1]. Both have gradually changed in response to internal perceptions of need for improvement and external criticisms, but remain subject to spirited medical, legal, moral and ethical debate. A question arises as to whether scope exists to develop a new variant of boxing that would be more broadly acceptable. This paper aims first to clarify the context of the question and then insofar as possible to resolve it.

2.3.3. Background

Boxing has a long history, with a form having been included in the Ancient Olympics [2]. Modern versions can be traced back to 1681, when the first documented professional contest took place in England [3]. In the years thereafter, the sport flourished, despite initially being illegal. By 1698, contests were sometimes held at the Royal Theatre of London. Participants vied for prize-money that was often supplemented by side-bets. They usually fought with bare knuckles and there were very few constraints. Contests typically continued until one participant was rendered incapable of doing so. They were often between people of markedly different size [3].

The first standard rules were introduced in 1743 [4]. They prohibited striking a contestant who was 'down' and provided for the match to be automatically concluded if this contestant was unable to rise after 30 seconds. Also in the mid-18th century, gloves known as 'mufflers' were developed [5], but their use was not mandated. The sport remained highly dangerous, with a number of deaths occurring [6]. This provided the stimulus for development of a new set of rules in 1838, and a revision in 1853 [2]. Among the principal changes were the introduction of a square 'ring' surrounded by ropes and the prohibition of biting, head-butting and hitting below the waist. At about the same time, the first efforts to introduce weight classes occurred.

In 1867, the 'Queensberry Rules for the sport of boxing' were published [7]. The use of 'fair-size' gloves was made compulsory and contests were limited to a 'defined number of 3-minute rounds' separated by 1-minute rest intervals. Wrestling was banned and a match was deemed to be over if a boxer remained down for 10 seconds.

The Queensberry Rules were not only largely adopted in professional boxing, but also spurred the development of an amateur version of boxing that had been initiated a few years earlier. Queensberry Amateur Boxing Championships were held from 1867 to 1885 [8]. In 1880, the Amateur Boxing Association was formed in England, with twelve member clubs. Its first championships were held the following year, with four weight classes contested [8]. From that time onwards, the amateur and professional forms of the sport diverged.

Historically, professional boxing has attracted substantial media attention and a wide public following. It has become big business, with reports that boxers have received purses in excess of USD 50 million for single world championship bouts [9] and that vast fortunes have been amassed also by entrepreneurial promoters of professional boxing events [10].

There is a strong focus on public entertainment and television appeal. A recent world championship contest was watched live by a worldwide television audience of 2.5 million people and generated television pay-per-view revenue of USD 150 million [9]. In addition, a bout held in 1988 is said to have produced gambling revenues of over USD 340 million in the host city alone [11].

Various developments have occurred that could be seen as being driven at least partly by desire for profit. For example, there has been a proliferation of weight divisions, with 17 now widely accepted [12], and more than a dozen different organisations currently sanction and conduct their own professional world championship bouts [13]. This means that there are typically multiple champions in each division.

Throughout the 20th century, most professional championship bouts were scheduled for 15 three-minute rounds, but in recent years the maximum duration has been shortened to 12 rounds with a view to improving safety [14]. It is quite common for a bout to be concluded in less than the scheduled time because of inability of one contestant to continue. Balmer et al. [15] reported that of 788 European championship contests held between 1910 and 2002, 50% ended in a knockout or technical knockout.

Amateur boxing has differed markedly from professional boxing in that its development generally has not been driven by the forces of capitalism. Rather, it has its origins in an attempt to make a form of the sport available to people wanting to use it as a vehicle for physical and personal development and the pursuit of virtue. In its early stages, it was derided as an attempt by people of relatively high socio-economic status to access and influence the course of an inherently working-class sport, but it was able to gain uptake in such settings as schools and universities [8]. Until very recently, there has been no prize money and the administration of the sport has been geared more toward providing a service to participants [16] than to overt profit-making. Amateur boxing has been included in all but one Summer Olympic Games since 1904 [8] and this has provided its primary means for public exposure. Internationally, it has remained under the control by a single organisation, the International Boxing Association (formerly the Association Internationale de Boxe Amateur), which subscribes to the Olympic charter. There are currently 10 weight divisions for senior athletes [12]. Since the inception of amateur boxing, bouts generally have been restricted to three or four rounds.

Other rules aimed at limiting the probability of injury also have been implemented [17]. For example, the gloves used in amateur boxing have typically incorporated more padding than those employed in professional boxing. In 1984 it became mandatory for amateur boxers to wear head guards during competition, and in 2002 a new rule allowed for a bout to be rapidly stopped if a contestant was seen to be ‘outclassed’ by an opponent.

As testament to the apparent effectiveness of the safety measures, almost 93% of the boxing contests at the 2008 Beijing Olympic Games were decided on points [18]. Presently, though, amateur boxing is undergoing major change. Within the past five years, the International Boxing Association has implemented a range of actions that it believes will increase the attractiveness of the sport [17]. It has mandated that senior male boxers will no longer wear head guards. The age limit for participation in amateur boxing has been raised from 34 to 40 years. The scoring system has been made similar to that used in professional boxing. A televised World Series of Boxing competition has been introduced and involves teams run by organisations that pay the International Boxing Association for franchises. Bouts held as part of the World Series are contested over five 3-minute rounds, with prize money on offer. The International Boxing Association has also established a professional division that allows for bouts of up to 12 rounds and will effectively enable boxers to compete as full professionals but remain eligible to take part in the Olympic Games [19]. Women's boxing has been added to the Olympic Games program [17]. Many of the changes appear aimed at capturing a major share of the market currently associated with professional boxing. It is arguable that after more than 130 years of separation, amateur and professional boxing are now converging [19] under the influence of a highly commercial focus.

A question arises as to whether the contemporary changes in amateur boxing are creating a place for a new form of the sport that is underpinned by the philosophy and quest for safety that amateur boxing originally represented. The answer is by no means certain, particularly as amateur boxing, following a period of decreasing popularity, is currently undergoing resurgence. In the UK, the number of people registered as members of amateur boxing clubs tripled between 2005 and 2009, and during the same period the number of schools including boxing in their curriculum increased from 20 to 1,931 [20]. This was at least partly a consequence of a high-level political decision that amateur boxing, which previously had been regarded as too violent to qualify for substantial public funding, was in fact a relatively safe sport capable of yielding important social benefits.

If there is strong consensus that amateur boxing is safe and is meeting community needs and standards, the case for developing a new form of boxing may be weak. However, many medical groups continue to oppose all existing types of boxing [21, 22], and there is increasing public concern regarding the long-term effects of repeated head impacts sustained in sporting situations [23]. There is also some opposition to boxing on non- medical grounds [24-26]. If a new form of boxing was able to successfully address the objections while preserving elements of the sport widely regarded as desirable, it could conceivably lead to further expansion of demographic reach. To assess the potential, it is first necessary to be fully aware of the current debate.

2.3.4. Objections to boxing

Davis [24] has provided an excellent overview of some major criticisms of boxing, namely those relating to levels of attendant pain and injury, glorification of violence, the social effects of the sport and a fundamental intent to harm the opponent. While he concludes that only the last of these criticisms is logically sustainable, they each merit further scrutiny.

Also deserving of consideration are concerns that boxing might be exploitative of vulnerable young people [27, 28], and assertions that in civilised nations the sport is essentially in breach of legislation relating to assault and battery [25].

2.3.4.1. Risk of death or injury

There is unequivocal evidence that participation in boxing entails serious risk. Analysing the period between 1890 and 2007, Svinth [6] documented the deaths of 923 professional boxers and 293 amateur boxers through injuries sustained during competition or training, and noted that there were likely others for which records had not been found. Overall, 91% of the deaths resulted from competition. The average age of the boxers at the time of death was 23.1 years for the professionals and 20.5 years for the amateurs. The numbers of deaths in the 1980s and 1990s were lower than in previous decades, but between 2000 and 2007 there was an average of more than 8 per year – not greatly below the average of 10 per year calculated for whole 118-year study period. In 2005, a female amateur boxer died following a bout. The vast majority of boxing deaths have been due to head or neck injuries, with acute subdural haematoma apparently the most common cause [29].

In addition to the deaths, there have been documented cases in which major surgical interventions have enabled boxers to survive acute subdural haematoma but have not prevented remainder-of-lifetime incapacitation [29].

Acute injuries, however, are not the only source of concern. Repeated head impacts over a period of time can cumulatively give rise to chronic traumatic brain injury that manifests in progressive dementia, Parkinson's disease with associated tremor and loss of motor control, reduced ability to perform cognitive tasks, slurred speech, unsteady gait, depression and predisposition to irrational anger [30-32]. It has been estimated that the condition, popularly known as punch-drunkenness, develops in about 20% of professional boxers [33], with symptoms typically appearing 12-16 years after boxing career commencement. Associated pathological changes to the brain include cerebral atrophy, damage to the corpus callosum, loss of neurons, formation of protein plaques and neurofibrillary tangles akin to those seen in Alzheimer’s disease and reduced cerebral blood flow (probably due to damaged blood vessels) [30, 32, 34-37]. The incidence of chronic traumatic brain injury in boxers is positively correlated with duration of career, number of bouts contested, age of retirement, ratio of losses to wins and time spent sparring [33]. In short, the extent of overall exposure to boxing influences the probability of developing the condition. It is believed that sustaining multiple concussions is a primary risk factor [38].

Classic symptoms of chronic traumatic brain injury associated with boxing are seldom seen in current or former amateur boxers apart from those with a very substantial history of involvement in the sport [33, 39]. However, this should not be interpreted as meaning that the problem is almost entirely confined to professional boxing. Recent research suggests that there is likely a continuum of injury related to degree of boxing exposure. Magnetic resonance imaging of the brains of 76 boxers showed that 38% of professionals, but also 11% of amateurs, had anomalies probably resulting from boxing [40].

Samples of cerebro-spinal fluid obtained from 30 amateur boxers one and six days after competition were found to have elevated levels of neurofilament heavy protein compared to levels seen in control subjects, indicating neuronal damage. A fortnight after competition, the readings for the boxers had declined but were still significantly above those of the controls [41].

Tanriverdi et al [42] observed raised levels of anti-hypothalamic and anti-pituitary antibodies in more a third of 61 current or former Turkish male amateur boxers but in none of 60 age-matched male control subjects, suggesting that head trauma experienced by the boxers had produced an auto-immune response that could compromise pituitary function. Taken together, the findings infer that the difference between professional and amateur boxers in regard to occurrence of chronic traumatic brain injury relates only to the typical degree of injury. The same may well be true of associated functional deficits.

Ongoing improvements in the regulation and medical supervision of professional and amateur boxing might reduce inherent injury risks associated with the sport [43], but cannot eliminate them. For example, earlier stoppage of bouts when a boxer is visibly hurt could be somewhat protective but can be implemented only after the hurt has occurred. In some circumstances, a single forceful impact to the head can have devastating effects. Also, since 1920, at least 61 boxers have died after contests that they officially either won or drew [6]. This emphasises the fact that even acute catastrophic brain injury is not always immediately obvious. Cumulative, chronic injury is still more difficult to detect.

It has been claimed that, from a purely statistical viewpoint, amateur boxers are more likely to die in a car accident on the way to or from training than from injuries received in the ring [6]. Such assertions need to be very carefully examined, since valid comparison of risk would require consideration of the total amount of time spent in the activities under consideration. Certainly, the dangers associated with participation in boxing, either professional or amateur, are significant and should not be trivialised. At the very least, they should be clearly explained to people contemplating involvement.

2.3.4.2. Intent to harm

There are sports in which the number of deaths and serious injuries per year is greater than in boxing – motor racing and equestrian sports are among the examples [44]. In general, though, these other sports are not subject to anything like the degree of medical and wider public criticism that has been directed at boxing. The reason for the difference is the perception that boxing entails a clear intent to harm the opponent [24, 30]. It is argued that in the other sports, deaths and injuries are essentially due to mishaps, whereas in boxing the infliction of injury is what contestants seek to achieve as a fundamental aim of the sport. The logical conclusion of this argument is that catastrophic consequences associated with boxing cannot be seen as entirely accidental.

Some proponents of boxing vehemently dispute the proposition that the sport necessarily involves intent to harm [45, 46]. They contend that the objective in boxing is simply to land impacts on well-defined target areas of the opponent, and that boxing is in fact similar to other sports in that injuries are simply unfortunate and unwanted by-products of the pursuit of victory [46].

Notwithstanding the highly threatening verbal and physical demeanour frequently exhibited by professional boxers attempting to attract publicity in the lead-up to bouts, it is maintained that opposing boxers typically have no malice toward each other. Indeed, there are often displays of mutual respect and goodwill, such as the 'touching of gloves' at the beginning and end of rounds and the occurrence of post-bout acknowledgements and embraces. Strong and close personal relationships are often formed within boxing communities.

The existence of malice, however, is not prerequisite to intent to cause harm. It would be difficult to deny that most boxers enter the ring with a will to deliver forceful blows to the head of the opponent and to capitalise on any opportunity to render the opponent unconscious or at least unable to continue competing. Since it is known that these actions are likely to be damaging beyond the immediate moment, intent to cause harm is implicit even if not conscious or malicious.

Supporters of boxing may assert that there are many other sports in which athletes deliberately make forceful contact with opponents in an attempt to gain an advantage [45]. The difference, though, is that these contacts are generally incidental to pursuit of the objectives of the sport rather than being a primary aim. In most sports, deliberate forceful contact to the head of an opponent is expressly forbidden by the rules and, if perpetrated, incurs significant penalty. This recognises the danger of such contact and illustrates effort to prevent deliberate infliction of harm. In boxing, by contrast, potentially dangerous impacts are allowed by the rules and actively encouraged.

Davis [24] opines that, from moral and ethical standpoints, the objection to boxing on the grounds that it entails intent to harm is impossible to dismiss. He points out that, when a boxer senses that an opponent is hurt, adoption of body language indicating viciousness frequently occurs. The unavoidable conclusion that the sport involves intent to harm is thus reinforced.

2.3.4.3. Inconsistency with common law

Expert consideration has been given to the relationship of boxing to common law in the United Kingdom, Australia and, by implication, nations with similar legal frameworks [25, 47, 48]. There is unanimous agreement that boxing consists of activities that in other circumstances would clearly constitute the criminal offence of 'aggravated assault' and, in some cases, assault occasioning grievous bodily harm. Offences of this nature carry lengthy prison sentences. It is considered anomalous that a pursuit that has illegal activities as its core is not itself deemed illegal.

The apparent anomaly is made possible by the fact that boxing is recognised as an organised sport. The law holds that actions normally regarded as assault may not necessarily be so when they occur in formal sporting contexts [25, 47]. Boxing is therefore legal only because its standing as a sport is implied and affirmed in policy documents produced by government instrumentalities.

At least in the Australian state of New South Wales, these documents have been produced primarily to ensure adequate regulation of boxing, rather than being based on a detailed determination of its legitimacy as a sport. It has been contended that, if the statutory recognition was withdrawn, boxing participants would immediately become liable to prosecution [25].

Issues surrounding participant consent are integral to debate on whether boxing should continue to be regarded as a valid organised sport. It can be held that if participants freely consent to enter the ring in full knowledge of the inherent risks, they should have the right to do so [45]. Under common law, though, a person cannot consent to be the victim of an assault that causes injuries of anything more than a temporary and trifling nature [25, 47, 48]. This is based partly on the principle that even moderate injury has implications for people other than just the injury recipient and therefore contravenes the public interest. Beran and Beran [25] raise a question as to how boxing contestants, in contrast to other members of the community, can be permitted to consent to potentially debilitating assault.

From a legal perspective, consent must be informed in order to be acceptable – i.e., the person giving consent must have a genuine understanding of the risks to which he or she agrees to be subject. In addition, there must be opportunity for the person to withdraw consent at any time. Doubts have been expressed as to whether these conditions are routinely met in boxing environments [25]. Competency to consent and minimum age of eligibility to consent are factors requiring consideration, along with the possible effects of blows to the head on ability to make rational decisions regarding withdrawal of consent during a contest. Leclerc and Herrera [49] point out that the matter of consent in boxing is complicated by the fact that a boxer effectively agrees not only to be a recipient of assault but also a perpetrator.

Over the past 150 years, there have been a number of court cases arising from boxing contests [25, 47, 48]. Most have occurred in the aftermath of the death or serious injury of a boxer. In general, it has been found that because boxing is conducted under strictly defined rules and is under the control of a referee who is in the ring with the contestants, it essentially entails a test of skills rather than an attempt by the contestants to knowingly harm each other. In an Australian case heard in the mid-1970s, the judge noted that if intent to inflict major harm could be demonstrated, boxing would be illegal [25, 47].

Brayne et al [47] point out that legal cases bearing on boxing typically have been resolved according to matters of public policy, and that no court has ever made a decision on the legality of boxing itself. They suggest that potential exists to mount a test case in which unprecedented attention would be given to legal arguments and scientific evidence concerning the sport.

In the opinion of Beran and Beran [25], recent irrefutable medical evidence demonstrating the long-term injurious effects of repeated impacts to the head means that in future legal cases it will be impossible to find that boxers do not knowingly seek to inflict harm on the opponent. They therefore believe that the grounds upon which boxing has been able to remain legal are becoming increasingly tenuous.

2.3.4.4. Glamorising violence

Inappropriate violence can be destructive to individuals, families and communities. Extensive scholarly effort therefore has been devoted to understanding its causes. There is evidence that some violent behaviour may have genetic and evolutionary foundations [50]. Implicit in the evolutionary process of natural selection is competition for passing on gene pools to subsequent generations. This entails ensuring survival by obtaining adequate shares of available food and other resources, establishing position within the community, vying for reproductive mates, protecting biological offspring and defending and/or expanding territory [51]. Insights into the methods by which these imperatives have been pursued throughout human history have been sought via studies of the current social systems of other primates - particularly those with the closest genetic relationship to humans. In these populations violent behaviour toward other individuals is much less frequent than cooperative and affiliative behaviour, but does form one end of a continuum of activities that can be seen as part of the function of competitive natural selection [50, 52]. The vast majority of violent and aggressive behaviour is perpetrated by males of reproductive age, an observation that applies also to humans and accords with the fact that this group has the greatest scope for passing on its genes [50]. It is possible that, during much of human evolution, genetic characteristics predisposing to aggressive and violent behaviour have favoured transmission of the gene pool and thus have become increasingly common, particularly among males [51]. Recent human research in molecular genetics has identified several genetic mutations that appear to be associated with inclination to violence, primarily through effects on production and/or responsiveness to neurotransmitters [51, 53, 54].

Based on the above, it can be argued that a tendency to sometimes act in violent ways is fundamental to the human condition, but this does not mean that violent conduct is acceptable in modern society. Violent impulses can be inhibited by human intellect, compassion and empathy [50]. In essence, violence may have a biological underpinning, but its expression appears to depend on complex socio-cultural factors.

Several somewhat overlapping explanatory theories have been developed in relation to the socio-cultural effects. One holds that much violence results from social inequality [55], with individuals higher in the 'pecking order' seeking to exploit those below them, and the latter rebelling against their position. Another theory points to the emergence of groups with sub-cultures in which violence is seen as a permissible and necessary means to an end [56]. Examples include organised crime syndicates and street gangs.

A widely recognised explanation for violent behaviour derives from the theory of social or observational learning [57], which suggests that many behaviours are learnt through seeing them modelled by others and then imitating them. The likelihood of imitation is influenced by observation of rewards or punishments received by the models – an effect known as vicarious reinforcement [58]. Additional salient factors include the extent to which the modelled behaviour captures the attention of the observer, the perceived relevance of the model, the ability of the learner to discern and reproduce the key features of the model, and the nature of any direct feedback resulting from the imitation [59]. The cognitive state of the learner, the perceived significance of the modelled behaviour and the characteristics of the learning environment therefore interact in shaping the learning experience. There is 'reciprocal determinism' in that the social environment affects the learning which in turn influences the ongoing nature of that environment [57]. It has been reported that people who consistently observe violent and aggressive behaviour within their social context are much more likely than others to adopt that behaviour [60].

It follows that social learning theorists are generally opposed to the modelling of violent actions, particularly in situations where those actions are overtly glamorised, rewarded and/or presented as fun. Movies, video games and advertising materials that involve graphic depiction of violence are seen as being counter- productive to attempts to develop harmonious communities [61], especially when viewers are encouraged to identify with the perpetrators of the violence rather than the victims. Inevitably, sports are also subject to scrutiny, with boxing at the forefront of criticism [61].

It is asserted that boxing models savage fist-fighting in which contestants aim to render each other unconscious. Because it is typically conducted in a colourful environment and the winner is accorded hero status while the pain and suffering of the contestants is largely ignored, there is thought to be a high likelihood of imitation and a risk of flow-on to violent behaviour in other circumstances.

Davis [24] points out that boxing does not model violence in general but only that specifically involved in boxing. He considers it doubtful that a society without boxing would be noticeably less violent than one that includes boxing but is equivalent in all other respects. Further, a case can be made that outside of the ring some boxers model behaviours that could decrease the probability of imitators becoming participants in social networks that foster multiple forms of major violence. There is, though, a quite strong school of community thought that boxing, together with other models of glamorised violence, could have negative effects on attempts to build societies in which there is minimal physical threat to citizens [30, 61].

2.3.4.5. Exploitation of participants

Boxing is frequently condemned as a vehicle for blatant exploitation of underprivileged people by profit-hungry entrepreneurs [10, 62, 63]. According to this view, young prospects are lured into the sport through deliberate encouragement to dream of fame and escape from poverty.

Once recruited, they are eventually induced to engage in brutal public fights that entail a high likelihood of severe injury and even a possibility of death, all so that boxing marketeers, boxer agents and gambling organisations can make large amounts of money [64]. The marketeers cynically use less talented and declining boxers to build the win: loss records –

and particularly the knockout statistics - of rising stars who as a result become highly valuable commercial commodities [64-66].

A few exceptionally gifted boxers do realise their initial dreams, but for a much greater number it inevitably turns out to be a highly painful and destructive illusion [67]. Even for those who become champions, success is often fleeting [65] and the subsequent fall can be precipitous, injurious, bewildering and lonely.

For some boxers, early career favours received from seemingly generous marketeers and agents create contrived indebtedness that can make escape from the sport difficult. Boxers can effectively become possessions of other people [10]. There is a history of association of organised crime with boxing [30, 63] and this can add to the complexity of the situation.

A group of Afro-American professional boxers studied by Wacquant [28] recognised their corporeal exploitation and described it as having parallels with prostitution, slavery and animal husbandry. The boxer-manager relationship was likened to that between prostitute and pimp and the boxer-marketeer relationship was seen to resemble that between slave and plantation manager. The boxers perceived that they were treated as livestock. Nevertheless, they regarded their exploitation as normal and this, combined with other practical beliefs, arguably made them complicit in it.

Sugden [27] notes that boxing gyms tend to be concentrated in areas of high socio-economic disadvantage. He rejects claims that this reflects altruistic desire to use the sport as a means of diverting young people from juvenile delinquency and anti-social behaviour, instead believing that it is based on ensuring access to recruits who are vulnerable to exploitation.

Although allegations of exploitation pertain primarily to professional boxing, Sugden [27] contends that amateur boxing cannot be excused since it essentially serves to enable training and grooming of potential professional boxers and hence forms a vital part of a fundamentally exploitative and morally corrupt network.

There are of course some people in the boxing industry whose motives are demonstrably honourable, but many social commentators believe that the industry as a whole is exploitative [10].

2.3.5. Calls for boxing to be banned

Numerous medical organisations around the world have formally documented their opposition to boxing and have called for it to be banned. Included here are the World Medical Assembly [68], the American Medical Association [21], the British Medical Association [69], the Canadian Medical Association [70] and the Australian Medical Association [22]. These bodies advocate the abolition of boxing in all its forms. In addition, the American Academy of Pediatrics and the Canadian Pediatric Society have stated their opposition to boxing as a sport for children and adolescents [71].

Professional boxing was banned in Sweden in 1970 but reinstated in 2007. In 2013, the Swedish Government announced that the sport was again under review following a near-fatal injury to a female professional boxer [72].

In Norway, a ban on professional boxing was implemented in 1981, but in 2013 the Government announced an intention to rescind it [73]. In 1991, a proposal to abolish professional boxing in Britain was defeated in the House of Lords by a margin of just three votes [74].

Warburton [45] argues that calls for the criminalisation of boxing are based on paternalistic, anti-libertarian attitudes supported by dubious legal moralism. He questions the right of the medical profession and legislative bodies to interfere with individual autonomy, even if a case can be made that boxing causes brain damage. In his opinion, an education campaign aimed at raising individual and general public awareness of the risks would be a more appropriate approach, and would be consistent with actions that have been taken in relation to other potentially damaging activities, such as smoking and alcohol consumption.

On the other hand, Leclerc and Herrera [49] contend that boxing is at odds with the central focus of libertarian philosophy – that of protecting individual autonomy – since the effects of the sport on the brain may eventually reduce the ability of the boxer to direct his or her own life. They suggest that physicians should cease providing direct support to boxing competitions, since such support lends the competitions an unmerited air of medical and ethical legitimacy. Brayne et al [47] have pointed out that refusal of medical attendance at boxing matches could effectively result in banning of the sport, since regulatory policies generally require a medical presence.

A frequent argument against the prohibition of boxing is that such action would do nothing more than force the sport underground where it likely would be conducted in a much less regulated and more dangerous way [45, 75]. A counter-view, though, is that the same logic could be used to justify re-introduction of legalised slavery [25].

While the above indicates that during recent decades the impetus for banning of boxing has been significant, it appears that at present the medical and other objections to boxing are being over-ridden by a more persuasive narrative. Part of that narrative may concern potential to generate large-scale economic activity [76], but it is germane to identify other elements that are commonly advanced.

2.3.6. The case for boxing

Boxing proponents have not been confined to just defending the sport against objections. Rather, they have proactively argued that boxing has many positive features, including some that make it well-placed to help governments address important contemporary issues beyond sport. A key theme is that boxing provides a medium for reaching and influencing lower socio-economic sectors of the population, where health and social problems are most prominent. Townson [77] notes that in Britain societal changes that occurred during the 20th century diminished involvement of the 'working classes' in sports that were previously their domain. Boxing, though, has continued to draw the vast majority of its participants from the lower socio-economic category and has been described by Shipley [78] as 'the most proletarian of all sports'. It is accessible even in densely populated urban areas where few sporting facilities are available, allows relatively large numbers of people to train within small spaces and can be undertaken without expensive equipment. Some of the commonly advanced attributes of boxing are outlined next.

2.3.6.1. Development of Physical Fitness

Boxing is an excellent activity for building general physical fitness. The physiological characteristics of high-level boxers provide insights into the demands of the sport. National male amateur boxing squads from France, Germany and England have recorded average maximum oxygen uptakes in the vicinity of 60-65 ml.kg.min^{-1} [81], indicating high aerobic capacity. This is similar to values reported for male professional soccer players [82] and far above the 42-46 ml.kg.min^{-1} that is considered 'good' for 20-29 year-old males [83]. Punch forces of senior male English amateur boxers measured in a laboratory situation averaged over 2600 Newtons for the dominant hand, and over 1700 Newtons for the non-dominant hand, reflecting extraordinary neuromuscular capability [81]. Post-bout blood lactate measurements on 75 international amateur boxers competing over four 2-minute rounds produced a mean value of 13.5 $mmol.L^{-1}$ [81]. This demonstrates that competitive boxing also requires highly-developed anaerobic capacity.

Preparation for boxing thus mandates participation in intensive exercise sessions that target and enhance multiple physiological systems and muscle groups. The effectiveness of typical sessions has been objectively shown [84] and has resulted in widespread community adoption of boxing training methodologies for fitness development [85, 86].

Increasing incidence of disorders such as obesity, diabetes and cardio-vascular disease – all of which can result from and/or be exacerbated by sedentary lifestyle - is of major global concern [87]. Boxing is currently providing the foundation and stimulus for a wave of exercise programs that at least in a small way may be contributing toward efforts to arrest and reverse the trend.

2.3.6.2. Character Building

It is popularly claimed that boxing, by its very nature, fosters the development of positive character traits among its participants [88]. Self-esteem, self-discipline, courage, perseverance, resilience, respect for others, and willingness to comply with rules are all sometimes identified as personal qualities that are likely to be improved through involvement in the sport, and there is a pervasive belief that the effects transfer to other aspects of life [88].

Upon initial scrutiny, scientific support for these claims appears scant. Bačanac [89] compared the psychological profiles of 104 experienced senior Yugoslav boxers who were vying for national selection with the profiles of 277 equally competitive athletes from other sports. The boxers were found to be relatively low in self-confidence, conscientiousness, reliability, responsibility, sociability, recognition of moral norms and desirable standards of behaviour, feelings of acceptance, and propensity to critically analyse problems. They were more likely to neglect rules and obligations, more reserved, and more inclined to guilt and self-reproach. Some of the personality traits were detected also in a group of much younger boxers, suggesting that they might have influenced the choice of sport rather than resulting from the sport. The low socio-economic background of boxers was thought to be a major factor influencing their profiles, and the research findings do not exclude the possibility that involvement in boxing might still have shifted at least some of the personality traits in a positive direction.

There is debate as to whether sports participation in general has character-building effects, and instances of athletes using prohibited performance-enhancing drugs, cheating in other ways, abusing officials, assaulting opponents and committing crimes outside of the sporting arena are sometimes cited as evidence to the contrary [90]. Current expert opinion is that sport does not inherently build character but can do so if the experience is structured in a way that places an imperative on specific behaviours and provides appropriate role models. Calling upon social learning theory, Omar-Fauzee et al. [91] emphasise that the ways in which sports participation influences attitudes and behaviours depend on the nature of both the learner and the learning environment. Boxing, therefore, may help to build desirable character traits, but is likely to do so only in circumstances where those traits are very clearly valued, modelled and rewarded. For many boxing participants, involvement with a boxing club does at least offer a possibility of encountering such circumstances in a context perceived as relevant and therefore worthy of attention. Other aspects of their lives might offer very few comparable possibilities.

2.3.6.3. Social benefits – Hope, Opportunity and Pride

To understand the potential social impacts of boxing, it is useful to consider the perspectives of boxers. Wacquant [92] conducted a comprehensive ethnographic study over a three-year period during which he became integrated into a boxing gym in a Chicago ghetto and interacted with almost all professional boxers in the area. Despite awareness of exploitation, the boxers (all males) were very willing participants in the sport and the great majority professed to love boxing. This attachment could not be explained in financial terms, since few were making much money from their participation and many were fitting boxing around other paid commitments. Their initial engagement was typically motivated by hope of escape from poverty and belief in a possibility of becoming a world champion, but even when (in most cases) it subsequently became apparent that these goals would not be attained, the boxers chose to continue involvement due to perception of other benefits.

Receipt of acclaim and respect from within ‘the small neighbourhood’ of family, friends and associates was important. The most critical factor, though, was access to a world very different from that of the ghetto and the opportunity to develop a new and transformed ‘hyper-masculine’ self. The boxing world was seen as offering the prospect of a career in which advancement depended on talent, hard work and willingness to sacrifice distracting pleasures.

It was felt that success in boxing required not just honing of the body to meet the demands of the sport but also the deployment of highly technical skills that could be acquired only through many years of rigorous, dedicated practice. The boxers took pride in their technical mastery – their socio-economic circumstances meant that outside of boxing they were largely confined to unskilled, repetitive jobs. Participation in boxing also provided them with greater personal autonomy, variety of experience and excitement than they had been able to find in the standard labour market. They recognised the risk inherent in the sport but considered it less than the ever-present danger on the streets outside.

The Chicago boxers subscribed strongly to the organisational ethics of the gym in which they trained [92]. Central to the ethical framework was that boxers should never fight other than in the ring against properly prepared opponents. Also notable was a view that quite marked asceticism - incorporating dietary restrictions and abstinence from alcohol, cigarettes and other drugs – was fundamental to the life of a boxer during periods of intensive training. As a result of these ethical commitments, the boxers were largely divorced from the gang warfare and the drug culture and commerce that pervaded their local community. They found delight in being identified as role models for children from the community and in exemplifying the viability of a quest for a better life.

Most of the boxers studied by Wacquant [92] thought that they had derived substantial net benefit from their participation in the sport, with less than 10% believing that they would have been better off if they had never become involved. While individual benefits are important in their own right, their sum might yield wider social good by signalling that there are legitimate and realistic channels through which hope, opportunity and pride can be pursued even in the midst of concentrated urban dereliction. It can be argued that in the ‘urban jungle’ the existence of boxing clubs might act as a force for reduction of overall social violence. Wacquant [92] did observe, however, that underneath the surface many of the Chicago boxers were troubled by contradictory feelings about their sport - over 80% of them indicated that they would not want their children to engage in it.

Fulton [93] carried out an ethnographic study with male boxers and members of the boxing industry in the north-east of England, where he became associated with an amateur boxing club and served as a judge at numerous boxing tournaments. His findings were similar to those of Wacquant [92] in that the boxers saw the sport as providing them with considerable benefits. Fulton [93] categorised these benefits as ‘social capital’ arising largely from the strong camaraderie that was present in the sport and the resultant formation of social networks that could be called upon outside of boxing. The generation of this capital seemed to depend on expression of attitudes and behaviours that reinforced male hegemony, but it was noted that the recent rapid increase in female boxing participation might change the situation. The social capital established by the boxers, although valuable, was only seldom translated into ‘cultural’ capital, defined as assets valued by the current ruling classes.

Because of its evident ability to attract the interest of young people in disadvantaged communities, boxing is at the centre of a range of programs aimed at influencing these young people and providing them with knowledge and life skills that may help to overcome their disadvantage. Included here is the ‘Fight for Peace’ program [94] that arose in the slums of Rio de Janeiro, now has a major presence also in London and is targeting under-privileged areas around the world. Participants in this program are able to undergo boxing and martial arts training but, to remain eligible, must also engage in personal development activities focused in the areas of education, employability, youth services and youth leadership.

The initiator of the program has received a Laureus World Sports Award in recognition of its success [95]. In addition, boxing forms the core of a youth outreach program in another Rio slum [96] and has been an element of the Positive Futures program [97] implemented by the UK Government with a view to crime reduction.

2.3.6.4. Aesthetic qualities

It is sometimes argued that boxing incorporates profound aesthetic qualities that have worth in their own right [5, 65, 98]. The movements involved in highly skilled boxing may be seen as exhibiting grace, elegance, nuance, temporal rhythms, spatial relationships and combinations of synchrony and asynchrony that make them exquisite and beautiful.

Chandler [65] points out that the movements are highly evolved and stylised, and provide boxing with definition and structure that fundamentally differentiates it from street fighting and allows rendition of a visual narrative. In this regard, skilled boxing can be likened to ballet [98] – in both activities movement fluidity and perfection allow narrative to be communicated more powerfully. The boxing style of a current undefeated world professional champion has been described as ‘a symphony of movement’ [99] and the most popular boxer of all time, Muhammad Ali, famously summarised his own modus operandi as ‘float like a butterfly, sting like a bee’ [100].

The notion that skilled boxing can be beautiful is captured in the common description of the sport as, for example, the ‘sweet science’ and the ‘noble art’.

The aesthetic appeal of boxing, though, extends far beyond just the movements of the performers and encompasses elements of the setting in which they occur [5]. The ring, the ropes, the bell, the lighting, the brightly coloured clothes of the contestants, the attire of the referee, the ring stools and even the contours of the gloves have evolved in ways that add to the visual allure of the sport. Scott [5] suggests that – as in the world more generally - such ‘aestheticisation’ serves to draw attention to objects and actions that have deep symbolic significance. For example, the silks and satins of the boxers may symbolise a feminine connection to a domain in which, historically, males have strived to assert and confirm their masculinity.

Throughout its history, boxing has shown an extraordinary ability to inspire artists, including painters, sculptors, potters, photographers, graphic designers, poets, novelists and filmmakers. According to Encyclopaedia Brittannica, ‘it is likely that more literary writing, as opposed to pure journalism, has been spent on boxing than on any other sport’ and fictional movies about boxers outnumber all other sports films [101]. The American essayist and cultural critic, Gerald Early, has noted that while boxing has prospered as a sport in mass industrialised society it has, surprisingly, also flourished as an aesthetic [102].

The vibrant interaction between boxing and the creative arts may relate at least partly to the fact that the dance-like qualities and colorful symbolism of boxing co-exist with real-life physical threat, uncertainty, and the constant possibility of a swift, destructive ending.

The writer Joyce Carol Oates comments that ‘Boxing has become America’s tragic theatre’ [62]. She proposes that there is no other sport in which ‘the connection between performer and observer is so intimate, so frequently painful, so unresolved’ and that the ‘theoretical anxiety’ associated with the sport is at the heart of its broad fascination. She believes that many boxing enthusiasts struggle with inner conflict related to a suppressed understanding that the sport, which can produce rare beauty, also has a potential for excruciating brutality [62]. The elemental incongruity is perhaps a stimulus for artistic interest.

Scott [5] argues that the professional and amateur versions of boxing are based on different but complementary views of the sport that reflect different aesthetic appreciations and moral constructions. It is undeniable that for some people who participate either actively or vicariously in boxing, the occurrence of knockouts and bloodshed is a real attraction. The ranks of this group probably have been swelled by television coverage of professional matches. It appears, however, that there may also be a sub-group for which violence is nothing more than an under-current to beauty found in other dimensions of the sport.

The artistic works motivated by boxing means that the sport has contributed to the recording, transmission and shaping of social history and culture, particularly during the past 120 years. This contribution should not be too readily dismissed.

2.3.6.5 Catharsis

There is a popular view that boxing provides participants with a controlled outlet for natural aggressive instincts and impulses that if not released would predispose to violent behaviour in other circumstances [103- 106]. This view is based on the Freudian concept that repeated suppression of emotions leads to progressive build-up of 'pressure' and that finding opportunities for socially acceptable discharge of these emotions is necessary to the avoidance of eventual pathology [107]. The process of socially acceptable discharge is termed 'catharsis'.

It is sometimes suggested that the sport serves a cathartic function not only for contestants but also for spectators [108], since it enables release of their pent-up aggressive emotions. Current scientific evidence, however, does not support this notion.

Bushman [109] conducted a large study in which some deliberately angered subjects were invited to punch a bag while others did nothing. Within the punching group, half of the subjects were encouraged to think about their provocateur during the activity while the remainder were asked to focus on fitness development. Afterwards, the subjects who undertook the bag-punching with the provocateur in mind showed the highest levels of anger and the most aggressive behaviour toward the provocateur, while those who did nothing following the initial stimulus to anger were the least angry and aggressive. This result was opposite to that predicted by catharsis theory, and instead was consistent with cognitive neo-association theory, which posits that aggressive thoughts can call up from memory complex associations of aggressive ideas, emotions related to violence, and impetus for aggressive actions.

Huang et al [110] compared athletes from high-contact sports with counterparts from low-contact sports and found that the former responded more aggressively to provocation, despite the fact that their sports might have been expected to offer greater catharsis. Also contrary to catharsis theory are the observations of Lemieux et al. [111], who used a questionnaire to determine self-reported hostile aggression for university athletes from high-contact and low-contact sports, and also administered the questionnaire to two control groups that were matched with the two sport groups on a range of variables including height and weight. Levels of hostile aggression were positively related to body size but were not lower in the athletes than the matched controls.

With regard to spectators, the majority of research indicates that watching a sport incorporating violence generally tends to increase rather than decrease subsequent aggressive behaviours [112]. This appears to be influenced by the attitudes brought to the situation, with the effect being particularly prominent among spectators who have greater preference for the violent aspects of the sport [113] and more likely to occur when spectators perceive that there is animosity between the sporting protagonists [114].

It remains possible that boxers have a relatively low predisposition to violence outside the ring, but if so it is likely due to fatigue produced by training, a dearth of free time and commitment to a sub-cultural code of behaviour [92], rather than to any cathartic effect of the sport. Similarly, there may be cases in which watching a boxing match provides a distraction from frustrating life stresses and yields a temporary net reduction in aggressive emotions [112]. It seems clear, though, that the idea that actual or vicarious participation in boxing entails quasi-therapeutic venting of submerged negative energy is untenable. Goldstein [112] points out that the theory of catharsis assumes that human emotions exist in finite quantities such that their use results in depletion, an assumption that is almost certainly incorrect.

2.3.7. A new variant of boxing?

The above highlights the point that while some very legitimate concerns surround boxing, the sport also has positive aspects. It therefore seems worth exploring whether it is any way conceivable that boxing could be modified to overcome the objections without loss of the benefits. There have been suggestions from various sources that impacts to the head should be prohibited [21, 25, 115, 116]. This single step would undoubtedly go a long way toward addressing the most strident criticisms of the sport.

Yet a ban on blows to the head may not necessarily be enough. One of the most fundamental and challenging objections to boxing – the existence of intent to harm – could still be seen to apply, since heavy body blows can be damaging. Consequently, other changes probably would be needed.

The American Medical Association [21] has recommended the development and deployment of impact-absorbing gloves. If a sufficient degree of impact absorption could be achieved, the possibility of inflicting harm would become minimal.

In making modifications, it would be important to ensure that the sport continued to demand high levels of physical fitness and retained its appeal to a significant sector of the population. Preservation of strong aesthetic qualities would be critical, and as part of this highly skilled performance would have to be encouraged and rewarded. Pearn [115] argues that the boxing without head impacts would still be an attractive spectacle, as the emphasis on skill might well be increased, but Smillie [76] suspects that for many boxing enthusiasts the appeal of the sport would be lost, and Zillman et al. [117] have demonstrated that likely occurrence of violence does increase spectator enjoyment of sports.

What is clear is that the required changes would be of monumental proportion, and probably would be subject to major resistance, since they would effectively create a substantially different sport [49]. Is it then unrealistic to even countenance them? Regardless of the scientific merits of the argument, it would be naive to think that boxing authorities would spontaneously resolve to adopt radical reform, particularly at a time when the sport is riding a wave of popularity. It might be feasible, though, to progressively develop and implement a new variant of boxing, co-existing with the current versions, as a concrete exemplar of a direction that the sport could eventually take and as a means of gauging reaction from participants in the boxing debate and the wider public. Looking to the future, it is perhaps more likely that boxing authorities would endorse a 'going concern' than decide to venture into an entirely uncertain space, especially if the former had demonstrable grass-roots support. In short, there may be value in showing what change could look like, as opposed to simply advocating the need for such change.

A modified form of boxing incorporating characteristics similar to those recommended by the American Medical Association [21] has recently emerged in Australia. It is known as Box'Tag and is providing a useful test case. We have been part of the project team.

2.3.8. The Box'Tag project

Box'Tag has evolved over an 8-year period [118] and is still undergoing refinement. Ability to gain insights from evaluation of the project requires understanding of the current nature of Box'Tag, the ways in which it has been promoted, the response to that promotion, possible next steps, and issues that have confronted members of the developmental team.

2.3.8.1. Overview of the Box'Tag concept

The rules of Box'Tag prohibit impacts to the head or neck, as well as any impacts above a moderate level of force [119]. Nevertheless, contestants are required to wear head guards and mouthguards as protection against accidental head impacts. It is also mandatory for male contestants to use groin protectors and for females to use chest protectors. Target areas consist of the front and sides of the torso and small regions on the upper arms. The arm regions, which are not part of the target in conventional boxing, have been added in lieu of the head so that the overall size of the target area is retained [119]. Bouts are typically contested over three rounds of 1-2 minutes. Specialised gloves with enhanced impact-absorbing qualities have been produced and deployed in field trials.

From the time of its inception in 2006, Box'Tag has made use of automated scoring technology. The historical development of that technology has been described by Hahn et al [18] and Helmer et al [120]. Presently, contestants wear T-shirt style vests with a sensor fabric defining the scoring regions. The sensor fabric incorporates stripes of silver-coated nylon yarn through which a low-level electrical current can be run. A small transceiver worn in a pocket at the back of the vest generates the current. Patches of conductive material are affixed to the gloves. When this material bridges two stripes on a vest a change in the electrical resistance of the vest occurs, enabling impact detection. Electrical resistance data are transmitted by Bluetooth to a ringside computer, where a customised software package applies various algorithms to determine whether a point should be registered [119]. Scores can be displayed in real time. An operator of the ringside computer can manually deduct points from competitors at the behest of the bout referee, who can impose penalties for inadvertent head contacts, excessively forceful punching or inappropriate behaviour. The accuracy of the scoring technology has been confirmed by empirical research [121].

2.3.8.2. Promotion of Box'Tag – the issue of 'push' vs 'pull'

The impetus for the development of Box'Tag has determined the manner of its promotion. The development did not originate from an identified market demand. Indeed, a recent survey of a sample of Australian health and fitness club members suggested that there is presently no large-scale market 'pull' for a modified form of boxing (Boxing Australia Limited, personal communication). The focus, then, has been on building a basic capacity for practical demonstration of Box'Tag. In effect, there has been a fairly low-profile 'push' aimed at capturing interest, but no advertising campaign or attempt at commercial roll-out.

Initially, a Box'Tag program was established at just one boxing and fitness club in Sydney [118]. Club members trained for Box'Tag competitions that were held approximately quarterly, and usually consisted of 8 - 14 bouts. Outside of this, one-off demonstrations were occasionally provided to interested groups. In 2010, a number of key people from the Australian sports industry accepted an invitation attend to a Box'Tag demonstration at the Sydney club. Included here were several representatives of Boxing Australia (the organisation responsible for national control of amateur boxing).

During the past four years, Box'Tag programs have been selectively introduced also in several locations outside of Sydney [119], namely Melbourne, Canberra, and the New South Wales coastal town of Ulladulla. While this has occurred only within the confines of an expanded demonstrator concept, it has led to an increase in the overall number of competitions and opportunities for demonstration. A few Box'Tag competitions have been held for recruits at the Victoria Police Academy in Melbourne, and single competitions have been run by request in each of four New South Wales regional towns. Demonstrations have been provided at Open Days for two universities and the Queensland Academy of Sport, and at two Australian sport expos.

In 2011, an opportunity was taken to run a pilot Box'Tag program at a school in a disadvantaged area of Brisbane [122]. In 2012, a Box'Tag competition was included in the Victorian Police & Emergency Services Games. It was retained in 2013, and in 2014 it was added to the program for the Australasian Police & Emergency Services Games.

Box'Tag has been the subject of six publications in the scientific literature [18, 118-122], five presentations at scientific or sports industry conferences, a presentation to a group of talented young scientists, and several presentations to undergraduate university students. In addition, it has featured in three different television science shows, although these have concentrated more on the scoring technology than on the Box'Tag concept itself. Although the extent of promotion has been limited, it has perhaps been sufficient to enable a reasonable assessment of response.

2.3.8.3. Indications of interest

Reactions of people directly exposed to Box'Tag generally have been favourable. The Sydney club at which the modified sport was first established has maintained its enthusiasm over eight years and still runs regular competitions. The Canberra Box'Tag program has grown tenfold from a small beginning to now include over 100 members. In Melbourne, the club at which Box'Tag was introduced has changed ownership but has continued to run a small Box'Tag program. The Ulladulla program is in its early days but appears to be thriving.

Boxing Australia has formally endorsed Box'Tag as a positive vehicle for community engagement [119] and is contributing to its development.

A leading Australian paediatrician has actively advocated for Box'Tag [118], as have three very well-known former champion boxers. The pilot Box'Tag program conducted in Brisbane attracted a very high rate of uptake from eligible students and achieved good program adherence [122].

Almost every club at which a Box'Tag demonstration has been held has subsequently expressed interest in implementing a program. In addition, there have been communications of interest from all states and territories of Australia. Enquiries have been received from overseas nations [119] including New Zealand, Tonga, England, Ireland, Canada, Poland, Dubai, Bermuda and the Bahamas.

The response has not been universally positive. A few attendees of Box'Tag competitions and demonstrations have commented that *'this is not boxing'* and there has been some criticism that Box'Tag requires development of a skill set that differs importantly from that required for conventional boxing. The early prototype impact-absorbing gloves have been considered uncomfortable and unnecessary by some Box'Tag participants. Although Box'Tag competitions have occasionally attracted audiences large enough to fill the small arenas in which they have been held, the audiences have consisted mostly of the family and friends of the contestants. This suggests that in its current form the modified sport might have relatively little spectator appeal.

Overall, though, the feedback has perhaps been sufficiently encouraging to justify a belief that reasonable community traction could be achieved by a version of boxing that addresses medical and other concerns regarding the conventional forms of the sport.

Within the clubs hosting Box'Tag programs, many of the participants would never have contemplated involvement in the conventional form of the sport [119]. Outside of those clubs, the interest has come primarily from people involved in conventional boxing, although some athletes from other sports have used Box'Tag for cross-training.

2.3.8.4. Next steps

A logical next step would be to capitalise on the interest that has been generated by moving from the demonstrator approach to a more substantial field trial entailing early roll-out of the modified sport. If Box'Tag maintains its current form, this would require an ability to ensure cost-effective supply of the wearable technology that permits automated scoring. To date, all of the vests and transceivers have been hand-made by a research agency [120], entailing significant expense. Cost minimisation, perhaps through bulk production of equipment by a commercial manufacturer [119], will be essential to reaching the demographic sectors from which boxing participants have been almost exclusively drawn [77].

A question naturally arises as to whether Box'Tag would be viable without the scoring technology. Box'Tag participants and spectators have generally opined that the technology is integral to the appeal of the modified sport [118]. It might, however, need at least to be scaled down to optimise potential for Box'Tag expansion.

From a research and development perspective, attention will need to be directed to ongoing refinement of impact-absorbing gloves to improve the degree of impact absorption and provide a level of comfort that is universally acceptable. If a larger field trial of Box'Tag is to be conducted, development of strategies for raising public awareness of the modified sport also will be necessary.

2.3.8.5. Confronting issues

During development of Box'Tag, the project team has encountered several issues that require serious reflection. On the surface, Box'Tag appears to be exempt from the primary objections to conventional boxing, since it involves minimal risk of injury and no intent to harm. It also provides for retention of most of the identified benefits of conventional boxing. It has been shown to demand high levels of physical fitness [123] and, if appropriately structured, should be as good as conventional boxing for character building. It could be very well-suited to social outreach purposes, although there would need to be an investigation of its ability to attract adolescent and young adult males, who seem attracted to violent sports as a way of demonstrating their masculinity [124]. When performed with skill, it can have excellent aesthetic qualities. Yet there seems a possibility that the attempt to satisfy two groups that currently have opposite views of conventional boxing could end up satisfying neither.

In contrast to comments occasionally received from members of the boxing community, some people from outside the sport have expressed the view that 'Box'Tag is still boxing', and this view has affected ability to obtain support. It is noteworthy that the recommendations made by the American Medical Association [21] for modification of boxing come with the caveat that they should apply only for an interim period until all boxing is banned.

This implies that even a very low-risk form of boxing would not be acceptable. Perhaps many people have doubts about the ethical legitimacy of any activity in which contestants deliberately strike each other, even when there is little possibility and no intent of harm. If this is the case, further pursuit of the Box'Tag project might be futile.

The extent to which Box'Tag (or a similar initiative) is likely to be backed by medical and other experts opposed to conventional boxing needs to be ascertained.

Another perplexing issue relates to the potential for Box'Tag to simply become a pathway into amateur and then professional boxing, rather than emerging as an alternative.

According to logic outlined by Sugden [27], this would make it subject to the very objections that it has been designed to address. Among members of the boxing community who have shown interest in Box'Tag, there has been a common view that it offers an excellent way to provide people with a first experience of the sport.

Already, several people who started in Box'Tag have moved to amateur boxing. It is not known whether this trend will continue. It may be that Box'Tag will become a niche version of boxing that for the most part attracts a demographic different from that of the conventional form of the sport, and one that has little interest in making the transition, particularly if not specifically encouraged to do so. Regardless, Box'Tag will need to achieve reasonable critical mass in order to be able to offer a pathway and suitable rewards in its own right. Until a roll-out of the modified sport is attempted, it will be difficult to tell whether this is a realistic vision.

Some concern has arisen that the attempt to develop a modified, low-risk form of boxing might be entirely counter to contemporary sociological trends affecting sport. A recent study [125] suggested that during the next 30 years there is likely to be a rise in the popularity of high-risk, high-adrenaline sports that are presently regarded as extreme.

Goldstein [126] has noted that Western society seems to be embracing increasingly violent forms of entertainment. These trends are perhaps reflected in the current boxing boom and the recent emergence and media uptake of activities such as Ultimate Fight Club. It is pertinent to consider whether an initiative like Box'Tag has any genuine chance of success in this sociological context. There is, however, evidence of a co-existing impetus to improve sport safety. Many parents are discouraging their children from playing sports with a high perceived risk of injury [127]. Public officials are concerned about the effects of sports injuries on health costs. Earlier this year, the US House of Representatives Energy and Commerce Committee convened a special hearing on improving sports safety with a particular focus on brain injuries [128]. It therefore seems that there may be an ongoing sociological rationale for the development of Box'Tag.

2.3.9. Conclusion

We conclude that while there are some valid objections to boxing, the sport also has some positive elements. It is possible to devise a form of the sport that overcomes the former while retaining most of the latter. Such a form is capable of capturing and maintaining some community interest. Imbuing the modified sport with a technological component that makes it more than just boxing without head impacts probably increases its appeal. The results of preliminary field trials with a modified, low-risk form of boxing suggest that a larger trial may be justified. Success of a larger trial is likely to depend on the degree of medical, scientific and other support that can be obtained. The trial would have to be carefully planned to ensure that an assessment could be made of the potential of the modified sport to achieve the purpose for which it was designed, rather than just subsidiary purposes.

Further fieldwork on a modified form of boxing will need to be surrounded by research. Refinement of specially designed impact-absorbing gloves is required as part of a quest for continuous improvement of safety. Equipment costs will have to be reduced, and an understanding of demographic and socio-cultural factors associated with uptake of the modified sport will need to be sought.

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Chapter 3: Why Do Community-Based Athletes Choose to Participate in a Modified, Low-Risk Form of Boxing?

3.1. Declaration for chapter 3

Declaration by candidate

In the case of Chapter 3, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC ? Y/N
Allan Hahn	Contributed to data analysis and assisted with manuscript preparation.	No
Richard Keegan	Contributed to study design and the preparation of manuscript.	No
Irmani Collis	Contributed to data collection and manuscript preparation.	No

Candidate's Signature **Date** 22/03/2019

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1:	Allan Hahn	25/3/2019
Signature 2:		26/3/2019
Signature 3:	I Collis	5/4/2019

3.2. Prologue

After reviewing the literature and reaching the conclusion that pursuit of a modified form of boxing was justified, it was noted that future fieldwork carried out as part of this pursuit should be surrounded by research, some of which should be directed toward understanding factors influencing uptake of the modified sport. My role as coach of a modified boxing program afforded me an excellent opportunity to undertake this research. I did so in several distinct ways. At the end of every training session, I had discussions with participants to identify which aspects of the sessions they had most enjoyed and valued, and which aspects they felt could have been excluded or differently organised. I documented the outcomes of these discussions in my reflective journal and adjusted the program based on emerging trends. Additionally, I structured the training program so that sessions focused primarily on fitness development were held on three evenings per week, while sessions concentrated on learning of skills were held on two evenings per week. Attendance at the two different session types, and changes in the relative attendance over time, provided a general indication of participant predilections. The data revealed that both session types were widely appreciated, with the skill sessions increasing in popularity over the course of the program. A third approach was implemented after two years of program operation, and entailed conduct of in-depth, semi-structured interviews with three program participants who had maintained their engagement throughout the whole of that period. The outcomes of this approach were documented in a published paper, which is reproduced below.

The paper contributed to meeting three of the six research aims identified in Chapter 1, as follows:

- **Aim 3:** To investigate the need and want for a modified and safer form of boxing.
- **Aim 4:** To implement a modified boxing program in a community setting and liaise with participants through everyday conversation, formal interviews and written surveys, thereby developing deep understanding of their perceptions of the program and enabling program refinement.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

3.3. Published paper 2 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Why Do Community-Based Athletes Choose to Participate in a Modified, Low-Risk Form of Boxing? An Interpretative Phenomenological Analysis.

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3.3.1. Abstract

Over the past eight years a modified, low-risk form of boxing known as Box'Tag has emerged in Australia. It has been designed to emphasise high levels of fitness, skill and personal enjoyment, while excluding those aspects of traditional boxing that have raised medical, ethical and legal concerns. Strikes to the head are prohibited, as are any impacts above a moderate level of force. Although uptake to date has been encouraging, a question remains as to whether Box'Tag can be developed in a way that will lead to sustainable large-scale community participation.

Presently, there are only a few exemplar clubs where Box'Tag programs are being conducted. The purpose of the current study was to investigate, analyze and interpret one of these programs to discover the factors that have influenced a number of community-based athletes to have a two-year involvement with a modified, low- risk form of boxing. This was accomplished by allowing the participants to recall their experiences free of any judgment and by making sense of their perceptions through an interpretative phenomenological analysis. Sustained participation in Box'Tag appears to have resulted from a sense of belonging to a special community, strong coach-athlete relationships, perception that the training is purposeful and a focus on safety.

Keywords: Box'Tag, Interpretative phenomenological analysis, Modified boxing, Qualitative inquiry, Sport for development.

3.3.2. Introduction

Boxing is a subject that has long been debated [1]. Since the 1860s the sport has diverged into two clearly differentiated forms - professional and amateur [2]. The evolution of professional boxing has been driven largely by profit motives whereas amateur boxing has placed greater emphasis on the welfare and safety of participants. At present, though, amateur boxing is changing and starting to resemble its professional counterpart [3] and this is perhaps creating a need for a new version of the sport.

Common objections to boxing are that it exposes participants to risk of serious brain injury and even death [4], involves deliberate intent to harm the opponent [5] and consists of activities that under other circumstances could result in the perpetrators being convicted of criminal assault [6].

Concerns also have been raised that boxing might have negative social effects by glamorizing and modeling physical violence and that it entails exploitation of vulnerable young people [7]. Based on the objections, there have been calls for boxing to be outlawed [8] and in some countries a ban on professional boxing has been implemented, though in most cases it has subsequently been rescinded.

Supporters of boxing dispute many of the objections and contend that the sport has numerous positive features. For example, they point out that boxing is an excellent vehicle for development of physical fitness and that boxing-related activities are being widely used in attempts to address the global problem of increasing incidence of diseases caused by sedentary lifestyles [9]. In addition, it is claimed that boxing can build desirable personality traits [10] and can yield considerable social benefits in disadvantaged communities where few sporting opportunities exist [11].

Several experts have noted that the sport has important aesthetic and symbolic qualities that have allowed it to act as a medium for transmission of artistic and cultural values and an agent of social change [12,13].

Given that some of the arguments both for and against boxing can be seen as having merit, a question arises as to whether it might be possible to develop a new form of the sport that overcomes the objections while retaining the beneficial elements. A leading medical authority has suggested specific modifications, including exclusion of the head and neck as targets and the introduction of special gloves with greatly increased capacity for impact absorption [14].

A modified form of boxing called Box'Tag incorporating these recommendations and other safety measures has recently emerged in Australia. It has gained a foothold in a few exemplar clubs but its potential for widespread uptake remains uncertain.

3.3.3. Overview of research strategy

An interpretative phenomenological analysis (IPA) was used in the present study to discover the significant factors that have influenced community-based athletes to have a two-year involvement with a Box'Tag program operating at Erindale in southern Canberra, Australia, where a Box'Tag Field Research Centre has been established through a partnership between the Canberra Police Community Youth Club (Canberra PCYC) and the University of Canberra Research Institute for Sport & Exercise.

The study was framed by a constructivist ontological understanding that the individuals could construct different versions of the reality and guided by an epistemological orientation that the researcher and participants are linked and will construct the knowledge together [15-18]. A comprehensive account of interpretative phenomenological analysis has been provided by Smith et al [19]. However, for this paper it is sufficient to understand IPA as a particular qualitative approach that was developed by Jonathan Smith during the mid-1990s. It should be considered as a methodology in its own right rather than simply a means of analysing data and is based upon the fundaments of phenomenology, hermeneutics, and idiography [20,21].

IPA rigorously explores how individuals make sense of their experience and acknowledges that the researcher's interpretations are necessary in order to understand the personal world being studied [19,22]. Instead of attempting to provide a definitive account of a certain experience, IPA researchers engage in an interpretive activity to provide an understanding of the phenomenon based on the narrative or written account of the participant. This approach has been termed 'double hermeneutics' and involves the researcher attempting to understand the participant, who is trying to make sense of their personal experience [19].

It has been reported that some phenomenologists are reluctant to use specific steps to report their research and that imposing a method on a phenomenon could do a great injustice to the integrity of that phenomenon [23]. However, as most members of the current research team are new to phenomenological research, use of a structured, sequential approach was found to be beneficial.

The literature concerning interpretive phenomenological analysis indicates that there is no correct sample size that should be used to establish saturation. However, IPA's idiographic approach usually reflects a small sample size as the preferred method to understand the 'depth' of the experience, and not the 'breadth' of it [19].

3.3.4. Ethical clearance

Ethics approval for this study was obtained from the University of Canberra Human Research Ethics Committee. However, it also should be noted that the principal researcher had a prior prolonged engagement with the participants through his role as coach of the Erindale program. His work in this capacity provided the opportunity for close working relationships, trust and rapport to be established with a majority of the athletes. As suggested by Cohan and Crabtree [24], the development of rapport and trust facilitates understanding and co-

construction of meaning between researcher and subjects. The Erindale program members who volunteered for this study were provided with sufficient information to ensure that they had adequate understanding of the risks, benefits and purpose of the research, but the participants were also advised that they could elect to disengage with the study at any time and that this choice would not predispose them to any prejudicial judgment and/or exclusion from the training environment. The purpose of providing potential participants with information about the study and seeking their consent was not merely a matter of satisfying a formal requirement. The aim was to develop a mutual understanding between the participants and the research team [25].

3.3.5. Methods

It has been suggested describing a phenomenon in sufficient detail enables readers to evaluate the extent of the conclusions and decide how they might be transferable to other times, settings, situations, and people [24]. For these reasons the following steps were used for this qualitative inquiry:

3.3.5.1. Selection of participants

In keeping with the belief that phenomenological researchers need to utilize a sample that has directly experienced the phenomenon being investigated [23], a purposive sample was chosen for the study. This was done by purposefully selecting athletes who had at least two years of experience with the Erindale Box'Tag program and were thought to be the most capable of providing the researchers with a thick description of their experience [26]. It was hoped that having these provisions in place would enable the participants to provide varying first-hand accounts of the experience that when analyzed would create a detailed understanding of the Erindale Box'Tag experience [27]. In the end a 'thick' and 'rich' description of the experience was provided by three female athletes aged 27-44 yrs (M=35.7 yrs). They are introduced below, although pseudonyms have been used to protect their identity.

- **Molly:** Is 28 years old, has no children and has been attending training three nights a week for the past two and a half years.
- **Jane:** Is a mother of two, who is 36 years old and has been a member of the club for a little over two years.
- **Susan:** Is 44 years old and has no children. Susan has developed her physical, technical and tactical qualities during a two-year involvement with the program.

3.3.5.2. Data generation

There are normally two ways in which researchers can generate data when using a phenomenological approach - conducting interviews, or utilizing a written account of the experience [28]. The current study collected data from in-depth interviews as a means of obtaining first-hand accounts of the participants' training and competition experience. The interviews were held in a private office located at Canberra PCYC. Each interview was audio-recorded and later given to a professional transcriptionist to transcribe the recordings verbatim. Before proceeding with the analysis phase, the transcripts were provided to the participants to confirm and verify their personal accounts.

3.3.5.3. Interview technique

Participants were interviewed separately by the principal researcher from whose perception the interviews were much more like a conversation between two friends than a formal question and answer session. This was probably due to the close bond that already existed and the fact that the participants and the researcher/coach regularly engaged in pre- and post-training discussions.

During the interviews the participants were initially asked a single open-ended question – '***Can you please tell me about your experience with the program?'***. The descriptions were investigated further by use of additional open-ended **'probes'** or **'prompts'**. This provided an opportunity for the participants to explore their personal experiences and give a more detailed account of their participation in the Erindale program, as evident in the figure below.

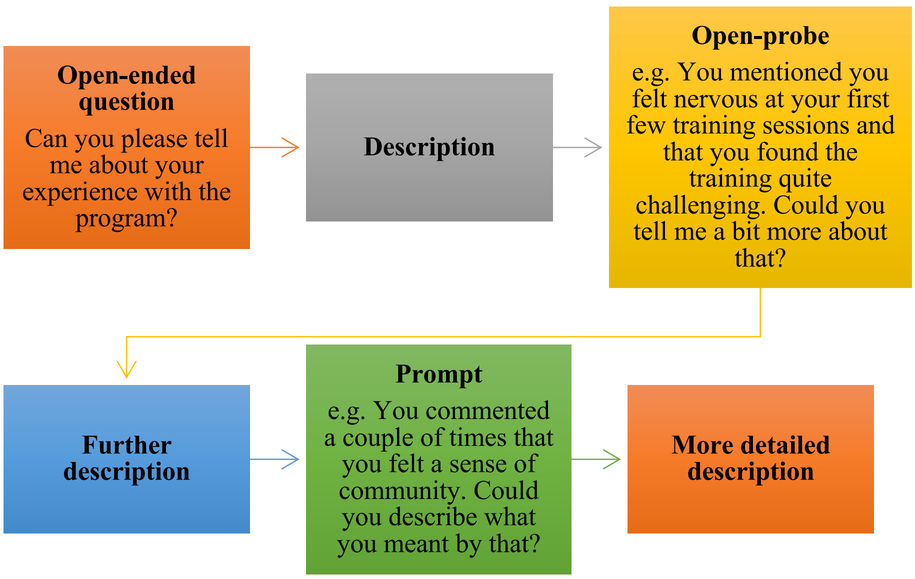

Figure 1: Overview of the interview process that was utilized to gather a rich and detailed account of each participant's experience with the Erindale Box'Tag program.

3.3.5.4. Data Analysis

In an attempt to ensure that the research objectives were met**,** the idiographic approach of analysis outlined by Smith et al [19] was followed and the participants' transcripts were rigorously explored one case at a time.

The individual accounts were then compared to identify the recurring themes within the group. The group themes that emerged were used to provide a detailed summary of the project. Figure 2 illustrates the evolutionary process of the analysis.

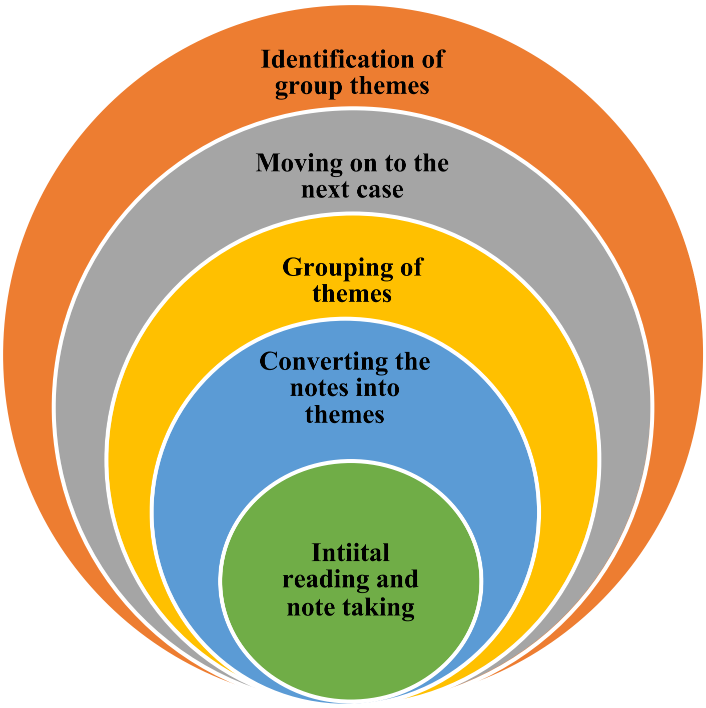

Figure 2: Schematic illustration of the steps by which data were analysed.

3.3.5.5. Initial reading and note-taking

The first step in the analysis process proved to be a highly time-consuming activity. It consisted of reviewing the text of the first transcript a number of times. It was found that re-reading the text provided a deeper understanding of the participant's interpretations. At this initial stage a record was simply made of any word or sentence considered potentially significant. Further exploratory notes were developed from additional reading, reviewing and then reflecting as shown in Table 1.

3.3.5.6. Converting the notes into themes

This stage entailed working mostly with the notes that had been developed and not as much with the transcript. The aim was to identify emerging themes and structure them into concise phrases. This was achieved by employing the strategies outlined by Pietkiewicz and Smith [20] and selecting the comments that were considered to be at a slightly higher level than abstract. Once identified, these emerging themes were listed in a separate column for further analysis. Table 2 is an example of the way in which emerging themes were selected from the original transcript.

Table 1: Illustration of approach through which transcript for each participant was initially explored.

Original Transcript	Initial Thoughts	Exploratory Comments
Interviewer/Me: *Can you please tell me about your experience with the program?* **Interviewee/Participant:** *It's been a lot of fun but also extremely challenging and rewarding- I really enjoy training here, there's a real sense of camaraderie.*	Jane described her experience as being fun, physically challenging and very rewarding. A feeling of sharing the experience with others is seen as important.	There is a sense of enjoyment and goal attainment with the training. The program provides a positive and rewarding experience for Jane. There is an emphasis on team work (Page 1, Paragraph 2, lines 1-4). Why is this so?

Table 2: Example of approach to conversion of initial thoughts and exploratory comments to emergent themes for each participant.

Initial Thoughts	Exploratory Comments	Emerging Themes
Jane described her experience as being fun, physically challenging and very rewarding. A feeling of sharing the experience with others is seen as important.	There is a sense of enjoyment and goal attainment with the training. The program provides a positive and rewarding experience for Jane. There is an emphasis on team work.	A great deal of personal satisfaction is achieved by Jane when she successfully masters challenging exercises and complex training drills. Jane experiences a sense of community

3.3.5.7. Grouping of themes

This phase of the analysis involved an attempt to discover the similar patterns in the emerging themes. The purpose here was to group the related cases together based on their theoretical similarities. The process involved developing themes for the entire transcript before eliminating the ones that did not appear to fit in with the emerging structure. Once identified, the major themes were grouped together in a table based on their conceptual nature as evident in Table 3.

Table 3: An interpretative phenomenological representation of the major themes arising from the original transcript.

The experience	The coach	The training
Positive Challenging Rewarding Exciting	Positive Supportive and encouraging Knowledgeable Empowering	Physically and mentally challenging Safe Structured Positive Purposeful

3.3.5.8. Moving on to the next case

In keeping with the idiographic commitment of IPA the other two transcripts were comprehensively explored one case at a time. Rigorously following the same process for each case separately allowed new themes to emerge independently of each other.

3.3.5.9. Identification of group themes

By comparing the data of the three individual tables it was possible to develop the major themes for the group. This process involved identifying and selecting the recurring themes that connected the separate versions together and that when combined would provide a richer account of the group experience [19].

3.3.6. Results

An analysis of the group data revealed three predominant themes. However, it is worth noting that these themes were underpinned by a number of overlapping and intertwined descriptions and comments. For example, when describing the environment the participants expressed it as challenging and rewarding and then they reused the same words to define the training.

Presented below are the three major themes that represent the contributing factors that have influenced Jane, Susan and Molly’s two-year involvement with the Erindale Box’Tag program:

- **The program provides a sense of belonging**
- **The coach-athlete relationship**
- **The training**

3.3.6.1. Theme 1: The program provides a sense of belonging

The emergence of the first theme highlights a fundamental and very important human desire. According to Bollen and Hoyle [29] a sense of belonging measures individuals’ perceived social cohesion to groups and/or environments, and occurs when the defining attributes, or characteristics of the concept, are evident [30]. Susan described how she felt a sense of belonging when she said *“The environment itself is a major factor why I come here. In the couple of years previously I’d joined a couple of gyms in the hope of losing weight and knew that physical activity can help with depression. But in those environments I became more self-conscious. I didn’t feel comfortable because of the type of people that frequented them and the lack of support and encouragement. So in some instances I only went in once and then didn’t return, but at the PCYC I didn’t feel there was any judgment or criticism of me - physically or otherwise, I just felt really comfortable. I immediately felt part of something quite unique. I could see that it was having a positive effect on me in a really short space of time. I felt like I was a part of something special - like doing the run through and slapping hands; it’s like an acknowledgement of being there and finishing the session. So there are lots of little things I think that add up to just a really big impact”*.

Molly shared this view when she noted *“ There’s really good camaraderie here and it feels like you’re part of something unique. I think it’s a really supportive and positive environment, like everyone’s really encouraging. Everyone wants to do their best and you encourage us all to make sure we do. I think that’s always nice in a sort of environment like this. I think if you’ve got a good environment you’re more likely to put in extra effort. Whereas, if you’re not really having fun and not with people who have similar values you’re just going there for the slog, then you do your thing and you leave. Whereas having people around you, who all want to perform to their best, then I think that always makes a big difference to how well you perform, which in turn affects everything”*.

When recounting how she felt a sense of belonging, Jane said*" I've been training for two years now and I guess to keep at something for two years, for me, says that I really enjoy it. There's definitely a sense of community with the training group and a feeling of knowing and respecting each other. It is a very supportive and positive place to train"*.

3.3.6.2. Theme 2: The coach-athlete relationship

A positive and supportive coach-athlete relationship has been described as important for enhancing the motivation of athletes [31] and for developing athletic performance [32]. The importance of the coach-athlete relationship for Susan, Molly and Jane is evident from the comments below. *"I've never felt ever that someone would think of me as an athlete. So I think, fundamentally, just putting that out there and saying you're athletes and you're not just coming off the street and trying to get fit, you're actually skilled and you'll become more skilled through consistent training and a desire to continually improve. Having those expectations on you and rising to meet those challenges I think is primarily the major difference with what we do"* – **Jane**. *"I've never considered myself as an athlete but now I do, and it has made such a difference with the way I view my training and has even changed my outlook on life. Like I mentioned earlier the reason I started attending was because I was overweight and suffering from depression. I think it's amazing the positive effect this has had on my life – training here has got me out of a space that was really unpleasant and uncomfortable to be in"* - **Susan**. *"There's a sense of working together when we train - it's always encouraging and very supportive. Even though you're the coach it's not like you're saying I'm the boss, I know everything and you can only do things my way. It's more like you want to help and support us to become the best we can be"* – **Molly**.

3.3.6.3. Theme 3: The training

Two different but equally important sub-themes emerged as the most significant factors concerning the training.

Providing purpose: This sub-theme illustrates how a progressive, structured and carefully planned training program enhanced the training experience for Molly, Jane and Susan and contributed to their two-year involvement with the program.

Jane revealed how her training provided a sense of purpose for her when she compared it to a previous experience. *"Before this I did other types of training but when I was doing gym classes, I quickly realized I was just a number and basically following a person out the front* *who was telling everybody what to do. There was no real focus on what you were doing, basically it's just doing something without any purpose or understanding why. What I find with this program though is a rationale for the training and a focus on progressing, which brings everything together".*

Later in the interview Jane went on to explain how experiencing Box'Tag competition provided further meaning for her training when she added. *"While I was in the ring I wasn't thinking about I have to hit, I have to win – I was thinking about, what's my next move? All this stuff we'd been learning was going through my head. I guess I was suddenly seeing everything I'd been doing, it was like, OK now, I understand what I've been doing and it felt great, because every week I'd be learning and developing and, all of a sudden, the application of it worked out and made so much sense".*

Susan echoed Jane's comments when she shared her thoughts about competition. *"Being in the ring with someone you've been training with is a great opportunity to display some of the things that we've learnt. I felt that even though nothing was said we were able to acknowledge each other's training and the amount of hard work we had put in. It was after my first competition that I recognized how everything we've been doing fitted in".* Susan went onto describe how the progressive nature of the training provided a sense of purpose for her by explaining. *"It's been two years now and I still get a buzz and excitement from the training. It's like each time we train, you discover how to do something a little better. Looking back, I can see how everything we do is linked and how it all connects. Even some of the stranger exercises like hopping while you punch makes sense to me now. I guess I had never really made the link before".*

The training also proved to be meaningful for Molly, who described it as *"having a reason and a real purpose to it".* When asked if she could elaborate on what she meant by this, Molly replied, *"Well, I've never felt like we train just for the sake of it, there is always a reason for everything we do. Like, we learn skills at some of our sessions and develop our fitness at other ones and then put it all together by demonstrating our fitness and skills in the ring".*

A focus on safety: The importance of participating in a modified, low-risk form of boxing with an emphasis on safety quickly became apparent in all three interviews. The focus on safety is evident from the following extracts.

"I guess I've always been a little worried about being punched, even though I know it's modified and you can't get hit in the head I still worry a bit about being punched hard. So for me, the development of the new gloves has been very important and demonstrates a real focus on providing a much safer form of boxing. There's just no way I can imagine these things hurting you, even with as much force as someone wanted to put behind them, so for me the fear of getting hurt is gone"- **Susan**. *"I've always been interested in boxing as a sport, my eldest brother used to watch boxing and he would talk to me about it. He would talk about the strategy – he appreciated the finer points rather than the hitting. So I guess that influenced me to want to learn boxing but I never really pursued it because I wouldn't want to get hurt, so for me Box'Tag has been perfect - I get to learn the skills, get fit and train like a boxer but know I won't get hurt"* – **Jane**. *"I'm not interested in boxing and I certainly wouldn't want to punch someone in the face, or have mine punched for that matter but what we do is different. There's a strong emphasis on safety and having fun, everyone knows it's not about trying to hurt each other and that comes through really clear with your coaching"* **- Molly**.

3.3.7. Discussion

The present study utilized an interpretative phenomenological analysis to discover the contributing factors that have influenced three community-based athletes to have a two-year involvement with a modified, low-risk form of boxing.

For Molly, Susan and Jane a sense of belonging was perceived as *'essential'* for their continued engagement with the program. This finding is consistent with the observations of other researchers [33,34] who provide examples of how sporting programs and recreational actives can give participants a sense of belonging.

McMillan and Chavis [35] argue that there are a number of elements required to facilitate a sense of belonging between individuals and a community – or in this case athletes and a sporting program. They regard ***'faith'*** as an important first step in the process and describe how individuals wanting to belong maintain a certain belief that they will be accepted. Having this faith represents a risk and requires a certain amount of courage on the part of the individual, as they could be embarrassed and humiliated if they are made to feel unwelcome by the community. The following statement from Jane demonstrates how she acted with good faith when she wanted to be a part of the program. *"It was quite challenging at first, coming in. I was a little nervous and intimidated, I was unsure if I would fit in but I really enjoyed the training and the atmosphere and wanted to keep coming"* – **Jane**.

The second element regarded by McMillan and Chavis [35] as critical to development of a sense of belonging is ***'acceptance'*** as an indication of the community's response to the display of faith. It is contended that communities have a responsibility to accept individuals and welcome them as members once an individual has acted with good faith, and when the acceptance occurs the individual develops a stronger attraction to the community. Bonds are developed between people when they believe they are wanted and welcomed. In the context of the present study, the development of this bond is evident in the following passage: *"I didn't feel like I belonged straight away but I always felt really welcomed"* – **Jane**.

'Cognitive dissonance' is the third requirement identified by McMillan and Chavis [35] for facilitation of a sense of belonging. It is considered essential that communities test new members to determine if they are willing to invest time and effort into becoming active and effective contributors. This idea of 'having to pay her dues' before she felt accepted was described by Jane when she said *"I found I had to put in before I got a sense of community – it was like I was being tested to see if I would stick with it, then it morphed into this feeling like I belong"*.

Molly, Susan and Jane also identified the coach-athlete relationship as an important influence for their two- year affiliation with the program and described the coaching as *"empowering, supportive and personal"*. The emergence of this theme suggests the autonomy-supportive coaching approach utilized in the program could have positively influenced the motivation and satisfaction of Molly, Susan and Jane, resulting in their prolonged engagement. This suggestion is consistent with the views of Deci and Ryan [36] and Vallerand and Losier [37]. They believe that social factors (in this case the behavior of the coach) can influence athletes' motivation indirectly by satisfying three psychological needs - competence, autonomy and relatedness - which, in turn, can nurture athletes' intrinsic motivation and self-determined types of extrinsic motivation. Mageau and Vallerand [38] have presented seven coaching behaviors that may assist in promoting athletes' perception of competence, autonomy and relatedness: (1) providing athletes with choices; (2) providing athletes with rationales for tasks; (3) acknowledging the feelings and perspectives of athletes; (4) giving athletes opportunities for initiative-taking and independent work; (5) providing athletes with information and feedback regarding their competence on a task or skill; (6) avoiding controlling behaviors; and (7) creating a task-focused rather than ego-focused environment.

It would appear that Molly, Susan and Jane have identified with some of these coaching behaviors, resulting in the development of three very positive and supportive coach-athlete relationships and the creation of a training environment that assists in nurturing and developing the self-determining motivation of the athletes.

The final theme that emerged from the analysis was a focus on the training. For Molly, Susan and Jane the training was perceived as being *'purposeful'*, *'challenging'* and *'rewarding'*. This finding is consistent with the literature on sport participation, which indicates that a sense of achievement, skill development, fitness enhancement, increased levels of self-esteem, enjoyment and family and social influences are the significant motivators for participation in sport and/or other physical activities [39-41].

The perception of benefit associated with training incorporating a sense of purpose is also compatible with the observations of Wacquant [11] who conducted a comprehensive three-year ethnographic study of a boxing gym in a Chicago ghetto. He discovered that the boxers who frequented the gym considered training an integral part of their lives. The boxers believed that training provided the opportunity to develop the physical attributes and technical proficiencies required to be successful in boxing. They felt that success in boxing required preparing the body to withstand the physical demands of the sport and developing technical skills that could only be acquired through many years of rigorous, dedicated practice [11].

The dedication and commitment to training as well as the willingness to undergo many hours of hard work in the quest for developing and improving relevant physical qualities and technical skills is as evident for Molly, Susan and Jane as it was for the boxers studied by Wacquant. However, the '*emphasis on safety'* described by Molly, Susan and Jane as being *'extremely important'* is at odds with the opinion of the boxers. The participants in this study considered *'not being able to hit to the head'*, *'using impact absorbing gloves'* and *'not intentionally harming anyone'* as *'vital'* for their involvement with the program. These views are totally inconsistent with the boxers' perceptions - they accepted the possibility of being injured and considered the risk as a part of their job. Nonetheless, 80% of the boxers indicated they would not want their children to be involved with boxing [11]. Although the reasons for the boxers' concerns are not expressly outlined, it is reasonable to conclude that the boxers had some misgivings in regard to exposing their children to the inherent dangers associated with boxing participation.

The Erindale program's '*emphasis on safety'* is based on unequivocal evidence that participation in boxing entails serious risk. It has been estimated that the condition popularly known as punch-drunkenness develops in about 20% of professional boxers, and there is evidence that amateur boxers can also incur neurological damage. Ongoing improvements in the regulation and medical supervision of professional and amateur boxing might reduce the inherent injury risks associated with the sport but cannot eliminate them [42-44]. It should be noted that Molly, Susan and Jane considered these risks as *'unnecessary', 'avoidable'* and *'inappropriate'* and noted that the emphasis on safety has a major influence on their involvement with the Erindale program.

3.3.8. Conclusion

Although the current study provides a detailed and rich description of athlete experiences of the Erindale Box'Tag program, the findings are limited to the responses of three participants and therefore cannot be considered as necessarily providing a representative view of all people involved in the program. Nevertheless, it is hoped this paper can act as a suitable starting point for future pertinent research. Interviewing additional athletes from the Erindale program and including the perceptions of some of the younger athletes and the views of their parents could significantly increase the understanding of why some people are choosing to participate in a form of boxing that is much safer than the traditional version.

Alternatively or as well, further research that examines each of the major themes presented in this paper could be conducted. For example, in the current study the participants considered the coach-athlete relationship as a significant factor for their prolonged engagement with the program. However, Molly, Susan and Jane did not fully describe why they thought the coaching was effective. Therefore future research into the perceived coaching practices that have influenced participation in a modified, low-risk boxing could prove to be instructive.

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Chapter 4. What are the perceived coaching practices that have contributed to participation in a modified, low-risk form of boxing?

4.1. Declaration for chapter 4

Declaration by candidate

In the case of Chapter 4, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC ? Y/N
Allan Hahn	Contributed to data analysis and assisted with manuscript preparation.	No
Richard Keegan	Contributed to study design and the preparation of manuscript.	No

Candidate's Signature **Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1:	25/3/2019
Signature 2:	26/3/2019

4.2. Prologue

The research outlined in Chapter 3 showed that the interviewed participants in the modified boxing program at the Canberra PCYC saw the coach-athlete relationship as one factor responsible for their sustained participation in the program over a two-year period, but the coach behaviours contributing to this relationship were not specifically identified. A further study utilising the same methodology was therefore conducted to obtain this additional information. Similar to the first study, risk of power imbalance during the interviews (resulting from the interviews being conducted by the program coach) was minimised by:

- Prior development, over a two-year period, of mutual trust and rapport through regular small group and individual pre- and post-training discussions (informal interviews and focus groups).
- Use of a relaxed, interactive and conversational approach to interviewing, and positioning of the interviews as a reciprocal information-sharing experience.
- Connectedness of both the subject and the interviewer to the work, creating a sense of joint endeavour that favoured the willingness of both parties to candidly express their thoughts.
- Implementation of a non-authoritative approach to investigation, underpinned by a constructivist epistemological belief that researcher and participants would be working together to generate new knowledge.

It is arguable that the relationship that existed between researcher and interviewees likely facilitated candour of discussion that would have been difficult for a detached researcher to achieve.

The study was subsequently summarised in a published paper that forms the remainder of this chapter, which aided accomplishment of the following research aims identified in Chapter 1:

- **Aim 4:** To implement a modified boxing program in a community setting and liaise with participants through everyday conversation, formal interviews and written surveys, thereby developing deep understanding of their perceptions of the program and enabling program refinement.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

4.3. Published paper 3 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

What are the perceived coaching practices that have contributed to participation in a modified, low-risk form of boxing? An interpretive phenomenological analysis

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4.3.1. Abstract

Previous research identified several factors that have motivated sustained athlete participation in a modified, low-risk form of boxing. The importance of the ‘coach-athlete relationship’ was highlighted. The present study used Interpretive Phenomenological Analysis (IPA) methodology to identify the particular coaching practices that have influenced this relationship and contributed to continued participant engagement with the program. The findings suggest that providing a holistic approach to athlete development, treating the participants as serious athletes, using modified games to promote skill acquisition and having a focus on athlete improvement rather than competition have been the most influential practices.

Keywords: Box’Tag, Coach/athlete relationships, Community-based athletes, Sport coaching, Sport participation.

4.3.2. Background

The present study is part of a project entailing investigation of the potential for a modified, low-risk form of boxing to achieve significant community uptake. Known as Box’Tag, this modified version of the sport has emerged in Australia over the past nine years. It is designed to add a new dimension to boxing by catering for people who are attracted by the fitness and skill aspects of the sport but do not wish to take part in the conventional form due to risk of injury. The need for such a new dimension in Australia is suggested by low rates of participation in conventional boxing relative to community interest in the sport [1].
In keeping with recommendations from various medical and other experts [2-8] the rules of Box’Tag preclude impacts to the head. Instead, the target zone is confined to the front of the torso and small areas on the upper arms. Even then, any impacts above a moderate level of force are prohibited, and as an additional safety measure contestants are required to employ various items of protective equipment, including head guards and mouthguards [1,9]. In competition settings the scoring of Box’Tag is achieved through the use of an automated scoring system [10] that has been described in detail by Hahn et al [1] and Helmer et al [9]. Participants wear specially constructed vests and gloves that incorporate sensor fabrics. This permits objective impact detection and continuous display of scores [1,9].

Initially, research surrounding the Box’Tag project was directed largely at progressive elaboration of the automated scoring technology and its use in occasional competitions.

However, it soon became apparent that due to substantial differences between Box'Tag and conventional boxing there was a need for design of Box'Tag-specific training programs. In 2012, such a program was established at the Canberra Police Community Youth Club (Canberra PCYC).

The principal author of this paper became the coach. He was able to call on a long history as a high-level boxing coach, but found it necessary and productive to explore a whole range of new approaches.

Some participants in the Canberra PCYC Box'Tag program are now quite long-term adherents and in 2014 research was carried out to identify factors that had motivated sustained involvement [11]. The findings suggested that sustained participation in the program was the result of feeling a sense of belonging to a special community, perception that the training was purposeful, a focus on safety, and strong coach-athlete relationships. However, the participants did not fully describe what coaching practices they considered were the most significant for the building of strong relationships with their coach. Therefore, the present study was undertaken to discover the specific coaching practices that have influenced the development of strong coach- athlete relationships and contributed to sustained participation in the Canberra PCYC Box'Tag program.

4.3.3. Outline and design of study

Interpretative Phenomenological Analysis (IPA) methodology was used to understand how certain members of the Canberra PCYC Box'Tag program make sense of the coaching they have experienced. The study was undertaken at Canberra PCYC where the prolonged relationship between the principal researcher/coach and the participants/athletes has enabled development of trust and rapport. The importance of strong relationships in qualitative research has been highlighted by Cohan and Crabtree [12], Goodwin et al [13] and Payne [14]. These authors have suggested that new meanings can be co-constructed between researchers and participants (co-researchers) when mutual feelings of trust and rapport have been developed. This constructivist epistemological belief that researcher and participants working together can generate new knowledge guided the approach of this interpretative phenomenological investigation [15-18].

IPA is a particular way of doing qualitative research and should be considered as a methodology in its own right rather than just a procedure for analysing data. It is underpinned by three key theoretical perspectives; phenomenology, hermeneutics and idiography [19,20]. The phenomenological orientation of IPA enables researchers to explore and provide rich descriptions of personal experiences [21,22]. The hermeneutic element provides an opportunity to interpret and provide contextual meaning to the descriptions [19,22]. The commitment to idiography allows a detailed and thorough analysis of relatively small numbers of cases [19,21,22].

Smith and his colleague [22] suggest that researchers who use IPA should immerse themselves in an interpretative process that incudes their own interpretations to provide meaning to a particular event based on the thorough examination of the narrative or written account of the participant. These authors define this dual interpretation as ‘double hermeneutics’ and one that involves the researcher attempting to understand the participant, who is trying to make sense of a personal experience [22].

Nevertheless, Larkin et al [21] and Smith et al [22] caution IPA researchers to be constantly aware of their personal beliefs throughout the research process and to use a flexible and adaptive form of bracketing to adjust any preconceptions as these personal beliefs may not become apparent until the phenomenon has started to emerge [21,22]. This approach to bracketing differs from the views of Moustakas [23] and Carpenter [24] who propose that researchers should put aside their personal beliefs and any knowledge of the experience in an attempt to suspend their assumptions.

In the context of the present study, data generated from three coach/athlete semi-structured discussions were individually and rigorously analysed in a way that included an ‘insider’s perspective’ from the principal researcher/coach to provide an interpretive representation of the participant/athlete experience [22,25].

4.3.4. Research procedure

There has been criticism of IPA for not ascribing to a fixed set of methods to obtain the findings. In particular, Giorgi [25] has argued that absence of fixed IPA methods makes the replication of IPA studies impossible. The present study made use of the steps outlined below in an attempt to address this concern.

4.3.4.1. Selection of participants and ethical considerations

The study followed the suggestions of Smith & Osborn [27] and used three participants/athletes to provide a detailed and rich description of the experience. Smith & Osborn [27] consider three participants as an acceptable number for graduate students using IPA methodology as a sample of this size can assist the learning process for the student while producing abundant data for a thesis.

However, because phenomenological researchers need to utilise samples that have directly experienced the phenomenon [28-30] a purposive sample was chosen for the study. It consisted of participants/athletes who: 1: had at least two years of experience working with the coach/researcher of the program, 2: had self-identified that the coach/athlete relationship was a significant reason for their sustained involvement with the program; and 3: were thought to be highly capable of providing a detailed account of the experience.

The participants/athletes who volunteered for the study were informed that the greatest risk associated with their participation was being identified through publication of data collected from them, but that every attempt would be made to prevent this from occurring. The participants/athletes were also advised of the benefits and purpose of the research and informed that they could disengage with the study at any time and that this decision would not result in any prejudicial treatment or exclusion from further participation in the Box'Tag program. The purpose of fully disclosing this information was not merely to satisfy a formal requirement, but also to develop a mutual understanding between the participants and the research team [31].

In the end a 'thick' and 'rich' description of the experience was provided by two female participants/athletes and one male participant/athlete (age range 37-47 yrs, mean = 43.3 yrs). They are introduced below, although pseudonyms have been used to protect their identity.

- **Phil:** Is 47 years old, has 4 children and has been attending training three nights a week for the past two and a half years.
- **Sara:** Is a mother of two, who is 37 years old and has been a member of the club for a little over three years.
- **Gina:** Is 46 years old and has no children. Gina has had a three-year involvement with the program.

It should be noted that the study was conducted as part of the routine program monitoring procedures of the Canberra PCYC, which agreed to make the data available for secondary analysis under an arrangement that was approved by the Human Research Ethics Committee of the University of Canberra.

4.3.4.2. Data generation and interview strategy

Data were generated through three one-on-one coach/athlete discussions that were audio-recorded and later transcribed verbatim. However, because the coach of the program was now performing the role of researcher/interviewer, both parties agreed to refer to the coach in the third person throughout the discussions. Adopting this approach provided an opportunity for the participants to give first-hand accounts of their experience free from any judgment, and in a relaxed and informal environment.

The discussions began with the principal researcher/coach asking each of the participants/athletes the same open-ended question – *'Can you please tell me about the coaching practices you've experienced with the program?'*

The individual accounts were then investigated further by use of a funnelling technique outlined by Smith & Osborn [27]. For example, one of the initial responses to the above question was, *'I'd describe the coaching as supportive, professional and experienced'*. A prompt was then used to 'draw out' the meaning of this reply, *'So having a supportive, professional and experienced coach is important to you?'* To which the participant answered, *'Absolutely, it's crucial that a coach has all of these qualities'.* An open-ended probe was used at this stage to further explore the previous response - '*Can you tell me why you think it's crucial for a coach to have these qualities?'* By this stage of the process a richer description of the original answer was being provided by the participant.

As evident from the example above, the use of this funnelling process throughout the interviews enabled each participant to reflect on his/her initial response and offer a more detailed explanation of the coaching practices they experienced.

The interview transcripts were provided to the participants for their confirmation and verification as a prelude to commencement of the data analysis phase.

4.3.4.3. Data Analysis

The transcripts underwent an interpretative process similar to one that was previously used by the research team in an attempt to understand the perceptions that have influenced a number of community-based athletes to have a two-year involvement with a Box'Tag program [11].

The process began with each transcript being thoroughly examined, scrutinised and notated. For each individual, the notes were used to establish themes, which were then arranged into categories based on similarities. Once this was completed the individual results were compared to identify the overall themes for the group. The major themes that emerged were then used to provide an interpretative summary of the overall study. The procedure is shown in the illustration below (Figure 1) and described more fully in the subsequent text.

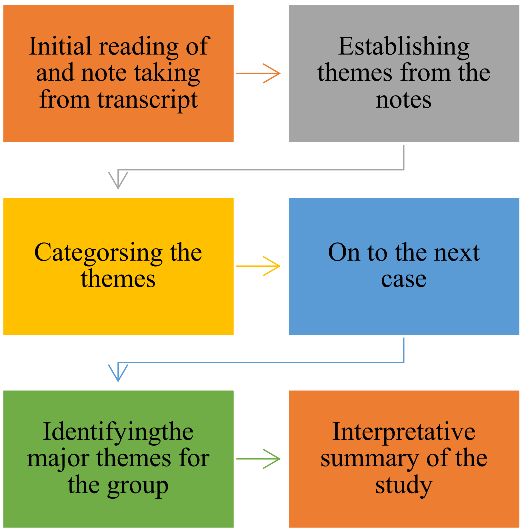

Figure 1: An overview of the steps by which data were analysed. The process provided an opportunity for the interpretation of the individual accounts and the emergence of the group themes.

4.3.4.3.1 Reading and note taking

The initial stage of the analysis involved reading and reviewing the first transcript a number of times. The purpose was to identify any sentence or word considered important. These initial thoughts were then recorded on a separate page for further reading, review and reflection that resulted in the development of additional exploratory comments. Smith et al [22] consider this first step as a way of moving from the descriptive to the interpretative because the researcher has already begun to question the meaning of the texts.

Figure 2 below provides an example of how the exploratory comments were developed from the original transcripts.

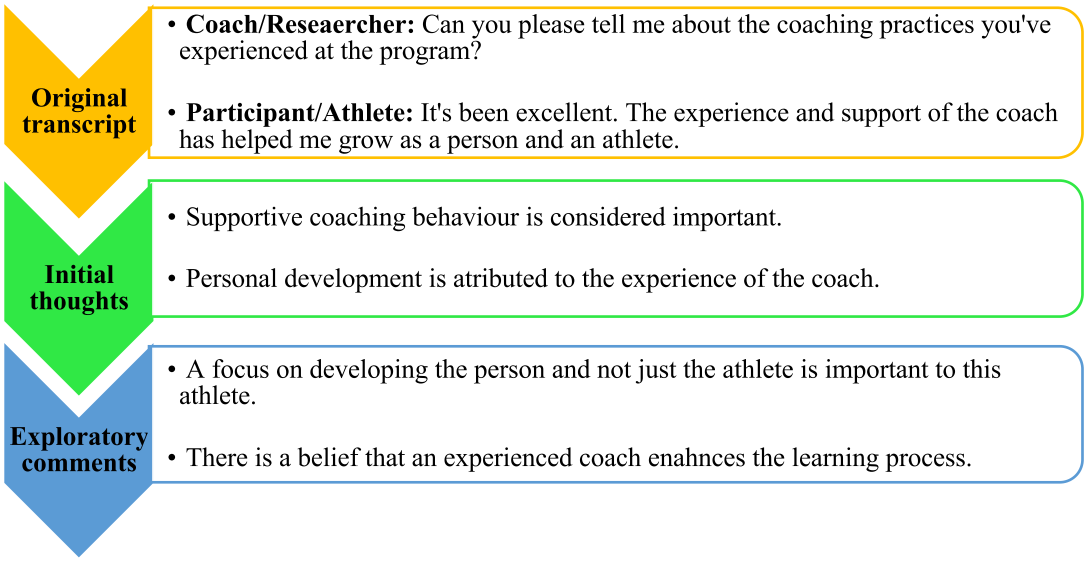

Figure 2: An illustration of the approach through which each transcript was explored.

4.3.4.3.2. Establishing themes from the notes

The purpose of the second step was to identify the emerging themes and construct them into short, meaningful phrases. At this stage of the process there was a shift away from the transcript and more of a focus on the initial thoughts and exploratory comments. Once identified, the themes then underwent further analysis. Figure 3 shows how the themes emerged from the notes. A connected trail can be seen that shows how the initial descriptions were interpreted in an attempt to provide meaning to the participants' points of view.

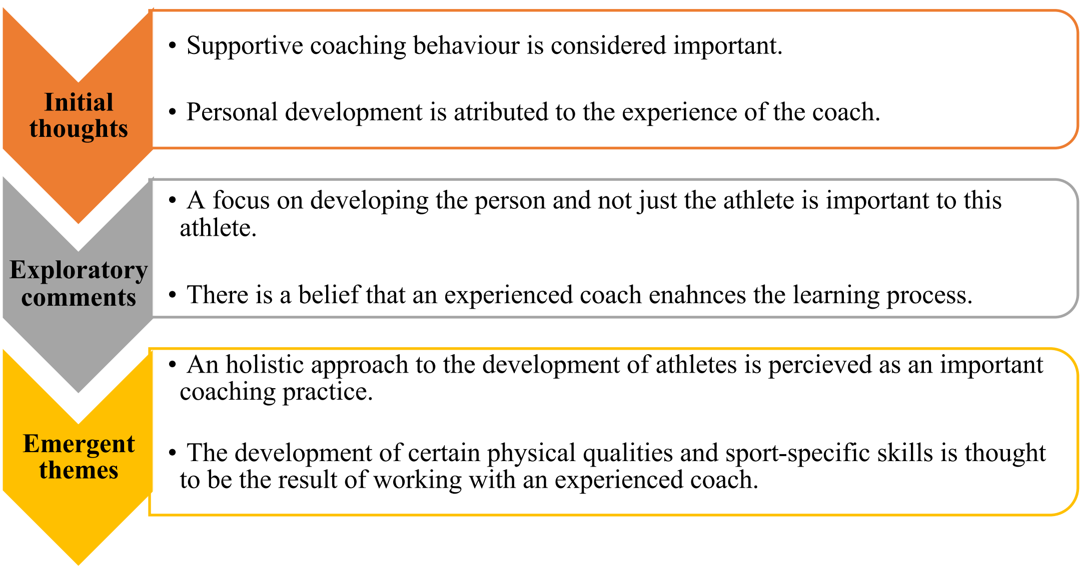

Figure 3: The approach used to convert the initial thoughts and exploratory comments into emergent themes.

4.3.4.3.3. Categorising the themes

An attempt was made during this phase of the analysis to discover commonalities among the emergent themes. The process included eliminating initially identified themes that did not appear to fit in with the evolving structure [22].

Once ascertained, the major themes for the first transcript were grouped together based on their conceptual nature as exemplified in Figure 4 below.

4.3.4.3.4. On to the next case

IPA requires researchers to remain committed to an idiographic approach when analysing data [19,22]. Therefore, the two remaining transcripts were rigorously explored one case at a time. Meticulously following the same process for each case separately enabled the emergence of new themes that were independent of each other.

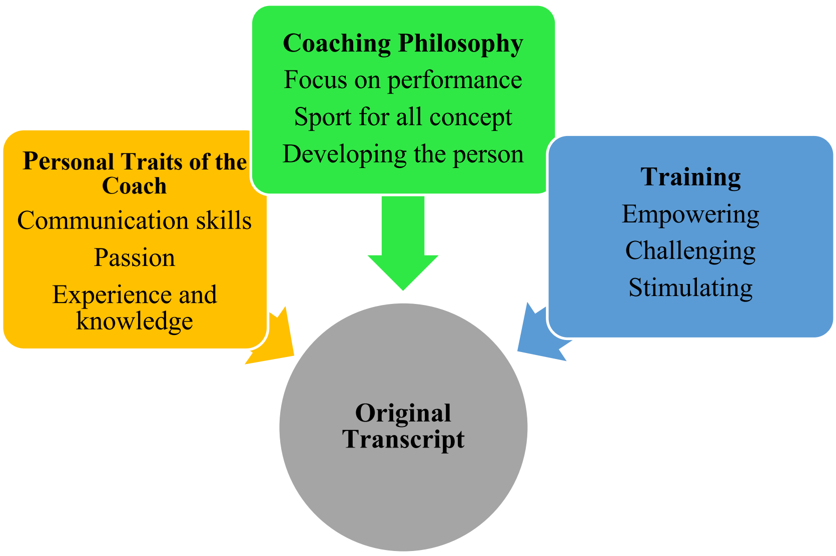

Figure 4: An Interpretative Phenomenological Analysis of the major themes arising from the first transcript.

4.3.4.3.5. Identifying the major themes for the group

The aim of the final phase of the analysis was to compare descriptions and comments from each of the individual tables and select the major themes for the group. This process involved placing the three individual tables beside each other and selecting the recurring themes that appeared to connect the separate versions together and that when combined would provide a richer account of the group experience [22].

After careful consideration and a thorough examination of the texts four predominant themes were eventually produced that present an understanding of the particular coaching practices most positively regarded by the three community-based athletes.

4.3.5. An interpretive summary of the study

The following summary reflects the 'double hermeneutic' approach of IPA by presenting an interpretative account of the participants' experience [22]. The major themes that emerged from an analytical interpretation of the participants' transcripts and that described particularly valued coaching practices that appear to be supportive of participation were:

- Being more than just a coach
- Treating participants as serious athletes
- Using modified games to promote skill acquisition
- Focus on athlete improvement rather than competition

It is important for IPA studies to present the major themes in order of significance [22]. The following sequence of themes accords with this requirement.

4.3.5.1. Theme 1: Being more than just a coach

The participants in the current study explained that for them a coach is someone who does much more than simply teach a sport. They saw an ideal coach as a passionate, experienced and highly motivated individual who is focused on assisting people to reach their potential in and out of the training area. As noted by Phil *'It's great that the younger guys are able to develop and grow here. I know training here has helped my son a lot'*. When asked how he thought being involved with the program had assisted his son, Phil said *'Well, his attitude towards schoolwork has changed a lot since training here. He's really focused now and I think it's because coach is always talking to him about the importance of education and the need to always do his best. (laughter) I should've brought him here years ago'*.

Participants also discussed the skills and personal traits that they thought were necessary to be a coach and opined that being able to manage complex situations, plan thoroughly, communicate effectively and generally care about people were the most salient. The participants concluded that a coach should use these skills to help develop the athletic qualities and technical proficiencies of the athletes, but also to assist with the overall development of the athletes by supporting them in other areas of their lives. This was particularly true for Sara who identified the *'care factor'* as the catalyst for her prolonged participation when she said. *'I'd say the care factor has been one of the main reasons I'm still involved with the club'*. Sara was then asked if she could elaborate on her response and added *'It's because the coach really cares about the people and from what I've seen and experienced has a positive influence on their lives'*. Gina echoed these thoughts when she said *'I think our environment is more focused on developing the person so it's not just about the training for me. It's the fact that the coach cares about everyone and wants the best for us'*.

The descriptions suggest that an approach to coaching focused on the overall development of the athletes with sport used as a vehicle to contribute to the wellbeing of the athletes has been positively regarded by the participants and could be considered a contributing factor for their continued involvement with the program.

4.3.5.2. Theme 2: Treating the participants as serious athletes

The participants indicated that they valued being regarded as talented and dedicated individuals whose aspirations are just as important as those of elite-level athletes.

For example, all the participants noted that they were welcomed and accepted by the other club members and explained that their quest to become better athletes was treated with sincerity and enthusiasm by the coach. As noted by Sara, *'During class our coach refers to us as athletes and, for me, it gives me a sense that as participants we are taken seriously, that our coach thinks we are able and that our goals are important'*.

Gina provided a similar response when she said *'I played a wide range of sports when I was younger and I enjoyed them all. However, I never considered myself to be an athlete, I thought the term was more suited and geared towards professional sports people. But, at training coach calls everyone an athlete and treats everyone the same. No one is belittled, excluded or put on a pedestal, creating an environment where everyone is treated with respect and every person is considered important'*.

Participants also noted that individualisation of the training was another indication that they were taken seriously. The individualisation was seen as demonstrating the commitment of the coach getting to know the athletes, understanding the reasons for their participation, and devising programs to meet their specific needs. As explained by Phil, *'Coach understands that we all have different needs and he accounts for this every time we train. I remember one* *time when I had an injury I couldn't do squatting or lunging, so he personalised my training for that period and this allowed me to continue to train with the group without disturbing them'*. Sara noted how her personal needs were constantly met when she said *'Even though the program is a group class, which varies in size from small to quite large, I always know that my needs are going to be met and that I will be supported. There are always individualised things that coach reminds me about that are specific to me'*.

Another somewhat surprising sub-theme that underpins this particular finding suggests that for the participants in this study being able to provide feedback to the coach also indicated that they were being taken seriously. This is apparent in the following passage from Gina, *'Coach always seeks feedback from us. Usually, this is done at the end of the session when we're cooling down. It was suggested a while ago that we could all benefit by using this time to reflect on our performances. The really cool thing is coach takes part in it and everyone's free to say what we liked and didn't like about the session. I find this very beneficial and it reinforces how serious he is about helping us to achieve our goals'*.

The above suggests that a coaching practice that values, respects and takes the needs of community- based athletes seriously by individualising the training process and encouraging athletes to provide feedback has been positively received by the participants and has been an important contributor to their long-term involvement with the program.

4.3.5.3. Theme 3: Using modified games to promote skill acquisition

The use of modified games for skill development was the third theme to emerge from the analysis. The participants described this approach as *'really beneficial'*, *'thought-provoking'* and *'stimulating'* and noted a number of advantages compared to the more traditional method for teaching skills. According to the participants, one of the main advantages was spending more time doing the activities and less time being told how to do them. For Phil, Gina and Sara, this was the result of not having to develop specific skills, or be of a certain level prior to participating in the games. Instead, they all suggested they were able to develop their skills and tactical appreciation of the sport by taking part in training drills that simulated *'real conditions'* and required them to make decisions, respond under pressure and experience the consequences of those actions.

As explained by Sara, *'I really like the trial and error approach at training 'cause whenever we do the game stuff I stop worrying about making mistakes and just focus on what I have to do, then later on it sort of dawns on me and I'm like, I get it now'*.

The participants noted that the use of game-based activities not only facilitated their active involvement in the learning process but also afforded them greater independence.

They valued a coaching practice that encouraged experimental learning by only providing suggestions rather than definitive answers. The benefit of using implicit learning with minimum explicit technical instruction is evident from the following excerpt from Phil, *'I really enjoy the way we train because I'm actually learning more'*. When asked why he thought he was learning more and what makes the training so enjoyable, Phil said *'For me, it's the right combination of trying to do something yourself and having a bit of guidance. I guess after a while we become less dependent on the coach for all the answers and learn more from each other and from simply doing the drills'*.

The use of modified games for skill development appears to have enriched the participants' experience, suggesting that a coaching practice that promotes an enquiry-based approach to learning has assisted development of a strong relationship with their coach.

4.3.5.4. Theme 4: Focused on improving not competing

The final theme to emerge from the analysis was a focus on athlete improvement rather than formal competition. The emergence of this theme suggests that the participants were positively influenced by a supportive and inclusive approach to training rather than a win-at-all-costs attitude. For example, the participants indicated that focusing on improving rather than competing reduced their stress, anxiety and fear of failing. This was particularly true for Sara, who said *'I've always found that I really suck when it comes to competing and even if there was a wisp of any sort of competition I would choke (figuratively) and never do as well as I did in training. This made it difficult for me to want to compete or to even train. But, in our program the focus is always on improving – but not to improve to be compared to anyone else, the sole purpose is to improve myself and as clichéd as it sounds to become better than I have been'*. Gina also supported an approach that focused on continual improvement rather than competition and noted several advantages when she said *'I'm not a competitive person and winning has never been a driving force for me so training here fits in perfectly with my personality. Knowing I can go to training and I won't be compared against other athletes* *eliminates feelings of not being good enough'*. Phil made a similar comment when he compared his current training to a previous experience. *'I grew up playing rugby league and it was all about winning. I used to put a lot of pressure on myself to win, and when this didn't happen I'd end up really disappointed and would put myself down a lot. It hasn't been like that here - instead of having to compete against the other athletes, everyone supports each other to do their best. This means there are no winners and losers...only winners. I now train so I can perform better and it makes training much more enjoyable'*.

Participants believed that having a focus on improving rather than competing also assisted in creating an environment that was supportive, rewarding and provided a sense of unity. As explained by Gina, *'When you forget about competition, you tend to enjoy seeing the improvements and progress in others a lot more. It uplifts you and leaves you feeling like a winner. I know at training I always feel like a winner and I've never felt defeated'*.

The importance of an emphasis on athlete improvement as opposed to competition was highlighted in all three interviews. It appears that a coaching practice focused on the progress and development of the athletes rather than promotion of competition has created an environment where the athletes feel a sense of camaraderie, not rivalry. This practice has clearly been positively regarded by the participants and has been instrumental in their at least two-year involvement with the program.

4.3.6. Discussion

The emergence of the first theme is compatible with the observations of other researchers. For example, Vallée & Bloom [31] and Lombardo [32] suggest that when coaches focus on the personal development of the athletes rather than just the athletic qualities, better long-term results can be achieved for both the athletes and the program. In addition, Dale and Janssen [33] contend that the success of a coach should not be measured purely by wins achieved but also by the quality and strength of the relationships developed with the athletes. Dale and Janssen [32] propose that truly successful coaches assist athletes to reach their full potential by underpinning the coaching of sport skills with the teaching of life skills.

The positive influences of an holistic approach for athlete development were very apparent in the present study. Long-term adherence to the program has been influenced by a particular coaching practice that Lyle [34] describes as 'humanistic'. Lyle [34] contends that this form of coaching is concerned with the growth and development of the person and not just the athlete.

The participants in this study indicated that being treated as serious athletes was another important coaching practice that has influenced their at least two-year affiliation with the program. According to Mackay [35] being taken seriously is one of ten basic human social desires. Mackay [35] believes that in addition to fundamental needs such as water, food and shelter every person wants to be taken seriously, to be shown respect and to be listened to rather than ignored.

The emergence of the second theme is also consistent with the literature on serious leisure [36-38], which highlights that participating in leisure activities including community-based sporting programs tends to become an important lifestyle choice when the participants strongly identify with their chosen activity. Dionigi [39] suggests that this is particularly true for participants who perceive that their needs are being taken seriously and when there is continual improvement in a way that increases their identity as serious athletes [39].

It would appear that the participants in the present study have self-identified as serious community-based athletes and have embraced a coaching practice that reinforced that identity.

Using novel games to promote skill acquisition was the third theme to emerge from the analysis. Known as ‘Game Sense’, this approach to athlete development offers coaches an alternative to the traditional highly structured sessions that focus on developing technique prior to any actual participation [40]. Instead, the Games Sense approach enables athletes to develop the tactical appreciations of their sports by actively engaging in modified games and/or game-specific situations [41,42].

Light & Georgakis [43] and Pill [44] have argued that Games Sense requires a new approach to coaching that is quite different from the more traditional directive style. These authors suggest that coaches who ascribe to Games Sense take on more of an ‘educator’ role and facilitate practice sessions that provide opportunities for athletes to discover the meaning and purpose of training drills by encouraging them to explore and discuss the tactical aspects of the activity [43,44]

In the context of the present study, the comments and description provided by the participants show that a suggestive and guided approach to coaching has been seen to create individual learning opportunities for the athletes to develop their knowledge and understanding. This suggests that use of the Game Sense approach contributed to the building of productive interaction between the participants and the coach.

The emergence of the final theme illustrates how the participants' experiences were enhanced by a focus on improving rather than competing. This finding is compatible with the views of Collins [45], who described sport development as *'a process of effective opportunities, systems and structures that are set up to enable people in all or particular groups and areas to take part in sport and recreation or to improve their performance to whatever level they desire'* [45]. However, success in sport is often measured only by victories, medals and/or records broken [46]. While this mindset is still present and perhaps essential at the professional level, other factors such as prolonged participation, achieving personal milestones and self-improvement have recently come to be recognised as significant accomplishments in their own right [47]. This change in perception could be due to the increasing number of people who are choosing to take part in sport and other recreational activities for reasons other than competing and winning [48]. For example, Bailey et al [49] propose that involvement with sport occurs for a number of reasons and note that for many people competing and/or winning is not a significant motivator for their participation. In 2010 Bailey et al [49] presented 3 categories of sport participation that are summarised below.

1. **Participation for Personal Well-being** (PPW): Participants who take part in sport for personal well-being reasons including the social and health benefits associated with participation.
2. **Personally Referenced Excellence** (PRE): Participants who gain enjoyment from skill development and the challenge of surpassing their previous performances.
3. **Elite Referenced Excellence** (ERE): Participants who engage with sport for the purpose of winning at the highest level possible and measure success by win/loss ratios.

It would appear that the participants in the current study fit into the first two categories (PPW and PRE), with little or no interest in inter-personal competition at any level. The findings of the study need to be considered in this context. It is likely that athletes in the third category

(ERE) would value a different set of coaching practices. For the participants in the present research, though, a particular coaching practice focused on assisting athletes to develop and constantly improve their physical qualities, technical skills and tactical appreciations has clearly been regarded as preferable to any emphasis on formal competition.

4.3.7. Overview and conclusions

The current study provides evidence of the coaching practices that community-based athletes involved with the Canberra Box'Tag program regard as positive and that appear to have contributed to their sustained participation. An holistic approach to athlete development, treating the participants as serious athletes, using modified games to promote skill acquisition and having a focus on athlete improvement rather than competition have emerged as the coaching practices most valued by the athletes.

However, due to the interpretative nature of the study the findings presented in this paper should not be considered as necessarily representing the opinions of all the athletes from the Canberra Box'Tag program. Since the findings are limited to the responses of three participants from a particular community-based sports program, they should be considered as having vertical generalisability (contributing to the building of an interpretative theory) and not horizontal generalisability (being applicable across settings) [50]. Essentially, readers should consider the ability of the findings to resonate with their own experiences, provide insights into the investigated phenomenon, develop an understanding of the situation and relate to existing theories [51,52], rather than concentrating primarily on how relevant they might be to other times, settings and people [53,54].

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Chapter 5: Reflections on Long-Term Development and Use of Automated Scoring Technology in a Sport (Modified Boxing) Context.

5.1. Declaration for chapter 5

Declaration by candidate

In the case of Chapter 5, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Contributed to data collection, data analysis and assisted with manuscript preparation.	No
Richard Helmer	Assisted with data analysis and manuscript preparation.	No
Colin Mackintosh	Contributed to data analysis and assisted with manuscript preparation.	No
Candidate's Signature		**Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

University of Canberra

Signature 1:	25/3/2019
Signature 2:	27/03/2019
Signature 3:	27/03/2019

5.2. Prologue

As indicated in Chapter 2, the availability of automated scoring technology was a core feature of the modified boxing program introduced at the Canberra PCYC. At a very early stage, a competition involving deployment of this technology was run, and was highly regarded by Canberra PCYC management. The technology was incorporated into training sessions aimed at skill development, and program participants were also afforded other opportunities to engage with it. Additionally, I assisted with operation of the technology to support events elsewhere. I recorded the reactions of competition participants and spectators in my reflective journal. I encountered some technical and practical problems with use of the equipment and carried out a series of field-based experiments aimed at understanding and resolving them. Eventually, I worked with several colleagues to produce and publish a paper that documented my auto-ethnographical experiences as a practitioner/researcher and identified actions needed to optimise the utility of the automated scoring technology in the modified boxing environment. That paper appears below. It contributed to realisation of the following research aims identified in Chapter 1:

- **Aim 5:** To explore and iterate specific technologies seen as having potential to enhance the experience of modified boxing program participants, particularly in terms of safety and program enjoyment.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

Post training comments as recorded in reflective journal
(Thursday 5th September 2013. 19:45 Canberra PCYC).

"That was so cool. I loved being in the ring" – **12 year-old male athlete.**
"It's a lot harder in the ring than you think. I got tired very quickly and kept thinking I've still got another 2 rounds to do. Next time I think I'll just try to do 1 round" – **30 year-old female athlete.** *"I enjoyed it, but it would've have been a lot better if the scoring worked properly"* – **18 year-old male athlete.** *"It was really good to put into practice what we've been doing"* – **40 year-old male athlete.** *"I'm not that interested in competing"* – **43 year-old female athlete.** *"I prefer the game stuff and group activities"* – **23 year-old male athlete.**

5.3. Published paper 4 (This remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Reflections on Long-Term Development and Use of Automated Scoring Technology in a Sport (Modified Boxing) Context.

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5.3.1. Abstract
Technology is being increasingly used to aid judging in sport, but its employment as the primary means of scoring is rare. We have developed and implemented a fully automated scoring system in the context of a modified, low- risk form of boxing. The system, which requires contestants to wear vests and gloves incorporating sensor fabrics, has been used in multiple settings over the past five years. During that period, it has undergone progressive iteration guided by action research methodology. Here, we summarise that iteration, reflect on present status and identify possible future directions. We have found that concept of automated scoring has wide appeal, and the wearable technology is almost universally considered comfortable. Nevertheless, some issues remain to be addressed. Use of the technology requires considerable prior and subsequent commitment of time. Apparently valid contacts occasionally fail to score. Causative factors include the configuration of electrical circuitry in the vests and deterioration of that circuitry with repeated vest use and washing. Also, false positive scores are sometimes generated by vest self-shorting and effects of sweat. Many contestants adopt unorthodox styles aimed at exploiting the characteristics of the automated scoring methodology, affecting the aesthetics of the modified sport. There is an expectation that technologically-based scoring should have much greater accuracy than human judging, and should be essentially fail-proof. Disillusionment can occur in situations where this expectation is not met. We have identified potential solutions to all the existing issues, with some now being actively explored. Continuation of the quest seems justified by popular dissatisfaction with subjective human judging of boxing and other sports, but we have come to realise that purely technological judging can introduce unforeseen complexities. Our observations could be relevant to various sports interested in the notion of technological judging.

Key words: Automated scoring technology, Box’Tag, Smart fabric, Sports technology. Wearable sensors.

5.3.2. Introduction
Over the past decade, a modified, low-risk form of boxing known as Box’Tag has emerged in Australia [1]. A key feature of the modified sport is that impacts to the head and neck are prohibited, as recommended by various experts seeking to enhance boxing safety [2,3,4,5]. Additionally, automated scoring technology is employed. This technology is comprehensively described elsewhere [1,6]. In summary, contestants wear specialised vests

incorporating sensor fabrics and boxing gloves that have patches of electrically conductive material affixed to their surface. The vest sensor fabrics include stripes of silver nylon yarn forming a circuit that can be connected to a transceiver located in a pocket on the upper back. The transceiver directs a low-level electrical current through the circuit. When a conductive patch on a glove bridges two vest stripes, a change in the electrical resistance of the vest occurs and is detected by the transceiver, which sends the data by wireless mechanisms to a ringside computer. A customised algorithm is then applied to determine whether a score should be registered. Scores can be displayed in real time. The major wearable components of the technology are shown in Figure 1.

The accuracy of scores produced through the above technology was evaluated by Bruch et al [7], who used frame-by-frame video analysis of 32 rounds of Box'Tag competition as the criterion for determining valid impacts. It was reported that the automated scoring system correctly identified ~90% of all legitimate impacts, and that of the ~10% of legitimate impacts not successfully detected, more than a third were directed to target zones located on the shoulders. False positive scores were rare. Based on these findings, the system was considered adequate for use in the Box'Tag context.

Figure 1: Box'Tag contest showing instrumented vests and conductive patches on gloves. Wires connecting vest to transceiver can be just seen behind the neck of the red boxer.

We have employed the automated scoring technology extensively in multiple different situations over a 5-year period and have implemented various actions aimed at continuous improvement. This has led to a range of insights beyond those provided by the initial, much more isolated analysis. Our observations are the subject of this paper and, since technology is being increasingly adopted to assist with sports judging [8], may be pertinent to the future plans of various sports.

5.3.3. Methods

In an effort to gain both broad and deep understanding of the evolution of the automated scoring technology, reactions to it, issues emerging from its use and its potential for further development, we integrated and examined qualitative and quantitative data from a range of sources. The data were collected over five years as part of an action research process [9] that guided iterations of the technology. In keeping with the principles of action research [9-12], that process entailed repeated cycles of observation, reflection, planning, action and evaluation conducted in collaboration with end-users of the technology and designed to enable progressive, holistic identification and resolution of real-world problems.
Materials gathered through the action research methodology included a comprehensive journal maintained by the first author of this paper, who was not only a member of the research team but also the coach of a Box'Tag program operating at a Police Community Youth Club (PCYC) in Canberra, where he was a primary user of the automated scoring technology. He was therefore a 'practitioner-researcher'. Campbell [13] has noted that practitioner-researchers can facilitate high-quality research outcomes because they are uniquely positioned to provide an insider's perspective on practical problems and the success of attempts to address them.

In our case, the practitioner-researcher 'lived and breathed' the Box'Tag program for the whole 5-year period encompassed by the present analysis. For all but the last year of this period, he conducted almost weekly sessions in which participants engaged with the automated scoring technology. In addition to these regular sessions, he oversaw use of the technology at numerous special Box'Tag events held at the PCYC and elsewhere, demonstrated it in the context of workshops and technology showcases held at multiple Australian locations, exhibited it at amateur boxing tournaments and draft camps, participated in its operation for filming of television programs, and assisted with its use for the purposes of Box'Tag competitions at the Victorian Police & Emergency Services Games in 2012 and 2013 and the Australasian Police & Emergency Games in 2014.

Importantly, the practitioner-researcher adopted a highly systematic and deliberate approach to the processes of observation and reflection, as recommended by action research experts

[9,14]. His journal served as a vehicle for documenting his experiences, impressions and ideas, recording comments made either formally (in interview settings or through surveys) or informally by Box'Tag participants, summarising salient discussions with other parties, logging the results of specific experiments conducted as part of the technology iteration, and making methodological notes. The journal, which was updated several times each week, eventually consisted of ~100,000 words. It related to all aspects of the involvement of the practitioner-researcher with Box'Tag, but a large volume of information concerning the automated scoring technology was included. While the continuous compilation of the journal was critical to the rigour of the action research process, the process itself was highly collaborative and produced numerous other significant historical records.

Apart from the practitioner-researcher, our research team includes the original developers of the automated scoring technology [15] and the software package that supports it. We interacted regularly throughout the whole five years through a combination of face-to-face meetings, video conferences, telephone discussions and email correspondence.

We all spent some time directly supporting Box'Tag events and sessions at which the automated scoring technology was used, and we all participated in the design and conduct of experiments aimed at obtaining information to guide its improvement.

As a consequence of this collaborative commitment to the action research methodology, it was possible for us to jointly supplement the journal with a substantial collection of video footage of Box'Tag contests and automated scoring technology trials, an archive of email correspondence in which aspects of the technology were discussed, research grant applications, 12 written project reports, software and firmware code iterations, PowerPoint presentations and a series of published papers [1,7,16-18].

Five years of action research has therefore enabled us to reflect on a very rich, diverse and extensive body of recorded information in order to facilitate the insights outlined below. Elliott [9] has noted the importance of such sources in permitting analytical reflection, or genuine "reconnaissance" as opposed to just casual observation. In advocating the value of reflective practice, Leitch and Day [19] describe reflection as the "engine" of action research and see it as critical to the instigation of change, a concept inherent in action research philosophy. They note that the process of collating and "writing up" data gives substance to reflection that otherwise could remain tacit and amorphous and produce little practical benefit. Accordingly, our latest phase of thorough reflection - undertaken for the purpose of preparing this paper - is seen as integral to the efficiency and effectiveness of ongoing decisions and actions regarding the automated scoring technology.

Access to the materials collected in association with the use of the automated scoring technology was provided by the organisations through which that use occurred, under arrangements that were approved by the Human Research Ethics Committee of the University of Canberra, Australia.

5.3.4. Results

5.3.4.1. Appeal of automated scoring technology

In our experience, the automated scoring technology makes a highly favourable first impression on almost everyone who sees it in action. The objectivity of the scoring and the excitement generated by dynamic, real-time display of scores (Figure 2) are the most commonly identified positive features. Also well-regarded is a feature that provides for occurrence of sounds to indicate the registration of scores, with the sounds differing for the two contestants. There has been some debate, though, as to whether the current sounds for the two contestants are sufficiently distinct from each other.

Figure 2 Real-time display of scores in a Box'Tag contest.

5.3.4.2. Comfort and "look" of specialised apparel

The instrumented vests worn by contestants closely resemble conventional T-shirts and the contestants almost universally consider them to be comfortable. They have been produced in a wide variety of sizes [6] and contestants therefore feel that good "fit" is generally achievable.

The original T-style vests had lycra as the base fabric and were somewhat stretchable, a characteristic that caused them to conform quite closely to body shape.

Some athletes indicated that they would prefer a looser-fitting garment, and in 2015 a new batch of vests was produced to cater for this preference.

The new vests, which incorporated a micro-mesh base fabric, were well-received, although approximately half of all athletes continued to find the original vests more to their liking.

To date, the vests have been made available in just two colours - red and blue. This is in keeping with colours historically employed in conventional amateur boxing [20], although both the red and blue vests used in the Box'Tag setting also include white sensor fabric on the front of the torso and small areas of the upper arms, defining the target regions. While the colours are widely regarded as having aesthetic appeal, there have been many suggestions that the choice should be expanded.

The transceivers that form part of the automated scoring technology are fitted into a specially designed pocket on the upper back of the vests just below the neck. Those used for most of the past five years have dimensions of 4 cm × 4 cm × 1 cm (with the last of these being the depth) and a mass of 19 grams. A new version produced earlier this year has dimensions of 5 cm × 2.5 cm × 1.3 cm and a mass of 25 g (including a cable for connection to the vest). The transceivers are shown in Figure 3. Their small size has meant that athletes have found them to be almost completely unobtrusive.

Figure 3. An original (left) and a newer transceiver employed with the automated scoring technology.

5.3.4.3. Software

The software package - named Spartan [1,7] - developed as part of the automated scoring technology has undergone progressive iteration over the past five years. It currently runs only on Windows operating systems.

The primary purposes of the package are wireless receipt (via Bluetooth) of vest resistance data from contestants, analysis of those data to enable detection of vest contacts, and real-time display of scores. From the outset, however, it has also incorporated ability to capture video data from two simultaneously operating, orthogonally positioned ethernet cameras and to display the video footage in concert with the sensor data both in real time and subsequently in replay mode. The replay facility has provided a means for checking on the accuracy of scores recorded in the real-time situation [7].

Over time, the user-friendliness of the Spartan software has continually increased through such actions as provision of augmented operator control icons, inclusion of an on-line help manual, implementation of capacity for slow-motion and even frame-by-frame replay of the video footage, and creation of an ability to achieve more precise temporal alignment between images from different cameras.

Additionally, it has become possible for users of the software to score three contests simultaneously, select a "countdown" scoring method in which each contestant is required to defend an allocated number of points, download all impact data recorded during a bout to an Excel file for further analysis, and produce automated summaries of impact data for each contestant (including mean contact duration, the number of impacts resulting in scores, the number of impacts not satisfying the scoring criteria and a percentage calculated from the ratio of scoring to non-scoring impacts). Similarly, monitoring of the equipment performance has been enabled, with transceiver operation evaluated in terms of number of Bluetooth data packets received and average sampling frequency, and baseline resistance of vests measured in real time and made available for post- contest display. Overall, the Spartan software package has become a powerful tool for deployment in competition, training, performance analysis and research environments.

Researchers have seen great value in the Spartan software due to its extensive analytical capabilities. However, some people with less technological background apparently have been overwhelmed by the range of possibilities that it provides, and therefore have been reluctant to use it in the absence of technical support. For several months, there were regular reports of the Spartan software sometimes “crashing”, and indeed we encountered this problem ourselves. We initially suspected that it might be due to momentary losses of transceiver function caused by mechanical or other stresses, but when we subsequently ran multiple transceivers for hours at a time and exposed them to various mechanical stresses including dropping on to floor from a height of ~30 cm, mildly forceful impact with one another and application of tension and minor jerking forces to cables connecting the transceivers to vests, we were unable to induce a single electrical interruption in any of the units. The crashing of Spartan was eventually rectified following identification of an intermittent software “bug” that had an effect only when the capacity of the package for video collection was being deployed, but it likely contributed to a perception of complexity in regard to the successful operation the automated scoring technology. Another perceived disadvantage of the Spartan software is that it requires the use of a dedicated laptop computer, which entails significant expense.

5.3.4.4. Apps for iPhone and iPad

To facilitate use of the automated scoring technology, an app that can be downloaded on to an Apple iPhone or iPad has recently been developed. Employment of the app, called ModBox, currently requires use of an additional bridging app to select and route transceiver signals and thereby enable pre-configuring of bouts.

Within the ModBox app, the bout can then be selected from a list. Once the selection has occurred, scoring via ModBox can be initiated, paused and stopped via the pressing of a single button. There is an option for selecting either "count-up" or "countdown" scoring methodology but all other parameters are fixed so as to provide maximum possible simplicity of operation. Scores are displayed in real time. The app does not provide for collection of video data. Field testing of the app has only just commenced and has been confined to a small group, but initial reactions have been positive.

5.3.4.5. Time requirements associated with use

We have found that optimal deployment of the automated scoring technology requires significant commitment of time, both in the lead-up and afterwards. For events involving multiple contests, prior checking of vests and transceivers to ensure their full functionality can easily take half a day. Even before this checking can be conducted, electrical charging of transceivers is necessary.

Time is needed also for computer set-up and (in some situations) positioning and adjustment of Ethernet cameras. Post-event washing, drying and re-examination of vests are time-consuming tasks. For people focused primarily on the coaching of athletes and/or the general running of community exercise programs incorporating modified boxing, the high time cost inherent in using the automated scoring technology has emerged as a definite disincentive to engagement.

5.3.4.6. Accuracy of scoring and robustness of equipment

Over the years, we have encountered a number of technical difficulties in the use of the automated scoring technology.

5.3.4.6.1. Vest shorting

Contact between stripes on a vest can cause an electrical short circuit and consequent acute reduction of vest electrical resistance, leading to registration of false positive scores. The problem typically occurs when the fit of the vest is not ideal, but occasionally the movements of a contestant can bring a stripe on a shoulder sensor fabric of an apparently well-fitting vest into contact with one on the torso region of the vest. The loose-fitting micromesh vests produced in response to participant feedback regarding vest comfort and appearance are more prone than the originals to this issue. "Flapping" of the sections of these vests that cover the shoulders is a primary causative factor, but contact between torso stripes also can sometimes occur.

5.3.4.6.2. Changes in electrical resistance of vests

Pre-contest checking of vests sometimes revealed losses of impact detection sensitivity. These were most common in the shoulder target regions. In 2014, we employed a multi-meter to measure the base electrical resistance of 78 vests that had been in operation for periods ranging from 3 months to more than 3 years. One multi-meter electrode was placed on a press-stud that was the connection point of the vest to the transceiver, while the other was placed on the most lateral stripe of silver nylon yarn on the vest shoulder target that formed the other end of the electrical circuit. The measured resistance consequently related to the entire circuit length. All of the vests were also subject to impacts with a glove incorporating a conductive fabric. The impacts were to the target areas on the torso and both shoulders. The results showed that:

- 44 vests had an overall electrical resistance of less than 2000 Ohms (Ω) and all were fully functional.
- 18 vests had resistance readings of more than 3600 Ω and none were fully functional, with the great majority failing to register impacts to the left shoulder.
- 16 vests had resistance readings between 2000 and 3600 Ω. Of these, seven were fully functional and nine were not.

Functionality within the last category was not distinguishable on the basis of resistance readings, with the average values for the functional and non-functional vests being almost the same. The lowest resistance reading for a vest with left shoulder insensitivity was 2260 Ω and the highest reading for a fully functional vest was 3600 Ω. It was therefore evident that resistance readings could be used to define a zone of definite vest functionality and a zone of definite non-functionality, with these zones separated by one in which functionality is unpredictable.

There was a tendency for vest resistance to become higher as vest size increased (see Figure 4), reflecting longer path lengths of the electrical circuitry in larger vests. Important here is the fact that, because of the methods used to determine valid impacts, even fully functional vests with different levels of baseline resistance could differ in terms of impact sensitivity, giving one contestant an advantage over the other. Impacts are registered when vest resistance falls (for a specified period that can be set in the Spartan software) to less than 80% of a running 10-second average of vest resistance determined during non-contact periods. The upper limit of the specified range within which the transceivers can reliably measure electrical resistance is 2500 Ω. This will be the baseline value recorded when true vest resistance is actually higher, meaning that for an impact to be recorded, resistance must decrease to below 2000 Ω. If the true baseline resistance is 3000 Ω, a decrease to below 2000 Ω would amount to ~33%, compared with the threshold of just 20% required when the baseline resistance is within range.

Increases in vest resistance across time probably have a range of causes. Mechanical stresses produced by impacts, washing and/or storage conditions may cause breakages in individual silver nylon fibres as well as reductions in the silver content of intact fibres. Regardless of the source, resistance differences between vests means that, to ensure the fairness of a contest, the two vests involved should have similar resistance readings at the outset, but this situation can be logistically difficult to achieve.

It is noteworthy that as the overall baseline resistance of a vest rises, the areas of the vest furthest from the source of the low-level electrical current directed through the vest are typically the first to lose impact sensitivity. Variation in sensitivity from one region of the vest to another can therefore occur and is obviously problematic. Also, failure of a region of the vest makes the whole vest effectively non-functional, and repair is complex and expensive.

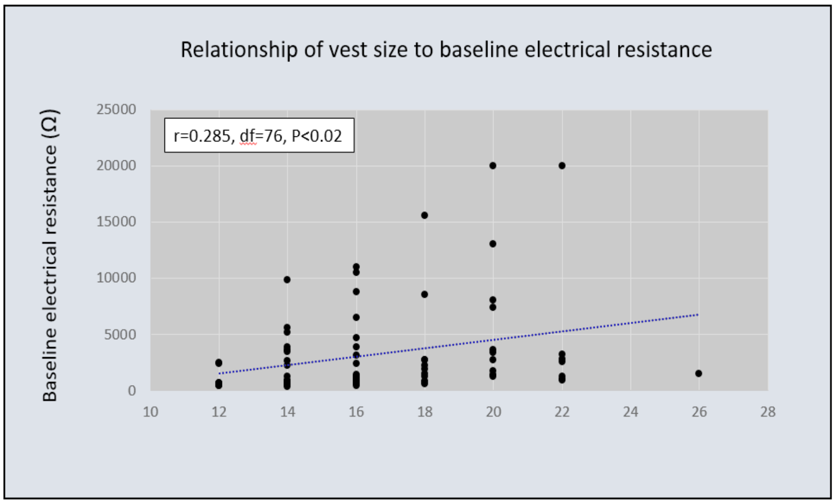

Figure 4: Relationship between vest size and baseline electrical resistance.

5.3.4.6.3. Effect of sweat

Because the electrolyte content of sweat makes it electrically conductive, sweat can cause "shorting" of vest electrical circuitry, thereby reducing the electrical resistance of the vests employed in Box'Tag and producing false positive scores. The use of a running 10-second average to calculate baseline electrical resistance of the vest, and the identification of valid impacts through evaluation of short- term reductions in resistance relative to this baseline, was originally implemented with a view to overcoming this issue [1,7].

That solution is predicated, however, on a premise that the influence of sweat in lowering vest resistance generally will be gradual. We have quite frequently experienced situations in which the premise has proven unjustified. For a vest in the process of becoming sweat-soaked, there can be a point at which athlete and/or vest movement can cause intermittent bridging of two sensor stripes by sweat. This can result in 'rapid-fire' recording of false positive scores for the opponent.

The outer surface of the sensor fabric incorporated into vests has a hydrophobic coating [6] designed to prevent dripping sweat (and also water that may be splashed on to contestants by trainers) from affecting vest performance. We have found, though, that this does not prevent the diffusion of sweat from the body surface of contestants through the base fabric of vests and into the sensor fabric. The effect is likely exacerbated by adverse vest washing.

We have sought to prevent the problem in several different ways, including restricting the duration of bouts (usually to a maximum of three 2-minute rounds separated by 1-minute rest intervals), encouraging contestants to wear their own T-shirt underneath the instrumented vest, and counselling against wearing of the instrumented vest during warm-up. In the most recently produced vests, the inner surface of the sensor fabric has been laminated to provide a barrier against sweat ingress. Although combination of these approaches has limited the extent of the occurrence of sweat-induced failures of the automated scoring technology, it has not yet entirely eliminated them.

5.3.4.6.4. Spacing of vest stripes

Slow-motion analysis of video footage that we have collected over the past five years has confirmed the published finding of Bruch et al. [7] that visible contacts to vests do sometimes fail to register scores.

Apart from diminished vest sensitivity, this apparently can be due to a glove happening to contact the vest at a point that prevents its conductive patch from bridging two vest stripes. Because the resultant occurrence of false negative outcomes occurs with sufficient frequency to be perceptible to Box'Tag contestants, there have been suggestions that vest stripes, which are currently ~ 4 cm apart, should be considerably closer together. Such action would of course have a downside through increasing the total length of the electrical circuit formed by the vest stripes and consequently increasing the vest electrical resistance.

5.3.4.6.5. Conductivity of glove patches

In the first iteration of the automated scoring technology, the conductive patches affixed to the surfaces of the gloves consisted of a conductive rubber material [1]. Since it was difficult to bond this material to the glove surface through use of readily available glues (and since eventual deterioration of the conductive rubber material started to cause discolouration of vests contacted by it), a move to silver-containing conductive fabrics soon followed.

Initially, a prototype conductive fabric manufactured by the Commonwealth Scientific and Industrial Research Organisation (Australia's leading Government funded research agency) was employed [1]. This fabric had a higher silver content on one side than the other. We tried some gloves on which the 'high silver' side was placed downward (i.e. on to the glove surface) and some on which it was placed upward.

Both versions were found to work almost perfectly in initial trials, but after only a few rounds of use the patches with high-silver side down showed substantial losses of conductivity, such that contacting vests with them no longer led to reliable registration of scores. The reason for the loss of conductivity was unclear, but we suspect that impacts may have caused silver particles to be driven into the glue matrix and consequently inactivated. The patches with high silver side placed upward continued to work effectively for many years. Eventually, we moved to making patches from either of two commercially available silver-containing fabrics, ArgenMesh and Silverell (Less EMF Inc, Latham, NY, USA), and to sewing the patches in place rather than gluing them.

This has provided excellent results but our experience has demonstrated that the selection of the conductive material, its orientation and perhaps also the method of its attachment to glove surfaces can be critical to the successful operation of the automated scoring technology Progression in the development of conductive glove patches is illustrated in Figure 5.

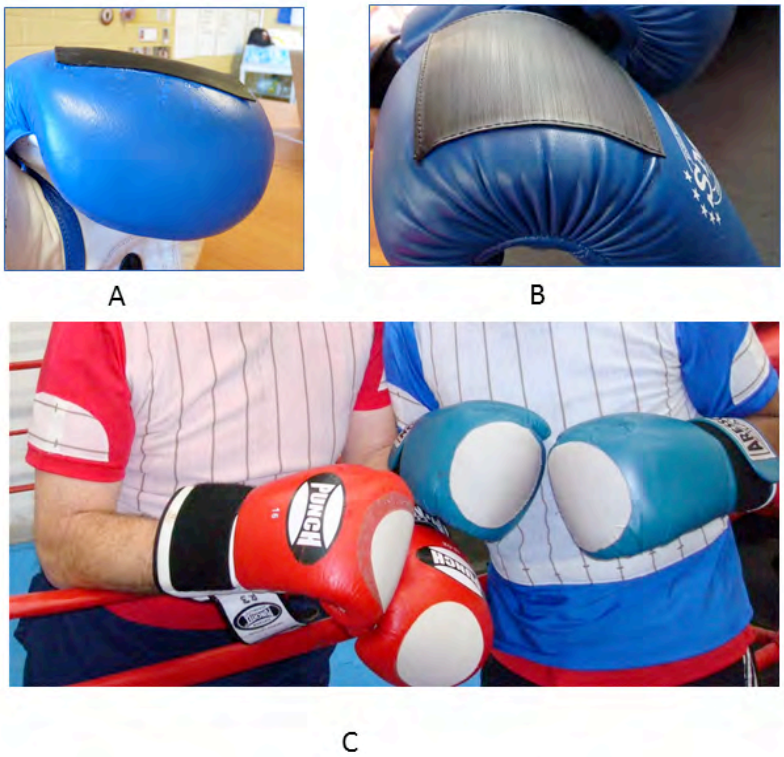

Figure 5: Evolution in the development of conductive patches for gloves, showing move from gluing to sewing as the method of fixing rubber patches to glove surfaces, and then progression to use of patches made from silver-containing fabric.

5.3.4.6.6. Possible influence of impact mechanics

In 2014, two of the authors of this paper completed 23 simulated Box'Tag contests in which they alternated impacts, using specialised gloves incorporating air-containing bladders designed to minimise peak impact forces in keeping with the requirements of modified boxing (16). Each person used the same fully functional vest throughout, but in combination with 9 different transceivers. The outcomes are presented in Table 1.

Although the number of impacts delivered by each participant in each bout was identical, the "red" participant recorded a higher score in 14 of the 23 simulations. Five of the simulations produced tied scores, and the "blue" participant recorded the higher score on just four occasions. In total, 1015 valid impacts were recorded for the red participant and only 983 for the blue. The mean scores per simulation were therefore 44.1 and 42.7 points respectively.

An independent samples t-test showed that the difference in scores, despite being small, was consistent enough to be statistically significant (P = 0.026). It is possible that the blue vest was slightly more sensitive than the red, but since both vests had baseline electrical resistance levels below 2000 Ω this explanation is considered unlikely.

Table 1: Results of 23 simulated bouts in which red and blue "contestants" alternated impacts and so delivered equal numbers of impacts to designated scoring regions. Columns 2 and 3 identify the specific transceivers worn by the two contestants. Columns 4 and 5 show the final scores, and Columns 6 and 7 show the average glove contact times in msec.

Bout #	**Red Transceiver #**	**Blue Transceiver #**	**Red Score**	**Blue Score**	**Red Contact Time (Ave)**	**Blue Contact Time (Ave)**	**Bout Winner**
1	9	5	40	37	107.9	63.4	Red
2	10	5	40	39	97.5	69.9	Red
3	10	11	38	35	98.4	79.2	Red
4	29	11	43	38	92.7	79.2	Red
5	29	9	40	36	93.4	83.8	Red
6	1	2	40	38	102	82.8	Red
7	23	2	39	34	109.7	89.4	Red
8	23	24	35	43	122.5	127.3	Blue
9	25	24	41	43	92.3	98.2	Blue
10	25	26	44	44	106.8	74.4	Draw
11	1	26	48	51	101.5	75.4	Blue
12	18	19	46	46	101.6	57	Draw
13	21	19	43	47	90.5	75.3	Blue
14	21	22	51	50	93.8	86	Red
15	18	22	48	46	100.2	68.8	Red
16	1	2	47	47	97.9	81.9	Draw
17	23	2	49	46	100.3	75.6	Red
18	23	24	45	42	95.8	70.5	Red
19	25	24	45	42	94.8	68.6	Red
20	25	26	44	39	111.9	99.7	Red
21	1	26	46	41	114.2	103.6	Red
22	30	31	52	52	117.3	82	Draw
23	30	31	51	51	105.8	87.2	Draw
Mean			**44.1**	**42.7**	**102.1**	**81.7**	
SD					**8.6**	**15.1**	

The mean contact time for impacts delivered by the red contestant was 102.1 (SD = 8.6) msec, while that for impacts delivered by the blue contestant was 81.7 (SD = 15.1 msec). This difference too was statistically significant (P < 0.000001). The lower mean contact time and greater variability for the blue contestant meant that a few contact times were less than the minimum duration required to register a score. The most likely reason for this outcome is that the two contestants differed slightly in terms of their impact delivery mechanics. Accordingly, there is a logical basis for believing that such differences between contestants may have at least small effects on scores produced by the automated scoring technology.

5.3.4.6.7. Effect of automated scoring technology on athlete technique

Our long-term experience suggests that the automated scoring technology has caused contestants to adopt techniques aimed simply at rapidly registering numerous points and depending more on capacity to sustain all-out attack rather than on the execution of highly-refined skills.

5.3.4.7. Other observations

For much of the history of our involvement with the automated scoring technology, it has been necessary to have multiple sets of gloves set aside purely for use in Box'Tag contests, as there was a risk that the conductive patches glued or sewn on to the gloves could be damaged during training activities so rendering them non-functional when automated scoring was required. This situation has now been addressed through the development of "pull-on" glove covers incorporating conductive patches. The covers have been specifically designed to fit over the specialised impact-damping gloves that we have designed and produced with a view to maximising the safety of modified boxing, but are usable also with standard glove types (Figure 6).

At present, the cost of the automated scoring technology is an apparent impediment to its uptake. Our investigations have shown that, with low-volume manufacture, vests would have to retail for ~AUD 250 (USD 190) in order to make their supply commercially viable. Several parties that have shown initial interest in obtaining the automated scoring technology have become deterred when advised of this price.

Figure 6: Gloves with pull-on Lycra covers incorporating sewn-on silver-containing conductive patches.

5.3.5. Discussion

Our finding that first exposure to the automated scoring technology elicits highly positive reactions is perhaps unsurprising, since the technology appears to offer a tangible solution to a problem that has long plagued many subjectively judged sports - the potential for outcomes to be influenced by conscious or unconscious human bias. In boxing, disputed judging decisions have been common over many years [22,23].

Boxing competitions at Olympic Games have been affected by highly controversial results over more than a century [22], and the 2016 Olympics in Rio de Janeiro were no exception [24,25]. There have been frequent accusations of official corruption [22,26,27] and, where judging is entirely dependent on expressions of a small number of human opinions, the risk of such corruption is difficult to exclude. Additionally, evidence exists that human judging may be prejudiced by subliminal factors including knowledge of the prior competitive records of athletes and their nations of origin [28], crowd noise [29,30], and even the colours of athlete uniforms [31]. Against this background, a demonstrable possibility of technology-enabled, completely objective scoring has obvious allure.

A further enticement of the automated scoring technology is the availability of a scoreboard that changes in real time so that progress toward the final result can be continually monitored by athletes, their immediate supporters and spectators.

This contrasts with the current situation in both amateur and professional boxing where official scores remain unknown until post-contest announcement. In amateur boxing, real-time scoring was implemented during the period between 1992 and 2012 but was contingent upon human ability to perceive legitimate contacts [26]. Each of five judges had a keypad incorporating a red and a blue button, and was required to press the appropriate button to indicate a perception that a contestant wearing that colour had registered a valid impact to the designated target region of the opponent. If three of the five judges pressed a button of the same colour within a 1-second window, a point was awarded to the corresponding boxer. Over time, shortcomings of this method became apparent, including the possibility that all five judges could press the button more times for one competitor than the other only to have that competitor lose because of the vagaries of the timing window. The use of the timing window meant that judges who pushed buttons frequently could have a disproportionate influence on results, but also led on several occasions to contests finishing in nil-all draws with outcomes then having to be determined through the casting votes of officials. The fundamental weakness was the inability of even the trained human eye to cope with the rapidity of action, and the problems eventually forced abandonment of the method [32] in favour of the present system in which each of five judges simply forms an overall impression as to which contestant is the winner of a round and awards that contestant 10 points, with the other contestant awarded a lesser number based on the perceived extent of the win [26]. At the end of the contest, the round-by-round scores are summed to produce final scores. The scorecards of three of the five judges are then randomly selected and the athlete with the higher score on at least two of these is declared the victor. The collation process typically takes several minutes.

It is arguable that this delay and the real-time invisibility of the scores is detrimental to the sport, particularly as it prevents build-up of excitement associated with empirically close contests. With the fully automated scoring technology described in this paper such issues are overcome, and our experience shows that this is commonly regarded as a major advantage. It may be particularly important in the context of modified boxing, where entertainment value deriving from the prospect of highly forceful impacts and knockouts is (by design) absent.

Over the past five years, though, it has become clear to us that in its current form the automated scoring technology is not without problems of its own. Cost is a significant barrier to its uptake but could be addressed if demand for the technology was eventually sufficient to enable manufacture of its components in higher volumes. Of more immediate concern are issues relating to the performance of the technology.

For the judging of sport through entirely technological means to be viable, it needs to be almost fail-proof, and this is a very difficult criterion to meet. We initially thought that, with Box'Tag having a community sport orientation rather than a high-performance focus, a scoring system capable of detecting and registering ~90% of all valid impacts - as determined by Bruch et al [7] - would be acceptable, particularly when compared with the very limited precision of alternative scoring methods utilised in conventional boxing settings.

It soon became evident, however, that even people competing in friendly community environments often have a fierce desire to win, and that the very notion of using technology for judging engenders an expectation that results should be unquestionable. We have regularly received complaints from contestants who have felt that some valid impacts to the target zones of their opponents have failed to score (possibly due to failure of the conductive patch on the glove to bridge two vest stripes).

On one occasion following a close contest, we recorded a comment to the effect that *"if you're going to be cheated by technology, you might just as well be cheated by human judges"*. It is thus evident that requisite standards for technological judging are higher than those for human judging.

While the above applies to situations in which the technology appears to be working perfectly, there are far greater ramifications when the system overtly fails, such as when impacts to a shoulder target region clearly stop scoring or sweat causes sudden generation of a series of false positive scores. Failures of this nature have sometimes caused participants to express profound disappointment and have exerted long-term effects on their enthusiasm. When considered in conjunction with the large time commitment that we have found necessary for the organisation of Box'Tag events, the risk of technological failures and consequent negative feedback creates a sense of caution with regard to the holding of such events and, in our opinion, has therefore restricted their frequency. In the context of the events, a single technological failure within a program of numerous bouts can leave an adverse impression. For this reason, it can easily happen that the focus of the events becomes directed more to the operation of the technology than to other vital aspects of participant experience.

A question obviously arises as to how the practical issues that we have encountered might be addressed. We have conceived and explored a wide range of possibilities. One of these has entailed experimentation with an alternative to the automated scoring technology. A method has been developed that allows judges and/or audiences to use a simple interface (see Figure 7), accessible via either mobile phone or tablet, to communicate their subjective impressions of a contest to a dedicated website. The communication occurs at the end of each round and requires use of a maximum of three screen touches.

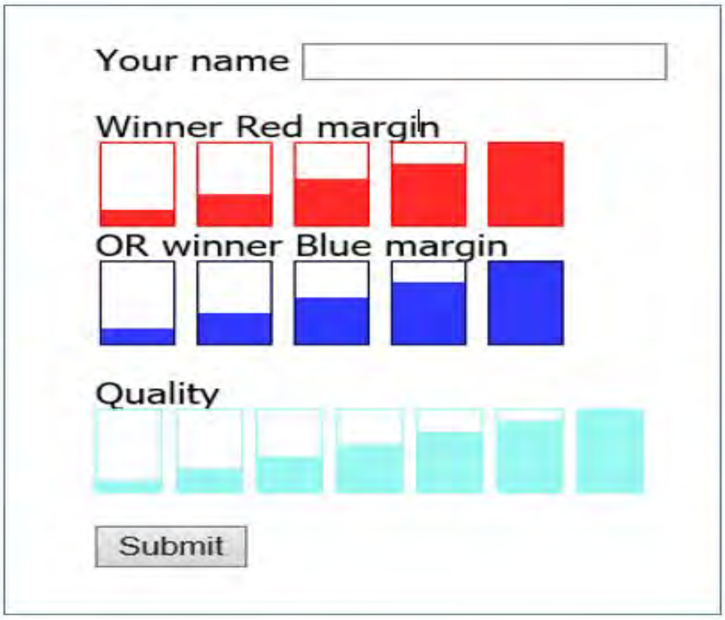

Figure 7: On-line interface for subjective judging of modified boxing contests.

The first touch identifies both the perceived winner of the round and (on a 5-point scale) the margin, while the second denotes the perceived technical quality of the contest (on a 7-point scale). The third touch leads to submission of the assessment. Once the information is received via the website, an algorithm is applied to convert the inputs of each judge to a score.

The number of points assigned to the perceived winner of the round is determined as the quality rating (which progresses in increments of 0.1429 corresponding to the 7 equally-spaced points on the rating scale) multiplied by 20. The score assigned to the opponent is one point below that of the perceived round winner if the margin is considered slight and five points less if it is considered extreme. Other ratings of margin lead to differences between these values. Scores calculated from the inputs of each individual judge are averaged to determine the official score for the round, and round scores are summed to provide the overall bout score.

The method is designed to reward technical proficiency, in that the loser of a high-quality contest can receive more points than the winner of a bout of lesser standard. It also permits selection of a ‘quality only’ mode in which judges give no opinion as to the winner of a round or the margin but instead enter just the quality rating. This feature provides for the possibility of competition between bouts as opposed to competition between individuals within a bout, a model comparable that which exists in, for example, dance sports, figure skating, synchronised swimming and synchronised diving.

This alternative to the automated scoring technology obviously does not require the use of instrumented vests or gloves and capitalises on the ubiquity of mobile technology. Although its employment of subjective human judgements exposes it to the same criticisms of potential bias as those directed to the scoring methodology presently employed in conventional boxing, it does have the advantage of being able to incorporate inputs from very large numbers of judges, thereby exploiting the notion of the “wisdom of crowds” [33]. In circumstances where live streaming of video footage is available, the judges need not even be physically present at the contest, with capacity for remote voting having at least some potential to minimise occurrence of “home-town” decisions.

We have tried this crowd-based scoring approach in a variety of settings. At a special Box’Tag session involving participants aged less than 12 years, the “quality only” option was utilised. The participants showed great enjoyment of the session and quickly realised that there was reward for skill and for working with rather than against their partner. Feedback from parents, some of whom took part in the judging, was highly positive.

Later we employed the method for the purposes of a Box’Tag competition associated with a Draft Camp held at the Australian Institute of Sport for athletes interested in moving into boxing from other sports. Again, the response was favourable, but when a similar camp was held a year later, the organisers specifically requested the use of the automated scoring technology, largely because they felt it would better contribute to the competitive atmosphere that they wanted to create.

Our most recent major trial of the alternative scoring method was at a 2015 Box'Tag event held at the Sydney club where the Box'Tag concept was first implemented. After three contests, the principals of that club chose to return to the automated scoring technology for the remainder of the program, based on an emergent realisation that the real-time scoring and the sounds associated with it were critical to maximising participant and audience enjoyment of the event.

Also, when another club expressed interest in establishing a Box'Tag program and the potential for it to save on costs by initially adopting the alternative scoring method was raised, its owner indicated that in his view, "Box'Tag without the automated scoring technology would no longer be Box'Tag". These experiences strongly suggest that, despite its current limitations, the automated scoring technology remains valued by users, and that effort to surmount the limitations is therefore merited. Objective and subjective approaches to scoring need not be mutually exclusive, with the latter possibly becoming a social media metric review or "check" with quite wide applications.

What, then, can be done? We reason that if increases in the electrical resistance of vests over time are largely or even partly attributable to mechanical stresses occurring during washing, decreasing the requirement for washing should prolong effective vest life. Accordingly, we have recently produced two prototype vests in which the base fabric is a thin mesh so that the capacity of the vest to hold sweat is greatly diminished. This could allow post-contest recovery of the vests to often occur by simple drying, rather than being always dependent on washing. The availability of the new prototype vests will permit testing of the idea in the near future.

As another possible way of restricting increases in vest resistance to levels consistent with continued vest functionality, the silver nylon vest stripes could be arranged into several electrical circuits of lesser length, rather than comprising a single circuit. This would necessitate quite substantial vest redesign, and transceivers would have to modified to enable integration of multiple input/output channels rather than just one, but if this could be accomplished it would seem highly likely to yield a positive outcome.

It would be particularly good to have the shoulder target regions on easily replaceable separate circuits, so that any loss of sensitivity of those targets could be immediately redressed, without need to take the whole vest out of commission and undertake complete refitting of the athlete.

If vests were adapted to encompass multiple electrical circuits, stripes of silver nylon yarn within each circuit could perhaps be closer together, making it easier for glove conductive patches to bridge two stripes and therefore reducing the incidence of false negative occurrences. Also, if each circuit was constrained to a length which meant baseline electrical resistance very rarely increased to levels preventing impact detection, the time requirement for checking of vests prior to their deployment could be considerably diminished, possibly leading to an increase in deployment frequency and substantial reduction in costs and inconvenience attendant upon needs for vest repair.

False positive scores resulting from vest shorting could be largely prevented by making all vests tight-fitting and giving further attention to relatively simple aspects of their design. Currently, vest shoulder stripes are at right angles to the long axis of the arm [6]. Logic suggests that if they were instead positioned parallel to the long axis of the arm, the probability of their contact with torso stripes would be substantially decreased.

The elimination of false positive scores due to vests being affected by sweat has proved to a challenging task. To date, lamination of the body-facing surfaces of vest sensor fabrics has been successful only in delaying the onset of the problem rather than in removing it altogether. Furthermore, we have observed cracking of the laminate after only a few uses and washes of the vests. This might be due to imperfections in the lamination process, particularly as the process has been carried out by people who had little prior experience with it. Accordingly, there could be benefit in at least short-term persistence with the idea.

It is of course evident that the sweat problem is resolvable through introduction of a sufficient barrier to movement of sweat from the body surface into the sensor fabric. We are currently investigating the feasibility of employing protective vests in Box'Tag as a means of lowering impact forces, thereby further augmenting participant safety. A first prototype of such a vest has been produced by one of our associates and, in addition, we have become aware of the recent release of a potentially suitable torso protector by the New Zealand company QP Sport. Participant receptiveness to the wearing of a protective vest will undoubtedly depend on whether the vest is comfortable and allows freedom of movement. If uptake can be achieved, fixing of a sensor fabric to the out-facing surface of the protective vest could well be the answer to the sweat predicament, since the thickness of the vest would provide a quite substantial separation distance between the body surface and the sensor fabric, and in any case the materials comprising the vest (including EVA foam and plastics) would have low sweat permeability. Notably, attachment of the sensor fabric to a relatively firm platform such as the surface of a protective vest would essentially negate any possibility of false positive scores caused by "flapping" of the vest and consequent electrical shorting though contact between vest stripes.

With regard to our observations concerning the unorthodox techniques and strategies that have been adopted by participants in contests involving use of the automated scoring technology, the seemingly common predilection to continuous all-out attack is probably explained by perceptions that the technology rewards such an approach and that the comparative safety of Box'Tag makes caution largely unnecessary. The prevalence of the attacking strategy has important consequences. One is that physical fitness attributes and physical characteristics of contestants often become primary determinants of contest outcomes.

While the development and expression of physical fitness deserves encouragement, beauty of movement and the demonstration of exquisite skill can be considered vital to the fascination of sport [34,35,36] and among the factors that differentiate sport and exercise.

The popular appeal of elite-level conventional boxing has been attributed partly to its inclusion of highly-evolved dance-like qualities [37,38], and the boxing style of a current world professional champion has been described as a "symphony of movement" [39]. We consider it likely that future uptake of Box'Tag and other technology-supported forms of modified boxing will depend on their ability to capture something of this aesthetic element.

Another effect of the "constant attack" strategy employed by many Box'Tag contestants is the occurrence of large numbers of impacts during bouts. We have observed contests in which scores at the end of three $1^1/2$-minute rounds indicate that each contestant has received ~200 impacts. Although none have been head impacts, we believe that the quest for participant safety - a quest that has underpinned the entire development of Box'Tag [1] - would be better served by reduction of impact frequency.

In general, then, a case exists for attempting to foster more skill-orientated Box'Tag styles. Several possible approaches already have been explored. An initial idea was to simply ask referees to ensure that periods of engagement between contestants were restricted to a few seconds, with instructions to separate issued at the end of each such period. Consistency and precision in referee compliance with this request proved difficult to achieve. We therefore looked into the feasibility of calculating a 'bout quality index' that could be used to adjust raw scores. The transceivers forming part of the automated scoring technology incorporate triaxial accelerometers. We reasoned that the sum of accelerometer readings across the three axes should provide estimates of contestant work outputs, and that if the sum of the readings for the two contestants was divided by the sum of their combined scores, the result might be an indicator of bout quality.

This was predicated on the assumption that the combination of high workloads and relatively infrequent scores would typically be due to the contestants displaying good defensive techniques, but the method had the disadvantage of adding an extra layer of complexity in that it demanded accuracy (and therefore pre-contest calibration) of the accelerometers, and in any case it produced a number of results that were markedly inconsistent with the subjective assessments of experts. There was also the problem that, once fully understood by contestants, the method could lead to deliberately inefficient actions aimed purely at increasing the accelerometer-derived workload estimate, and to excessively low levels of effort to score points.

In 2014, we implemented a different approach through modification of the Spartan software so that no contestant could register more than three points in any running 4-second period. The idea was that a contestant who registered three points in very rapid succession would then find it best to disengage so as to avoid the possibility of the opponent scoring during the remainder of the four seconds. This failed to have the desired effect, perhaps because contestants found it hard to perceive exactly when they had scored three points and so tended to simply ignore the constraint.

Our next experiment was the introduction of the "countdown" scoring method under which each contestant starts each round with an allocated number of points and is required to defend them, with a point being lost every time a target area on their vest is contacted by the opponent. At the end of the round, the contestant with the most points remaining is the round winner. A round can be concluded inside its scheduled duration if the score of one contestant diminishes to zero. At the end of the bout, the contestant who has won most rounds is the bout winner (just as in tennis each set starts afresh and the player winning the most sets is the eventual match winner). To date, use of the countdown method has been the most successful of all our efforts to encourage more skilled athlete technique in the modified boxing context. It also has the advantage of enabling implementation of a handicap system since contestants in the same bout may start with different numbers of points. "A count-up" method in which each contestant was restricted to obtaining a certain number of points per round might have a similar effect.

We recognise that our perspectives on the present status and potential of the automated scoring technology have been influenced by the historical context in which the development of the technology has occurred, and by our own backgrounds. The project commenced at the Australian Institute of Sport, an organisation focused on the high-performance component of the sport spectrum. Three of us have been employed there, and the other has collaborated with the organisation on a range of research activities. One of us has an extensive background in amateur boxing, and another two have a history of interest in the sport.

Originally, the development of the automated scoring technology was aimed primarily at providing a more objective scoring system for conventional amateur boxing [40], and the project was therefore somewhat constrained by practices associated with that sport. In particular, the technology was designed for use in situations involving two highly-trained contestants competing against each other in a ring, watched by an audience, and with the result often having substantial consequences. These constraints largely persisted when the technology was later deployed to support modified boxing, since the new application was instigated by a former amateur boxer whose own vision had its roots in traditional high-performance boxing protocols. As modified boxing has evolved, it has become evident that conventional competition formats represent only one of many possible embodiments, and that there may be scope for the automated scoring technology to engage new communities of users willing to understand and accept the limitations to its accuracy and to tolerate occasional system failures while progressively developing their own games and rules in concert with the technology iteration. The perceptions of these communities regarding the aesthetics of their activities could well differ from ours since they would be relatively uncontaminated by knowledge of techniques and movement styles typically seen as constituting the “art” of boxing. The value proposition associated with the current cost of the automated scoring technology also might be seen in a different light. Potential exists for the technology to be gainfully employed in specific non-combative but still competitive situations, such as counting the number of impacts to punching bags or training pads, and even counting the number of repetitions of standard physical fitness exercises entailing a series of contacts between two surfaces. The practical utility of the technology for applications of this nature remains to be investigated. If it was confirmed, the modified boxing concept would be augmented. At present, though, our observations are necessarily confined to the circumstances in which we have operated - circumstances dictated by habituated views concerning the characteristics of boxing.

Our experience suggests that the automated scoring technology is valuable in giving modified boxing a visible “point of difference” capable of capturing public attention. The issues that we have documented in relation to the technology could very likely be satisfactorily addressed through concerted input from product development specialists if this input could be afforded. Up to now, development of the automated scoring technology has been funded almost entirely through small research grants and the community of ‘niche’ users has not been required to pay for it. This obviously is an unsustainable situation. Over time, existing components of the technology will progressively deteriorate, making failures more common. Pursuit of further development will be contingent on ability to attract new investment from research agencies, the community of users and/or other sources.

Since the current users are largely community-based boxing clubs with tight budgets, any inputs from them are likely to be small. Even if investment can be secured, success in addressing the issues that have emerged with respect to the automated scoring technology cannot be guaranteed. Exploration of low-cost alternatives to the technology therefore remains essential to the goal of building a long-term future for modified boxing.

Continuing refinement of the automated scoring technology will be worthwhile if it can contribute to accomplishment of that goal. Assessment of the prospects in this regard should take account of expanding notions as to the range of activities that eventually might be encompassed under the banner of modified boxing.

5.3.6. Conclusions

This paper highlights challenges associated with an attempt to implement an objective, automated scoring system in a sport context. While we have focused on experience in the specific situation of modified boxing, the insights that we have obtained may have relevance also to other sports. Although there is an increasing trend for sports to use technology as an aid to judging, and particularly as a means for "on-the-spot" resolution of uncertainties concerning human judging decisions [8], complete replacement of human judges through deployment of technology is unusual. Despite recent rapid increase in the availability of wearable technology, we are among the first groups to attempt to use it to achieve completely objective judging of sport contests in which results would otherwise depend on subjective human determination. Indeed, we are perhaps the very first to make such an attempt in a sporting environment where scoring frequency can be high.

Our work has yielded lessons that could be relevant to other sports investigating the use of technology to address problems arising from human judging. For example, we have found that appetite does exist for removal of judging subjectivity, but that even a technological solution that initially seems quite simple can turn out to have unforeseen complexities. Also, athletes expect very high precision from a technologically-based scoring system - precision far greater than that currently demanded of human judges. To be truly viable, automated scoring technology needs to be virtually fail-proof, since any breakdown can lead to considerable disruption of an event, and to athlete and spectator disappointment. During the developmental phase, when some failures are almost inevitable, a subjective scoring method is likely to be needed as a back-up. The developmental phase can prove to be quite long. Contestants may tend to alter their techniques in response to introduction of new scoring methodology, and new interventions might then be required to protect the aesthetics of the sport. The new scoring method may favour athletes with particular physical or physiological characteristics, thereby diminishing the success rates of others and influencing their levels of enjoyment.

We have come to realise that while technology can presently provide an effective means for such basic tasks as detecting and counting impacts, it is not yet able to discern more subtle aspects of performance, such as beauty of movement and quality of skill execution. Because these subtleties are central to the appeal of sport, a strong argument exists for retaining some contribution of human perception to sports judging, perhaps in concert with a technological approach.

Finally, our efforts over the past five years have emphasised the importance of designing and progressively refining technologies to meet the needs of sports, without expectation that sports should adapt to fit with the capabilities of the technologies. At the same time, however, it needs to be recognised that technological developments can yield opportunities for sports to take on new dimensions.

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Chapter 6: Evaluation of Ability of Two Different Pneumatic Boxing Gloves to Reduce Delivered Impact Forces and Improve Safety

6.1. Declaration for chapter 6

Declaration by candidate

In the case of Chapter 6, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Contributed to study design, data collection, data analysis and assisted with the preparation of manuscript.	No
Alex Jamieson	Assisted with study design, data collection and manuscript preparation.	No
Wayne Spratford	Contributed to data analysis and assisted with manuscript preparation	No
Candidate's Signature		**Date** 22/03/2019

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

University of Canberra

Signature 1: Alln Hhn.	25/3/2019
Signature 2:	26/3/2019
Signature 3:	2/4/2019

6.2. Prologue

The literature review provided in Chapter 2 identified the development of specialised boxing gloves capable of substantially mitigating impact forces as one suggested means by which boxing could be modified to improve safety. The studies described in Chapters 3 and 4 showed that participants in the modified boxing program at the Canberra PCYC placed high value on safety and supported the use of specialised impact-damping gloves. Consequently, an intensive quest was initiated to produce such gloves in a form that would make them attractive to the participants. As will be made clear later in the thesis, this entailed an iterative design process. The research team was eventually able to test two different pneumatic boxing gloves (i.e. gloves that used air for impact cushioning) under controlled laboratory conditions. The findings were exciting and stimulated publication of a paper that is presented below.

The paper was relevant to the following research aims identified in Chapter 1:

- **Aim 5:** To explore and iterate specific technologies seen as having potential to enhance the experience of modified boxing program participants, particularly in terms of safety and program enjoyment.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

Journal entry

(Wednesday 3rd February 2016. 17:00 Canberra PCYC)

"All that is worth seeing in good boxing can best be witnessed in a contest with soft gloves. Every value is called out: quickness, force, precision, foresight, readiness, pluck, and endurance. With these, the rowdy and 'rough' are not satisfied" **- John Boyle O'Reilly.**

6.3. Published paper 5 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to fit in with the requirements of the thesis).

Evaluation of Ability of Two Different Pneumatic Boxing Gloves to Reduce Delivered Impact Forces and Improve Safety

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6.3.1. Abstract

Two prototype pneumatic boxing gloves of different design were compared against conventional 10 oz (Std 10 oz) and 16 oz (Std 16 oz) gloves in terms of ability to reduce impact forces delivered to a target. One of the pneumatic gloves (SBLI) contained a sealed air bladder inflated to a pressure of 2 kPa. The other (ARLI) incorporated a bladder that allowed release of air to the external environment upon contact with a target, followed by rapid air reuptake. Each glove was placed on to a mechanical fist and dropped 10 times on to an in-floor force plate from each of nine heights ranging from 1.0 to 5.0 metres, with the 5-metre drop generating a peak pre-impact glove velocity close to the reported maximum for elite boxers. Compared to the conventional gloves, the ARLI glove substantially reduced peak impact forces at all drop heights, with the reduction exceeding 30% even at the 5-metre level. The SBLI glove was as effective as the ARLI glove in reducing peak impact forces at drop heights of up to 2.5 metres, but its performance then progressively diminished, and at drop heights of 4.0, 4.5 and 5.0 metres it produced peak force readings similar to those recorded for the Std 10 oz and Std 16 oz gloves. The superiority of the ARLI glove was even more evident in relation to peak rate of force development, with reductions relative to the Std 10 oz glove being ~60% at drop heights up to 3.5 metres and still ~47% at 5 metres.
Peak rate of force development for the SBLI glove exceeded that for the ARLI glove for all drop heights of 2.0 metres and above, and at 4.0, 4.5 and 5.0 metres it was higher than the readings for the Std 10 oz and 16 oz gloves. The protective effect of the ARLI glove was associated with an increase in impact compliance and prolongation of contact time between glove and target. It is concluded that a pneumatic boxing glove that provides for air exchange with the external environment can greatly reduce impact magnitudes across the whole range of pre-impact glove velocities likely to be encountered in boxing, thereby mitigating risks associated with the sport. While acceptance of the gloves by the boxing community is uncertain, opportunity may exist for almost immediate uptake in modified boxing programs.

Keywords: Boxing, Boxing Safety, Box’Tag, Modifed Boxing, ModBox, Pneumatic Boxing Glove, Sport Technology.

6.3.2. Introduction

The sport of boxing has been subject to criticism on various grounds. Its safety is a central concern, with 1216 boxers (923 professionals, 293 amateurs) known to have died during the period between 1890 and 2007 from acute injuries received [1], and increasing evidence that there is a dose-response relationship between exposure to repeated head impacts and the occurrence of chronic traumatic brain injury that can produce serious functional disorders such as dementia, Parkinson's disease, compromised cognition, slurred speech, unsteady gait, depression and irrational anger [2-5]. Although the incidence of chronic traumatic brain injury is higher in professional than amateur boxing because of the longer duration of professional contests, magnetic resonance imaging reportedly shows discernible structural anomalies in the brains of ~11% of amateur boxers [6].

Another common argument against boxing is that it entails fundamental intent of contestants to harm each other by delivering blows so forceful that they have potential to cause loss of consciousness, and that injury therefore cannot be considered accidental [7,8]. There have also been claims that boxing has negative social effects through exploitation of vulnerable young people [9-11] and glamorising of violence [12].

In view of the objections, medical authorities have called for boxing to be banned [13-17]. In two Scandinavian countries, bans on professional boxing were actually implemented 35 - 50 years ago but later rescinded [13,14]. Some commentators see prohibition as an anti-libertarian option that would serve only to drive the sport underground where it would operate in a much less regulated environment [15,16]. These commentators contend that cooperative development and deployment of risk mitigation strategies is likely to be a more efficacious approach. There have been suggestions that risk reduction could be accomplished through modification to boxing gloves used in contests [17]. Gloves are readily available in different sizes, with masses ranging from 8 oz to 20 oz (~227 to 567 g). Generally, greater mass corresponds to more padding. Over recent years, there has been a small shift toward use of heavier gloves in competition in an attempt to promote safety. Since 2013, amateur boxers competing in weight divisions with an upper limit of 64.1 kg and above have been required to use 12 oz gloves [18], whereas previously 10 oz gloves were used in all weight divisions. Similarly, professional boxers in the heavier weight divisions now wear 10 oz gloves, while those in lighter divisions continue to use 8 oz gloves [18]. Scope exists for further shifts since boxers routinely use 14 oz or 16 oz gloves in sparring [19], but no scientific information is presently available concerning the extent to which heavier gloves with more padding alter peak impact forces.

Historically, several attempts have been made to produce gloves with novel characteristics aimed at improving safety. For example, thumbless gloves designed to prevent eye injuries caused by thumbs have been manufactured [20-22] and employed in competitive settings [23]. Additionally, efforts have been made to develop gloves capable of damping impact forces delivered to an opponent. Such efforts have included the use of intra-glove elastic restraints to impede forward movement of the fist within its glove cavity [24]. There has even been a prototype “Uni Boxing Glove” that effectively joins left and right gloves together, so that users are required to punch with both hands simultaneously and therefore have limited capacity for force generation [25].

The most common approach to design of impact-damping gloves, however, has entailed replacement of standard padding with air. Beginning from the 1890s, at least 20 patents have been registered for pneumatic or air-inflated boxing gloves [26-45], with a minimum of one in every decade except the 1980s. Numerous novel concepts have been incorporated. One inventor, Joseph Slizus of Seattle, USA, obtained three patents spanning a period of 28 years [33-35,41], progressively addressing problems encountered in practical experimentation with the gloves, and a Finnish physician, Lyderik Löfgren, pursued development and uptake of pneumatic gloves for at least seven years [46,47]. The gloves produced by Löfgren were subjected to laboratory testing which showed that, compared to standard gloves, they substantially reduced acceleration of a struck mass attached to a pendulum, with the protective effect increasing as a function of impact force and as the glove air pressure was increased from 3.5 to 20.5 kPa [46,47].

To date, neither the pneumatic gloves nor any of the other novel gloves have achieved sustained acceptance and uptake by the boxing community. The reasons for this are unknown but undoubtedly reflect the difficulty of changing established practice in a sport with a long history and strong traditions.

During the past decade, modified forms of boxing that emphasise safety have emerged in Australia [48] and elsewhere [49]. It is conceivable that the communities participating in these forms of the sport might be more receptive than conventional boxers to the use of modified equipment, and that this could eventually provide a pathway to wider uptake.

Accordingly, we have worked in the context of a modified boxing program to develop, test and iteratively refine gloves capable of substantially reducing peak impact forces delivered to an opponent. We have actively sought to maximise both the effectiveness of the gloves in impact buffering and their attractiveness to users. This paper reports on the laboratory evaluation of two specific prototypes.

6.3.3. Methods

An apparatus allowing the dropping of gloves containing a mechanical fist on to an in-floor Kistler force plate (Kistler, Amherst, MA, USA) was used to compare the two prototype low-impact gloves against standard 10 oz (Std 10 oz) and 16 oz (Std 16 oz) gloves commonly used by boxers. One of the prototypes incorporated a sealed air-filled bladder as its primary cushioning element and is hereafter identified by the abbreviation SBLI (Sealed Bladder Low-Impact). The other incorporated a bladder that enabled rapid release of air to the external environment upon contact of the glove with a target, and subsequent rapid air return. It is hereafter identified by the abbreviation ARLI (Air-Release Low-Impact).

6.3.3.1. Construction of SBLI glove

The fundamental aspects of construction of the SBLI glove are illustrated in Figure 1. A latex bladder from a small soccer ball was cross-sectionally cut at the point indicated by the red line in the Figure. The cut was made parallel to the orientation of the valve used for bladder inflation. The open end of the bladder was then sealed by means of a truck tyre patch that was glued into position. This effectively created a bladder of hemispherical shape. The bladder was then positioned in a leather casing that had open-cell urethane foam on its inner surface, enabling formation of an intact thumbless glove into which a closed fist could be inserted to sit immediately behind the bladder, such that the whole bladder was located between the fist and the glove target. The position of the bladder is shown by the blue outline in panel D of Figure 1.

The bladder valve was juxtaposed with an opening on the under-surface of the glove casing so that the glove could be inflated and deflated using a conventional bicycle tyre pump. For the purposes of the testing, the bladder was inflated to a pressure of 2 kPa as measured using a Ross Brown model KPCh low-pressure gauge with a range of 0 - 10 kPa.

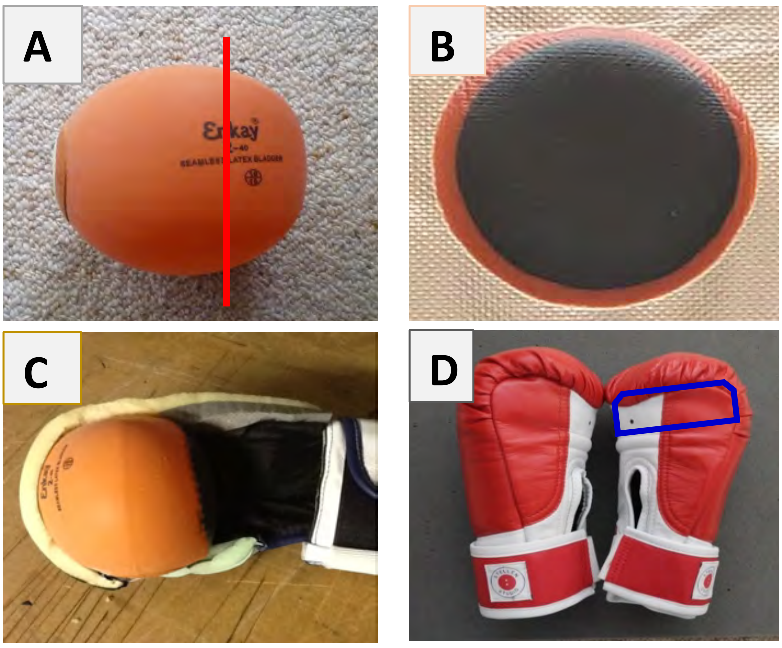

Figure 1: Basic elements of SBLI glove. (A) = Small soccer ball bladder with red line indicating where the bladder was cut, (B) = Truck tyre patch used to seal the bladder after cutting to create hemispherical shape, (C) = longitudinal view of glove showing position of bladder within glove casing and fist compartment behind bladder, (D) = Intact gloves with leather casing in place and blue outline illustrating location of bladder. Note that upper portion of white region of gloves includes openings allowing inflation and deflation of the sealed bladder by use of a bicycle pump and needle valve.

6.3.3.2. Construction of ARLI glove

In this design the bladder was provided with a resilient, elastic internal 'skeleton' that could collapse under conditions of high internal pressure during impact but would immediately recover its shape thereafter, with the recovery causing the internal bladder pressure to fall temporarily below the ambient pressure, so driving air inflow. Figure 2 shows the components of this bladder and the product of their assembly. The internal skeleton consisted of a "ball" of high-density, medium-firmness open cell foam (Joyce Foam Products HR 36-140), which was placed inside the bladder prior to sealing with the truck tyre patch. A hole was then made in the bladder and a plastic tube with an internal diameter of 10mm was inserted. Thereafter, the area around the insertion was sealed. The bladder was then integrated into a whole, thumbless glove in a way that allowed location of the air vent on the palmar glove surface (Figure 3).

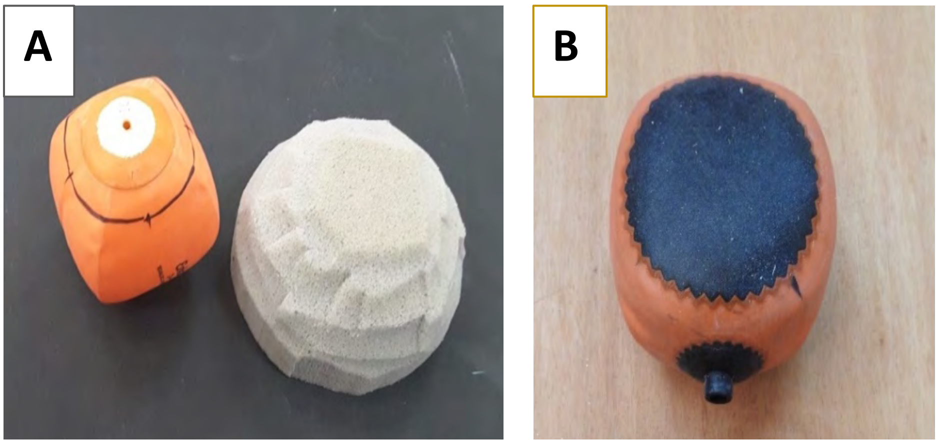

Figure 2: Bladder for ARLI glove with capability for air release. The bladder in panel A was cut at the point indicated by the black line. The foam skeleton was then inserted and the unit was sealed with a truck tyre patch (panel B). A port to allow air egress and ingress (panel B) was then added.

Figure 3: A prototype low-impact glove allowing air release and return. The port can be seen on the front surface of the glove toward the top.

6.3.3.3. Std 10oz and Std 16oz gloves

The Std 10z and Std 16oz gloves used for comparison with the SBLI and ARLI gloves were manufactured by Sting Sports (Melbourne, Australia), which was the official supplier of boxing gloves for the 2014 Commonwealth Games and the 2016 Olympic Games. The gloves evaluated were of the type used by elite amateur boxers in competition and training.

6.3.3.4. Mechanical fist

A prerequisite to our experiment was the development of a mechanical fist that could be inserted into gloves to properly simulate real-world practice for different glove types. This meant that it had to cater for the Std 10oz and Std gloves to be put on with fingers extended, and the fist subsequently clenched, and for SBLI and ARLI gloves to be put on with the fist already in the clenched position. The mechanical fist was designed and constructed to our specifications by a Melbourne-based team consisting of an engineer and an aircraft mechanic. As illustrated in Figure 4, it consisted of three metal sections hinged together to simulate the long axis of the forearm, the proximal section of the fingers and the distal sections of the fingers. It incorporated a ratchet system for clenching the fist and locking it firmly in the clenched position. The centre of mass of the clenched fist was aligned with the long axis of the unit.

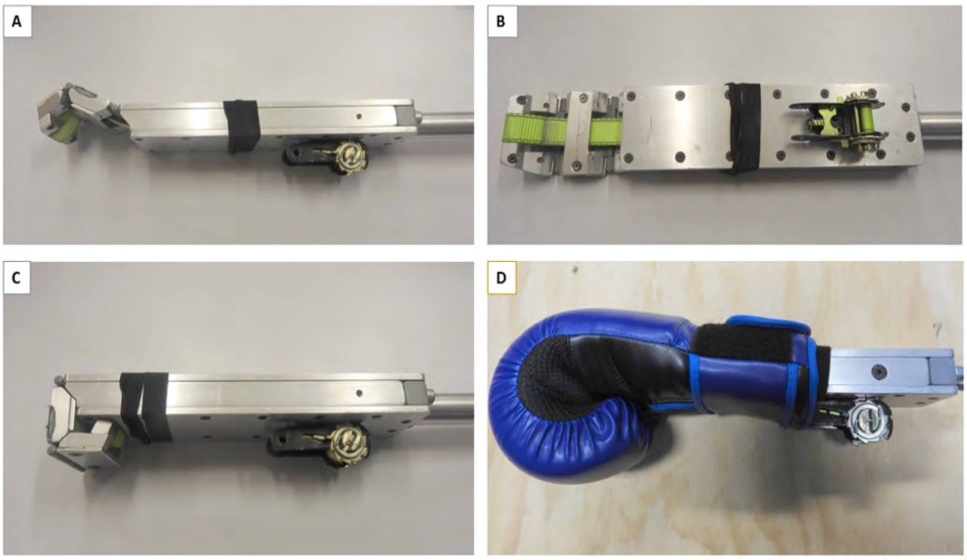

Figure 4: The mechanical fist used in the experiment. Panel A is a side view with the fist open and shows the three hinged metal sections of the device. Panel B is a view from underneath and shows the mechanism used to draw the fist closed. Panel C shows the fist locked in the closed position. Panel D shows the fist inside a glove and highlights the accuracy with which normal glove positioning on a fist was simulated.

The design of the mechanical fist was such that a rod made of high tensile steel could be securely screwed into it at the end opposite that designed to receive the gloves. At the other end of the rod was a hook for attachment of a cord forming part of the drop-testing apparatus. With the rod incorporated, the mechanical fist had a mass of 3.046 kg which, based on the findings of Walilko et al [53], is close to the effective mass associated with punches delivered by elite boxers.

6.3.3.5. Experimental configuration

The drop testing apparatus employed in our experiment is shown in Figure 5. We calculated that a drop height of 5 metres should produce a pre-impact glove velocity of 9.90 $m.sec^{-1}$ which is very close to the average maximum velocity reportedly achieved by elite boxers [50]. We were able to access an in-floor Kistler force plate in a University of Canberra laboratory that had a ceiling height of more than 5 metres. In consultation with a Canberra-based company, AJA Engineering, we designed a pulley system to enable the drop testing experiments. A frame to support a low-friction, flanged pulley was constructed by AJA Engineering and installed in the laboratory. It included a bar that protruded outward from a wall mounting so that the pulley was positioned directly above the centre of the force plate at a height of 5.5 metres. A cord placed over the pulley allowed the gloves to be drawn up to any required drop height.

Figure 5: Drop testing system used for glove evaluation at the University of Canberra. The cameras shown in the photograph are part of a Vicon Motion Capture System.

The force plate had a surface area of 600 × 400 mm. To protect against damage from glove impacts, it was covered by a 25 mm thick mat of Ultralon EVA 75 material with a guaranteed Shore A durometer hardness rating of 30 - 35, which is at the upper end of the range for healthy human skin [51,52] but well below the levels observed for human cortical and trabecular bone [53]. Outputs from the force plate were sampled at 10,000 Hz.

A Vicon Motion Capture System (Oxford Metrics Ltd., Oxford, UK) with four cameras each sampling at 500 frames per second was used to determine glove velocities just before and after impact with the force plate. Markers were placed on gloves to enable determination of displacement and thus calculation of velocity over successive 2-msec time periods. Data from the four cameras were integrated to ensure the accuracy of the calculations and to obtain 3-dimensional images of glove trajectories.

Set-up of measurement parameters for the Kistler force plate and subsequent collection of data from the plate was accomplished via Vicon software run on a standard PC, permitting synchronization of force plate and Vicon data. Throughout all testing sessions, known masses were regularly placed on the force plate as a means of checking the accuracy of the force plate readings.

6.3.3.6. Experimental Protocol

The Std 10 oz, Std 16 oz, SBLI and ARLI gloves were each dropped 10 times on to the force plate from each of nine heights ranging from 1 to 5 metres, with increments of 0.5 metres. The testing was conducted over two sessions, separated by eight days. In the first session, drop heights ranged from 1.0 to 3.5 metres.

For each glove, the initial drop height was 2.0 metres, and we then progressed sequentially to 2.5, 1.5, 1.0, 3.0 and 3.5 metres. The Std 10 oz glove was tested first, followed by the SBLI, ARLI and Std 16 oz gloves. In the second session, the order of drop test heights was 4.0, 4.5 and 5.0 metres, and the order of glove testing was ARLI, Std 10 oz, Std 16 oz, SBLI. In both sessions, each glove was tested at all drop heights before progression to the next glove.

6.3.4. Results

There was a tendency for peak force readings to increase over the course of a 10-drop series, and particularly over the first four drops. When data from all glove types and drop heights were combined to calculate overall mean peak forces for drops 1-10, there was a significant positive correlation (r = 0.61, P < 0.05) between drop number and peak force, and the correlation was even higher (0.73, P < 0.01) when instead of arithmetic mean values for each drop number we used geometric means to minimise potential for over-representation of particular glove types or drop heights. To allow for this order effect, we calculated the peak force associated with any particular condition as the mean of the highest five readings obtained from the 10 drops.

The peak forces determined in the above way are presented in Figure 6. The two prototype pneumatic gloves provided similar protective effects up to and including a drop height of 2.5 metres. Beyond that point, the protection afforded by the SBLI glove progressively diminished, and at a drop height of 4.0 metres was gone. By contrast, the ARLI glove continued to give substantial protection, with the peak force readings at drop heights of 4.0, 4.5 and 5.0 metres all being lower than those for the Std 10 oz glove by ~30%.

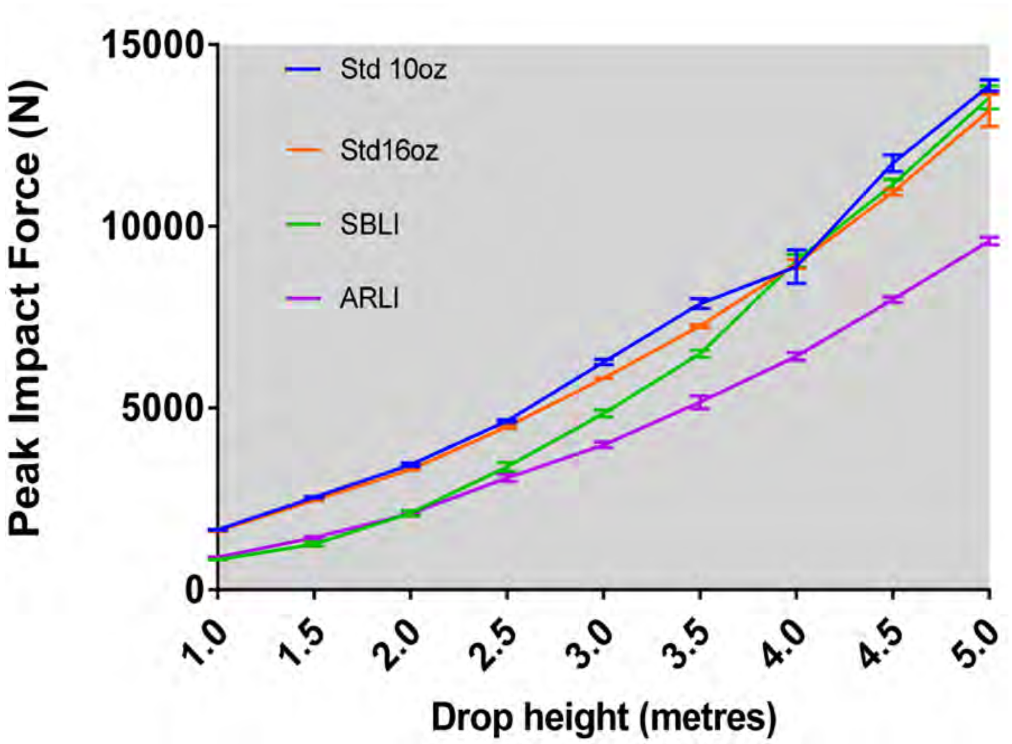

Figure 6: Peak impact force readings as a function of glove type and drop height. Each point on the graph is the mean of the highest five readings recorded in a series of 10 drops. Std 10 oz = conventional 10 oz boxing glove, Std 16 oz = conventional 16 oz boxing glove, SBLI = low-impact glove with sealed bladder, ARLI = low-impact glove with air release. Bars indicate standard deviations for the five readings under each condition.

The mean peak glove velocities for the various drop heights were close to expected values. Figure 7 shows that for any given combination of drop height and glove type, peak velocity measurements were highly repeatable.

The mean peak velocities for the two pneumatic gloves were slightly less than those for the two conventional gloves. This may have been due to the padding of the pneumatic gloves extending further out from the mechanical fist than was the case for the conventional gloves, with the drop height therefore being marginally less. The readings for Std 10 oz and Std 16 oz gloves were very similar to each other, as were the readings for SBLI and ARLI gloves.

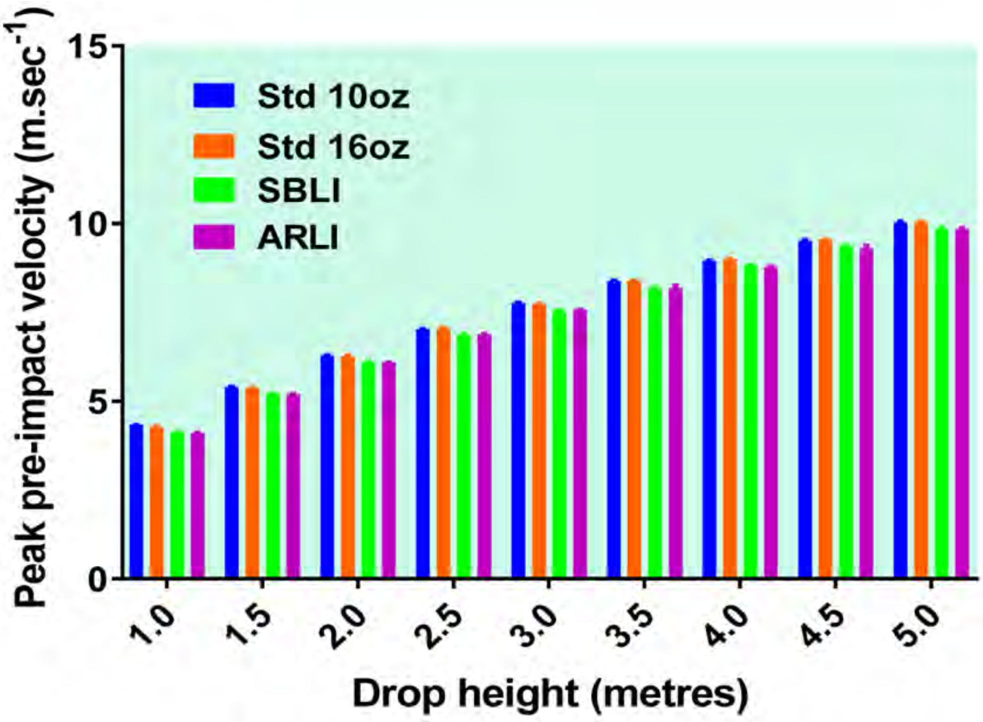

Figure 7: Pre-impact glove velocities for various glove types and drop heights. Each bar represents the mean of the five drops that produced the highest peak force readings from a total of 10 drops. Standard deviations for the five drops are also indicated but are so small as to be barely perceptible.

To correct for the differences in peak pre-impact glove velocities between glove types, peak force readings were plotted against the measured velocities. Exponential regression curves were then fitted to the data for each glove type (Figure 8).

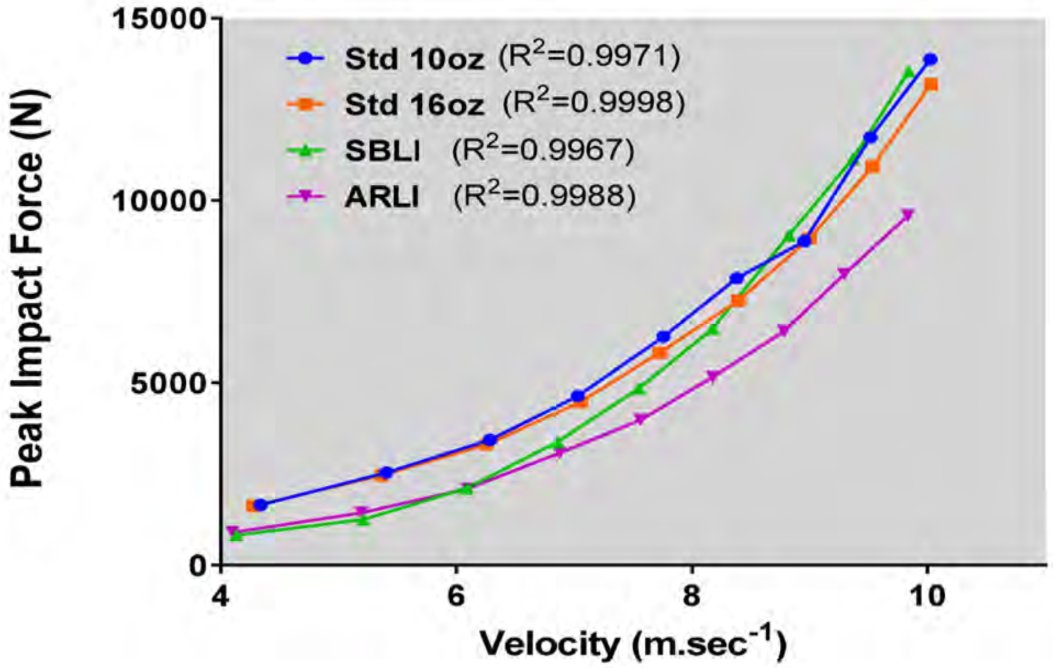

Figure 8: Effect of glove type on relationship between peak pre-impact glove velocity and peak impact force.

The curves provided excellent description of the data, with R^2 values exceeding 0.996 in each case. Calculations based on the exponential regression equations revealed that, compared to the Std 10 oz glove, the ARLI glove substantially reduced peak impact forces for all pre-impact velocities. The reductions ranged from 37% at a velocity of 4.0 m·sec^{-1} to 25% at a velocity of 10.0 m·sec^{-1}. The ARLI glove also decreased impact forces relative to those measured for the Std 16 oz glove, with the magnitude of decrease being 35% at a glove velocity of 4.0 m·sec^{-1} and 20 % at 10 m·sec^{-1}. This is salient since 16 oz gloves are commonly used by boxers in sparring with a view to lowering impact forces [19]. The protective effect of the Std 16 oz glove tested in our experiment relative to the Std 10 oz glove was very much less than that of the ARLI glove across a wide range of glove velocities.

Figure 9 shows velocity measurements obtained from the Vicon Motion Capture System for 16 frames covering the period from just before to just after glove impact. Each curve represents an average for the five glove drops that produced the highest peak force values from an average of 10 drops. The velocities for the two pneumatic glove types slowed much more gradually following contact. This affords some insight into the mechanism of peak force reduction, since it demonstrates "softer" initial collision between glove and target.

The “rebound” in post-contact velocities for the Std 10 oz and Std 16 oz gloves following glove contact at the higher drop heights is indicative of velocities recorded in the upward direction as the glove bounced away from the force plate.

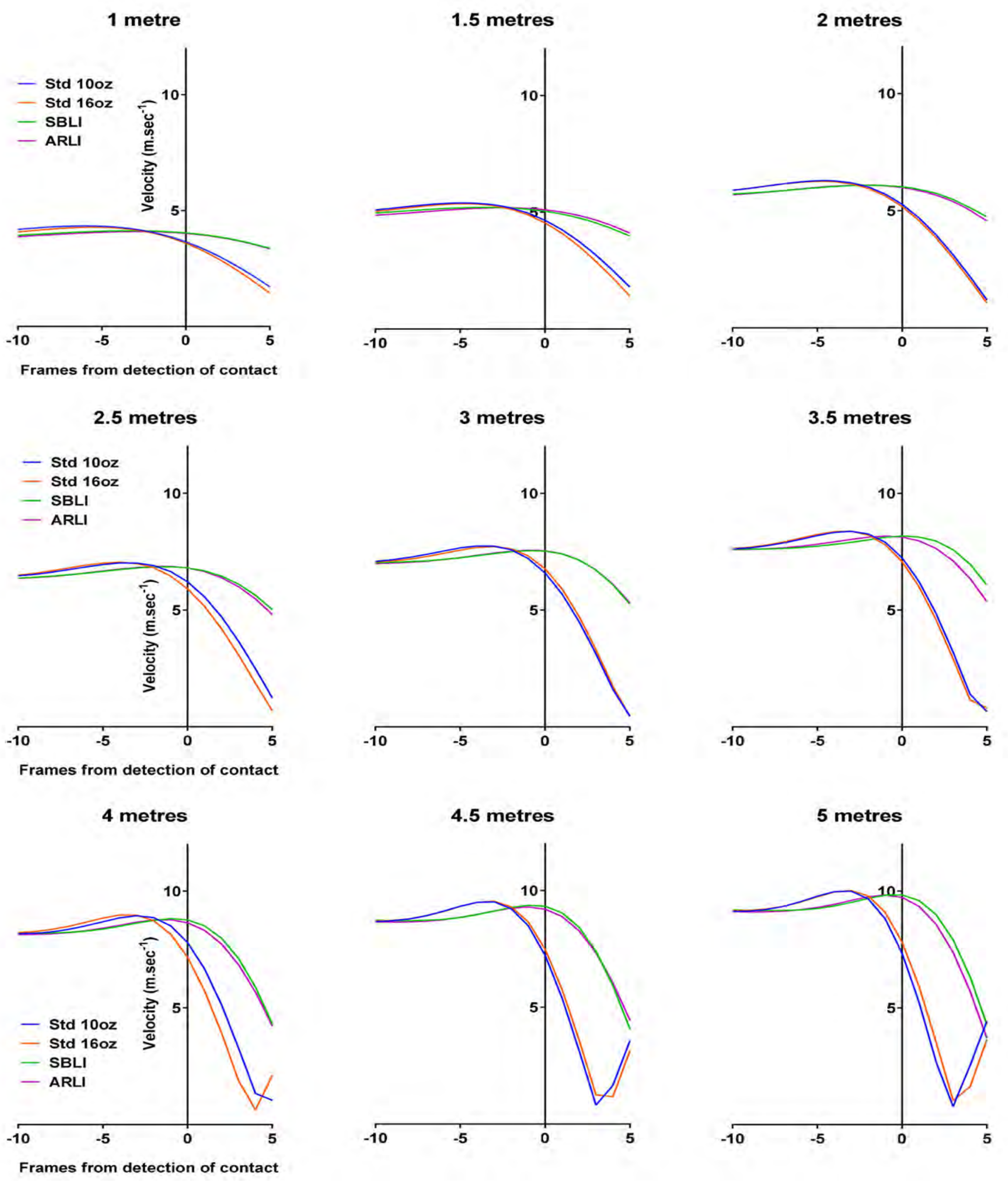

Figure 9: Velocity measurements obtained from Vicon Motion Capture System from 10 frames before to 5 frames after impact. Each curve represents an average for five glove drops.

Contact times between glove and force plate are shown in Figure 10. The times were calculated as the period from when the force plate reading first reached and remained above 20 N in the ascending phase to when it became continuously less than 20 N in the descending phase. The threshold value of 20 N was set with a view to ensuring that detection of the beginning and end points of contact would not be contaminated by baseline noise in the electrical activity of the force plate and was based on advice from previous force plate users. Figure 10 demonstrates that, for all drop heights, contact time between glove and force plate was substantially longer for the prototype low-impact gloves (SBLI and ARLI) than for the conventional (Std 10 oz and Std 16 oz) gloves.

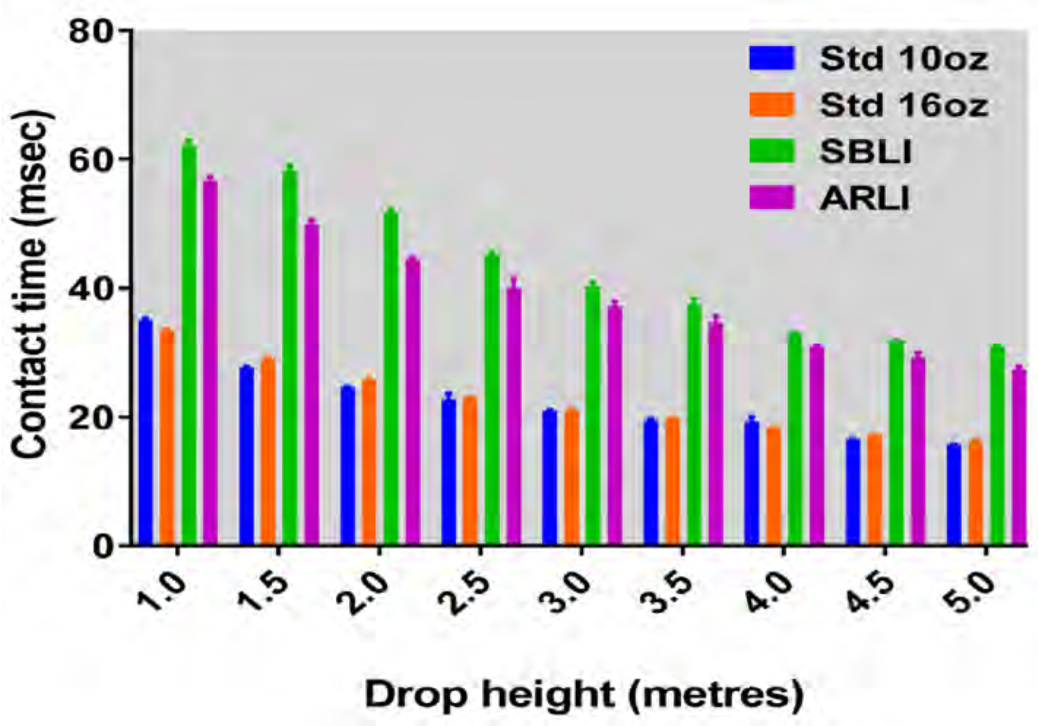

Figure 10: Contact times for different glove types and drop heights. Each bar represents a mean value for five glove drops that produced the highest peak impact forces within a series of 10 drops. Standard deviations for the five drops are also shown.

While it could be expected that dissipation of force over a longer period would favour occurrence of lower peak forces, Figure 11 - which shows force-time relationships recorded from the force plate - permits greater understanding of what transpired. The data presented relate to drops that produced the third highest peak force values within a series of ten (and therefore the median values for the five trials used to calculate representative peak force values for various conditions).

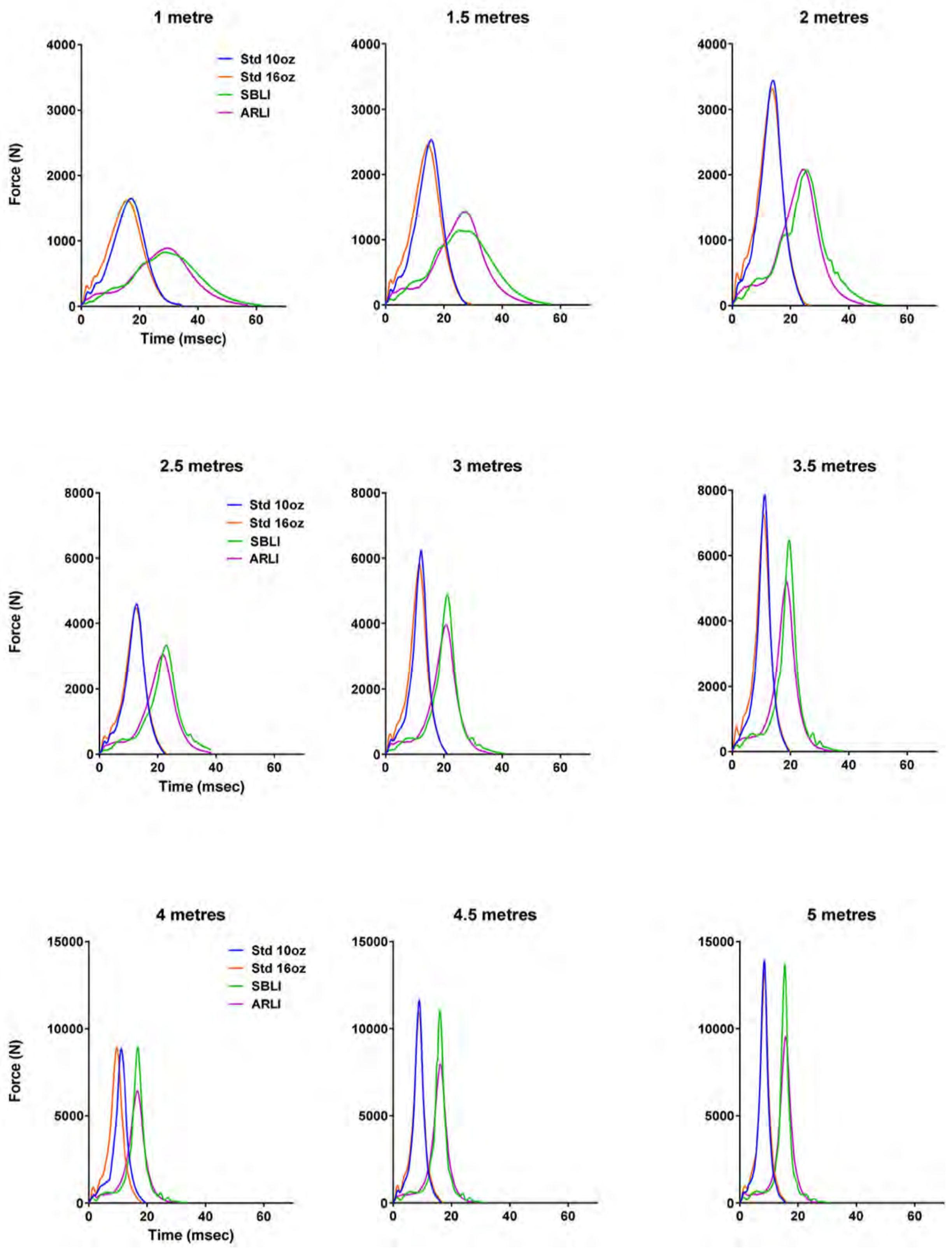

Figure 11: Force-time curves for different glove types and drop heights. Each curve relates to the glove drop that produced the third highest peak force reading from 10 drops. Note that the scales of the y-axis differ between the three lines of graphs.

At all drop heights, the curves for the Std 10 oz and Std 16 oz gloves closely resembled each other, being characterised by quite rapid rise in force following contact. By contrast, the curves for the two pneumatic gloves revealed that in the first few milliseconds post-contact there was very little increase in force. Once the force did begin to rise, the increase was less steep than that observed for the conventional gloves, at least for drop heights up to and including 3.5 metres. For the ARLI glove, this remained the case right through to the drop height of 5.0 metres, and the peak impact force was always well below the levels observed for the Std 10 oz and Std 16 oz gloves. In the case of the SBLI glove, the delay in the onset of the rapid phase of force increase continued at drop heights of 4.0 metres and more, but beyond the point of that onset, the steepness of the curve became similar to that seen with the conventional gloves, probably because the air in the glove bladder was compressed to such an extent as to produce a “hard” glove surface. Essentially, the impact damping capacity of the SBLI glove was substantial at low to moderate impact magnitudes but ‘bottomed out’ when the impact magnitudes became high.

Force measurements for dropped objects are related to total energy at impact, which is affected not just by pre-impact velocity but also by the mass of the dropped object. We used standard digital kitchen scales to determine the masses of all gloves used in the above trial.

The results appear in Table 1.

Table 1: Masses of gloves as measured by digital kitchen scales.

Glove	**Mass**
Std 10 oz	278 g (9.8 oz)
Std 16 oz	455 g (16.0 oz)
SBLI	227 g (8.0 oz)
ARLI	298 g (10.5 oz)

Using these masses, the known mass of the mechanical fist and the measured pre-impact velocities, we calculated total impact energy for all glove types at all drop heights. The results suggested that on average the total energy for the Std 16oz glove would be ~4.8% greater than that Std 10 oz glove and the ARLI glove, and ~6.5% greater than that for the SBLI glove. To gain an indication of the actual total energy for each of trials, we employed the trapezoid method to calculate the area under the force-time curve for each drop. The mean values for each glove type and drop height are shown in Figure 12.

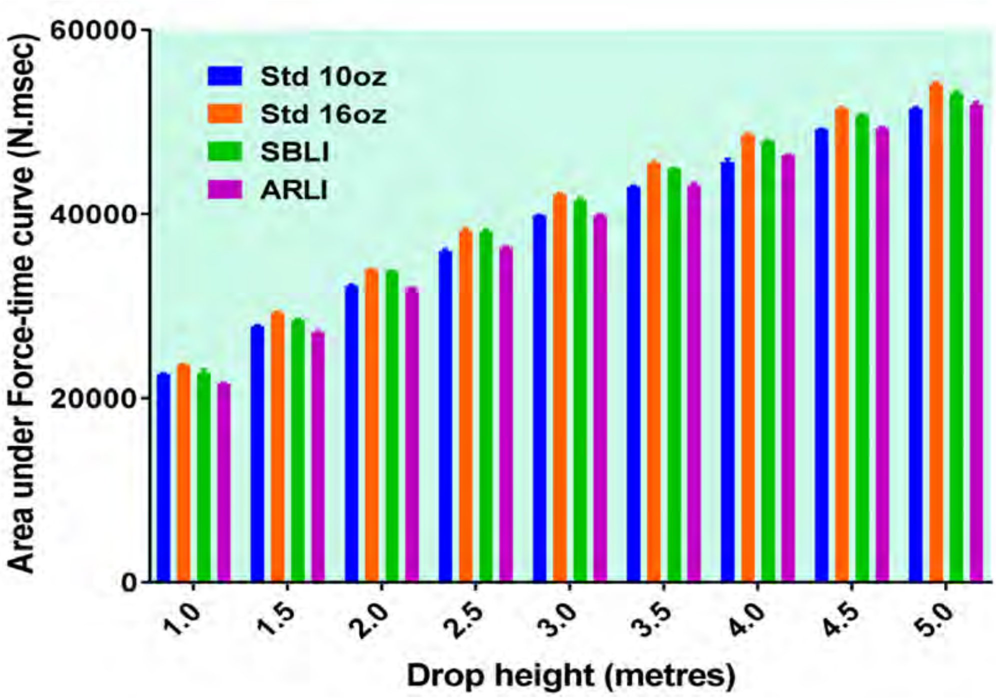

Figure 12: Calculated area under the force-time curve for different glove types and drop heights. Each bar indicates the mean for five glove drops that produced the highest peak forces within a series of 10 drops. Standard deviations for the five drops are also shown but are so small as to be barely perceptible.

As expected, the values were always highest for the Std 16 oz glove. They were ~5.5% higher than those for the Std 10 oz glove, which produced values very similar to those for the ARLI glove. This too conformed closely to theoretical surmise. The only anomaly concerned the SBLI glove. For this glove, the calculated area under the curve was on average only 1.6% less than that for the Std 16 oz glove and was higher than the values for the other two gloves, whereas we had expected it be the lowest of all.

The reasons for the anomaly are unclear, and experimental error cannot be excluded, although it might be relevant that the SBLI glove contained less urethane foam than any of the other gloves, possibly lessening the capacity for the glove itself to take up and temporarily store some of the energy.

The potential for an impact to cause injury is likely related not just to the peak impact force but could depend even more on the peak rate of force development, since the latter will affect the peak accelerative impetus imparted to the target. We therefore calculated peak rates of force development, which equates to maximum steepness of the force-time curve, for each glove type at each drop height. For every test condition, the calculation was made for the glove drops that produced the highest five peak force readings. Running mean values were calculated over 0.5 msec intervals, advancing by 0.1 msec each time. The mean values were then doubled to yield measures in N·msec^{-1}. The results appear in Figure 13.

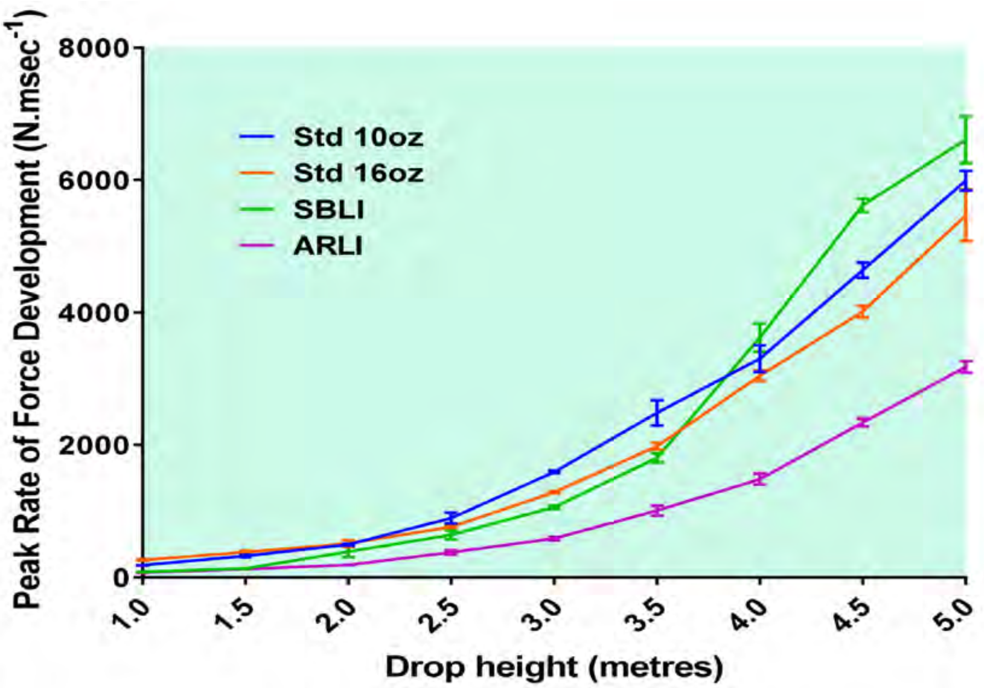

Figure 13: Peak rates of force development for various combinations of glove type and drop height. Each point on the graph represents a mean of five glove drops that produced the highest five peak impact force readings from 10 drops under the specified condition. The bars indicate standard deviations.

The effect of the ARLI glove in reducing the peak rate of force development was greater than its effect on peak impact force. The reduction relative to the Std 10 oz glove was ~60% at drop heights up to and including 3.5 metres and 55, 50 and 47% at drop heights of 4.0, 4.5 and 5.0 metres respectively.

The SBLI glove was nearly as good as the ARLI glove in decreasing the peak rate of force development at 1.0 and 1.5 metres, but its protectiveness progressively reduced from that point onwards, and at 4.0, 4.5 and 5.0 metres it yielded peak rates of force development exceeding those recorded for the Std 10 oz and Std 16 oz gloves. Values for the Std 16 oz glove were less than those for the Std 10 oz glove at drop heights above 2.5 metres but were still much greater than those for the ARLI glove.

6.3.5. Discussion

Our ARLI glove reduced peak impact forces and peak rates of force development across a wide range of impact magnitudes. The protective effects markedly exceeded those currently provided by conventional gloves, including a 16 oz glove of the type commonly used by boxers to diminish injury risks associated with sparring. This appears to have been due to an ability of the ARLI glove to distribute impact energy over a longer contact time without ever reaching maximum compression. Although the SBLI glove had an even greater effect in prolonging contact time, the sealed nature of its air compartment apparently caused it to approach and perhaps reach maximum compression at higher impact magnitudes, with consequent loss of protective effect.

Given practical limitations on the size of a bladder that can be incorporated into a glove, a capacity for air release from the bladder seems a vital inclusion for pneumatic gloves intended for employment in situations where moderate- to high-velocity impacts are likely. This accords with a design proposed by Carrillo [45] in 2006 but not by any of the prior developers of pneumatic gloves [26-44].

6.3.5.1. What Range of Impact Magnitudes is Relevant?

We found that for impacts producing peak forces up to ~4500 N with Std 10 oz and Std 16 oz gloves the reductions in peak force provided by the ARLI and SBLI gloves were fairly similar. Assessment of the practical importance of the clearly superior performance of the ARLI glove beyond that point therefore requires consideration of the forces delivered by boxers in the real world. Studies aimed at quantifying these forces have yielded widely varying results. This seems largely due to variation between studies in methods of measurement and the levels of the participating athletes.

An early attempt to measure peak forces entailed use of a water-filled punching bag containing a submerged pressure sensor [54]. Increase in water pressure resulting from impact to the bag enabled calculation of forces. Mean peak impact force for 24 elite international boxers was 3453 N and, within this group, peak force showed a significant positive correlation with body mass. An estimate based on linear regression indicated that for every additional kg of body mass, peak force produced by the boxers increased by 26.6 N. Since the mean body mass of the group was 69.2 kg, it can be surmised that boxers weighing ~100 kg would have generated peak impact forces of ~4300 N despite some impact energy being converted into movement of the bag relative to its point of suspension. Lower mean peak forces of 3023 N and 2932 N were observed for a group of 23 national-level boxers and 23 novice boxers respectively, and in these groups there was no significant correlation between peak force and body mass.

Atha et al. [55] conducted a study involving a leading British heavyweight professional boxer who subsequently became a European and world champion and was renowned for his punching power. The boxer, wearing standard gloves of unstipulated mass, delivered punches to a target plate attached to a suspended 7 kg cylindrical mass. The target plate had a mass of 0.8 kg and was mounted on a shaft that moved freely on lubricated bearings. A piezoelectric force transducer was sandwiched between the target plate and the cylindrical mass. The front surface of the plate was padded with felt and leather. For initial trials, the padding had a thickness and yield designed to simulate characteristics of the human face, but it was subsequently found necessary to add an unspecified amount of extra padding in order for the boxer to be willing to strike the plate with maximal force. Using forces recorded for submaximal punches with and without the extra padding, a regression equation was developed to express the relationship between results for the two conditions. The boxer delivered seven maximal punches to the target plate and based on "direct hit" criteria one was selected for detailed analysis. The measured peak impact force was 4096 N and through application of the regression equation it was determined that this was equivalent to a force of 6320 N in the absence of the additional target plate padding. The ecological validity of this finding was subsequently questioned by Margetts [56] who argued that in the real world impact forces would be dampened by movement of the target, there would be significant counterforce generated by cervical muscles, and part of the impact energy would be transmitted to the torso, thereby increasing the effective mass of the target.

Using a force plate incorporating strain gauges as the measurement device, Karpilowski et al. [58] recorded a maximum impact force of 2697 N for a heavyweight boxer. Their paper provides no details as to how the force plate was mounted, whether its surface was padded, or the rate at which it was sampled.

Smith et al. [59] developed a punch measurement system entailing use of a wall-mounted force plate. Four triaxial piezoelectric force transducers were positioned between two rectangular aluminium sheets, one with a thickness of 25 mm and the other with a thickness of 50 mm. The unit was bolted to a 400 mm thick mounting wall with the 25 mm aluminium sheet against the wall. A manikin simulating the head and upper body of a boxer was fixed to a 20 mm thick aluminium sheet which was then attached to the outer (50 mm) aluminium surface of the force plate. The manikin, which had a mass of 21.7 kg, consisted of reconstituted chip foam within a leather covering attached to a 20 mm thick plywood back panel. It was designed with the aim that striking it would produce kinaesthetic sensations similar to that associated with striking an opposing boxer. The system was calibrated using a pendulum to which known weights could be added. In the quantification of impacts, the triaxial force transducers were sampled at 330 Hz. Peak impact forces associated with maximal straight punches delivered by elite boxers were found to markedly exceed those delivered by intermediate and novice boxers, and within each performance level the peak forces were greater for the rear hand than the lead hand. The mean peak force for the elite boxers was 4800 N and one of them recorded a peak force of 5771 N.

Subsequent studies using the measurement system of Smith et al. [58] produced comparable results. Dyson et al. [59] reported that for six competitive amateur boxers wearing 10 oz gloves the mean peak force associated with maximal straight rear hand (dominant hand) punches to the head of the manikin was 4236 N with a standard error of 181 N (which equates to a standard deviation of ~443 N). Smith et al. [60] found that for members of the English senior international amateur boxing team tested under these same conditions the mean peak force was 2643 N with a standard deviation of 1273 N. This suggests occurrence in both studies of individual peak force readings exceeding 5000 N.

In an effort to enable best possible laboratory simulation of real-world conditions, Walilko et al. [50] used a Hybrid III crash test manikin to study the effects of maximal straight punches to the face on the biomechanics of the head. Since the Hybrid III manikin had been engineered to closely mimic human structural characteristics, no padding of the face was required. The manikin included a segmented neck with flexible polymer discs to allow flexion-extension and lateral movements resembling those of the human neck. Seven boxers ranging in weight from 48 to 109 kg and wearing standard gloves each delivered three straight punches to the face of the manikin. A six-axis load cell in the upper neck of the manikin was used to measure neck forces and was sampled at 14,700 Hz. The mean peak force for a total of 18 punches that met criteria for inclusion in the study was 3427 N and the highest peak force recorded by any of the boxers was 4741 N. Peak force was significantly correlated with boxer weight, with two super heavyweights producing the highest readings.

Mack et al. [61] later used the Hybrid III manikin to measure punch forces of 42 amateur boxers competing in an international tournament, but on this occasion the sampling rate of the six-axis upper neck load cell was reduced to 10,000 Hz. Each of the boxers delivered four punches, consisting of two straight punches and two hooks with the dominant hand. The straight punches were directed to the jaw of the manikin and the hooks were directed to the side of the manikin's head. Mean peak force values are not presented in the paper, but graphical representations reveal that with straight punching one boxer generated a peak force of just over 4500 N and another recorded a value of ~4100 N.

Hooked punches produced much higher peak forces, with six boxers recording measures above 5500 N and one attaining a reading of 8000 N. This observation contrasted with the earlier observation of Smith et al. [60] who found that for English international amateur boxers the peak forces associated with rear-hand hooks to the head of a manikin attached to a wall-mounted force plate were not greater than those associated with rear-hand straight punches to the head. This difference in findings is likely due to a difference in the experimental conditions including the sophistication of the manikins.

The first attempt at quantification of peak punch forces during actual boxing matches was carried out by Pierce et al. [62]. Lightweight, flexible capacitive force sensors were inserted into 8 oz and 10 oz boxing gloves immediately beneath the striking surface. Within each glove, the force sensor had an effective measurement area of 120 cm^2 and was connected via a thin wire to a transceiver located in the wrist region. Through radio telemetry, the transceiver could send data obtained by the sensor to a receiver located up to 35 m away. The accuracy of the measurements provided by the glove sensors was checked by securing instrumented gloves in a vertical position on a force plate and dropping a 3.6 kg padded platform on to them from various heights. This allowed the establishment of polynomial regression equations expressing the relationship between glove sensor and force plate measurements. The average error of measurement, calculated from the differences between measured forces and those determined using the regression equation, was 4% for the 8 oz glove and, although not specified, presumably of similar magnitude for the 10 oz glove. The instrumented gloves were used by contestants in each of six professional bouts involving a total of 20 rounds. The bouts were in six different weight categories and the contestants ranged in weight from 59.0 to 99.8 kg. For the great majority of punches delivered during the bouts, peak forces were below 2000 N, but single highest readings for the 12 boxers averaged 3295 N. For one boxer, the single highest reading was 5358 N and for another it was 5033 N.

Taken together, the findings indicate that boxers have been capable of producing peak impact forces well above 4000 N and even up to 8000 N in laboratory simulations, depending partly on target characteristics, and that forces within this range are occasionally delivered during actual boxing competition. It is very likely that even higher peak forces can occur, since the laboratory studies involved striking of stationary objects, whereas in the real world there can be situations when the target is moving toward the impact, thereby increasing the effective velocity of the collision. Although the monitoring of professional boxing matches by Pierce et al. [62] did not reveal any peak impact forces above the highest levels observed in the laboratory studies, many of the 12 boxers who participated in those matches were inexperienced, with eight having previously participated in less than 10 bouts and four having participated in three or less bouts. Additionally, none of the six bouts ended in a knockout. It is probable that wider sampling of competitive boxing matches would occasionally reveal peak force values beyond those recorded in the initial sample.

The above suggests that to improve safety under all real-world conditions, low-impact gloves should be engineered to reduce peak impact forces of up to a 'standard glove' equivalent of at least 10,000 N. They should also be protective at levels below 2000 N, since most punches delivered during boxing matches appear to fall into this category, and there is evidence that exposure to repeated impacts of relatively low force can still cause serious injury [63]. We have demonstrated that our ARLI glove meets and even exceeds these specifications.

6.3.5.2. Importance of Peak Rate of Force Development

There is direct relationship between the rate at which force is applied (often termed the "loading rate") and the risk of bone fractures.

Tran et al. [64] subjected bovine lumbar spine segments to impacts that differed in terms of loading rates but delivered the same total amount of energy. The low loading rate caused compressive fractures and a mean spinal canal encroachment of 6.8%, whereas the high loading rate produced more severe burst fractures and a mean spinal canal encroachment of 47.6%.
Ewers et al. [65] exposed knees of human cadavers to peak impact forces of 5000 N at high (5 msec to peak) or low (50 msec to peak) loading rates. There was greater incidence of gross fractures and micro-fractures when the loading rate was high.

Averaged across all nine drop heights used in our experiment, the time from first contact to occurrence of peak force was 12.4 msec for the Std 10 oz glove and 21.5 msec for the ARLI glove. While the difference in the time to peak was therefore less than in the research of Ewers et al. [65], it seems reasonable to suggest that the lower loading rate associated with the ARLI glove could reduce the incidence of nasal and other facial fractures that sometimes occur in boxing.

Rather than basing our analysis just on the overall time from force plate contact to peak force, we calculated the peak loading rate for any period of 0.5 msec on the ascending phase of the force-time curve. This approach negated the possibility of drawing an erroneous conclusion that otherwise could result simply from a longer initial delay before onset of a rapid rise in force. It showed that across all drop heights the peak loading rate for the ARLI glove was never more than 55% of that observed with the Std 10 oz glove. The conclusion that the ARLI glove is likely to be protective against bone fractures is therefore reinforced.

The loading rate also affects the likelihood of impact injuries to the chest and abdomen and the organs contained within them. Cooper and Taylor [66] have noted that the nature and severity of such injuries depends on both the magnitude of distortion of the body wall and the rate of that distortion. Substantial compression of the torso can be tolerated with minimal injury if the distortion rate is slow, while severe internal injury can occur with relatively little compression when there is a high distortion rate [66]. This is partly because mechanical failure of many physical structures (including many body tissues) in response to the application of force is rate-dependent. It suggests that the ability of our ARLI glove to markedly reduce loading rates compared with conventional boxing gloves can therefore be expected to decrease the risk of impact-induced chest and abdominal injuries.

The effect of loading rate on the likelihood of brain injury due to impact is less clear. This is partly because the mechanisms of brain injury are complex [67] and understanding of them is still developing [68]. Most impacts to the head cause it to undergo a combination of linear acceleration (acceleration in the direction of the impact) and rotational acceleration (angular acceleration relative to the head's centre of gravity).

Linear acceleration produces compressive stresses that can cause substantial inward displacement of the skull with or without consequent fracture, brain contusion adjacent to the impact site and on the opposite side of the brain in line with the direction of impact, and occasionally epidural haematoma resulting from damage to meningeal blood vessels [69]. Susceptibility to injuries resulting from linear acceleration of the head appears to increase with loading rate. Viano and Lovsund [70] examined databases relating to studies entailing controlled delivery of linear impacts to the brains of ferrets and concluded that degree of injury could be best predicted by an index calculated as the product of strain and loading rate. They noted that strain alone was not a sufficient indicator of the injury risk.

Human brain tissue, however, has very low compressibility, and is therefore relatively resistant to injury caused by compressive stress. By contrast, it is highly vulnerable to shear forces [68]. Rotational acceleration of the head can generate damaging shear forces through a mechanism that has been explained by analogy of the head to a bowl of porridge, with the bowl representing the skull and the porridge representing the substance of the brain [71]. If the bowl is subjected to a direct hit on one side, the porridge moves essentially *en masse* toward the opposite side. If on the other hand the bowl is spun, the part of the porridge at the edge of the bowl moves with the bowl, while the part toward the centre is left behind. Consequently, there is relative motion within the porridge, demonstrating the creation of shear forces.

In the case of the brain, relative motion of the type described above can cause tearing of fixed blood vessels that run from the surface of the brain to various sinuses in the dura [69]. This can lead to subdural haemorrhage and haematoma—the most common acute cause of boxing-related deaths [72]. Early studies indicated that subdural haemorrhage typically resulted from impacts producing high angular acceleration of short duration [73]. This was thought due to an effect of loading rate on the strain threshold for failure of blood vessels [74], but based on subsequent research it seems that the threshold might be absolute, and therefore independent of loading rate [75]. Accordingly, there is now uncertainty concerning the influence of the rate of force application to the head (and consequently of the strain rate experienced by tissues exposed to the force) on the risk of subdural haemorrhage, and a question remains concerning the value of the decreased loading rates associated with our ARLI glove in protecting against this injury.

There is evidence, however, to suggest that damage to neural tissue is affected by loading rate. Galbraith et al. [76] subjected a giant axon from a squid to tensile loading and found that as the loading rate increased, the physiological response of the axon changed from a small reversible hyperpolarisation to depolarisation, and that the time taken to return from the depolarised state increased with the loading rate. LaPlaca et al. [77] applied shear stresses to cultured neural cells and reported that whereas slow application of stress produced no change in peak free intracellular calcium concentration, rapid stress application caused increases to 2.6 to 3.9 times the baseline level, with higher values corresponding to greater cell injury. Also, disruption of cell membranes, as indicated by lactate dehydrogenase release from the cells, increased as a function the loading rate. When the loading rate was high, lactate dehydrogenase continued to increase for 24 hours after stress administration, showing that damage was prolonged. Jin et al. [78] have reported that strain rate has a clear effect on the magnitude of tissue stress induced by compressive and shear testing of samples of human grey matter obtained from the cerebral cortex and thalamus, and of white matter obtained from the corpus callosum and corona radiata.

Analysis of data obtained from laboratory reconstruction of helmet impacts filmed during American football matches led Zhang et al. [79] to identify loading rate as likely being a key parameter in the biomechanics of concussion. For the midbrain region, the product of strain and loading rate was more than threefold higher for impacts that resulted in concussion compared to those that did not.

Although our studies included no measures of the effect of our ARLI glove on loading rate in contacted human tissues, we have demonstrated that the glove markedly reduces loading rate (measured as peak rate of force development) for a contacted force plate. It seems reasonable to assume some transfer of this effect to the tissue environment. Based on the above, a consequent reduction in the risk of brain injury could be expected but, because there is ongoing debate regarding the mechanisms of such injury [80], this is not certain.

6.3.5.3. Could Increasing Impact Duration Have Negative Consequences?

There is presently much public interest and concern in relation to the acute and long-term effects of cerebral concussion. The syndrome can be due to one or more of several different types of injury, including brain contusions and diffuse damage to the axons of neurons in the cerebral hemispheres and subcortical white matter [81].
Current consensus, though, is that rotational acceleration of the head is a major aetiological factor. The magnitude of rotational acceleration required to produce concussion is inversely related to the duration of that acceleration [82], and it appears that for some types of injury associated with concussion, duration may be the predominant risk factor. In controlled studies conducted with rats, Stemper et al. [83] found that while time of recovery from an anaesthetic administered to the rats before head impact was significantly affected by the magnitude of rotational acceleration but not the impact duration, behavioural abnormalities following the impact were related more to duration than magnitude. Also, diffusion tensor imaging showed that increases in magnitude and duration produced different microstructural changes within the brain, with the effect of duration evident throughout much of the brain but particularly at the interface of grey and white matter. It is therefore conceivable that when a decreased force loading rate occurs in association with an increased impact duration, as observed with our ARLI glove, there might not be a reduction in the risk of concussive injury but simply a change in the nature and mechanism of pathology [84].

Meaney and Smith [68] have noted that enhancement of understanding of the mechanisms of head injuries requires concurrent use of different approaches, with advanced computer modelling being complemented and progressively refined through field and laboratory research. It is therefore pertinent to consider what the different approaches can reveal as to how injury outcomes may be affected by 'softening' impacts (i.e. increasing impact compliance) in a manner resembling that achieved with our ARLI glove.

There is strong evidence that increasing impact compliance reduces peak linear and rotational acceleration associated with the impact. Oeur et al. [85] assessed relative effects of three different impact variables - compliance, velocity and location on the head - on linear and rotational acceleration measurements. A specially designed monorail drop tower was used to drop an instrumented Hybrid III headform on to three different surfaces at impact velocities ranging from 1.5 to 6.0 m·sec^{-1}.

The orientation of the headform was varied to provide five distinct impact sites. The three different surfaces were steel, a 25 mm thickness of vinyl nitrile, and a 67 mm thickness of rubber foam. They were selected to encompass diverse impact conditions encountered by athletes through falls in their real-world sporting environments. Compliance was found to be inversely related to both peak linear and peak rotational acceleration, such that increased compliance reduced the acceleration magnitudes. The effect of compliance was greater than that of either velocity or impact site. It tended to be greater for rotational acceleration than for linear acceleration, whereas impact velocity - though always secondary to compliance in terms of its influence - tended to affect linear acceleration more than rotational. In view of the findings, the researchers recommended that efforts aimed at head injury avoidance in sport should prioritise increase of impact compliance above mitigation of impact velocity. This recommendation was based on previous evidence of association between acceleration measures and risk of head injury [86-88] and assumed that any protective effects of reductions in acceleration resulting from enhanced impact compliance would not be fully or more than fully counterbalanced by increased impact durations.

While noting that modern helmets have greatly decreased the incidence of traumatic brain injury caused by falls in equestrian sports, Clark et al. [89] pointed out that concussions remain common, and wondered whether this could be due to inconsistency between conditions used for testing of helmets and those experienced in real-world situations. Using the same monorail system employed in the above experiment, they dropped an instrumented Hybrid headform on to three different anvils consisting of steel, turf and sand. In each case, the peak pre-impact velocity was 5.4 m·sec^{-1}. The steel anvil was in keeping with existing standards for helmet testing, while the turf and sand anvils were included because these are surfaces on to which equestrian riders generally fall. For each anvil type, the headform was dropped in three different configurations resulting in impact to the front, side and rear of the head. Regardless of the impact site, peak linear acceleration with turf and sand anvils was only 20% - 26% of that observed with the steel anvil. The effect of anvil type on peak rotational acceleration varied according the headform impact site, with the readings obtained with the turf and sand anvils being 41% - 48%, 20% - 21% and 39% - 47% of those for the steel anvil for front, side and rear head impacts respectively. Impact durations were in the range of 23 - 27 msec for the turf and sand anvils and 8 - 9 msec for the steel anvil. The linear and rotational acceleration measurements were used as inputs to a Finite Element Analysis model in which the scalp, skull, pia mater, falx, tentorium, cerebrospinal fluid, grey and white matter, cerebellum and brain stem were all represented. The model enabled calculation of the maximum principal strain in the cerebrum. The maximum principal strain is an index of the extent to which shear strain in the brain approaches the yield point of brain tissue as previously determined in tensile tests, and takes account of impact duration.

A value of 1.0 therefore predicts gross failure of the tissue, but injury to sub-components occurs at lower levels. When the steel anvil was used, the maximum principal strain was 0.304, 0.347 and 0.310 for impacts to the front, side and rear of the head respectively. Corresponding values were 0.192, 0.125 and 0.135 for the turf anvil, and 0.190, 0.135 and 0.145 for the sand anvil. The increased impact compliance provided by the turf and sand anvils therefore appeared to lessen the risk of brain tissue injury despite the lengthening of impact duration, although the values of maximum principal strain observed with these anvils were still within the concussive range.

Very similar findings have recently been reported by de Grau Amezcua [90], who used a pneumatic device to deliver controlled impacts to five different sites on a helmeted Hybrid III headform. For every impact site, three different impact velocities (4.5, 6.0 and 7.5 $m \cdot sec^{-1}$) were each tested in combination with three different caps on the impactor. The caps varied in compressibility so that impacts of low, medium and high compliance could be produced. Since the study was aimed at gaining insights into head impact dynamics resulting from collisions in ice hockey, the low, medium and high compliance conditions were designed to simulate collisions with ice, the elbow of an opponent and the padded shoulder of an opponent respectively.

It was hypothesised that increasing impact compliance would reduce peak linear and rotational acceleration of the headform yet increase maximum principal strain due to longer impact duration. The expectations concerning peak linear and rotational acceleration were confirmed, but maximum principal strain was in fact substantially reduced under the high compliance condition. Averaged across the five impact sites, it never reached more than 51% of the value recorded under the low compliance condition, and at the highest impact velocity the figure was just 34%. The data therefore did not support a prior notion that relatively low-intensity but long-duration impacts between heads and padded shoulders could be a major reason for a continuing high incidence of concussion in ice hockey.

It appeared that any negative effect of increased impact duration resulting from higher impact compliance was more than offset by a positive effect of reduced linear and rotational acceleration.

Post et al. [91] recently conducted a study in which various acceleration-time curves previously shown to be associated with occurrence of concussion in sport environments were used as inputs to a finite element model. It was found that for each of a range of linear acceleration levels from 20 to 200 g, maximum principal strain in the corpus callosum (a brain structure believed to be commonly affected in cases of sport concussion) increased as the duration of the impulse increased from 2.5 to 30 msec, with the duration effect becoming greater at higher levels of acceleration. The same was true for rotational accelerations varying from 1500 to 10,000 radians·sec^2. Importantly, however, the upward drift in maximal principal strain as a function of duration was essentially complete by 15 msec. Examination of the data suggests that reducing either peak linear acceleration or peak rotational acceleration by 30% would always produce a substantial reduction in maximum principal strain in the corpus callosum, even if it was associated from with a doubling of impact duration from 15 - 20 msec to 30 - 40 msec. These figures approximate our observations of changes produced by our ARLI glove relative to a Std 10 oz glove for drops on to a force plate from heights of 3 m and above. For example, it can be ascertained that a peak rotational acceleration of 5000 radian·sec^2 and a pulse duration of 15 msec would lead to a maximum principal strain of 0.26, while a peak rotational acceleration of 3500 radians·sec^2 and a pulse duration of 30 msec would give a maximum principal strain of 0.19, a reduction of ~27%. The reduction appears to become larger as levels of acceleration become higher. Accordingly, it is likely that our ARLI glove can lower the risk of concussive head injury resulting from any specific combination of impact velocity and effective mass within the range occurring during boxing. It has been reported, though, that maximal punches delivered by Olympic boxers to the Hybrid III headforms have produced peak rotational accelerations of almost 9000 radians·sec^2 with an impact duration of 10 msec [50]. While a 30% reduction in acceleration and a doubling of duration would markedly decrease the maximum principal strain resulting from such an impact, the maximal principal strain would remain above the level denoting a 50% risk of concussion.

Having plotted known magnitudes of 61 real-world head impacts against the durations of those impacts, Hoshizaki et al. [67] noted that incidents typically responsible for the most severe injury tended to have high relatively high impact magnitudes and short pulse durations, while those producing transient or no concussion had the opposite characteristic. Impacts that produced persistent post-concussive syndrome were generally of higher magnitude and shorter duration than those which did not. This has led Hoshizaki et al. [67] to speculate that the interaction between impact magnitude and duration may be a determinant of the nature, severity and mechanism of brain injury, and of the variability in symptoms.

For example, in the case of rotational acceleration, impulses of high magnitude and short duration may cause the skull to move relative to the brain, creating shearing forces capable of tearing blood vessels and injuring neuronal axons, resulting in subdural haematoma and/or diffuse axonal injury. When the impulse is of lower magnitude and longer duration, the brain may tend to move with the skull, with stresses and strains thus transferred to the more central parts of the brain and any resultant injury less acutely dramatic.

The concept of the injury severity continuum advanced by Hoshizaki et al. [67] implies that our ARLI glove, by reducing impact magnitude and prolonging impact duration relative to the levels produced by standard boxing gloves, should shift any injury caused by impact to the head in the direction of being less severe. When this is considered in combination with the scientific literature suggesting that the ARLI glove should considerably decrease the risk of torso injuries [66,92] a rationale for practical deployment of the new glove seems clear.

6.3.5.4. Acceptance of the New Glove—A Case of History Revisited?

The development of boxing gloves employing air as an impact-damping medium has attracted the attention of inventors on a regular basis over the past 120 years [26-45]. Despite the efforts and ingenuity of the inventors, the development of the pneumatic gloves seems to have attracted only a small amount of media attention over the years [93-96], with the coverage obtained sometimes having elements of levity, as in the case of a magazine article that raised a question as to whether in the future boxing judges would “give a man credit if he achieves a blowout but fails to achieve a knockout” [96].

It appears that none of the designs were successfully commercialised. We have been able to locate only one record of pneumatic gloves being made available for purchase, and that was through the classified advertisements section of a magazine, with the number of gloves on sale being just four [97].

Additionally, there is very little evidence of field use of pneumatic gloves. Smith [98] records that in 1916 such gloves were employed in an exhibition bout held in New York between a male and a female boxer. Because the bout contravened existing legislation it was halted by police intervention after just one round (which according to onlookers was clearly won by the female). The only substantial field usage seems to have occurred in Finland, and involved pneumatic gloves invented by Löfgren. These gloves were described in a 1957 publication [46] that also outlined the results of experiments showing that they were effective in reducing the acceleration imparted to a struck pendulum.

Over the following few years, they were reportedly used in 'hundreds of contests' conducted under the auspices of the Finnish Amateur Boxing Association, but by 1961 Löfgren [99] felt compelled to make a spirited defence of them. He attempted to address several major criticisms relating to the weight of the gloves (which was 12 oz compared with the 8 oz gloves then mandated for official competition), their comfort, their prevention of the ability to block punches through use of an open hand, and their cost. He also responded to a perception that the gloves had produced 'no change in the number of injuries', claiming that this was true only if analysis was confined to minor injuries such as superficial bruising and abrasions. Nevertheless, the gloves disappeared from the scene shortly afterwards.

A question arises as to whether the result is likely to be any different now. In demonstrating our ARLI gloves to members of the Australian boxing community, we have encountered reactions akin to some recorded by Löfgren [99], particularly concerning comfort, departure from the "feel" of standard gloves, a possible influence on boxing technique, and cost. An important difference, though, is the context in which we are seeking to introduce the gloves. Positioning them for use in modified boxing, rather than conventional boxing, gives the initiative a different dynamic, since participants in modified boxing tend to have a greater focus on safety and therefore may be more receptive to use of new equipment aimed at safety enhancement. Also, there is arguably a natural link between the notion of a modified sport and expectation of a requirement for deployment of modified equipment. Indeed, the availability of specialised equipment may reinforce the credibility of the modified sport.

Another point in our favour is that methods for evaluating the impact-damping qualities of gloves are now far more extensive than those that Löfgren [46] could access. Consequently, we may be able to provide more compelling evidence of the worth of our prototype glove.

The force plate and motion capture research already conducted testifies to the effectiveness of the ARLI glove but in the future could be supplemented by studies entailing the use of instrumented manikins and contemporary finite element models. We envisage that ongoing generation of high-quality information in laboratory, field and virtual environments will guide progressive glove refinement and, provided that test results remain affirmative, create additional impetus for uptake of the gloves in modified boxing settings.

Acceptance and widespread use in those settings might eventually cause relevant authorities to seriously consider the applicability of the gloves to conventional boxing, but at present our fundamental objective is develop them as a means for advancing modified forms of the sport.

6.3.5.5. Are Low-Impact Gloves Needed in Modified Boxing?

In the version of modified boxing that we have been supporting, impacts to the head and neck are prohibited [48,100]. Under this circumstance, a question may be asked as to whether gloves capable of reducing impact forces are needed. We believe that use of low-impact gloves in the modified boxing context is advantageous for several reasons. Experience has shown that accidental head impacts can sometimes occur, and it is important that their effects should be minimised. It is also true, however, that impacts to the torso with standard gloves have potential to be highly injurious. Oelman et al. [101] reported that amongst British Army personnel, boxing-related injuries were responsible for a total of 437 medical unit admissions between 1969 and 1980. While head injuries were the predominant reason for admission, with 296 cases, there were 20 admissions for trunk injuries, with the more serious cases including fractures of the ribs, larynx or vertebrae. Additionally, there were 13 admissions for internal injuries, including injuries to the kidney and pelvic organs. The average hospitalisation time for the internal injuries was 6.2 days.

Timm et al. [102] collated data from amateur boxers who sought support from medical staff for injuries sustained while training and competing at the United States Olympic Training Centre within the period from 1977 to 1992. From a total of 1219 injuries, there were 49 to the lumbopelvic region, 46 to the chest and ribs, 21 to the thorax and 10 to the abdomen. Injuries to the torso therefore constituted more than 10% of all injuries. Potter et al. [103] reported that between 1990 and 2008 there were 165,602 presentations to United States Emergency Departments for injuries sustained in boxing. Of these, 6.3% were for trunk injuries. Post-bout hematuria (blood in the urine) is common amongst boxers and is considered primarily attributable to direct kidney trauma rather than to other factors that can produce the condition [104,105].

Rib fractures can cause damage to lung tissue, leading to pneumothorax [106], a condition in which air collects in the space between the lung and the chest wall and exerts pressure that can result in partial lung collapse. There is a case report of pneumothorax in a boxer even in the absence of rib fracture [107].

Boxing has been known to cause myocardial contusion (bruising of the heart) [108]. Blunt impact to the chest wall can cause sudden death due to cardiac arrhythmia, often in the form of ventricular fibrillation, even without injury to the ribs, sternum or heart [109,110]. Sudden death of this nature is called commotio cordis, and typically results from impact to the left chest. There have been at least 107 cases in organised sports and recreational sports [111], including a few in boxing [109,111-112]. Athletes below 18 years of age are statistically the most susceptible. The impacting object is typically quite hard. In all but one of the documented sport-related cases it had a solid rather than an air-filled core [111]. Svinth [1] notes that ruptured spleens and punctured lungs have been amongst known causes of death associated with boxing.

The above makes it clear removal of the head and neck from the target zone is not of itself sufficient to make modified boxing safe, and that "softening" of impacts to the torso is also required. It is evident that our ARLI gloves can contribute importantly toward achievement of the latter objective, particularly if used in combination with other relevant measures such as athlete education and appropriately designed protective vests. In the aftermath of our experiment, the gloves have already undergone refinements to make them suitable for field use. The air exchange portal has been modified so that it does not protrude beyond the glove surface. Scope exists for further enhancement. For example, the bladder could be altered to include not just the hemispherical component but also an additional section extending over the entire back surface of the glove, thereby increasing overall bladder volume and perhaps augmenting the protective effect at high pre-impact glove velocities. Nevertheless, the experiment reported in this paper highlights the potential utility of appropriately designed pneumatic gloves.

6.3.6. Conclusion

We have produced pneumatic boxing gloves that reduce the peak magnitude of impact delivered to a target and the maximum rate of force increase. The reduction in peak force compared to conventional 10 oz gloves currently used in boxing competitions occurs across a wide range of pre-impact glove velocities extending to the highest that world-class boxers are reportedly capable of generating and is typically in the order of 25% - 40%. The reduction in peak rate of force increase is even greater, ranging from 47% - 63%. These changes are associated with a more than 50% increase of glove-target contact times, and analysis of the available scientific literature suggests that they should substantially reduce severity of impact-induced injuries. Although the new gloves are unlikely to be rapidly adopted by the conventional boxing community, they may well prove to be almost immediately acceptable in the context of modified boxing programs that place high emphasis on safety, and this could provide a stimulus for their uptake and progressive improvement.

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Chapter 7: Performance of Prototype Pneumatic Boxing Gloves under Two Different Conditions of Target Padding

7.1. Declaration for chapter 7

Declaration by candidate

In the case of Chapter 7, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Contributed to the study design, data collection, data analysis and assisted with manuscript preparation.	No
Alex Jamieson	Contributed to study design, data collection and preparation of manuscript.	No
Wayne Spratford	Contributed to data analysis and manuscript preparation.	No
Candidate's Signature		**Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1:	25/3/2019
Signature 2:	26/3/2019
Signature 3:	2/4/2019

7.2. Prologue

The peak impact forces recorded when a conventional boxing glove was dropped on to a force plate from a height of five metres as part of the experiment described in Chapter 6 were markedly greater than those reported to occur during boxing matches. It therefore seemed likely that the ability of the target to buffer impact forces might tend to be greater in the real world than in our contrived laboratory situation. This raised a possibility that our experiment might have led to overestimation of the real-world protective effect of the pneumatic glove with capability for air release and reuptake. A further study was therefore conducted with characteristics of the laboratory target adjusted so that peak impact forces measured for a conventional glove more closely resembled those measured in field conditions by other researchers. A publication outlining this study appears hereunder. It contributed to meeting the following research aims identified in Chapter 1:

- **Aim 5:** To explore and iterate specific technologies seen as having potential to enhance the experience of modified boxing program participants, particularly in terms of safety and program enjoyment.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

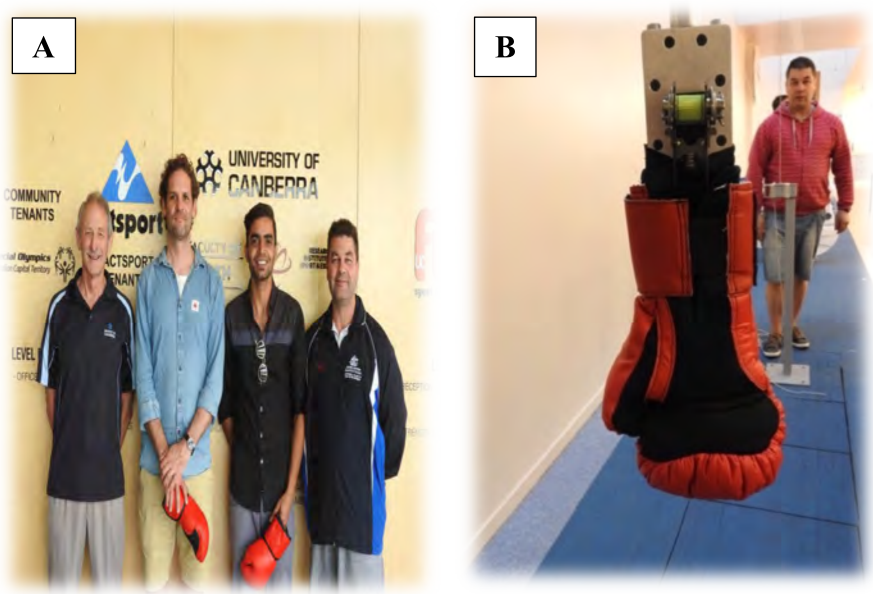

Image A: Members of the glove design and development team (Left to right) Professor Allan Hahn, Mr Geordie Ferguson of Stellen Studio, Canberra, Mr Jalaj Anand of Paramount Enterprises, Dehradun, India, and myself after a day of glove testing at the University of Canberra. **Image B:** Laboratory testing of impact-damping glove.

7.3 Published paper 6 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Performance of Prototype Pneumatic Boxing Gloves under Two Different Conditions of Target Padding

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7.3.1. Abstract

The impact damping capabilities of four different boxing gloves were assessed under two different conditions of target padding to determine whether target characteristics might influence previous conclusions concerning potential for impact mitigation through novel glove design. A conventional 10 oz glove (Std 10 oz), a conventional 16 oz glove (Std 16 oz), a prototype pneumatic glove with a sealed bladder (SBLI) and a prototype pneumatic glove with a bladder allowing air exchange with the external environment (ARLI) were each dropped three times on to a force plate from six heights ranging from 2.5 to 5.0 metres. The force plate was covered by a 50 mm thick mat of EVA material and results obtained were compared with those of an earlier experiment involving use of a similar protocol but a 25 mm thick EVA force plate covering. The thicker mat greatly reduced peak impact forces for all gloves, with values for the Std 10 oz glove becoming much closer to those reported by other researchers for punches delivered by elite boxers to crash test manikins. Peak rates of force development were also substantially decreased. Protective effects provided by the ARLI glove relative to the Std 10 oz glove were diminished but still in the order of 17% - 22% for peak impact force and 27% - 49% for peak rate of force development across the range of drop heights. With the 50 mm mat thickness, the SBLI glove was as effective as the ARLI glove in reducing peak impact force, whereas this was not the case with the 25 mm mat. It was, however, always inferior to the ARLI glove in decreasing peak rate of force development. The ability of the ARLI glove to afford protection across a spectrum of impact conditions could yield important practical advantages.

Keywords: Boxing Safety, Low-Impact Boxing Gloves, Modified Boxing, Protective Equipment for Boxing, Sport Technology, Sport Safety.

7.3.2. Introduction

A paper recently published by our group showed that a pneumatic boxing glove allowing transfer of air between the glove bladder and the external environment substantially reduced peak impact forces and rates of force development (i.e. loading rates) across the whole range of impact magnitudes likely to occur in boxing [1]. We described a study in which prototype pneumatic gloves containing a mechanical fist with a mass of ~3 kg were dropped on to a force plate from heights of up to 5 metres to simulate the effective impact mass and preimpact glove velocities previously reported by Waliliko et al. [2] for a group of elite boxers.

Even though the force plate was covered by a 25 mm thickness of ethylene-vinyl acetate (EVA) material known to have high capacity for shock absorption, we recorded peak impact forces of more than 13,000 Newtons (N) when conventional 10 oz and 16 oz gloves were dropped from a height of 5 metres. There have been some studies in which boxers have delivered maximal punches to the heads of Hybrid III crash test manikins designed to closely simulate human structural characteristics [2,3]. In this situation, mean peak impact forces have been less than 4000 N although several boxers have generated readings of more than 5000 N. The highest value recorded in the scientific literature is 8000 N [3]. Pierce et al. [4] used in-glove capacitive force sensors to record peak impact forces during six professional boxing bouts incorporating a total of 20 rounds. Single highest peak force readings for the 12 contestants averaged 3295 N and the highest reading produced by any boxer was 5358 N.

The above suggests that human anatomical structures typically provide considerably more impact damping than the EVA-covered force plate used in our experiment.

This accords with a contention by Margetts [5] that published data on the peak forces produced by a champion heavyweight boxer in a laboratory setting may lack ecological validity because of differences in the characteristics of the experimental and real-world targets.

We thought it logical that an impact-damping boxing glove that was effective in reducing the peak forces of impacts to a relatively undamped target might be much less so when additional impact buffering mechanisms are brought into play. It also seemed possible that testing of gloves in the latter situation might influence the relativity of the protective effects offered by the air-release pneumatic glove and a prototype with a sealed bladder. In our initial work, we found that performance of the two gloves was similar at drop heights of 1 - 2.5 metres, but that at higher drop heights the impact-damping capacity of the sealed-bladder glove progressively “bottomed out”. It was evident that in a more damped system such loss of protective ability might not occur, and that a pneumatic glove with a sealed bladder might therefore perform as well as one enabling air exchange.

Accordingly, we decided to test the gloves used in our earlier experiment under conditions in which the force plate was more padded and the peak impact forces therefore would be more akin to those recorded in research involving the use of Hybrid III manikins [2,3] and measurements made during boxing contests [4].

7.3.3. Methods

Four different boxing gloves were placed on to a mechanical fist and dropped on to an in-floor Kistler force plate (Kistler, Amherst, MA, USA) three times from each of six heights starting at 2.5 metres and progressing in 0.5-metre increments to 5.0 metres. The four gloves were a conventional 10 oz (Std 10 oz) glove of the type used in competition by male amateur boxers weighing up to 64 kg and by female amateur boxers in all weight divisions [6], a conventional 16 oz glove (Std 16 oz) of the type often used by boxers in sparring [7], a prototype pneumatic glove with a sealed bladder (SBLI), and a prototype pneumatic glove with a bladder that allowed air release to the external environment and subsequent air reuptake (ARLI).

The Std 10 oz and Std 16 oz gloves were made by Sting Sports (Melbourne, Australia) and were commercially available. Sting Sports was the official supplier of gloves for the 2016 Olympic Games and 2018 Commonwealth Games.

The SBLI and ARLI gloves were manufactured by Stellen Studio (Canberra, Australia) for our research purposes. An overview of their construction is available elsewhere [1]. Precise glove masses, as measured with digital kitchen scales, were 278 g (9.8 oz), 455 g (16.0 oz), 227 g (8.0 oz) and 298 g (10.5 oz) for the Std 10 oz, Std 16 oz, SBLI and ARLI gloves respectively.

The mechanical fist, shown in Figure 1, had a mass of 3.046 kg which is close to the average effective mass of punches delivered by elite boxers [2]. It consisted of three sections simulating the long axis of the forearm, the proximal section of the fingers, and the distal sections of the fingers. These sections were hinged together and a ratchet mechanism enabled them to be drawn and locked into a position resembling a closed fist [1]. In the case of the Std 10 oz and Std 16 oz gloves, the mechanical hand was placed into the glove and the fist was then closed. For the SBLI and ARLI gloves, the fist was closed and then placed into the glove such that the bladder was located between the fist and the target. These approaches accorded with intended placement of human fists into the gloves in the real world.

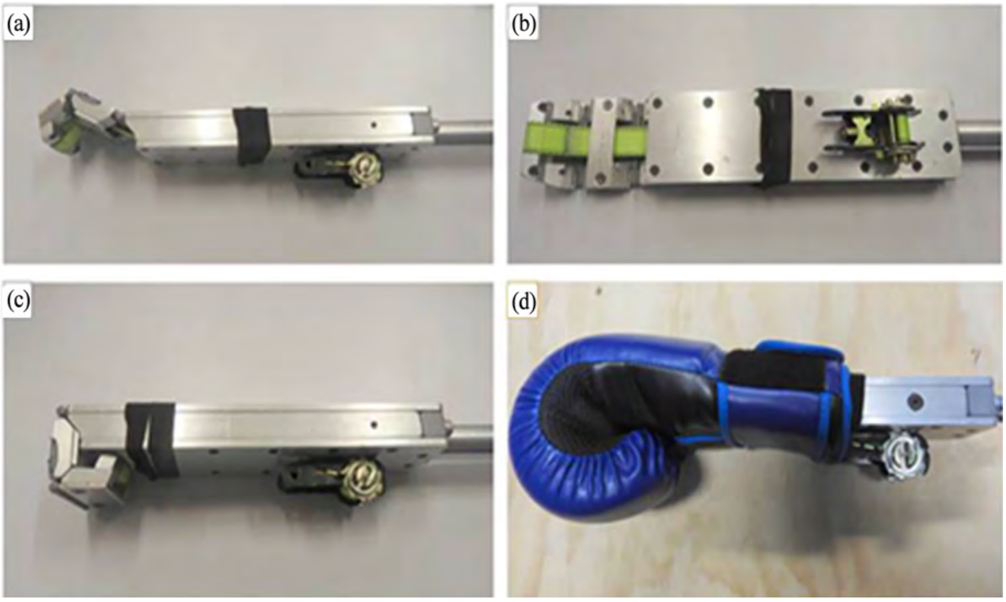

Figure 1: The mechanical fist used in the experiment. Panel (a) shows the three hinged metal sections of the fist; Panel (b) shows the mechanism used to draw the fist closed; Panel (c) shows the fist in the locked position; Panel (d) shows a glove fitted to the fist and highlights the accuracy with which normal glove positioning on a fist was simulated.

The force plate had a surface area of 600 mm × 400 mm. This surface was covered by a 50 mm thickness of EVA75 material (Ultralon Foam Group, Sydney, Australia) comprising two 25 mm thick layers joined together by double-sided tape. For each glove drop, the force plate was sampled at 10,000 Hz. Throughout the experiment, known masses were repeatedly placed on the force plate to check its measurement accuracy.

A Vicon Motion Capture System (Oxford Metrics Ltd., Oxford, UK) with four cameras each sampling at 500 frames per second was used to determine glove velocities just before and after impact with the force plate. Markers placed on gloves allowed determination of displacement and thus calculation of velocity over successive 2-msec time periods. To facilitate data synchronization, the Vicon software was used to capture data from the cameras and the force plate. Glove contact with the force plate was defined as the period between occurrence of a force continuously above 20 N in the ascending phase of the force-time curve and return of the force to readings below 20 N in the descending phase. Employment of the 20 N threshold ensured that identification of contact would not be contaminated by previously quantified levels of baseline noise in force plate electrical activity. The drop testing system used in the experiment is shown in Figure 2.

Figure 2: Drop testing system used for the experiment.

The SBLI glove was tested first, followed by the ARLI, Std 10 oz and Std 16 oz gloves in that order. Each glove was tested at all drops heights before progression to the next glove.

Data obtained with the 50 mm thickness of EVA75 material covering the force plate were compared to those derived from an earlier experiment [1] in which the thickness of the covering was only 25 mm. The earlier experiment was conducted during the preceding week, meaning that the time between the experiments with the 25 mm and 50 mm mats was sufficiently short to allow valid data comparison.

Also, exactly the same gloves (rather than just the same glove types) were used in the two studies. In the research involving deployment of the 25 mm mat, each glove was dropped on to the force plate 10 times from each height [1], but for the present purpose only the data from the first three of these drops were analyzed. This permitted direct alignment with the three drops made from each drop height in the experiment with the 50 mm mat.

7.3.4. Results

The peak impact forces recorded with the 50 mm mat covering the force plate are shown Figure 3.

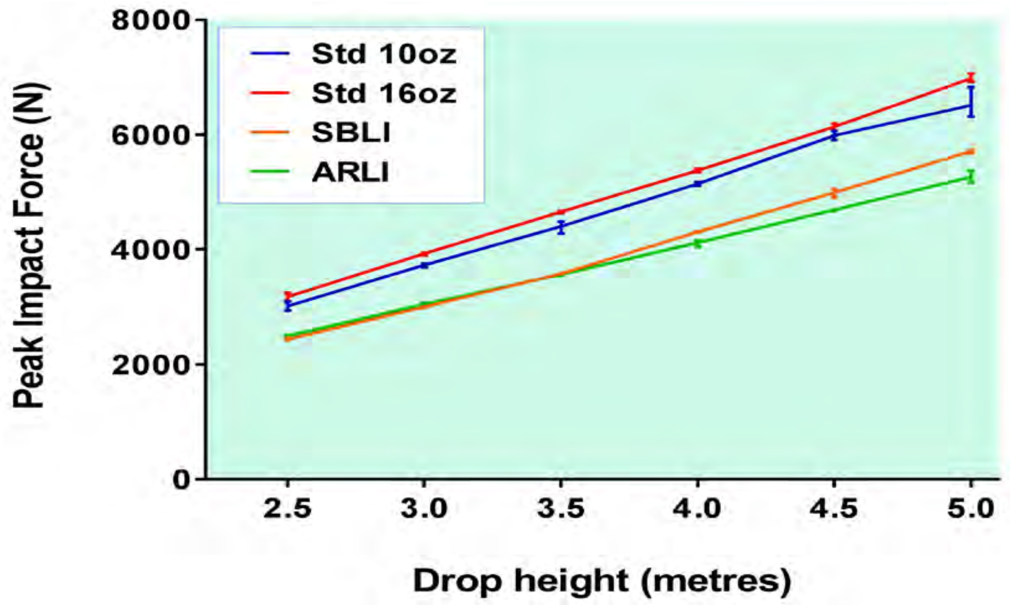

Figure 3: Effect of glove type and drop height on peak impact force when gloves were dropped on to a 50 mm thick mat consisting of EVA75 material with a guaranteed Shore A hardness rating of 30-35. Each point on the graph shows the mean and the range for three glove drops. In some cases, the range is too small to be perceptible.

For all glove types the values were lower than those we obtained in the experiment conducted during the preceding week with a thinner (25 mm) mat covering the force plate. The peak forces measured when the Std 10 oz glove was dropped from 5 metres were much closer to the maximum levels that others have reported for boxers in laboratory or real-world competitive situations [2-4]. The two prototype pneumatic gloves reduced peak forces relative to those seen with the Std 10 oz and Std 16 oz gloves, but in contrast to our finding when the thinner force plate covering was used, the SBLI glove was now almost as effective as the ARLI glove across the whole range of impact magnitudes.

The values for the Std 16 oz glove were slightly higher than those for the Std 10 oz glove, whereas before they had been slightly lower.

Figure 4 shows how the peak impact forces for specific combinations of glove type and drop height were influenced by the thickness of the force plate covering. The grey-shaded regions of the graphs highlight the magnitude of change in peak force as a function of mat thickness. It can be readily seen that mat thickness had less effect on the ARLI glove than on any of the others.

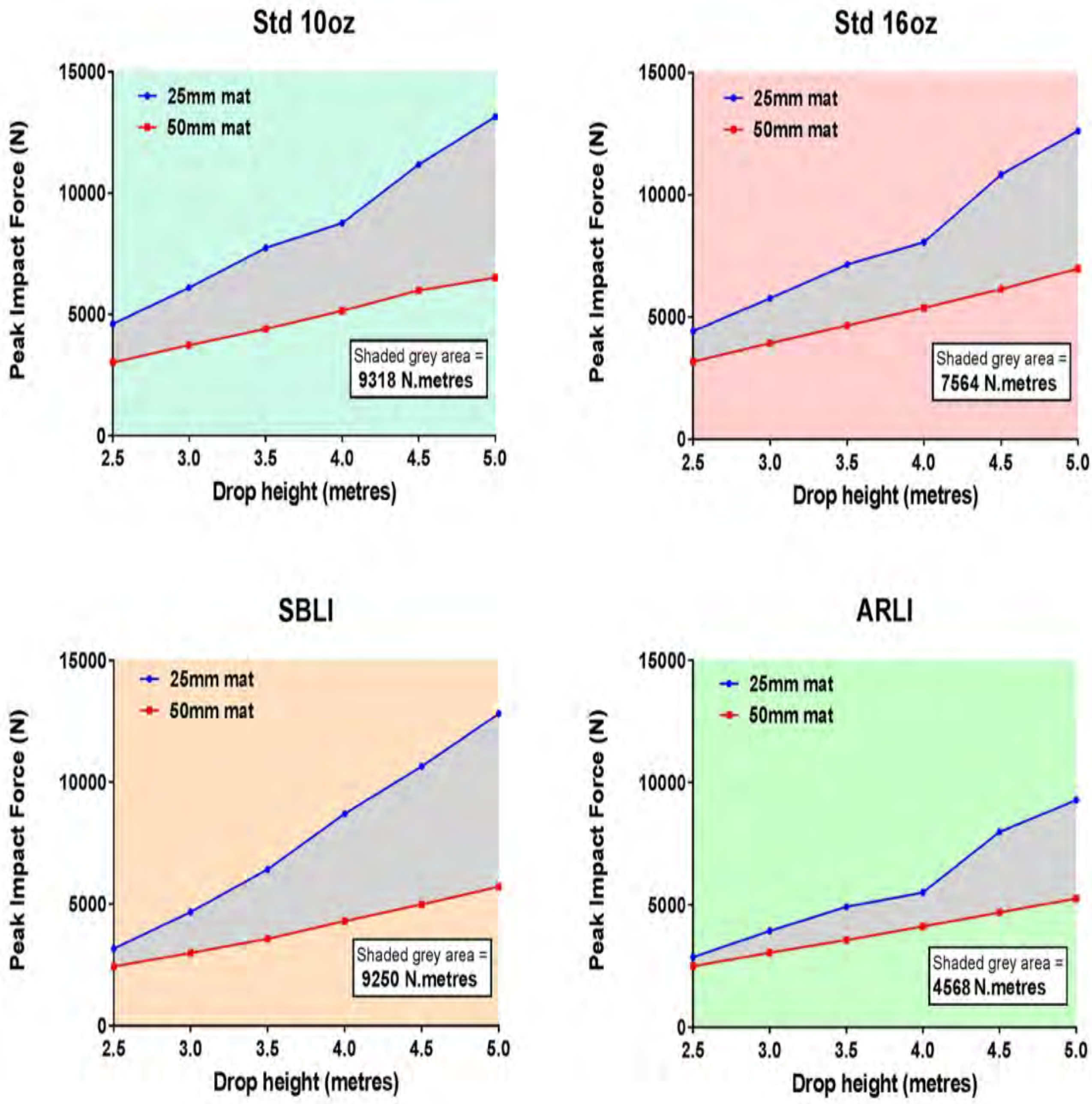

Figure 4: Effect of thickness of force plate covering on peak impact forces associated with dropping different gloves from various heights. Each point on the graphs is a mean value for three glove drops.

The areas of the grey regions were computed, and the results, which are presented in the figure, provided objective quantification of the visual impression. The calculated areas showed that overall, the Std 10 oz and SBLI gloves were most affected by mat thicknes, followed by the Std 16 oz glove and then the ARLI glove. For each glove type, both the absolute and proportional magnitude of the reduction in peak force with increase in mat thickness tended to become greater with drop height. Percentage reductions for the various drop heights are shown in Figure 5.

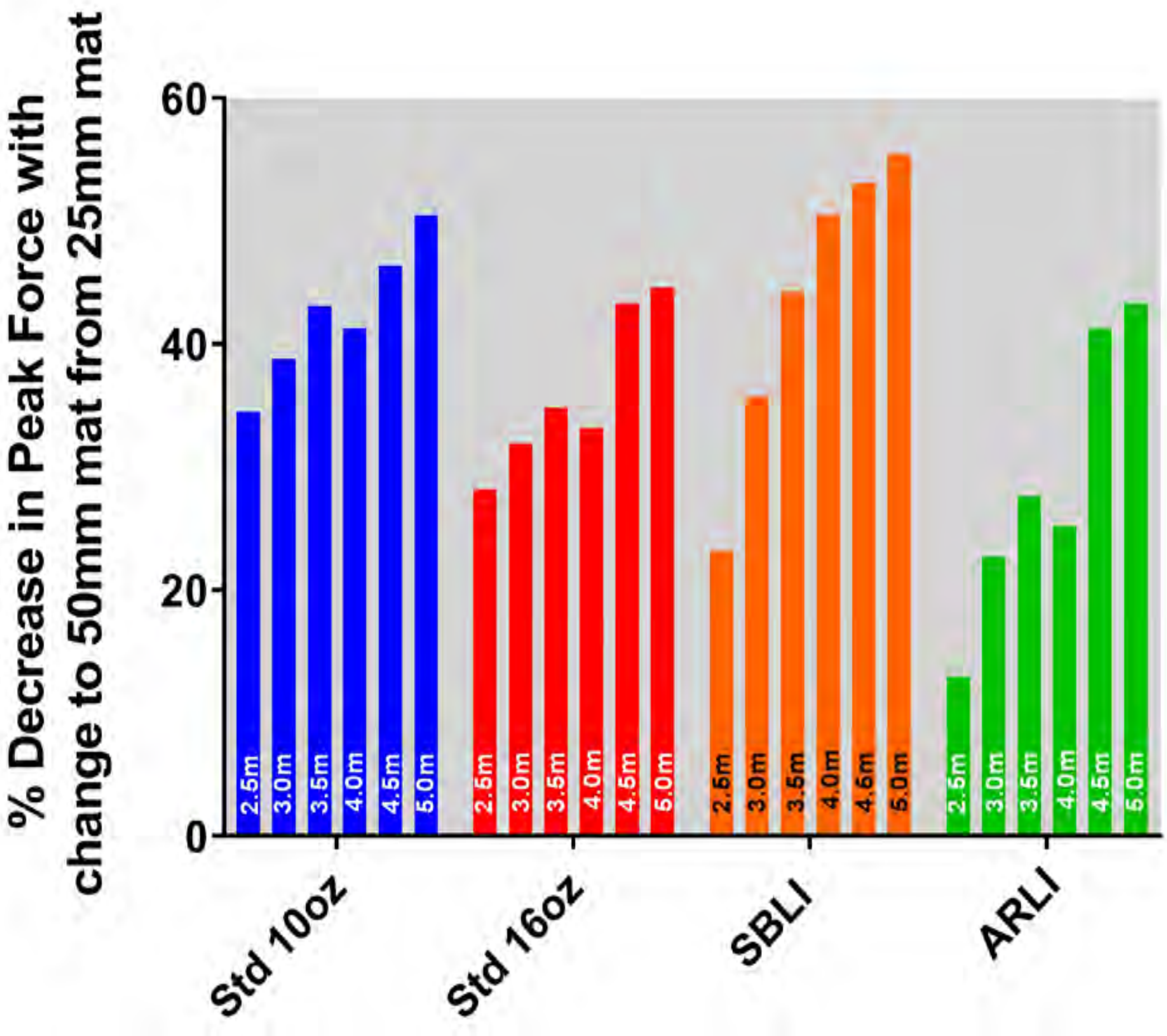

Figure 5: Percentage reduction in peak impact force resulting from covering the force plate with a 50 mm thickness of EVA75 foam as opposed to a 25 mm thickness. Each bar represents the decrease calculated from means of three peak force readings obtained with each mat thickness. Drop heights are shown on the bars.

Because the four gloves were differently affected by mat thickness, the relativity of their protective performance was influenced. For example, Figure 6 shows that compared to theStd 10 oz glove, the ARLI glove reduced peak impact force by 29% - 37% when the thickness of the mat covering the force plate was 25 mm, but only by 17% - 22% when the thickness was 50 mm. With the thinner mat, the percentage reduction in peak force provided by the ARLI glove tended to decrease as drop height increased. When the thicker mat was used, it was relatively stable across the range of drop heights. Consequently, for the ARLI glove, the difference in percentage reduction of peak force observed with the two mat thicknesses was least when the drop heights were highest.

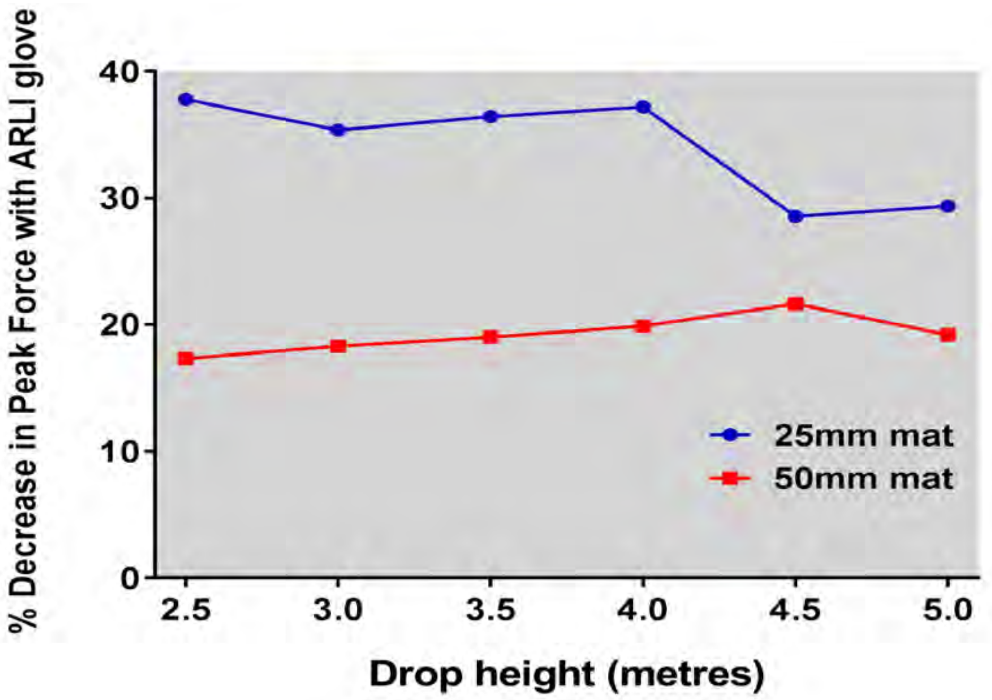

Figure 6: Effect of thickness of force plate covering on percentage reduction in peak force provided by ARLI glove relative to Std 10 oz glove.

For all glove types, the peak pre-impact glove velocities determined by the Vicon Motion Capture System were slightly less with the 50 mm force plate padding than in our previous experiment where 25 mm padding was used. This reflected the fact that the additional padding of the force plate decreased the actual drop heights by 2.5 cm. The peak impact velocities were always slightly lower for the two prototype pneumatic gloves than for the two conventional gloves (Figure 7), as was observed also in our immediately preceding research entailing use of 25 mm padding.

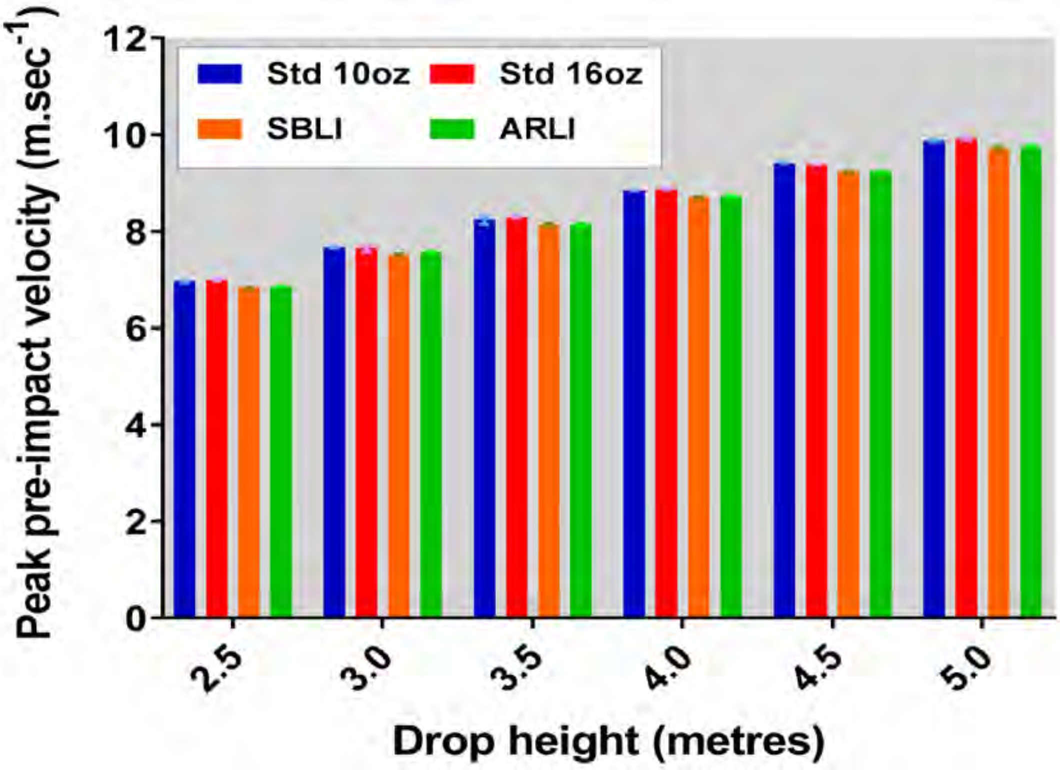

Figure 7: Peak pre-impact glove velocities (in m·sec^{-1}) for four different gloves dropped from various heights on to a force plate covered with a 50 mm thick mat of EVA75 material. Each bar indicates the mean for three glove drops under the specified condition and the range of the readings is also shown.

The velocity data revealed that at drop heights of 2.5 to 3.5 metres, slowing during the first few video frames after contact was essentially unchanged by extra force plate padding for any of the gloves. At a drop height of 4.0 metres, higher velocities during the immediate post-contact period became evident for the Std 16 oz glove and this was observed also at 4.5 and 5.0 metres. For the Std 10 oz and SBLI gloves, higher velocities were seen only at 4.5 and 5.0 metres. In the case of the ARLI glove, there was no change up to and including 4.5 metres, and only a very slightly higher post-contact velocity even at 5.0 metres. For illustrative purposes, data for the Std 10 oz and ARLI gloves at drop heights of 2.5 and 5.0 metres (the extremes of the range of drop heights employed) are presented in Figure 8. We interpreted the data as indicating that the initial dynamics of the interaction between glove and force plate padding were determined by the properties of the padding material rather than its thickness, and that the added thickness became important in reducing glove deceleration only once the ability of the structural characteristics of the gloves to exert that effect began to approach a maximum.

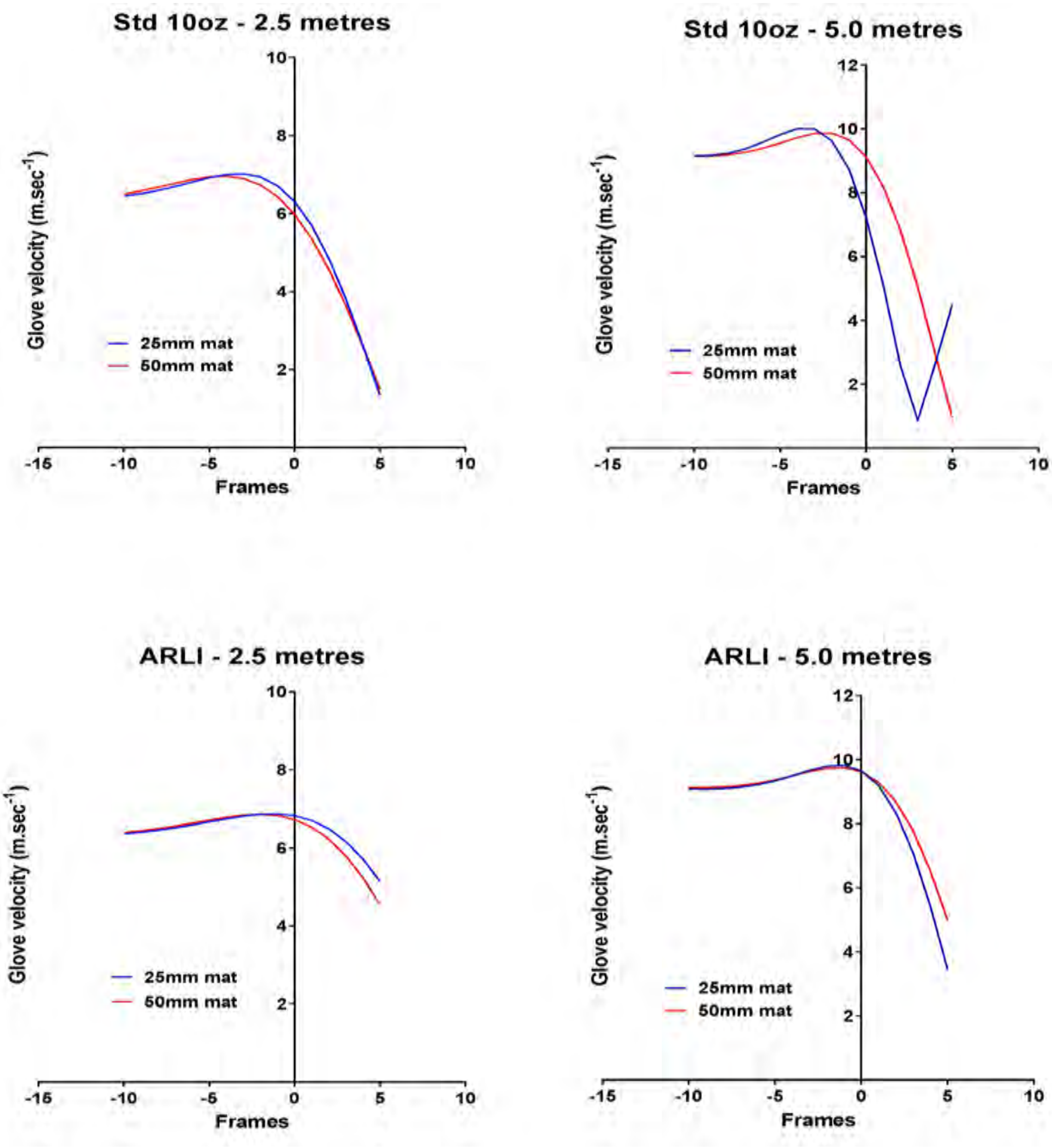

Figure 8: Glove velocities measured using Vicon Motion Capture system. The velocities are shown from 10 video frames before to 5 frames after contact between glove and force plate and represent means of three glove drops. In the top right panel, the upward inflection of the blue line from 3 - 5 frames after glove contact with the force plate reflects velocities recorded as the glove rebounded away from the force plate.

The above interpretation was supported by analysis of force-time curves recorded from the force plate. For each glove type at every drop height, there was a period of a few milliseconds after contact when force-time curves obtained with the 25 mm and 50 mm mats covering the force plate essentially overlaid each other (Figure 9).

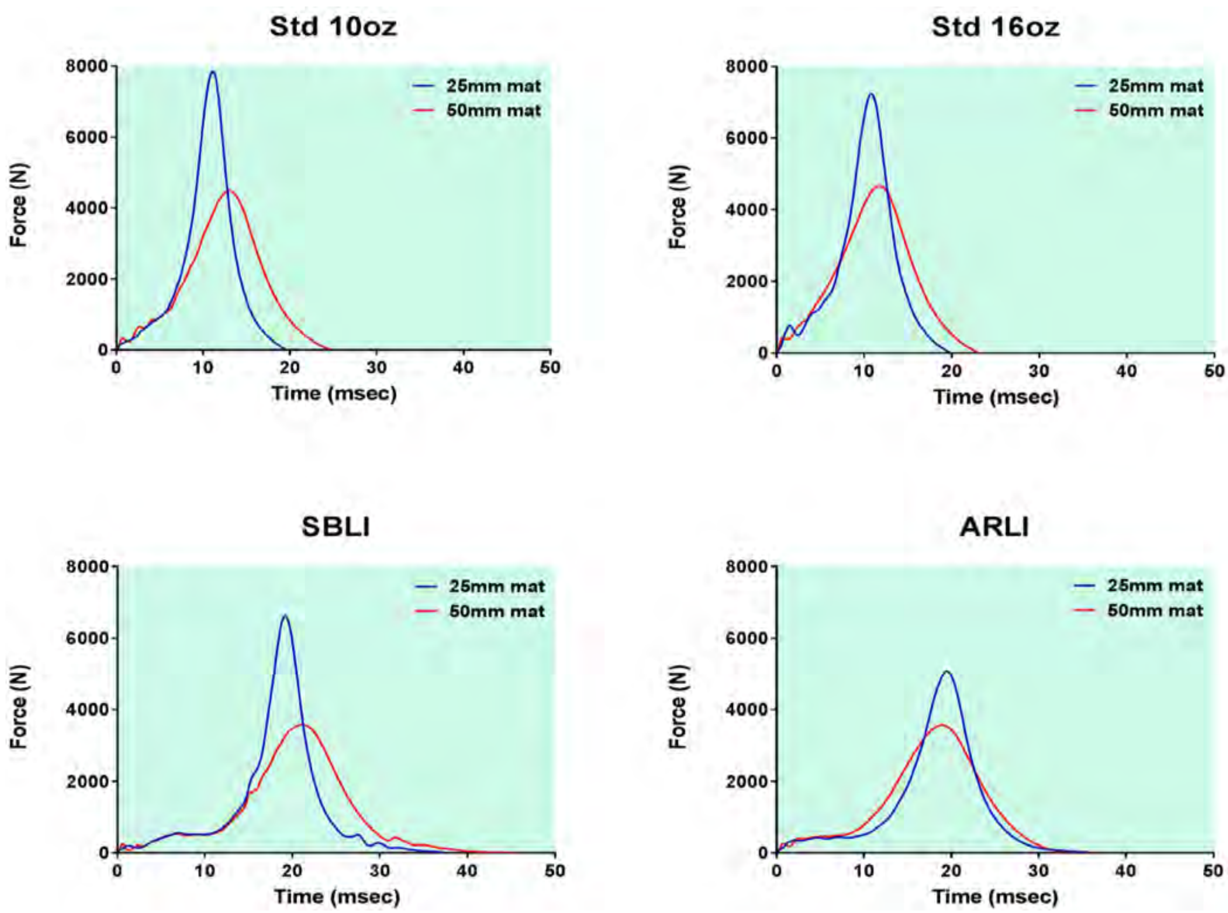

Figure 9: Force-time curves for different gloves dropped from a height 3.5 metres on to a force plate covered by EVA mats of two different thicknesses. The blue line relates to a mat thickness of 25 mm and the red line to a mat thickness of 50 mm. The results shown are indicative of those obtained across the whole range of drop heights.

It seems logical to presume that during this period (which was generally longer for the two prototype pneumatic gloves than for the Std 10 oz and Std 16 oz gloves), the primary influence on the curve was glove compression. With the gloves being softer than the target, it can be easily envisaged that their deformation would be the predominant event in the initial phase of the impact, and that only after substantial glove compression and consequent hardening would capacity for target deformation become the main determinant of the force curve.

The magnitude of impact buffering provided by the target material would then depend not just on the properties of the material but also on the extent to which buffering had already occurred during glove deformation. Accordingly, in the case of the ARLI glove, the fact that the protective effect of increasing the thickness of the force plate covering was smaller than for the other glove types may have been largely due to prior occurrence of more substantial force damping through glove compression and air release.

Our examination of the force-time curves led us to simplistically conceptualise them as being describable in terms of four sequential but somewhat overlapping events - glove deformation, target deformation, target recovery and glove recovery - with the first two occurring during the lead-up to peak impact force and the latter two following it. Doubling the thickness of the mat covering the force plate appeared to have little effect on the timing of the glove deformation phase or the extent of impact damping resulting from it. It did, however, provide scope for greater target deformation and therefore a longer period of impact. For the Std 10 oz, Std 16 oz and SBLI gloves contact time was increased at all drop heights, while for the ARLI glove there was little or no increase until the final drop height of 5.0 metres, and even then the change was relatively small (Figure 10). This suggests that the performance of the ARLI glove was less dependent on target characteristics. In general, greater increases in contact time were associated with proportionally greater protective effects of the additional force plate padding.

Computation of areas under the force-time curves yielded values very similar to those calculated in our previous study, where the thickness of the mat was only 25 mm (Figure 11). Over 24 combinations of glove type and drop height, there were 17 in which values for the 25 mm and 50 mm mat thicknesses were within 2% of each other, and another five where the difference was less than 2.5%. Given that pre-impact glove velocities determined with the Vicon Motion Capture system were slightly lower with the thicker mat, we expected that the calculated area-under-the-curve might also be lower under this condition, but no such effect was detected.

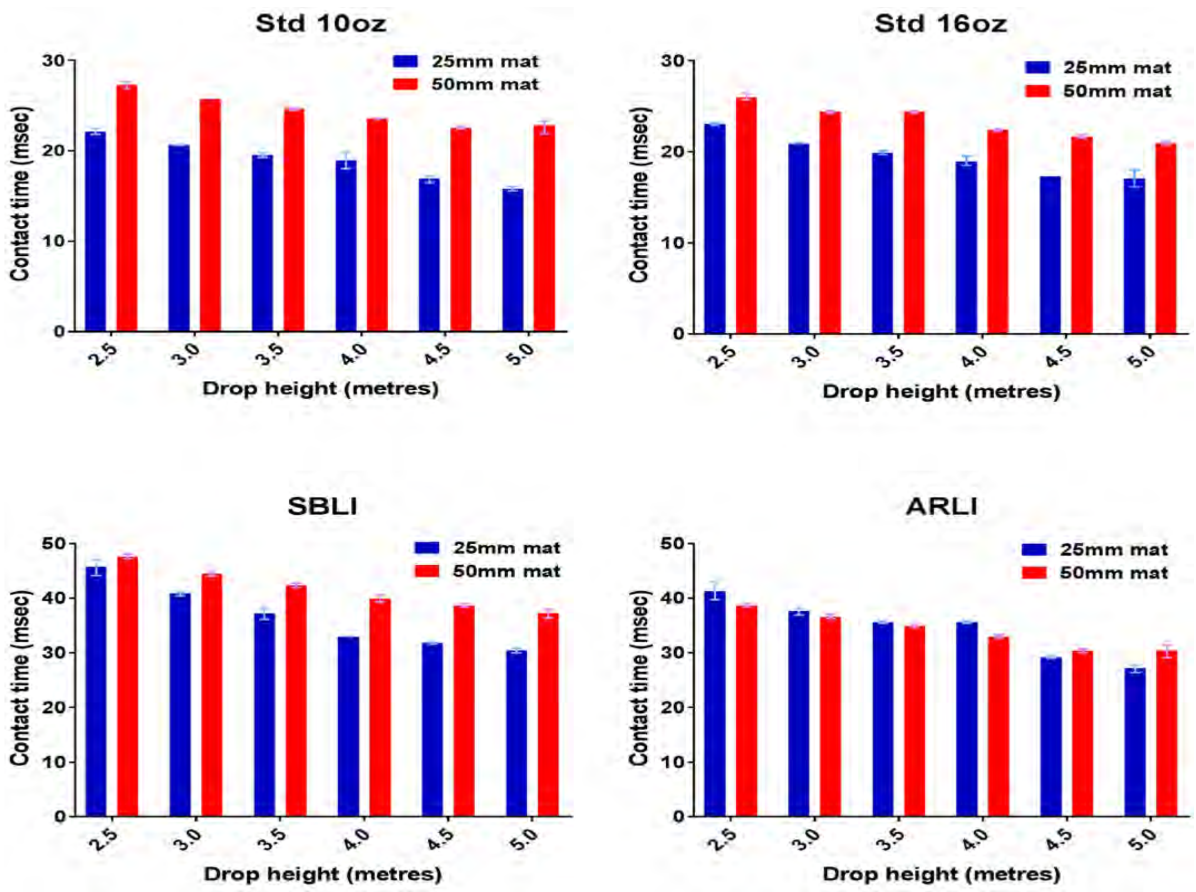

Figure 10: Effect of the thickness of force plate padding on force plate contact times with different combinations of glove type and drop height. Each bar represents a mean for three drops and the range of the readings is also shown.

As in our earlier research with a 25 mm thick mat, the area-under-the-curve values with the 50 mm mat were greatest for the Std 16 oz glove and the values for the Std 10 oz and ARLI gloves were very similar to each other. Again, the values for the SBLI glove were less than those for the Std 16 oz glove, but slightly higher than those for the other two glove types. Given that the SBLI glove had the lowest mass, the explanation for the latter finding is unclear, although the fact that this glove contained the smallest amount of foam may have caused it to have less capacity to internally store some of the impact energy.

In addition to the above variables, we determined rates of force development. This was accomplished by calculating changes in force over running periods of 0.5 msec and multiplying the results by two to yield measurements in $N.msec^{-1}$. Consequently, our first data point corresponded to 0.6 msec after glove contact ceased.

Curves showing progression in rate of force of development when gloves were dropped on to the force plate covered with the 50 mm mat are presented in Figure 12.

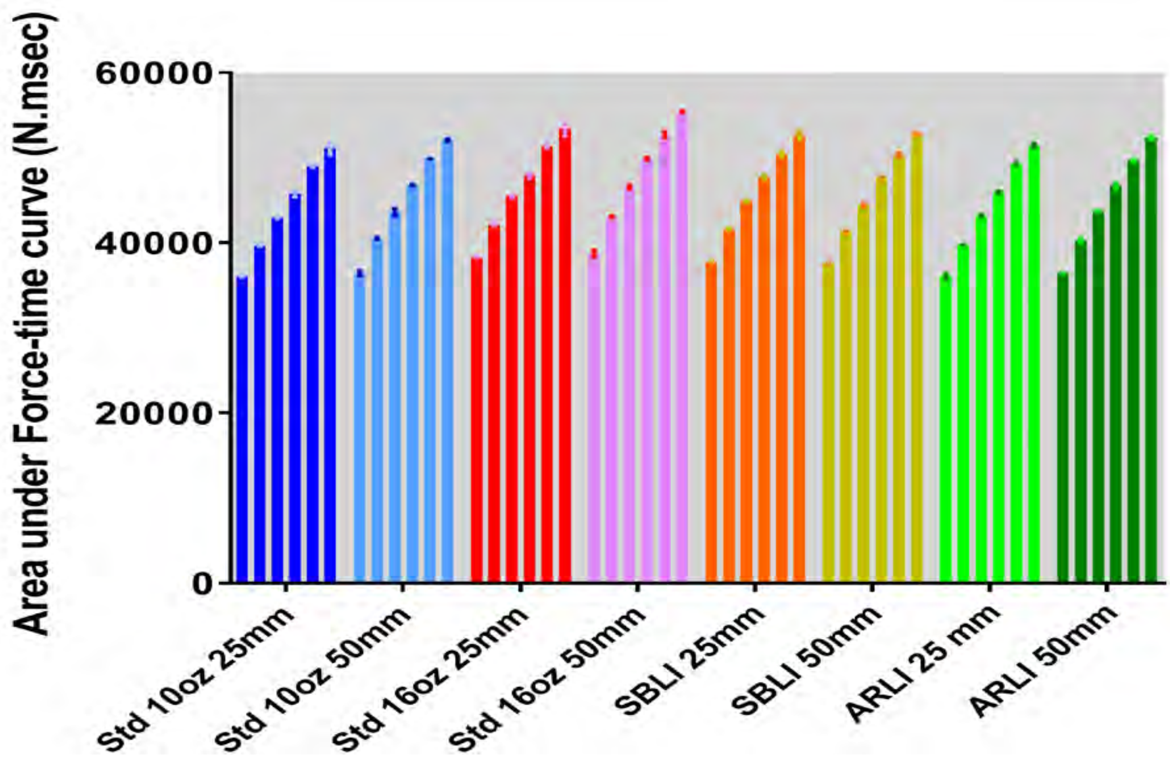

Figure 11: Effect of combination of glove type and mat thickness on area under the force-time curve for different drop heights. The bars show means and ranges for three glove drops. For each glove type, the progression of bars from left to right is associated with 0.5 increments in drop height, with the first bar relating to a drop height of 2.5 metres and the last to a drop height of 5.0 metres.

For each glove, a distinctive "signature" curve was evident. In the case of the Std 16 oz glove, there was a sharp rise in rate of force development immediately upon impact with the force plate, followed by a period of marked oscillation. The curve for the Std 10 oz glove also had these characteristics, but the spike associated with initial impact and the subsequent oscillations were generally smaller in magnitude. Peak rate of force development always occurred slightly later for the Std 10 oz than for the Std 16 oz glove. The curve for the SBLI glove showed much less initial oscillation but its subsequent ascending phase always incorporated a sharp spike followed by oscillation. The ARLI glove produced a much smoother (less oscillating) curve, suggesting less force plate vibration. Compared to the Std 10 oz and Std 16 oz gloves, both pneumatic gloves delayed the occurrence of peak rate of force development. Importantly, the ARLI glove generated a lower peak than any other of the other gloves.

Curves incorporating essentially the same distinctive features were observed also in our experiment where the thickness of the mat covering the force plate was only 25 mm, but in that experiment the rates of force development were considerably higher (Figure 13).

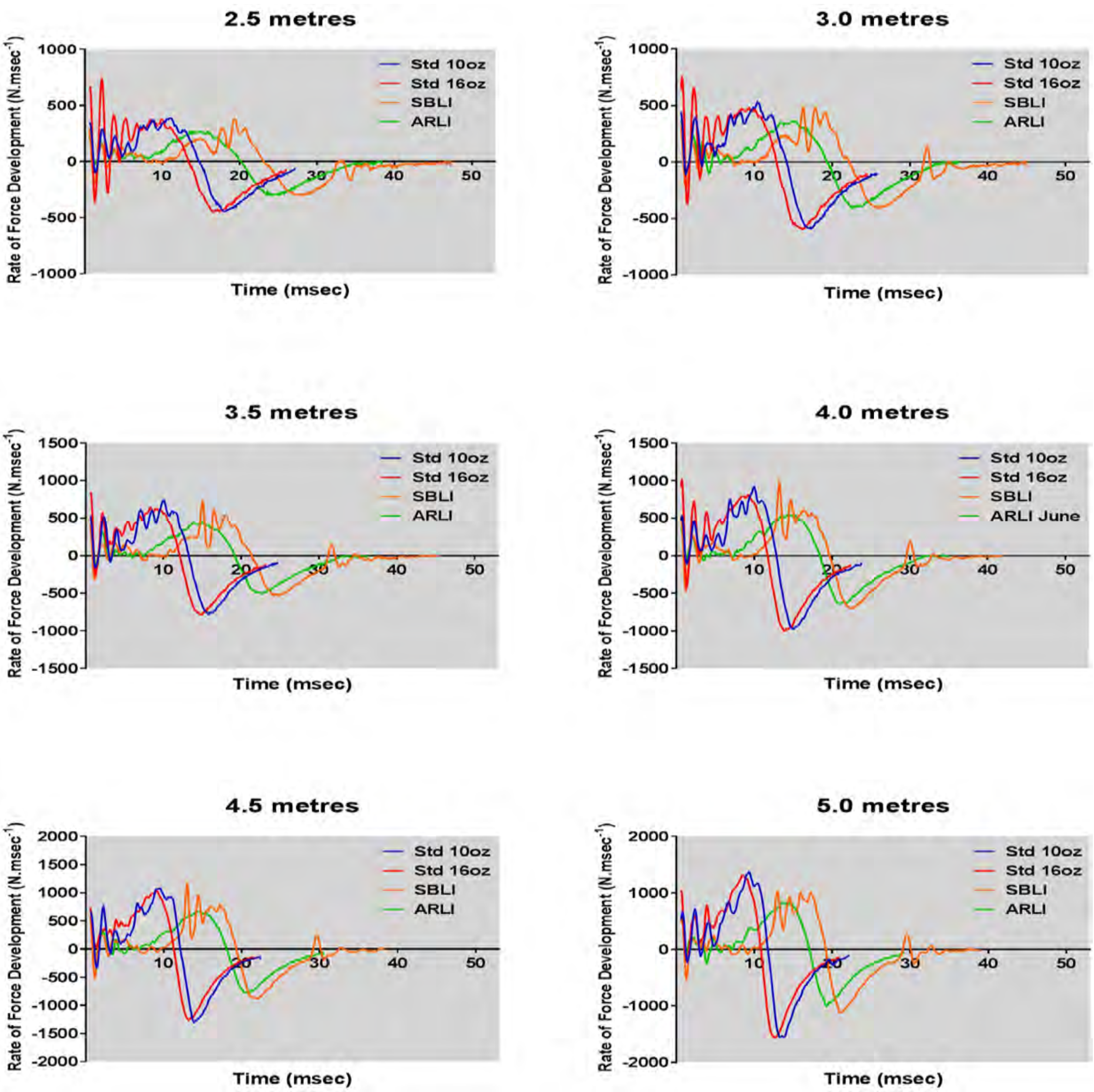

Figure 12: Curves showing rates of force development for four gloves dropped from various heights on to a force plate covered by a 50 mm thickness of EVA75 material. Each curve relates to the glove drop that produced the highest peak impact force reading from three drops performed under the specified condition.

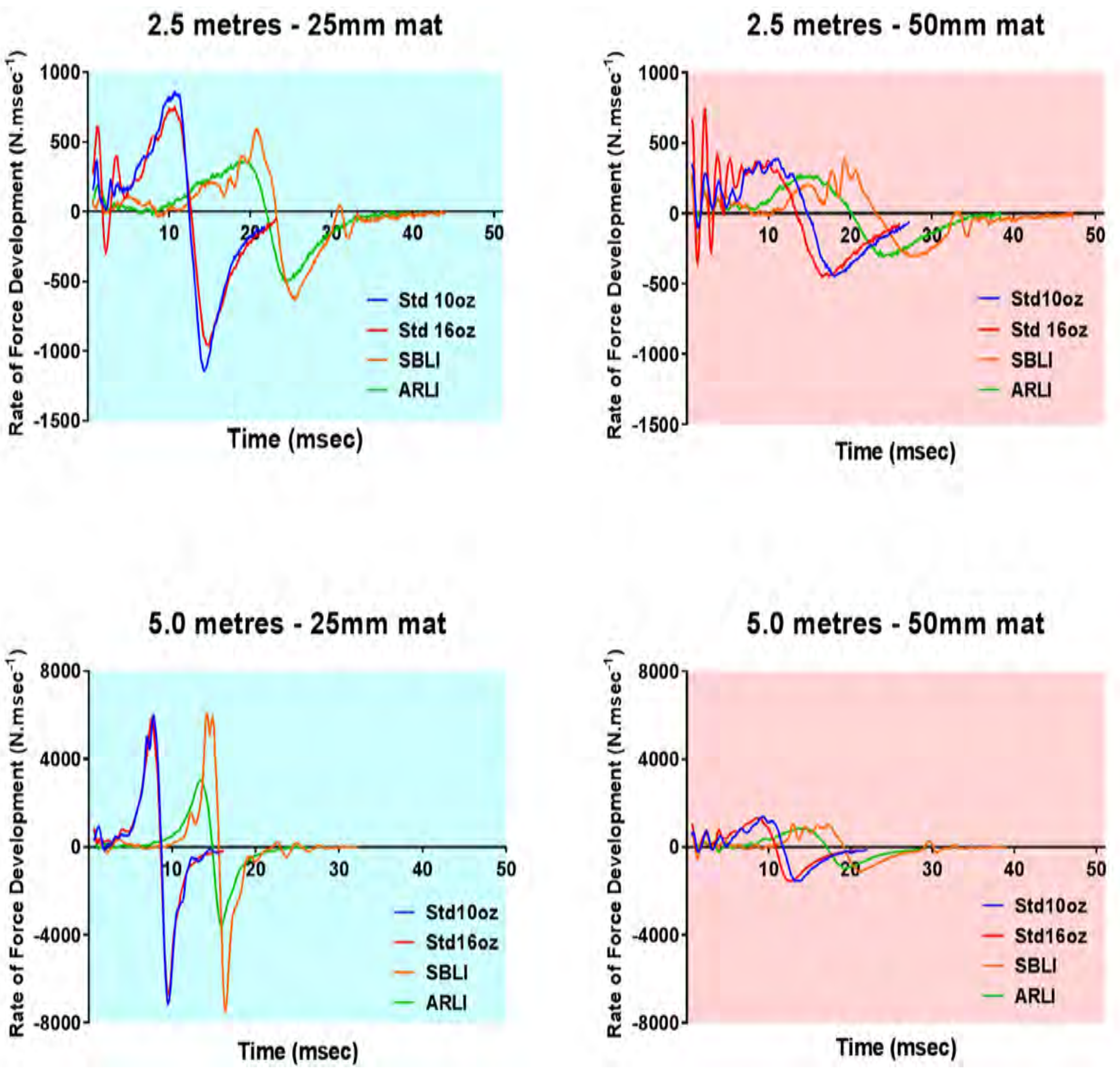

Figure 13: Effects of thickness of force plate covering on rates of force development recorded with dropping of different gloves from heights of 2.5 and 5.0 metres. Note that scaling on the y-axis of the graphs differs between the top and bottom rows.

The influence of glove type and drop height on the peak rates of force development recorded with the 50 mm mat covering the force plate is presented in Figure 14. The ARLI glove produced both lower and more consistent values than any of the other gloves. The greater consistency was likely due to the smoother curves.

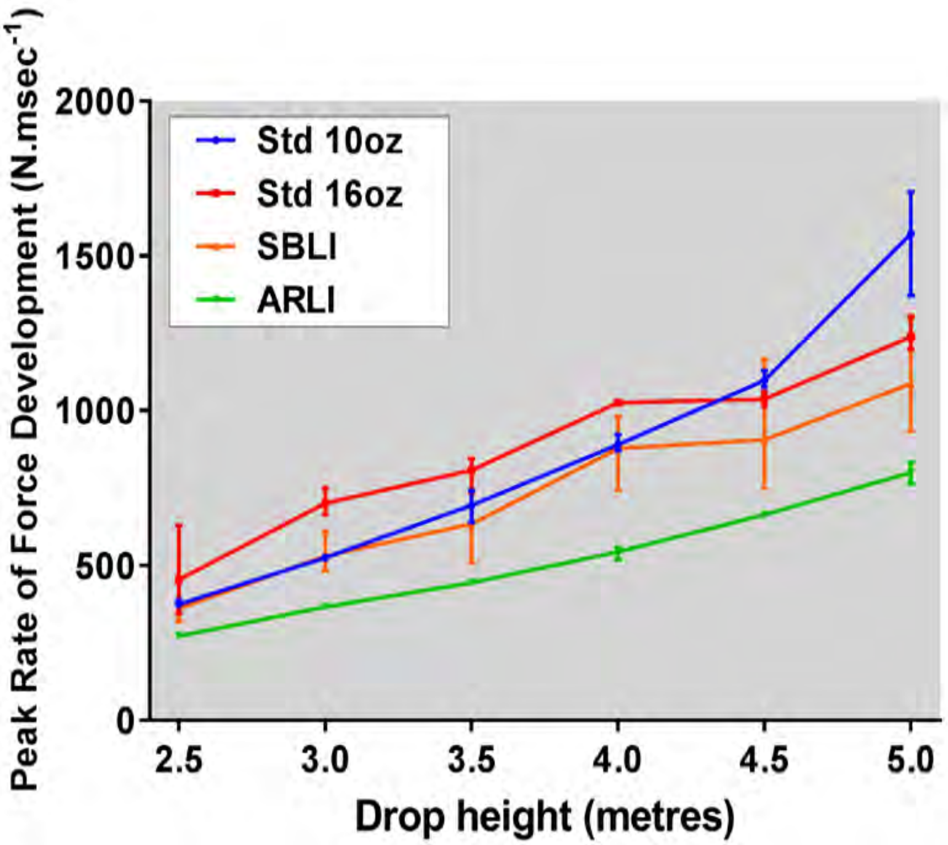

Figure 14: Effect of glove type and drop height on peak rate of force development when gloves were dropped on to a force plate covered by a 50 mm thick mat of EVA75 material. Each point on the graph is a mean of three drops, and ranges for the three drops are also shown. There are some points at which bars indicating the range cannot be seen because the range was of very low magnitude.

Figure 15 shows how mat thickness influenced the percentage by which the ARLI glove reduced the peak rate of force development relative to that seen with the Std 10 oz glove. The effect of mat thickness lessened as the height from which gloves were dropped increased, and at a drop height of 5.0 metres the reduction in peak rate of force development provided by the ARLI glove was ~49% with both the 25 mm and 50 mm mats.

The progressive convergence occurred because the slope of the curve relating peak rate of force development to drop height decreased less for the Std 10 oz glove than for the ARLI glove in response to doubling of mat thickness (Figure 16). T his meant that increasing mat thickness resulted in gradual widening of the gap between values for the Std 10 oz and ARLI gloves as drop height increased, with consequent rise of the relative protective effect offered by the ARLI glove.

The key point here, though, is that when a 50 mm thick mat was placed over the force plate with a view to making peak impact force readings for the Std 10 oz glove close to those reported by other researchers for punches delivered by boxers to the heads of Hybrid III crash test manikins [2,3] or to opponents during actual competition [4], the ARLI glove was able to reduce peak rate of force development by 27% - 49% compared to that measured with the Std 10 oz glove. Furthermore, the reduction became larger as drop height and therefore pre-impact glove velocity increased. The ARLI glove also produced peak rates of force development that were 25% - 37% below those observed with the SBLI glove, despite these two gloves generating quite similar peak force readings across the range of drop heights.

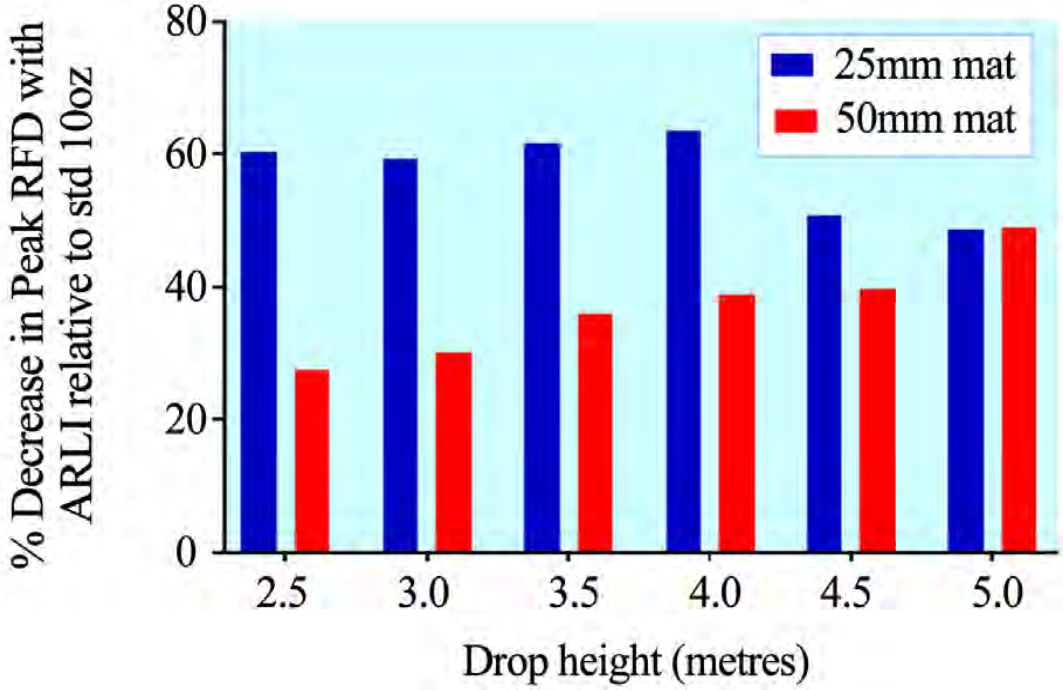

Figure 15: Effect of thickness of force plate covering on percentage decrease in peak rate of force development (Peak RFD) provided by ARLI glove relative to Std 10 oz glove at various drop heights. Each bar on the graph represents a mean of three glove drops.

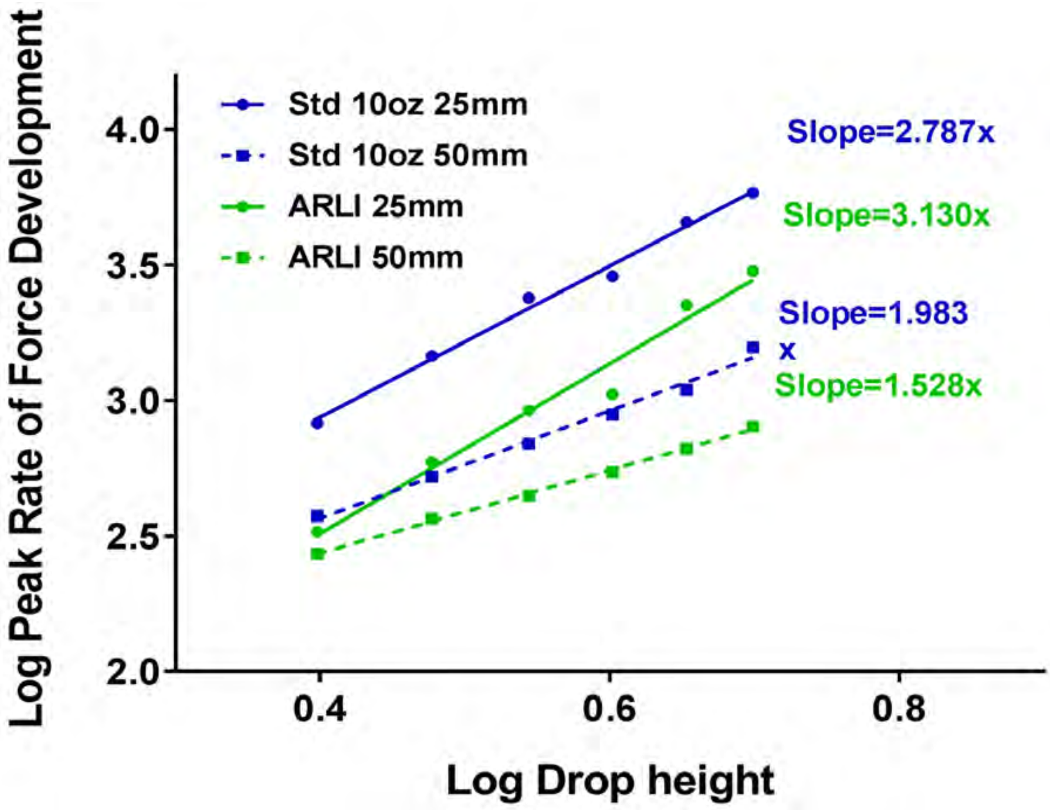

Figure 16: Changes in slope of relationship between drop height and peak rate of force development for two different gloves (Std 10 oz and ARLI) as a function of thickness of force plate covering.

7.3.5. Discussion

To facilitate assessment of real-world ability of pneumatic boxing gloves to mitigate risk of injury to an opponent, we sought to produce a target that could buffer impacts to an extent that is apparently characteristic of humans. To guide us in this task, we depended primarily on scientific literature describing peak impact forces measured when accomplished boxers delivered maximal punches to the heads of Hybrid III crash test manikins [2,3], since considerable effort has been devoted to validating these manikins as human surrogates. We also took account of data from one study in which peak forces were measured during boxing matches [4]. Synthesis of the available literature suggested that the characteristics of our target should be such that the combination of a pre-impact impact glove velocity of ~10.0 m·sec^{-1} and an effective impact mass of ~3.0 kg would produce a peak force of ~5500 N for a conventional 10 oz glove. We found that covering an in-floor force plate with a 50 mm thick mat of EVA75 material came acceptably close to meeting this criterion. With the 50 mm covering in place, dropping of a Std 10 oz glove containing a mechanical fist with a mass of just over 3.0 kg on to the force plate from a height of 5.0 metres produced a mean pre-impact glove velocity of 10.01 m·sec^{-1} and a mean peak impact force of 6514 N - approximately half the level that we measured in earlier research with a 25 mm mat covering the force plate.

We set out to determine whether use of a target with greater inherent impact-damping capability would substantially or even completely negate the protective effect that our previous research [1] had shown could be provided by a pneumatic glove incorporating a mechanism for air release upon impact and subsequent air reuptake (i.e. the ARLI glove). The data revealed that the magnitude of the protective effect afforded by the ARLI glove relative to the Std 10 oz glove was reduced. Nevertheless, the ARLI glove still afforded clear protection across a whole range of drop heights that generated peak pre-impact glove velocities from just under 7.0 m·sec^{-1} to ~10.0 m·sec^{-1}. It decreased peak impact force by an overall average of 19.5%, whereas this average was 33.0% when a 25 mm force plate covering was used. It also decreased peak rate of force production, a parameter known to be influential in many tissue injuries [8] [9] [10] and perhaps in the pathogenesis of concussion [11]. This decrease was considerable and became greater as drop height increased, reaching 49% at a drop height of 5.0 metres.

Another aim of the current experiment was to investigate the possibility that with a more damped target, a pneumatic glove with a sealed bladder (SBLI) could be just as comprehensively protective as one permitting exchange of air with the external environment (ARLI), since the impact-damping capability of the SBLI glove might no longer “bottom out” at higher impact velocities as had evidently occurred in our earlier trials with a 25 mm force plate covering. We found that with use of the 50 mm covering the bottoming out was indeed avoided. At all drop heights from 2.5 to 5.0 metres, the reduction in peak impact force provided by the SBLI glove relative to the Std 10 oz glove became quite similar to that afforded by the ARLI glove. The ARLI glove remained superior, however, in terms of its ability to reduce peak rate of force development. This superiority was evident at every drop height. Overall, values for the ARLI glove were lower than those for the SBLI glove by an average of 29.7%.

A question arises concerning the degree to which the impact-damping characteristics of the 50 mm EVA75 mat truly represented those of the human body. It is entirely conceivable that the efficacy of devices such as pneumatic gloves in complementing other impact-damping mechanisms might relate not just to the quantitative effects of those mechanisms but also to their nature. For example, a target that has low compressibility but considerable scope for movement could offer the same total impact damping capacity as one with the opposite characteristics but might interact differently with a given impacting object. Consequently, our findings will eventually need to be checked through studies involving targets with greater bio-fidelity.

Impact damping capacities and characteristics of the human body obviously differ between anatomical locations. Studies of peak impact forces generated when boxers strike Hybrid III crash test manikins [2,3] have been confined to impacts to the head, which through its connection to the neck has some freedom of movement. Peak impact forces with impacts to the torso may be quantitively quite different, and this is pertinent since rib, lung, heart and abdominal organ injuries are known to occur in boxing [12-16]. Even for the head, impact damping characteristics appear to be site-dependent. It has been reported that when the head is unprotected, impact to the side of the head (the temporo-parietal region) poses the highest risk of concussive injury [17-19]. The temporo-parietal region deforms more in response to a given standardized impact [18], and while this may be due largely to the geometric shape of the human head, the fact that bone is thinner in this region of the skull than in the frontal and occipital regions could be a contributing factor. Ruan and Prasad [20] have reported an inverse relationship between skull bone thickness and deformability and have noted that protection of the skull and brain increases with increasing bone thickness.

Individual differences in anatomy may also influence impact damping qualities. There is large inter-individual variation in bone thickness. In post-mortem autopsies of 65 adult males, Mahinda and Murty [21] found that the range in bone thickness was 3.5 - 7.2 mm for the parietal bone, 2.6 - 8.0 mm for the temporal bone, 4.0 - 11.0 mm for the frontal bone and 6.0 - 10.1 mm for the occipital bone. The thickness of the sternum at the junction of the manubrium and the body ranged from 9.0 - 21.0 mm. Comparable variations were observed amongst 10 adult females. Schlecht et al. [22] noted the existence of distinct skeletal phenotypes characterized by “slender” and “robust” bones. After adjusting for differences in body size, they observed a significant positive correlation between robustness (quantified as bone cross-sectional area relative to length) and bone strength. For men and women respectively, slender bones were 1.7 - 2.3 and 1.3 - 2.8 times less stiff and strong than robust bones.

There are also large individual differences in the thickness of muscle and subcutaneous fat. Rankin et al. [23] used real-time ultrasound imaging to measure the resting thicknesses of four abdominal muscles (internal oblique, external oblique, tranversus abdominis and rectus abdominis) in 68 adult females and 55 adult males. Total thickness of the abdominal muscular wall was also determined at precise anatomical locations in its upper and lower regions. For each of the muscles, between-subject variability in thickness was substantial as indicated by coefficients of variation ranging from 14.4% - 30.5% for the females and 16.6% - 28.9% for the males. Total abdominal muscular thickness in the lower right region of the wall averaged 2.96 cm for the females but the 95% confidence interval extended from 2.04 to 3.88 cm. For the males, the mean thickness was 3.86 cm with the 95% confidence interval extending from 2.58 to 5.14 cm (values that coincidentally corresponded quite closely to the two different mat thicknesses employed in our experiment). Subcutaneous fat thicknesses are even more variable. Using an ultrasonic measurement technique, Leahy et al. [24] found that the abdominal subcutaneous fat thickness of 83 young adult men ranged from 1.0 to 57.3 mm, while the range for 52 young adult women was 10.1 - 74.0 mm. There is evidence that increased thickness of abdominal subcutaneous fat is protective against abdominal injuries resulting from motor vehicle accidents [25], highlighting the potential role of this layer in impact damping.

The implication of the above is that within human populations participating in boxing there is likely to be considerable diversity in the thickness, proportional composition and mechanical qualities of the interface between an impact site and internal anatomical structures. Studies based on average characteristics of the interface may have limited applicability to people at the extremes of the distribution. Comprehensive determination of the potential protective effects of pneumatic boxing gloves requires understanding of the effects of realistic interface variation. The experiment reported in this paper provides a step toward development of this understanding. It suggests that the effectiveness of the ARLI pneumatic glove is relatively greatest when biological impact damping is least. This can be regarded as a key feature of the glove.

An interesting and possibly very important finding of our study concerns the effects of the different gloves on rate of force development. The relatively smooth curve observed with the ARLI glove probably indicates that it caused the least force plate vibration. Although the mechanisms of cerebral concussion are complex [26] and not yet completely understood [27], it has long been suspected that vibration of the skull, and hence the brain, might play a role. Stoyanovski and Grozeva [28] report that the possibility was first raised in 1774. It was also mentioned by Franke [29] in the mid-1950s. One idea is that an impact producing a vibration frequency close to the natural resonant frequency of the brain elicits an increase in the amplitude of brain oscillation, producing strains that can damage neural tissue [30]. This is analogous to a situation in which structural failure of a building may occur due to an earthquake that causes the building to sway at its natural resonant frequency. It has also been proposed that with the cerebral cortex pushed hard up against the skull due to differences in the timing of impact-induced acceleration or deceleration of the two structures, vibration of the skull can produce cortical contusion [31].

Recently, Laksari et al. [32] used head impact kinetic data from 189 collisions occurring in sporting events as inputs to a finite element model. Two of the impacts had caused concussions, and one had been associated with loss of consciousness. The modelling revealed that in the latter case vibration frequencies in different regions of the brain became less uniform, leading to out-of-phase oscillations between regions. This produced high levels of strain, particularly in the corpus callosum and periventricular white matter, areas in which neuronal axons are known to be susceptible to injury produced by stretching. Axonal injury is thought to be integrally involved in the pathogenesis of concussion [33-34].

Laksari et al. [32] considered that non-uniformities in vibration were likely due to a combination of impact magnitude, skull-brain geometry and variation in the material properties of the brain. It was concluded that the way in which the brain vibrates in response to impact may be a major determinant of the risk and severity of concussion. It is possible that vibration asymmetries contribute also to injury of other organs and structures. In any event, the apparent ability of our ARLI glove to greatly reduce target vibration may be another positive attribute. Martin [31] argues that the risk of acute brain trauma resulting from an impact is highly dependent on what happens in the first five msec after impact initiation, partly because this is when vibration characteristics are typically established. It is during this 5-msec period that rate of force development differs most between our ARLI pneumatic glove and conventional boxing gloves. The SBLI glove likewise differs from conventional gloves during this period but because of its particular mechanics some oscillation in rate of force development, probably indicating target vibration, occurs later.

An unexpected finding of our research was that whereas the peak impact force was slightly lower for the Std 16 oz glove than the Std 10 oz glove when the thickness of the mat covering the force plate was 25 mm, the reverse was true when the 50 mm mat was used. It can be speculated that the thicker force plate padding diminished the effects of the additional padding incorporated into the Std 16 oz glove and increased the relative effect of its extra mass. It is noteworthy, however, that testing of the Std 16 oz glove with the 50 mm mat occurred at the very end of a long series of glove drops. A possibility that by then the impact damping capacity of the mat was becoming imperceptibly compromised cannot be excluded.

The merits or otherwise of boxing are subject to fervent debate [35]. Arguments against the sport are centred largely around the intent of contestants to harm each other and the attendant risks of serious acute and chronic injury, and even death [36]. Smillie [37] contends that while many sports are metaphors for battle, boxing is the real thing, and should have no place in the modern sporting landscape. Over recent years, though, modified forms of boxing aimed at addressing such objections have emerged in Australia [38] and elsewhere [39].

The first author of this paper ran a popular modified boxing program at a Police Community Youth Club in Canberra for five years. The high value that the participants placed on safety [40] stimulated a quest to develop gloves capable of markedly reducing impact forces. For us, that quest remains focused chiefly on augmenting modified boxing initiatives, where early adoption of the gloves is more likely. In most modified boxing situations, forceful punching is actively discouraged, although impacts of higher than desired velocity can sometimes accidentally occur. Suitability of pneumatic gloves to these situations therefore depends on their ability to diminish impact forces and rates of force development across a wide range of impact conditions. The results of the present study engender confidence that the ARLI glove satisfies this requirement.

7.3.6. Conclusion

Target characteristics influenced not just the peak impact forces produced by given levels of total impact energy generated by simulation of boxing punches, but also the relative protective effects of different glove types. Even with a doubling of target padding, however, a pneumatic glove incorporating a mechanism for air exchange with the external environment remained capable of reducing peak impact forces to levels well below those observed with conventional 10 oz and 16 oz gloves, and this was true across a wide range of pre-impact glove velocities. Its damping of peak impact forces was no longer greatly superior to that of a pneumatic glove incorporating a sealed bladder, but it still surpassed that glove and the conventional gloves in terms of ability to reduce peak rates of force development. Its sustained effectiveness under altered impact conditions suggests that it deserves to be the focus of continuing developmental efforts.

Acknowledgements
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Chapter 8: Iterative Design of Impact-Damping Gloves for Safer Boxing

8.1. Declaration for chapter 8

Declaration by candidate

In the case of Chapter 8, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Contributed to study design, data collection, data analysis and manuscript preparation.	No
Alex Jamieson	Assisted with study design, data collection and manuscript preparation.	No
Wayne Spratford	Contributed to data collection, data analysis and manuscript preparation.	No
Geordie Ferguson	Contributed to study design and data analysis.	No
Candidate's Signature		**Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1:	25/3/2019
Signature 2:	26/3/2019
Signature 3:	2/4/2019
Signature 4:	2/4/2019

8.2. Prologue

As noted in Chapter 6, there have been numerous attempts to develop pneumatic boxing gloves, beginning in the late 19th century. Although designs have been published in the form of patents, there has been very little documentation of experiments leading to the designs, or of either field or laboratory evaluations of prototype effectiveness. For this reason, the research team of which I was part was little able to draw upon the work of the prior developers. To ensure that future researchers will be less affected by such a limitation, my colleagues and I considered it important to publish a full account of the iterative design process that we undertook. That publication is presented below. It aided achievement of three of the six research aims identified in Chapter 1 of this thesis, as indicated below:

- **Aim 4:** To implement a modified boxing program in a community setting and liaise with participants through everyday conversation, formal interviews and written surveys, thereby developing deep understanding of their perceptions of the program and enabling program refinement.
- **Aim 5:** To explore and iterate specific technologies seen as having potential to enhance the experience of modified boxing program participants, particularly in terms of safety and program enjoyment.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

Journal entry (Tuesday 18th March 2014. 19:50 Canberra PCYC)

Most of the participants at tonight's session appeared really interested in the specially-designed gloves and said they supported the idea of making modified boxing safer through their introduction, as can be seen from the examples below:

"The gloves felt a little strange at first, but I like the idea of using them" - **32 year-old female athlete**. *"I think it's a great idea and would be very comfortable using them against my son"* - **44 year-old male athlete**. *"Introducing the gloves is a very good idea and something that is really needed. Sometimes I leave training feeling a bit sore from where I've been punched"* - **16 year-old female athlete**. *"These gloves could really help with the uptake of the sport. I know I'd be happy to let my kids be involved with a form of boxing that used them"* - **42 year-old mother**. *"The gloves felt a bit too restrictive around my hand and I'd prefer a separate thumb compartment"* - **18 year-old male athlete**.

8.3. Published paper 7 (The remainder of this is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Iterative Design of Impact-Damping Gloves for Safer Boxing

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8.3.1. Abstract

Design methods were employed over a 5-year period to develop boxing gloves capable of substantially buffering impact forces delivered to an opponent, thereby permitting safer boxing. Multiple concepts were explored, with sophistication of prototypes gradually increasing. The prototypes underwent both quantitative laboratory testing and qualitative evaluation in the field. The laboratory testing methods were evolved over time to enhance test reliability and ecological validity. Feedback from the laboratory and field trials was highly instrumental in guiding the process of glove development. It was eventually found that, compared to standard boxing gloves, pneumatic gloves with sealed bladders were effective in reducing peak impact forces and peak rates of force development when impact magnitudes were low to moderate but not when they were high. By contrast, pneumatic gloves incorporating a bladder enabling air exchange with the external environment were protective across the entire range of impact magnitudes likely to be encountered in boxing. These gloves are configured differently from standard gloves in terms of the positioning of the fist relative to the glove padding, but now have close visual resemblance to standard gloves. The aesthetics of the gloves have proven critical to their acceptance.
Wearer comfort is also vital and, although we extensively pursued the concept of thumbless gloves, we finally deemed it necessary to include separate thumb compartments to accommodate user advice.

There is scope for further glove refinement, but recent experience indicates that the latest version is currently sufficient for use in modified boxing programs that emphasise safety, with such targeted contextual sufficiency realising a fundamental aim commonly associated with projects employing the design approach. Small batches of the gloves have recently been manufactured to cater for modified boxing programs.

Keywords: Boxing Safety, Modified Boxing, Pneumatic Boxing Gloves, Protective Equipment for Boxing, Sport Design.

8.3.2. Introduction

Boxing has a presence in almost every nation throughout the world [1]. It has been included in all but one Summer Olympic Games since 1904, but has been subject to criticism on medical, ethical, legal and sociological grounds [2]. In 2003, a paper published in the British Columbia Medical Journal included the following:

"In boxing, the ultimate achievement is to knock somebody out. And to knock somebody out is to injure his or her brain ... Every year we read of some poor boxer who collapses and dies after a boxing bout as a result of repeated blows to the head. Moreover, we know ... that blows to the head have a cumulative and devastating effect. Twenty years on and the commonly referred to condition of being punch drunk (is) all too easy to recognise ... slurred speech, unsteady legs, lapses of memory, violent tendencies and the general appearance of having had a few too many" [3].

A decade later, the eminent neurologist and geneticist John Hardy expressed the view that: *"Boxing is a special case. No other sport has the express goal of causing injury to the brain. That is certainly the aim of professional boxing. Even in amateur boxing blows to the head are crucial ... No doubt I will be called a killjoy for espousing the view that boxing should be banned ... I would return the charge: nothing can be more killing of joy than personality changes, violence, substance abuse and dementia"* [4].

Such views cannot be lightly dismissed. Between 1890 and 2007, there was an average of more than 10 deaths per year from acute injuries received in boxing, with amateur boxers accounting for almost a quarter of these [5]. Several studies have demonstrated structural pathology in the brains of boxers, including changes resembling those associated with Alzheimer's disease [6-12]. Biochemical indicators of neuronal damage have been detected in amateur boxers but not age-matched controls [13,14].

Boxers also show a relatively high incidence of electro-encephalographic (EEG) abnormalities and deficits in cognitive function [15-18]. Boxing-related injuries were responsible for a total of 437 British Army medical unit admissions from 1969 to 1980 [19]. Head trauma accounted for ~68% of these, but there were 20 admissions for trunk injuries including rib and vertebral fractures, and 13 for kidney and pelvic organ injuries that required an average hospitalization time of 6.2 days. Between 1990 and 2008, there were 165,602 presentations to United States Emergency Departments for injuries sustained in boxing, with more than 37,000 of these relating to head or neck injuries [20].

Legal experts have argued that boxing consists of activities that in other contexts would constitute criminal assault and have raised issues relating to the legitimacy of participant consent [21-23]. Sociologists have claimed that boxing has negative effects by overtly glamorising and rewarding violent conduct [24] and is exploitative of vulnerable young people [25,26].

There is potential to address objections to boxing through modifications to the rules and equipment. Common suggestions include removal of the head and neck from the target area [21,27,28] and the development of gloves capable of substantially reducing impact forces delivered to an opponent [28]. Considerable doubts have been expressed as to whether the boxing community would ever be amenable to such changes [3], since it is believed that the visual, emotional and cultural appeal of the sport to that community is largely tied to its inherent risks [29]. This belief is partially supported by the fact that since the 1890s, there have been more than 20 patents lodged for gloves aimed at markedly decreasing impact forces, but none has led to widespread or sustained adoption of a new glove design [30].

Nevertheless, a few modified boxing programs emphasising participant safety have recently emerged in Australia [31] and elsewhere [32]. After many years of coaching conventional amateur boxing, the first author of this paper spent five years running a modified boxing program at a Police Community Youth Club (PCYC) in Canberra. A survey of long-term participants in that program revealed that they placed high value on safety [33].

This stimulated subsequent efforts to progressively incorporate various safety procedures, including design, development and deployment of impact-damping gloves. The intent was to produce gloves that would not only reduce injury risks but would also be attractive to users in the modified boxing setting and augment the appeal of the modified boxing concept. Although we entertained a vague hope that our work might eventually provide impetus for exploration of similar ideas in the conventional boxing context, our focus was entirely directed toward creating gloves that would be enthusiastically taken up in the modified boxing situation. The purpose of this paper is to outline the progress made.

8.3.3. Overview of approach

The project was pursued through an iterative design process incorporating a series of quantitative scientific experiments and the use of various techniques to obtain qualitative feedback. Approval was provided by the Human Research Ethics Committee of the University of Canberra.

Available literature indicates that the design process begins with identification of a practical problem [34] and entails use of solution-focused cognitive strategies derived from abductive and/or appositional thinking [35]. Although deductive and inductive methods typical of the natural sciences may play important roles in the quest for a solution [36], particularly in validation of a designed artefact and evaluation of its field performance [34], they are not the fundamental elements of the design process, since the latter is directed primarily toward creation of value rather than determination of facts [36]. Creation of value can consist in finding a satisfactory solution to the problem rather than necessitating achievement of an optimal solution [37]. Unbiased consideration of multiple possible solutions is seen as vital, although questions have been raised concerning the extent to which this typically occurs [38], and it has been proposed that in practice design is often somewhat conjectural, with initial rapid conjecture on what is likely to work guiding subsequent design requirements and constraints [39]. It has been argued that the core challenge of design is the parallel development of an artefact and its way of working [36], as opposed to use of a sequential or linear approach. Cross [40] suggests that in design the relationship between problem and solution is "commutative", implying that the order in which they are addressed need not be fixed.

Hatchuel [41] notes that the design process incorporates a concept of "expandable rationality" since the very act of pursuing a solution to a problem can lead to conceptual expansions. He sees social interaction as a critical component of design.

There is debate as to whether design is a specialised branch of science or a distinct epistemological entity. It has been argued that while science is primarily hypothesis driven, the design process is outcome-driven [42,43]. Science can be seen as focused on a search for universal truths, whereas design is directed toward context-specific invention and often has aesthetic components [44]. Cross [40] contends that method is vital to science but not to design, since design outcomes are intended to be situation-specific, not universally repeatable.

Mahdjoubi [42] questions the popular belief that most innovation stems from scientific research and argues that, historically, non-linear design approaches initiated by a desire to create effective solutions to real-world practical problems have been a prolific source of innovation across numerous fields. He further contends that while science can be useful in guiding the design process, there are also cases in which design approaches provide a stimulus for scientific endeavour [42].

We started this project with a clear goal in mind. We investigated several glove designs that we believed might enable attainment of that goal, and gradually honed our thinking. Our ability to build upon prior designs for impact-damping gloves was limited by a dearth of information on their practical effectiveness. Only one of those designs has undergone published scientific assessment [45]. Since we were also quite restricted in terms of the financial and other resources available for glove development, we operated with a high degree of self-sufficiency in attempting to develop a solution that would meet the specific needs of our modified boxing initiative.

Critical elements of our journey are described below. Since illustration is considered a central element of the language of design [44], substantial use is made of photographs and other graphical representations.

8.3.4. Initial attempt to reproduce pneumatic gloves

The one scientifically assessed glove aimed at impact damping was produced by a Finnish physician, Lyderik Löfgren, more than 60 years ago [45]. Like many earlier designs, it incorporated an air-filled bladder in place of standard glove padding. Laboratory testing showed that, compared to conventional gloves, it substantially reduced acceleration of a struck mass attached to a pendulum. An effort to reproduce that glove seemed a logical starting point for our work, although inability to locate relevant drawings made it a challenging task. After discussion with engineers from RMIT University (Melbourne), we initially engaged an external consultant to manufacture a few pairs of pneumatic gloves with characteristics resembling those described by the original inventor. The external consultant was an enthusiastic modified boxing participant with a strong background in technological innovation. He approached the glove development with zeal and during the second half of 2013 produced some early prototype gloves that contained open-cell foam in place of standard glove padding. The surfaces of the foam were coated with rubber. There was a valve that allowed air to be pumped into or extracted from the foam structure to adjust its internal air pressure. As an additional feature evidently not included in the original pneumatic gloves, a small hole was made in the rubber coating to permit air release from the foam structure upon impact, in keeping with a concept patented by Carrillo [46]. The form of the pneumatic gloves was quite similar to that of standard gloves (Figure 1).

Figure 1: Front and side views of early prototype pneumatic gloves designed to resemble those produced six decades ago in Finland.

Within three months of commencement of the project, the air-containing foam was tested against standard glove padding at the laboratories of Swinburne University of Technology in Melbourne. The testing consisted of dropping samples of the different materials from selected heights on to a Kistler load cell that measured the impact profiles.

Additionally, an INSTRON system was used to enable impact force measurements when the different samples were accelerated to known velocity over a set distance. The air-filled foam was tested both with the air hole open and occluded. The experimental set-up is shown in Figure 2.

The drop-weight and INSTRON tests produced highly repeatable results for any particular material. The prototype foam structure was softer than standard glove padding. The peak impact force produced when it was attached to a mass of 2.076 kg and dropped from a height of 0.7 metres on to a load cell was lower than that measured when the same procedure was applied to the standard padding and to a standard intact boxing glove. The situation was reversed, however, when the drop-weight test was performed from a starting height of 1.1

metres, presumably because the prototype material became quite hard once its maximum deformation had occurred. Similar findings were obtained from the INSTRON testing, which indicated that the prototype material offered a protective effect only up to a peak impact force of ~500 Newtons (N), beyond which point the standard glove padding performed better. The air hole that had been included in the prototype structure had almost no effect in reducing the peak impact force, since the time to peak force was too short for any substantial air release to occur.

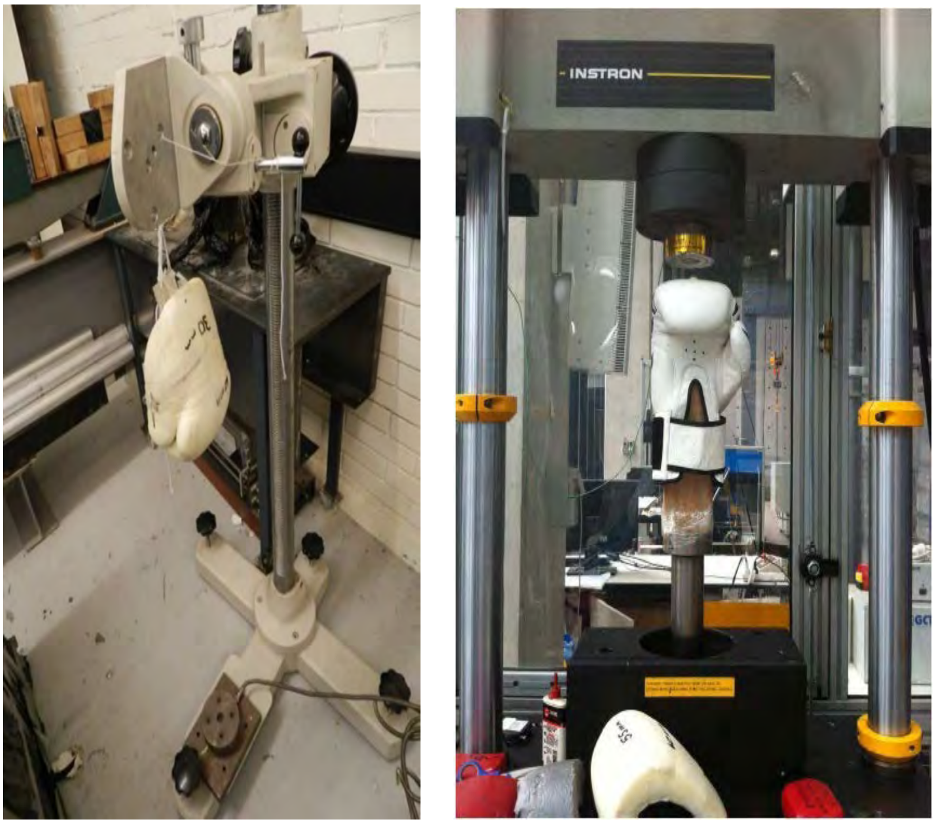

Figure 2: Equipment set-up for drop-weight and INSTRON testing of prototype gloves and air-filled foam materials.

Despite these initially disappointing findings, it was recognized that it should be possible to ‘tune’ the shape of the force curve and reduce the peak value by changing the air pressure inside the prototype structure and either increasing the size of the air release hole or incorporating a series of holes. Some doubt arose, however, as to whether enough tuning could occur to provide protective effects up to the very much higher peak forces - perhaps as high as 8000 N [47] - that reportedly can be generated by boxers.

A new version of the prototype foam structure was produced and an Australian company that manufactures standard boxing gloves was commissioned to supply glove covers specially designed to contain it, but when the covers were delivered the compartment for insertion of the structure was found to be too small. Following this further setback, the external consultant advised that he could not deliver the intended outcome of the project within the available budget and therefore had no choice but to discontinue his involvement.

8.3.5. Alteration of fist position relative to glove padding

With the endeavour to produce effective pneumatic gloves at least temporarily on hold, focus was directed to another idea that had arisen during initial discussion as to how impact buffering might be achieved. This idea concerned the possibility of reducing peak impact forces through alteration of the positioning of the fist relative to the main section of glove padding. We initially conducted some informal trials amongst ourselves by sparring with standard boxing gloves but employing a novel fist position within the gloves. Based on our subjective impressions of the effect, a decision was made to further explore the concept. With assistance from the Brisbane-based company HART Sport Pty Ltd., prototype gloves were produced that required the whole closed fist to be placed into the compartment beyond which the fingers would usually extend (in contrast to the normal process of placing an open hand into the glove and then closing the fist). The portion of the glove that would otherwise contain the fingers was therefore left free, increasing both the thickness of padding in front of the knuckles and the scope for that padding to flex upon impact.

The new gloves were manufactured in vibrant red and blue colors to maximise their visual appeal. After informal tests in training settings, they were used in a 7-bout modified boxing event held at the Canberra PCYC in March 2014 (Figure 3).

All but one of the contestants subsequently completed an anonymous on-line survey. There was unanimous agreement that the gloves reduced impact forces compared with standard gloves. Four athletes indicated that the degree of impact buffering was substantial, eight considered it moderate, and one thought it slight.

Four athletes said that they did not enjoy using the prototype gloves, whereas three greatly enjoyed the experience. The remaining six athletes were neutral. Four athletes were either satisfied or very satisfied with the comfort of the gloves, five were neutral, three were unsatisfied and one was very unsatisfied.

In consideration of the formal feedback, and of casual comments subsequently made by the trial participants, we perceived that we were still far from realizing our over-riding project goal.

Figure 3: Modified boxing contest with gloves incorporating altered relationship between fist position and padding. Fist was contained in area of glove shown by white circles.

8.3.6. Highly deformable gloves

We noted the ability of air-containing party balloons to buffer impact forces as a result of their high elasticity and deformability and imagined that there might be potential to develop boxing gloves embodying these characteristics. It seemed possible that a balloon-like structure contained in a compartment much more elastic than standard glove leather or vinyl could form the "padding" of the glove, with the whole fist positioned behind it in a manner consistent with that tried in the above HART Sport gloves.

With the emergence of this concept, the project moved into a new phase in which we began constructing prototype gloves ourselves rather than arranging for established manufacturers to implement designs. As a first step, we evaluated several different air bladders with a view to finding one that was reasonably balloon-like but resistant to bursting when exposed to high impact forces.

On advice from HART Sport, we eventually selected a Size 1 latex soccer ball bladder manufactured by Enkay [India]. We then cut off the end-section (i.e. the finger section) of a standard training glove and replaced it with a sewn-on, stretchable lycra bag with a sealable opening for insertion of the bladder, which could then be inflated.

A second lycra bag could subsequently be pulled over the whole complex to confer stability and shape and to enclose the thumb, effectively making the glove thumbless as has been recommended by medical authorities [48,49]. The construction process is illustrated in Figure 4.

Figure 4: Construction of highly deformable prototype gloves. The end-section of a standard training glove was cut off and replaced by a sewn-on, stretchable lycra bag with a sealable opening for insertion of a small spherical bladder, which could then be inflated. A second lycra bag could subsequently be pulled over the whole complex to provide shape and stability and to enclose the thumb. A glove with fist in position behind the bladder is shown on the bottom right.

In initial play amongst ourselves, the new gloves seemed subjectively to have greater impact-buffering capacity than our previous prototypes. We produced multiple pairs in red and blue colors, and in April 2014 they were used at modified boxing (Box' Tag) [31] events in

Sydney and Melbourne, with the Melbourne event being part of the Australasian Police & Emergency Services Games. There were mixed reactions from the contestants. Negative comments on the "look" and "feel" of the gloves were common. On the other hand, all 22 of the Sydney competitors and 11 of 14 Melbourne competitors perceived that the gloves reduced impact forces, with the majority rating the reduction as large. There were some reports that, when impacts were forceful, the bladders could occasionally 'turn under', causing impact to be made with only slightly padded knuckles. In later investigation of possible reasons for these reports, it became clear that inappropriate positioning of the hand within the glove (particularly through extension of the fingers) could lead to the bladder being pulled downward into a position entailing a risk that it would not be the first point of contact with the opponent. To overcome this problem, we subsequently produced "inner" gloves that prevented finger extension.

During the ensuing months, the gloves were occasionally used for sparring sessions held as part of the modified boxing program at the Canberra PCYC. Some positive responses were received, particularly from junior and female athletes and the parents or guardians of program participants, but the athletes never actively sought employment of the gloves and it was evident that, overall, a preference for standard gloves remained.

In December 2014, the prototype low-impact gloves were employed for a modified boxing competition that formed part of a Draft Camp held at the Australian Institute of Sport (AIS) in Canberra for athletes interested in transferring into conventional boxing from other sports. Each of seven athletes interviewed after the competition thought that the gloves were either extremely effective or quite effective in reducing impact forces. Particularly salient were the following comments from two experienced boxing coaches who were present at the event:

Coach 1: *"The gloves helped in achieving tonight's intended purpose. It was possible to assess the movement abilities of the athletes without exposing them to significant risk. To evaluate the potential of the athletes for boxing, it will still be necessary to see how they react to taking a solid punch, but tonight the gloves were central to a useful game. I think that when the big boys were involved and there were some power punches, the bladders sometimes bent under allowing the knuckles to make contact, so there are perhaps some design issues that need further attention. For kids, though, the gloves already could be great in allowing safer learning of boxing skills."*

Coach 2: *"I had some initial reservations about using the gloves as I thought it would be better to see how the athletes respond to being hit. However, I now think the gloves worked very well with the game the athletes played. I don't think the gloves are appropriate for established boxers but they could be used for beginners, especially kids."*

These comments were interpreted as suggesting that, although ongoing work was required, we were tracking quite well toward the development of gloves that could be suitable for a modified, low-risk form of boxing.

Examination of the gloves after the AIS Draft Camp revealed that some had been damaged, presumably due to the occurrence of harder punching than that typically associated with modified boxing. The most common form of damage was tearing of the lycra bag sewn on to the glove, but stitching was also broken on a few outer bags. In one case, stitching was torn away across virtually the whole area of attachment of the inner lycra bag to the glove under-surface, meaning that the lycra bag was no longer performing its intended function of stabilisation and bladder positioning. It seemed probable that when bladders were greatly compressed, the ability of the lycra to stretch to accommodate lateral expansion was exceeded. This implied a necessity to either search for lycra or other material with more elasticity or impose some structural limit on the scope of lateral bladder compression, even though the latter solution would presumably also reduce the magnitude of impact force buffering.

8.3.6.1. Refinement of highly deformable gloves

At the beginning of 2015, we gave considerable further thought to possible reasons for reports that buffering of impacts by the prototype gloves combining the bladders and lycra covers occasionally seemed to fail. Displacement of the spherical bladder from its intended position was recognized as one likely cause of the problem. It was also apparent that even when the bladder was in position, hooked punches (as opposed to straight punches) could sometimes result in the opponent being contacted by the back of the glove in the area behind the bladder, meaning that protection afforded by the bladder would not occur.

We therefore implemented several changes to the gloves. We covered the area behind the bladder with a 2.5 cm thick layer of medium-density open cell foam. The top of this layer extended to half-way up the bladder and had two arms that extended forward to provide a circular 'cradle' for bladder support.

The upper edge of the foam was cut to a shape that enabled efficient seating of the bladder. The changes had the disadvantage of adding to the bulk of the gloves (Figure 5) but were perceived as addressing important deficiencies of the prior prototype.

Figure 5: Prototype low-impact gloves with additional foam added to perimeter of glove to increase protection against impacts delivered with a part of the glove other than the bladder. The white areas at the top of the gloves are electrically conductive patches that formed part of automated scoring technology used in Box' Tag [50].

In April 2015, two of us and a colleague with a background in kick-boxing took part in a trial in which each person used the new prototype gloves, conventional 12oz (Std 12oz) gloves of the type used in competition by amateur boxers in the heavier weight divisions [51], and conventional 16oz (Std 16oz) gloves such as those commonly used by boxers in sparring [52] to deliver a series of subjectively light, medium and heavy impacts to a commercially available apparatus designed and built by the Institut Für Angewandte Trainingswissenschaft [Institute of Applied Training Science] in Leipzig, Germany, specifically for measuring punch characteristics. This apparatus, located at the AIS in Canberra, consisted of a wall-mounted force plate covered by a pad with a thickness of 290 mm including a leather covering, multiple foam layers, two layers of plywood board and a 20 mm thick aluminium plate to which the load cell was attached. The pad had a frontal surface of 330 mm square and at the point of maximum width it was 460 mm square. The aluminium plate at the back of the pad was 350 mm square.

The apparatus, which is shown in Figure 6, incorporated a two-beam laser system that enabled measurement of pre-impact glove velocities. The beams were positioned 44 mm apart and very close to the target area of the pad.

Figure 6: Apparatus at the Australian Institute of Sport, Canberra, for measuring punch characteristics.

To enable data for the three individuals to be included in a single analysis despite individual differences in the levels of force that could be generated, each peak force reading was converted to a percentage of the personal highest peak force reading recorded on the day, and the same procedure was adopted for pre-impact glove velocities. A plot of percentage force against percentage velocity (Figure 7) suggested that the prototype gloves yielded substantial impact buffering effects across almost all the observed glove velocity range. It was also true, however, that very high glove velocities were seldom attained when the prototype gloves were used. This may be explained partly by the fact that the prototype gloves were ~ 4-5 cm longer than the standard gloves, meaning they would have tended to travel over less distance before contacting the target. The decrease in distance could be expected to limit the time available for glove acceleration, hence lowering the velocity eventually reached.

It is also possible, though, that some aspect of the form or comfort of the gloves caused the subjects to be slightly more tentative.

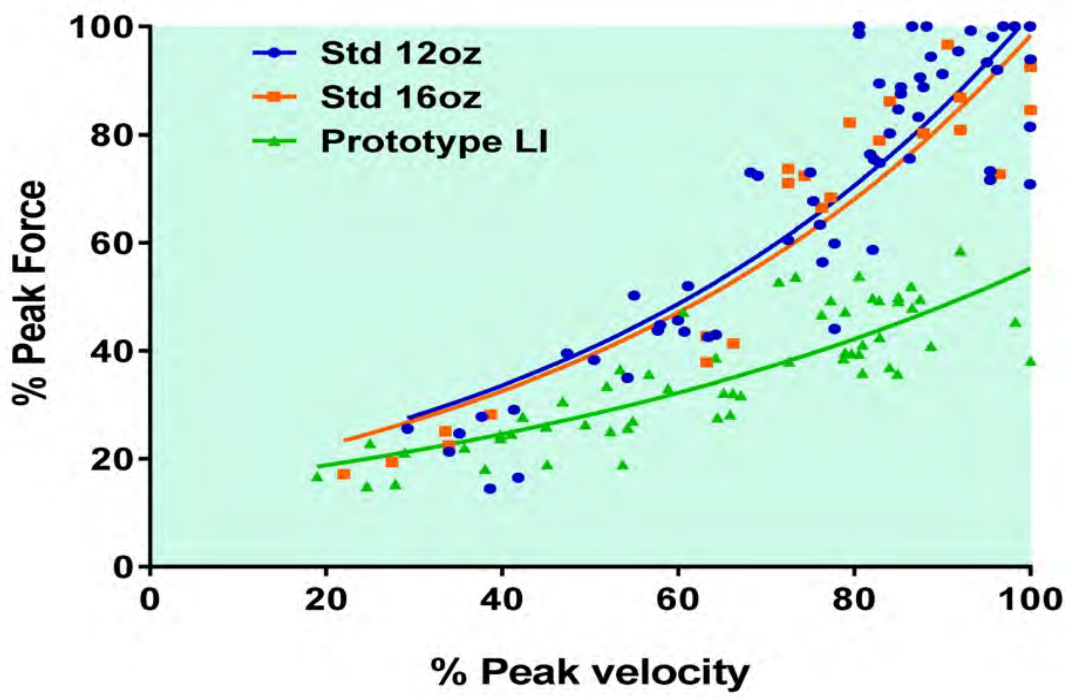

Figure 7: Comparison of performance of the prototype low-impact glove (Prototype LI) against that of conventional 12oz and 16oz gloves in initial “punch integrator” tests.

Although the test results were encouraging, the aesthetics of the gloves remained unsatisfying. We attributed this partly to the makeshift and rudimentary nature of our manufacturing process (e.g. the use of kitchen scissors and scalpels to cut foam to required shapes). We took the gloves to a modified boxing event in Sydney, where they were used in two bouts between junior males. In that context, they looked unacceptably large. During the remainder of the event, we showed the gloves to numerous attendees. Although there was interest in what we were trying to achieve, the appearance of the gloves drew broad criticism, and one adult female participant in the Sydney program commented that regardless of the impact-buffering capabilities of the gloves, she “would not be seen dead wearing them”. It was evident that further thought concerning glove design was necessary.

8.3.7. A Breakthrough: Building of gloves around bladders

Shortly after the laboratory testing at the AIS it was decided that, instead of using commercially available training gloves as a base and adapting them to enable accommodation of a bladder, we should focus on the bladder as the core element of our approach and work out how best to build a glove around it. In retrospect, this decision constituted a major advance in the project. It reduced material costs as the need to purchase training gloves was eliminated, and it also removed constraints as to how various glove components could be arranged as part of the assembly process.

Initially, cardboard cut-outs of a glove "frame" were produced to enable experimentation that culminated in determination of optimal shape and dimensions. Once the characteristics of the frame had been finalized, a cut-out consisting of 0.5 mm thick rubber was made.

Velcro "hook" material was then sewn on to the bottom section of the frame. To one side of it, a strip of elastic was sewn. To the other, a section of Velcro "loop" material covered with grey ripcord fabric was attached. The frame was then flipped over and a rectangular section of 2 cm thick open cell foam was glued to most of its surface. A triangular strip of the same open cell foam was glued to the rubber and the upper surface of the rectangular strip. The outer ends of the rubber frame were then brought together to create a circular, slanted cradle for the bladder. A notch was cut in the frame to provide access to the bladder valve. After placement and inflation of the bladder, a lycra bag was pulled over the whole unit. The elastic and Velcro materials formed a secure wrist strap (Figure 8).

Figure 8: Overview of the construction of the first prototype low-impact gloves designed around the bladder.

The glove made in this way had all the features of the previous prototype but its outer surface was smooth and it was much shorter and sleeker. It elicited a positive reaction from participants in the modified boxing program at the Canberra PCYC and, with help from an Industrial Design student from the University of Canberra, a few minor improvements were made in response to their feedback. The impact-buffering effects of the glove were subjectively perceived as substantial. Consequently, several pairs of the gloves were produced to permit more comprehensive field trials. It was found that after delivery of multiple moderately forceful impacts, creasing of the glove frame began to occur close to the bottom of the bladder. This area of the frame obviously would be subject to considerable compressive and shear forces during impact.

Investigation of the cause of the creasing problem suggested that it could be due partly to a tendency for the triangular section of foam forming the bladder cradle to become separated from the main (rectangular) section of the glove padding. We therefore made some new prototypes in which the foam element consisted of a single piece, instead of two pieces glued together. We also added a second layer of rubber to the glove frame to increase overall frame strength.

We showed the prototype gloves to colleagues at the University of Canberra and they opined that, in view of the progress made, the time had come to involve a professional industrial designer in the ongoing glove development.

8.3.7.1. Further key enhancements - greater visual resemblance to conventional boxing gloves and more robust construction

In June 2015, a small Canberra-based industrial design business, Stellen Studio, was commissioned to assist with the project. Its Principal recommended that to maximize the appeal of our prototype gloves to potential users, attention should be directed to increasing their visual resemblance to standard boxing gloves. Over the following month, he made several new prototypes consistent with this recommendation (Figure 9). They incorporated no lycra. In each case, the entire glove surface consisted of kangaroo leather, which although less elastic than lycra, has several advantages over bovine leather in that for any given thickness it has much greater tensile strength, is more resistant to stitch tearing, feels softer, is more abrasion-resistant and is less prone to uptake of sweat [53-55].

Pleating of the joins between the upper and palm sections of the glove meant that there was still reasonable scope for lateral bladder deformation. A port on the under-surface of each glove allowed for inflation and deflation of the bladder with the glove remaining fully intact.

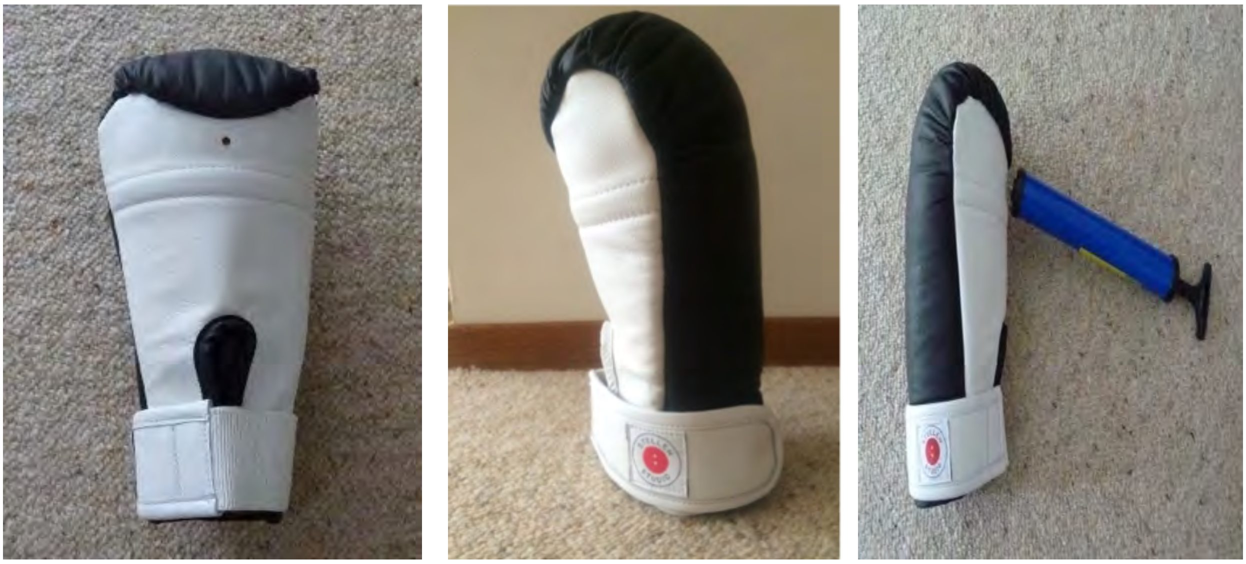

Figure 9: The first prototype low-impact gloves made by Stellen Studio, Canberra, Australia, with mechanism for easy inflation and deflation incorporated.

The new prototypes were introduced to participants in the modified boxing program at the Canberra PCYC and the reaction was highly positive. Although the gloves were functionally quite similar to our previous version, they were immediately perceived as superior and there were numerous comments to the effect that we were now “really getting somewhere”.

Several pairs of the gloves were made and used in a series of specially organized sparring sessions at the Canberra PCYC. It was found that the gloves seemed to work best when the air pressure within the bladder was only slightly above ambient atmospheric pressure. A Ross Brown model KPCh low-pressure gauge with a range of 0 - 10 kPa was used to measure bladder air pressure before and after each bout and showed that the bladder valves were resistant to leakage.

With regard to glove comfort, comments from the modified boxing participants were generally favorable and one participant who was a former amateur boxing champion considered them more comfortable than conventional gloves. There were some concerns, however, that they provided less wrist stability and could therefore predispose to wrist injury.

Several athletes indicated that the spherical nature of the bladder could lead to unusual and unexpected glove contact characteristics and that this too might entail risk of injury to the person delivering the contact. There were occasional complaints that the gloves could rotate on the fist during impact.

To address the potential wrist and glove issues, changes to the wrist strap of the gloves were made, particularly in relation to its width. Also, in October 2015, a hemispherical bladder was produced and incorporated into new glove prototypes. The new shape was achieved by using a slightly larger bladder (Enkay India Size 2 soccer ball bladder), then cutting off the its lower third and sealing the hole with a truck tyre patch. The changes enhanced the structural and functional stability of the gloves as well as their visual appeal (Figure 10), and the interest of Canberra PCYC athletes in using the gloves became greater and more sustained than ever before.

Figure 10: Low-impact gloves with hemispherical bladder, improved wrist support and inclusion of new leather sections providing the gloves with the appearance of having thumb compartments.

At the beginning of 2016 the gloves were used at another AIS Draft Camp for potential boxers. Each of seven aspirants completed two rounds of modified boxing against a former Australian champion amateur boxer.

The feedback following the session was very positive. The Coordinator of the Draft Camp advised that the coaches thought the session was “fantastic” and really provided them with an indication of the skill level of the athletes.

One of the scientists supporting the camp noted that it was great to be able to gain that indication without need to place the athletes at risk of being hurt.

Of their own volition, three of the aspiring boxers came to speak to us about the gloves, as did the former champion boxer. There was universal agreement that the gloves were very effective in reducing impact forces. A female competitor commented that, upon quickly realising that there was little possibility she could be hurt, she became more daring in her approach to the sparring. There was an overall feeling that the gloves could be excellent for beginners and a great aid to skill development, although one male athlete noted that, from his own perspective of preparing to participate in conventional boxing, he would rather become accustomed to normal gloves from the outset. Two athletes commented that their hands started to feel slightly uncomfortable due to the need to always keep their fists tightly clenched, but it was recognized that this might have been because the inner gloves that we provided were too small. There was also an impression that the gloves were not tight enough around the wrists. Two athletes advised that they occasionally felt the gloves bend when they delivered hooks or uppercuts. The former national champion boxer, who used the gloves continuously for 14 rounds, said that he found them comfortable throughout, but thought they could be improved by incorporating still larger wrist straps.

Examination of the gloves after the session showed that they stood up very well to the stresses, with no damage or deterioration evident.

Shortly after the AIS camp, we conducted another experiment in which three individuals struck the punch testing apparatus at the AIS. Each delivered 10 maximal punches to the wall-mounted, padded force plate with both left and right hands, and with each of three different glove types - prototype low-impact gloves with a bladder pressure of 2.0 kPa, conventional 10oz (Std 10oz) gloves and conventional 16oz (Std 16oz) gloves. The order in which the glove types were used was varied between individuals. Within each set of 10 punches, the interval between punches was 20 - 30 seconds. The intra-subject interval between sets was 15 - 20 minutes.

One of the participants in the experiment was a male former Australian amateur boxing champion, another was a female participant in the modified boxing program at the Canberra PCYC, and the third was a 64-year old male who is one of the authors of this paper.

The results of the experiment are shown in Figure 11.

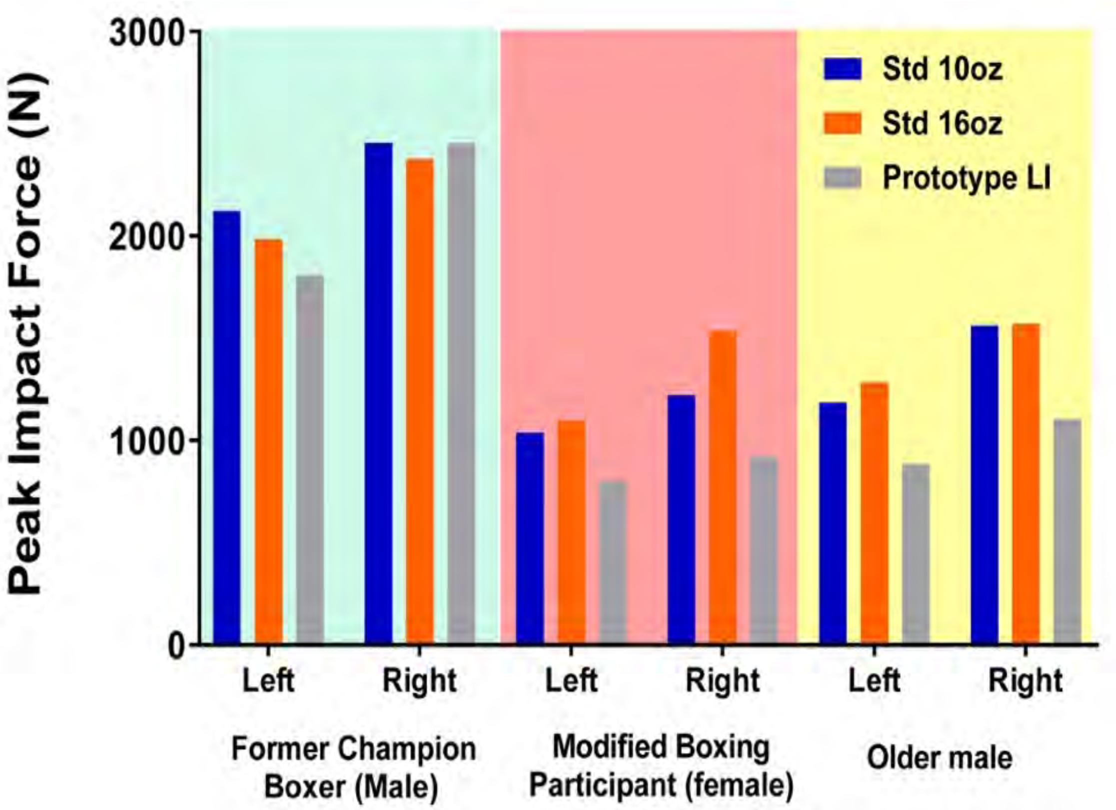

Figure 11: Effect of glove type on peak force recorded on punch integrator by three different subjects. Each column represents the highest single reading recorded from 10 attempts.

The variability in peak force readings within sets was greater with the prototype low-impact gloves than with the conventional gloves, particularly in the case of the former champion boxer. To avoid the possibility of this greater variability giving a falsely elevated impression of the protective effect of the prototype gloves, it was decided to confine comparisons to the single highest readings recorded by each of the athletes under the various conditions. This approach showed that, for the female and the older male participant, the prototype low-impact gloves reduced peak impact force by 22% - 31% compared with Std 10oz gloves. For the former national champion boxer, who generated much higher absolute peak force levels, there was a reduction of ~15% for the left [non-dominant] hand but almost no reduction (1.5%) for the right hand.

The findings were interpreted as suggesting that while the prototype low-impact gloves could substantially reduce peak forces associated with even moderately heavy impacts, they became ineffective when impacts when were very heavy, presumably because maximum compression of the bladder had been approached. A need was apparent, however, for a testing method less dependent on human factors and more suitable for allowing quantitative assessment of the gloves across a wide range of controlled impact magnitudes.

8.3.8. Progression in glove evaluation

In accordance with standard practice, we had used a pendulum system to check the calibration of the AIS punch-testing apparatus. This entailed releasing a steel pendulum arm with a length of 1 metre and a mass of 9.4 kg from a horizontal position so that a hammer on the end of the arm struck the centre of the force plate padding when the arm reached the vertical position. It was known that for the particular apparatus this process should yield a peak force reading of ~1,500 N. It occurred to us that adapting the pendulum to enable fitting of different glove types to its hammer end could provide a means for enabling repeatable evaluation of the influence of the gloves on peak impact forces.

To implement this approach, we needed to develop a “mechanical fist” that could be attached to the pendulum and provide for the addition of known masses to the pendulum arm to permit generation of peak impact forces at least as high as those produced by elite boxers. It was also necessary to modify the frame supporting the pendulum arm so that the swivel point of the arm could be further away from the target, such that the arm with mechanical fist and glove attached would still be vertical when impact to the target occurred. Additionally, the position of the swivel point had to be adjustable to cater for different glove lengths.

There was a requirement for the mechanical fist to be designed in a way that allowed its insertion into gloves to properly simulate real-world practice for different glove types. This meant that it had to cater for conventional gloves to be put on with fingers extended, and the fist subsequently clenched, and for prototype low-impact gloves to be put on with the fist already in the clenched position. With assistance from a Senior Technical Officer at the University of Canberra, we designed a mechanical fist with the necessary characteristics and arranged for a local engineering company to build it to our specifications. The device is shown in Figure 12.

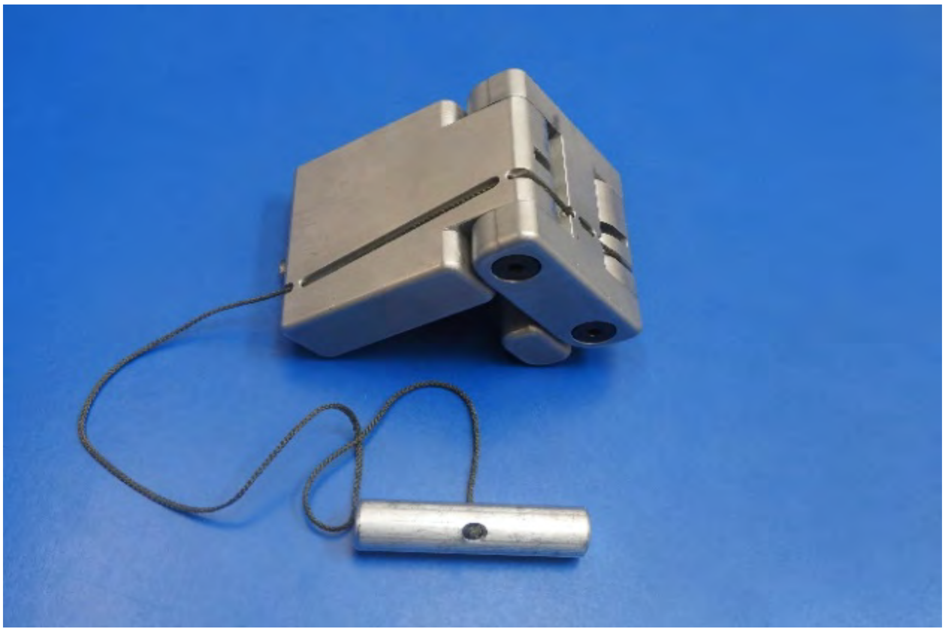

Figure 12: A first prototype mechanical fist manufactured for glove testing. The cable could be pulled to draw the device into a position simulating the position of an open hand for insertion into a conventional glove.

At the same time a new pendulum arm was produced that had a mass of 5.54 kg and provided for screw attachment of the mechanical fist at one end (at 90˚to the shaft of the arm) and for placement and securing of extra masses behind the fist on the other side of the shaft. A metal sleeve was manufactured to enable extension of the frame providing the swivel point for the pendulum. The sleeve incorporated a series of holes to cater for alteration of the swivel point.

The first tests with the new method (see Figure 13) produced some valuable data. When we used the pendulum arm with no additional weight added, the mean peak force (±standard deviation) for eight releases of a Std 10oz glove from a horizontal position was 1241 ± 8 N, and in a repeat test involving 14 releases it was 1247 ± 9 N. Under the same conditions, a prototype low-impact glove with a bladder pressure of 2.0 kPa gave a mean peak force of 997 ± 19 N, a reduction of ~20%. With 5 kg of weight added to the pendulum, the mean peak force for 12 releases of the Std 10oz glove was 1878 ± 17 N. For the prototype low-impact glove (also across 12 releases) it was 1249 ± 26 N, a reduction of 33.5%.

Figure 13: First tests involving use of a pendulum apparatus with attached mechanical fist for glove testing. The photograph shows a prototype low-impact glove contacting the pad covering the wall-mounted force plate.

The variability in peak force measurements associated with any given condition was very much less than in our prior human trials. Nevertheless, some problems were encountered in the conduct of the experiment. The fit of the mechanical fist into the gloves was sub-optimal, necessitating minor modification of the gloves to ensure achievement of the desired fist position within them. The bar for addition of masses to the pendulum proved to be slightly too small in diameter and had to be taped to prevent the 5 kg mass used in the trial from moving. With the heavier impacts the prototype low-impact glove seemed first to deform and then “buckle under”. This was perhaps because the centre of mass of the mechanical fist was somewhat below the long axis of the “wrist” - a situation differing from the real world. Most importantly of all, it proved difficult to maintain the mechanical fist in a fully clenched position inside the Std 10oz glove, preventing continuation of the experiment to include very high impact magnitudes.

To address the shortfalls of the initial mechanical fist, a new one was designed and built by a Melbourne-based team consisting of an engineer and an aircraft mechanic. It incorporated a ratchet system for clenching the fist and locking it firmly in the clenched position.

The mass of the fist was distributed around the long axis of the unit rather than being largely below it (Figure 14). The pendulum was modified to increase the robustness of its connection to the fist.

Figure 14: A conventional glove attached to the new mechanical fist, with the fist locked into the clenched position through use of a ratchet mechanism.

In February 2016, a trial entailing use of the new mechanical fist was conducted (Figure 15). Initially, we compared a Std 12oz glove to a prototype low-impact glove with the bladder inflated to a pressure of 2.0 kPa. Both gloves were new. In each case, a 10 kg mass was attached to the pendulum and the glove was successively released to travel through arcs of 15˚, 30˚, 45˚, 60˚ and 75˚ as measured using a digital goniometer (Imex EL Series EL-20). There were 20 releases per glove per pendulum arc.

The results of the experiment are shown in Table 1.

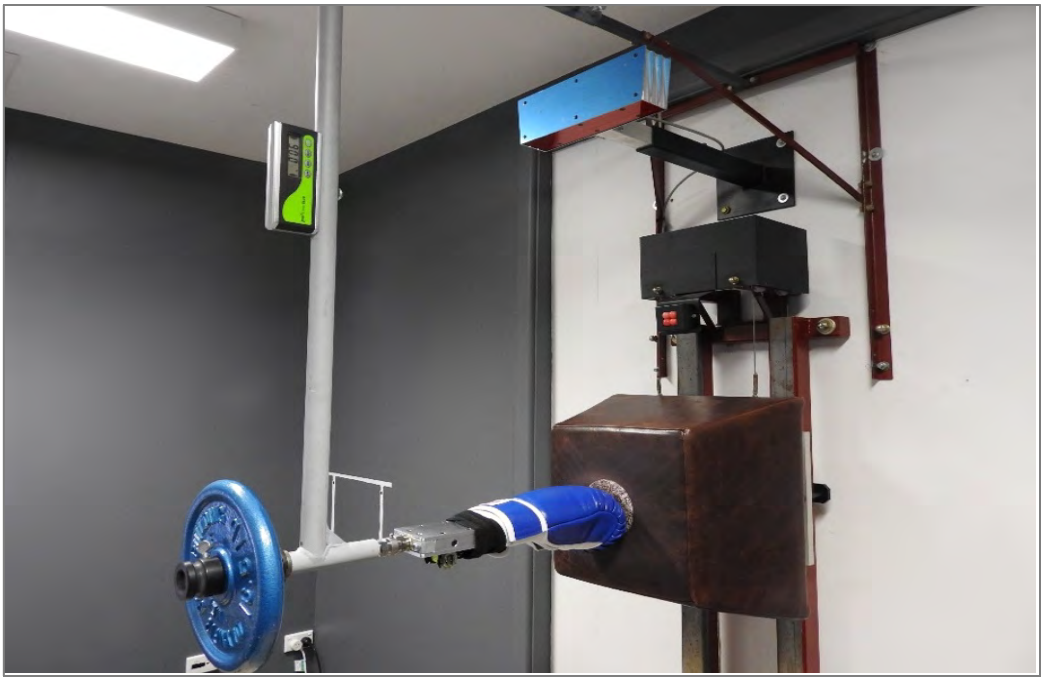

Figure 15. Glove testing using the pendulum apparatus, the new mechanical fist and the wall-mounted force plate at the Australian Institute of Sport. The digital goniometer used to measure pendulum release angles can be seen on the pendulum shaft.

Table 1: Effect of glove type and pendulum arc on peak impact force. For each condition, mean peak force for 20 trials is shown, along with the associated standard deviation.

Pendulum Arc	Std 12oz glove	Prototype Low-impact glove	% Reduction In Peak Force
15˚	249 ±3 N	190 ± 4 N	23.7
30˚	541 ± 7 N	394 ± 8 N	27.1
45˚	927 ± 19 N	675 ± 7 N	27.2
60˚	1344 ± 14 N	1038 ± 34 N	22.8
75˚	1772 ± 11 N	1567 ± 31 N	10.7

We had intended to proceed also to a pendulum arc of 90˚ but the pendulum frame began to show signs of damage so the trial had to be discontinued and temporary repairs implemented. The repairs involved stabilizing the pendulum mounting bar at its outer end to take the pressure off the support frame.

Further analysis of the data collected up to that point showed that using just the first five of the 20 releases under each condition would scarcely have changed the mean values. Accordingly, after the repairs we carried out a further experiment in which five different gloves types were compared - Std 10oz, 12oz and 16oz gloves, an inexpensive recreational 10oz glove, and a prototype low-impact glove with the bladder inflated to a pressure of 2.0 kPa - but this time each glove was dropped only five times through each arc. The arcs were as above and a 10 kg added mass was again employed.

The results of this follow-up experiment appear in Figure 16. In terms of the peak forces recorded with the various pendulum arcs, the Std 10oz, 12oz and 16oz gloves and the cheap recreational 10oz glove were virtually indistinguishable from one another.

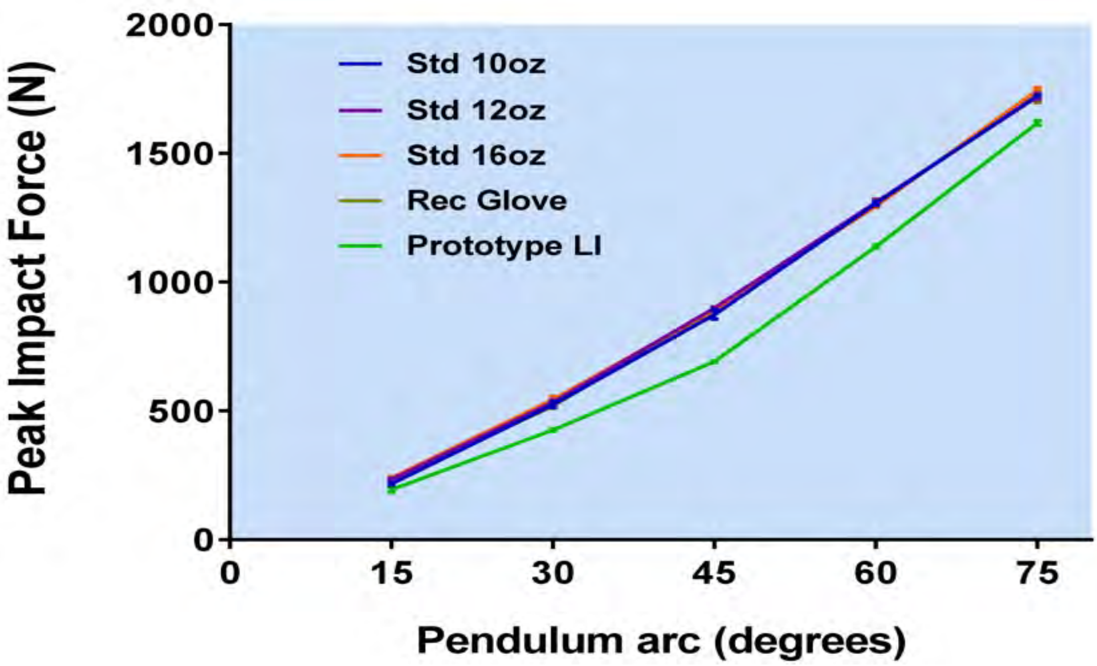

Figure 16: Effect of glove type on peak impact force in force plate testing involving release of weighted pendulum from various heights. Each data point is the mean of five pendulum releases.

The readings for the prototype low-impact gloves were 15.9%, 19.9%, 22.3%, 12.7% and 6.3% lower than the mean value for the other four glove types for the pendulum arcs of 15˚, 30˚, 45˚, 60˚ and 75˚ respectively. The differences between the Std 12oz glove and the prototype low-impact glove were less than those observed earlier, due to the peak force readings being slightly lower for the former and slightly higher for the latter.

This may have been due to subtle changes introduced by the repairs to the pendulum support structure, and highlights the potential for research outcomes to be influenced by seemingly minor adjustments to experimental apparatus. Nevertheless, the general trend that we had observed in the earlier experiment was essentially confirmed, with the low-impact glove producing considerable reductions in impact force when impact forces were low to moderate but showing diminished effectiveness at higher impact forces.

We began to wonder whether the protective effect of our prototype low-impact glove was being influenced by the relationship between the pre-impact velocity and the effective mass of the striking object. Figure 17 shows that, even for the best-case scenario associated with our addition of a 10 kg weight to the pendulum arm used with the AIS punch testing system, fitting of a curve to the relationship between peak force measured with the Std 12oz glove and the reduction in peak force achieved with the low-impact glove suggested that the protective effect would fall below 20% when the peak force for the Std 12oz glove exceeded ~1453 N and would disappear altogether at 2053 N. However, protective effects considerably exceeding these predictions were observed in our earlier experiments involving the addition of only a 5 kg weight to the pendulum or human delivery of maximal punches.

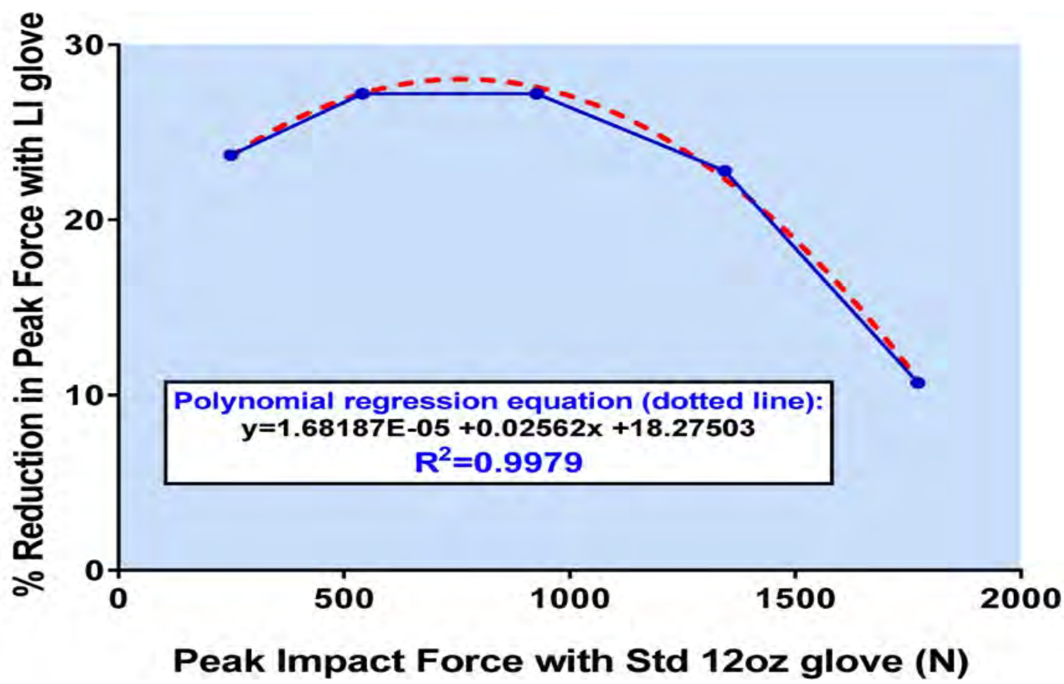

Figure 17: Effect of Low-Impact Glove on % peak force reduction as a function of peak force magnitude. The solid line joins observed data points. The dotted line is a curve fitted to the data through a second-order polynomial regression equation.

Release of our 1-metre long pendulum to travel through an arc of 75° resulted in a pre-impact velocity of ~3.8 m·sec^{-1} and addition of a 10 kg mass to the pendulum provided a total effective mass of ~18.5 kg, whereas Walilko et al. [56] have reported that the peak pre-impact glove velocity attained by seven elite boxers averaged 9.14 m·sec^{-1} and the effective mass averaged only 2.9 kg. It seemed reasonable to imagine that vastly different approaches to generation of impact forces might affect impact contact times and the ability of specific structures to buffer the forces. We therefore perceived a need to develop a laboratory-based glove testing method that was more closely aligned to real-world conditions.

8.3.9. A step toward greater ecological validity

After evaluating several options, it was decided that the best approach would be to carry out straight drop test experiments involving the dropping of gloves from known heights on to an in-floor force plate. We determined that to reproduce the glove velocities that Walilko et al. [56] found elite boxers capable of generating we would need to drop gloves from a height of close to 5 metres. We were able to access a University of Canberra laboratory with a 600 mm × 400 mm in-floor Kistler force plate (Kistler, Amherst, MA, USA) and a ceiling height that made glove drops from up to 5 metres possible. A wall-mounted metal frame supporting a low-friction, flanged pulley was constructed and affixed to a wall of the laboratory such that the pulley was located directly above the centre of the force plate a height of 5.5 metres. Gloves could be drawn up to any required drop height by means of a cord placed over the pulley. The cord was manually pulled through an eyelet positioned at the top of a floor-mounted post. It was marked at intervals corresponding to 0.5 metre increments in drop heights between 1 and 5 metres. Alignment of the marks with the eyelet on the post ensured accuracy of the drop heights. The mechanical fist employed in our final pendulum experiments was modified so that a high-tensile steel rod could be securely screwed into it at the end opposite that designed to receive the gloves. At the other end of the rod was a hook for attachment of the cord. With the rod incorporated, the mechanical fist had a mass of 3.046 kg which was close to the 2.9 kg found to be the average effective mass associated with maximal punches delivered by elite boxers [56]. A photograph of the experimental configuration appears in Figure 18.

Figure 18: Drop testing system used for glove evaluation at the University of Canberra.

A pilot trial with the new drop testing system was conducted in early April 2016. A Std 10oz boxing glove and a prototype low-impact glove with a bladder pressure of 2.0 kPa were each dropped ten times on to the force plate from heights of 1, 1.5, 2, 2.5 and 3 metres. The force plate was unpadded and its outputs were monitored at a rate of 3000 Hz using Kistler Bioware software run on a standard PC. Throughout the testing session, known masses were regularly placed on the force plate to check the accuracy of the force plate readings. The results of the pilot trial are shown in Figure 19.

We were greatly surprised by the magnitudes of the peak force readings, with the conventional glove producing a mean peak force reading of more than 3000 N even when the drop height was only 1 metre. This finding was considered due to the absence of protective padding over the force plate and the resultant lack of "give" in the target. It served to emphasize the importance of target characteristics in the determination of peak force readings. Detailed analysis of the data revealed that, at the higher drop heights, rise in force readings was so rapid that a sampling rate of 3000 Hz was insufficient to ensure precise identification of peaks.

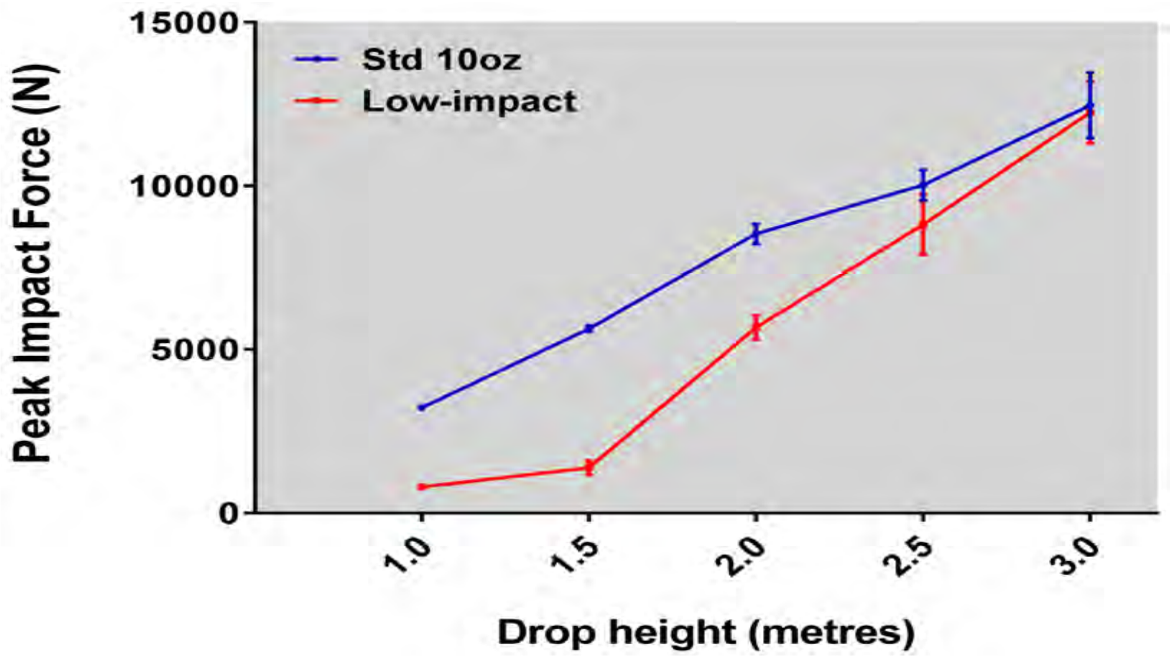

Figure 19: Effect of drop height on mean peak impact force recorded with prototype low-impact and standard 10oz boxing gloves dropped on to an unpadded force plate.

The most important finding, though, was that while the prototype low-impact glove substantially reduced peak forces associated with drop heights of 1, 1.5 and 2 metres and still offered some protection at 2.5 metres, there was no protective effect at 3 metres. Since the peak forces with a drop height of 3.0 metres were in the vicinity of 12,000 N which is far above the level reportedly generated by boxers [47], the real-world implications of the finding were unclear. Even so, examination of force curves was undertaken and revealed that although the low-impact glove always served to delay the onset of rapid increase in force, the shape of the curves beyond that onset became progressively more similar for the two glove types as drop height increased. At 3 metres, the shapes were very similar indeed (Figure 20).

This suggested that the low-impact glove had reached a point of maximum bladder compression beyond which it began to act like a conventional glove. In view of the insights gained from the pilot work, it was resolved that in subsequent drop testing some padding should be placed over the force plate and the sampling rate should be increased. Critically, a decision was also made to develop a new prototype glove that permitted occurrence of some air release from the bladder when pressure within the bladder became high. This meant a return to the first idea that we had explored, but now with a different glove configuration, different materials, and insights gained in the intervening period. It was reasoned that capacity for some air release should decrease the rate of pressure build-up, thereby changing the effect of heavy impacts on the shape of the force curve and yielding lower peak force readings.

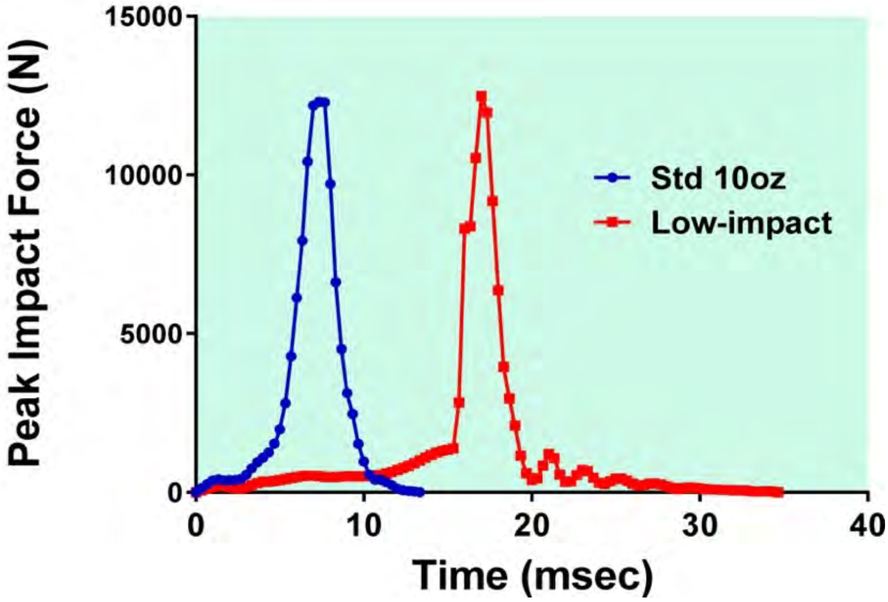

Figure 20: Force-time curves for standard 10oz and prototype low-impact gloves dropped on to an unpadded force plate from a height of 3 metres. The force plate sampling rate was 3000 Hz.

8.3.10. A new prototype glove incorporating air release

It was clear that any glove incorporating a bladder with capacity for air release during impact would need to also have a mechanism for rapid return of the air following impact release. We mooted the possibility of achieving this through inclusion of separate one-way valves for air outflow and inflow, as described in the patent registered by Carrillo [46], but eventually settled on a solution that we considered simpler and less susceptible to failure.

In our design there was a single hole in the bladder. The bladder was provided with a resilient, elastic internal “skeleton” that could collapse under conditions of high internal pressure during impact but would immediately recover its shape thereafter, with the recovery causing the internal bladder pressure to fall temporarily below the ambient pressure, so driving air inflow. With this approach, no valves were required.

Figure 21 shows our first prototype of the new bladder. The internal skeleton consisted of a “ball” of high-density, medium-firmness open cell foam (Joyce Foam Products HR 36 - 140), which was placed inside the bladder prior to sealing with the truck tyre patch. A hole was then made in the bladder and a plastic tube with an internal diameter of 10 mm was inserted. The area around the insertion was then sealed.

The next step was manufacture of a new prototype glove containing the modified bladder, which was positioned in a way that allowed location of the air vent on the palmar surface of the glove (Figure 22).

Figure 21: Construction of bladder for new prototype low-impact glove with capability for air release. The Size 1 soccer ball bladder in panel (A) was cut cross-sectionally at the point indicated by the black line. The foam skeleton was then inserted and the unit was sealed with a truck tyre patch (panel B). A port allowing air release and reuptake was then added.

Figure 22: Prototype low-impact glove allowing movement of air between glove bladder and external environment. The port for air exchange can be seen on the front surface of the glove.

8.3.11. Comparison of gloves through drop testing

In late April 2016, we conducted a study in which the drop testing apparatus was used to compare a Std 10oz glove, a Std 16oz glove, a prototype low-impact glove with a sealed bladder (SBLI), and the new prototype low-impact glove with air release capability (ARLI).

This experiment is described in detail elsewhere [57]. Briefly, each glove was dropped on to the force plate 10 times from each of nine different heights ranging from 1 to 5 metres.

The glove weights, as measured by digital kitchen scales, were 278 g, 455 g, 227 g and 298 g for the Std 10oz, Std 16oz, SBLI and ARLI gloves respectively. The force plate was covered by a 25 mm thick mat of Ultralon EVA 75 material (Ultralon Foam Group, Sydney, Australia) with a guaranteed Shore A durometer hardness rating of 30 - 35, which is at the upper end of the range for healthy human skin but well below the level for human bone [58] [59]. Outputs from the force plate were sampled at 10,000 Hz. The results are summarised in Figure 23.

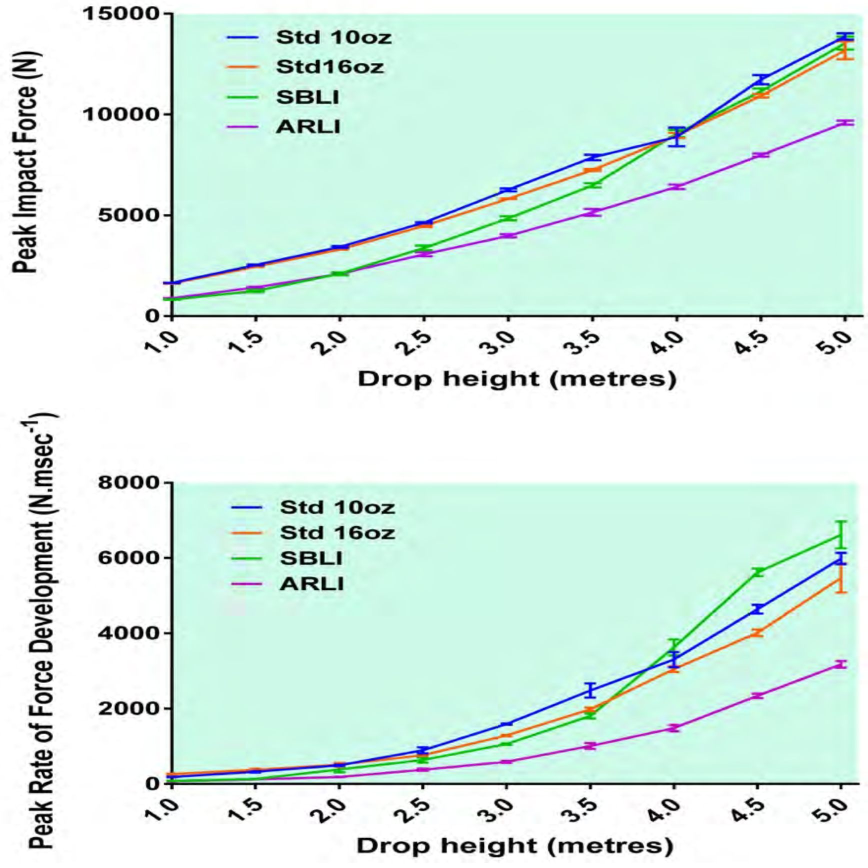

Figure 23: Peak impact forces and peak rates of force development as a function of glove type and drop height. Each point on the graphs is the mean of the highest five readings recorded in a series of 10 drops. The bars show standard deviations for the five drops. Std 10oz = conventional 10oz boxing glove, Std 16oz = conventional 16oz boxing glove, SBLI = Pneumatic glove with sealed bladder, ARLI = Pneumatic glove with air release.

The covering of the force plate with the EVA mat caused peak force readings to be lowered by approximately half compared to those recorded in the pilot trial when no such covering was employed. Compared to the Std 10oz and Std 16oz gloves, the two pneumatic gloves reduced peak impact force by approximately the same amount up to and including a drop height of 2.5 metres. Beyond that point, the performance of the ARLI glove was superior. At drop heights of 4, 4.5 and 5 metres, the SBLI glove was essentially no longer protective, whereas peak impact forces observed with the ARLI glove were lower than those seen with the Std 10oz glove by just over 30%.

An even greater effect was seen in relation to the peak rate of force development, which was calculated by determining the largest increase in peak force over any running period of 0.5 msec, then doubling the result to obtain a reading in $N \cdot msec^{-1}$. With the ARLI glove, the reduction in peak rate of force development relative to the Std 10oz glove was ~60% at drop heights up to and including 3.5 metres and 55%, 50% and 47% at drop heights of 4, 4.5 and 5 metres respectively. The SBLI glove was nearly as effective as the ARLI glove in decreasing the peak rate of force development at 1 and 1.5 metres, but its effectiveness then progressively reduced, and at 4, 4.5 and 5 metres it produced readings exceeding those for the Std 10oz and Std 16oz gloves.

Both pneumatic gloves increased contact times between glove and target (Figure 24), allowing distribution of impact energy over a longer period.

It is evident, however, that when impact energy was high, air within the sealed bladder of the SBLI glove approached and perhaps even reached maximum compression, causing the glove to become hard and peak force to then undergo rapid increase.

In Figure 25, force-time curves are presented for each of the different gloves at drop heights of 1, 3 and 5 metres. Each curve relates to the glove drop that produced the third highest peak force reading from 10 drops under the specified condition (i.e. the median peak force from the highest five readings obtained). The trend evident in the Figure is representative of that observed across all nine drop heights.

The impact-damping capacity of the SBLI glove eventually ‘bottomed out’ as drop height increased, while that of the ARLI glove was maintained.

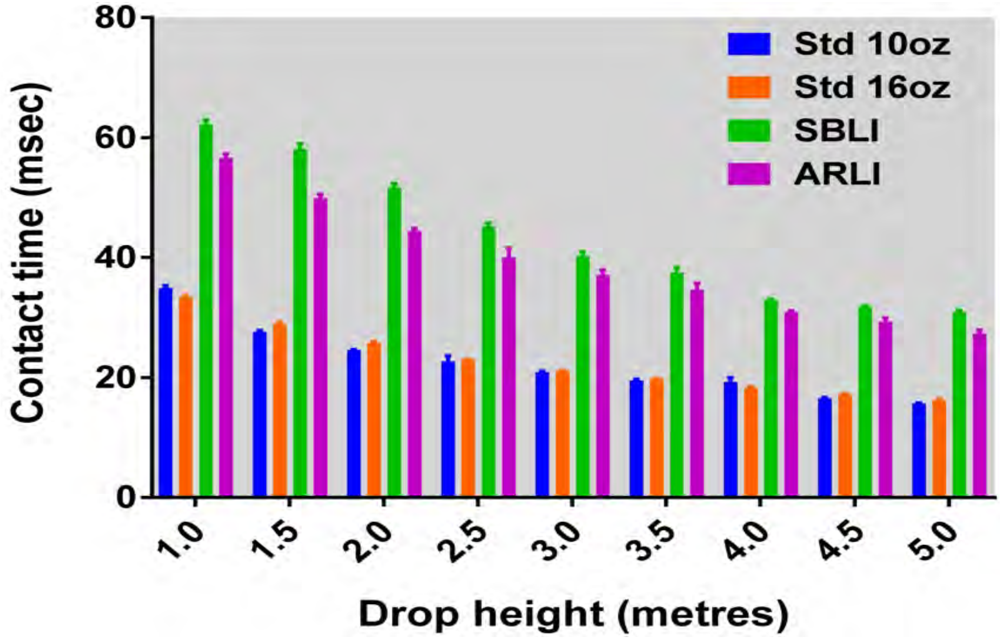

Figure 24: Force plate contact times for different glove types and drop heights. Each bar represents a mean value for five glove drops that produced the highest peak impact forces within a series of 10 drops. Standard deviations for the five drops are also shown.

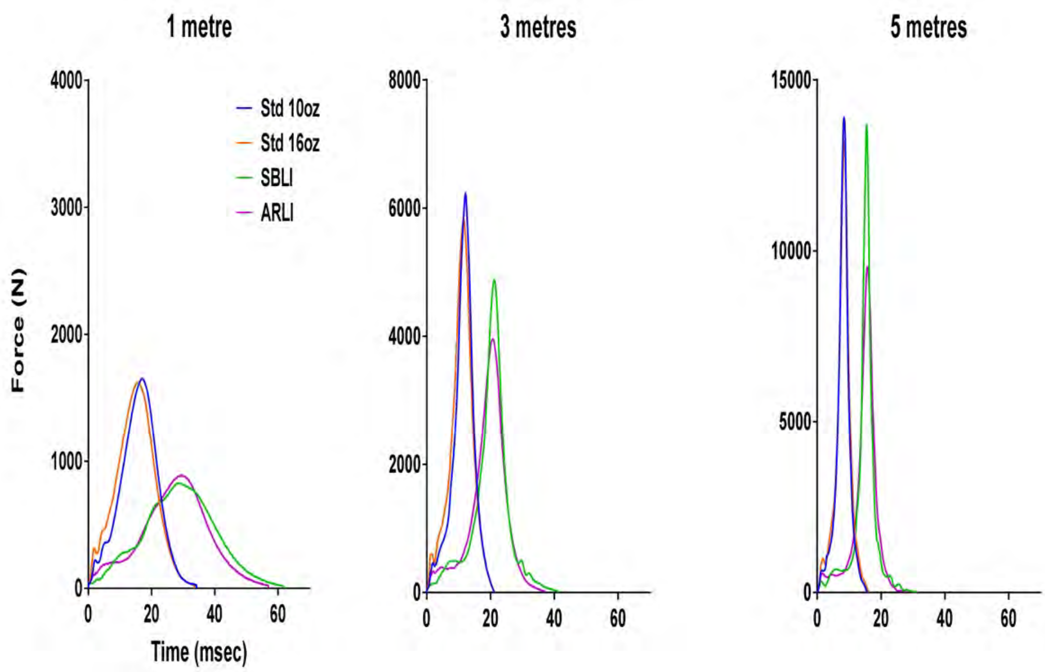

Figure 25: Force-time curves for different glove types at selected drop heights. Note that the scale on the vertical axis differs between the three panels.

Overall, the results of the experiment clearly suggested that future efforts should be concentrated on refining the ARLI glove, since only this glove proved capable of providing significant protection across the whole spectrum of impact magnitudes assessed.

8.3.12. Experimentation with hole pattern for air exchange and importance of bladder foam density

It was evident that in an air-release glove intended for field use, there could be no projection of an air pipe beyond the palmar surface of the glove. After considering various possibilities for a more practical air transport pathway, we produced some bladders that each incorporated six small air openings rather than a single larger one, with the openings extending only to the glove surface. Effort was made to ensure that their total cross-sectional area was similar to that of the air channel in our original ARLI glove. There was an obvious need to test the effectiveness of the new arrangement. We also wanted to determine the extent to which characteristics of the foam forming the bladder skeleton could influence the performance of the glove when the nature of the air openings was held constant.

To enable achievement of the above dual purposes, we manufactured three new ARLI gloves, all with the six-hole system for air exchange. In one of these gloves, the bladder contained a relatively soft, high-density open cell urethane foam (Dunlop HR 36 - 80). In another, a relatively firm high-density open cell urethane foam (Dunlop HR 38 - 200) was employed. The firm open cell urethane foam was incorporated also into the third of the new gloves, but as a series of small blocks or “crumbs” rather than as a single, hemispherical piece. It was reasoned that use of crumbed foam would increase the total air content of the bladder and that this might positively influence the impact-damping qualities of the glove.

In June 2016, we conducted an experiment in which the three new gloves were compared, and in which our original ARLI glove and a Std 10oz glove were also included for reference purposes. The gloves used in the experiment are pictured in Figure 26. The Std 10oz glove had a mass of 278 g and the original ARLI glove had a mass of 298 g. The gloves with the soft open cell urethane foam, firm open cell urethane foam and crumbed firm open cell urethane foam had masses of 264 g, 288 g and 241 g respectively.

Figure 26: Gloves used in testing the effects of a new pattern of air openings and variation in foam characteristics of the bladder skeleton on the impact damping performance of ARLI gloves.

Each glove was dropped on to the force plate 10 times from heights of 1, 2, 3, 4 and 5 metres. The force plate was again covered with a mat of EVA 75 foam with a thickness of 25 mm. The Std 10oz glove was tested first, followed by the original air-release glove (Original ARLI), then the gloves with bladders consisting of the soft high-density open cell urethane foam (Soft Foam), a single piece of firm high-density open cell urethane foam (Firm Foam) and multiple pieces of firm high-density open cell urethane foam (Crumbed Foam). For each glove, the initial drop height was 3 metres, followed by 4, 5 and 2 metres and finally 1 metre. Figure 27 shows the peak impact forces recorded.

All the low-impact glove prototypes diminished the peak forces compared to the Std 10oz glove, but at drop heights of 3 metres and above, the Soft Foam prototype was the least effective of them. The Firm Foam and Crumbed Foam gloves reduced peak impact forces to much the same extent as the Original ARLI glove, although the latter was associated with slightly lower readings at all drop heights. Peak impact forces observed with the Original

ARLI glove were ~43%, 40%, 35%, 32% and 32% less than those for the Std 10oz glove at drop heights of 1, 2, 3, 4 and 5 metres respectively. This was consistent with the findings of our earlier testing.

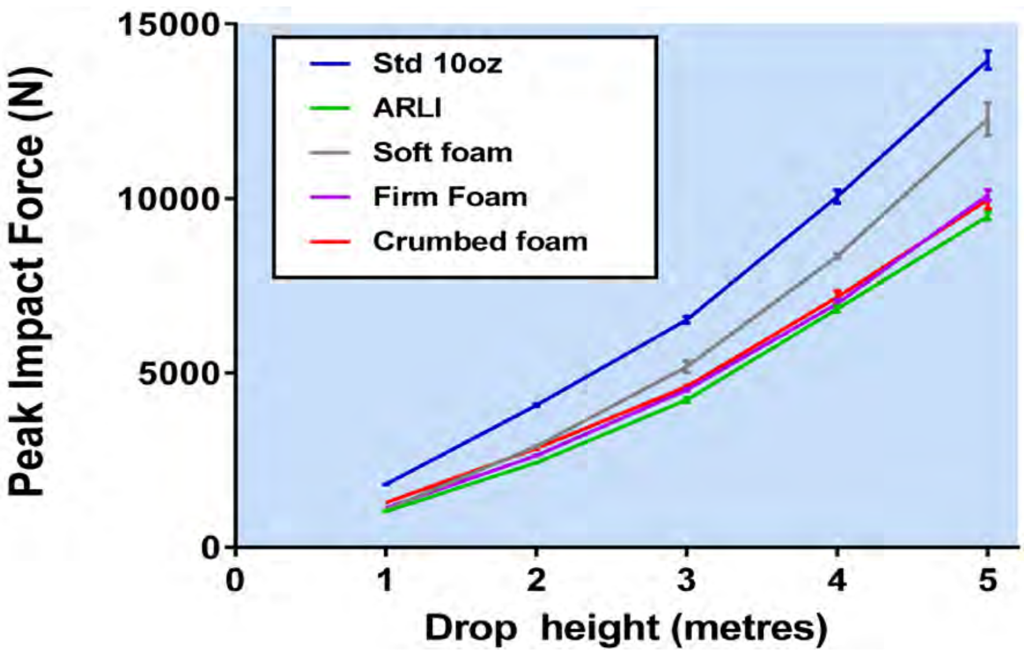

Figure 27: Effect of glove type and drop height on peak impact force. Each point represents the average of the highest five readings from 10 drops under the specified condition and the bars show standard deviations of the five readings. The force plate sampling rate was 10,000 Hz.

With all the prototype low-impact gloves, the onset of rapid rise in force after contact was delayed compared to that associated with the Std 10oz glove (Figure 28).

The delay was related to the firmness of the foam, being longest with the softer foam and shortest for the two gloves incorporating the firmer foam.

This suggests that the period for which glove deformation was the primary determinant of the force-time curve increased as the firmness of the foam decreased. However, it seems likely that the peak force reached in the succeeding phase of the interaction between glove and target was influenced by the amount of air remaining available for expulsion during that period. Since at drop heights of 3 metres and upwards the Firm Foam and Crumbed Foam gloves were more protective than the Soft Foam glove when the air release hole pattern was controlled, it seems likely that the soft foam allowed too much air release during the initial glove deformation phase.

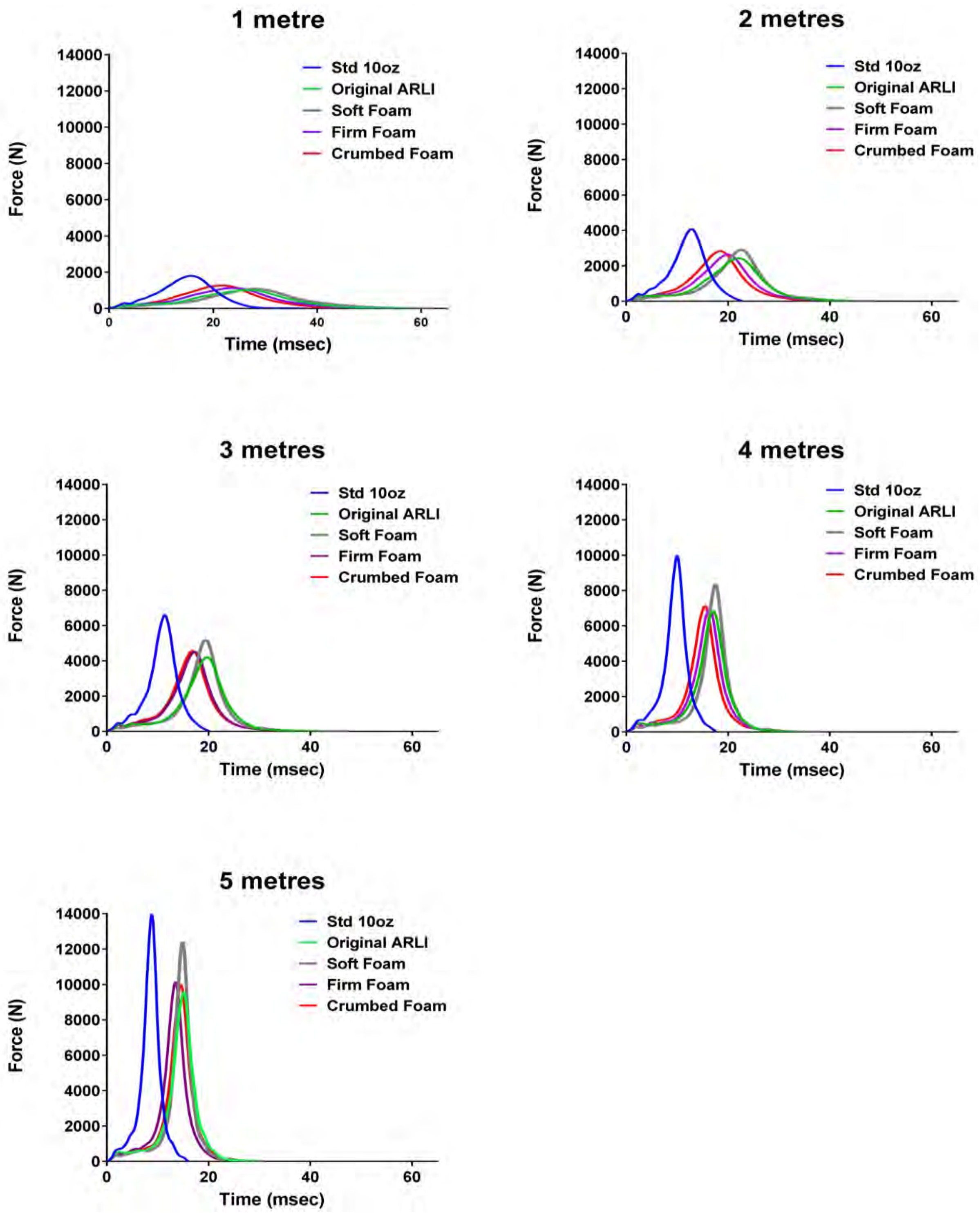

Figure 28: Force-time curves for different glove types and drop heights. Each curve relates to the trial producing the third highest peak impact force from a series of 10 drops.

As can be discerned from the force-time curves, the peak rate of force development (maximum curve steepness) was less for the Original ARLI glove than for any of the other gloves. This is highlighted also in Figure 29. At a drop height of 1 metre, the mean peak rate of force development for the Soft Foam glove was similar to that of the other low-impact gloves, but at all other drop heights it yielded values considerably higher than them, presumably because the characteristics of the foam allowed relatively rapid compression. The means for the Original ARLI glove were ~58%, 68%, 61%, 51% and 49% less than those for the Std 10oz glove at drop heights of 1, 2, 3, 4 and 5 metres respectively. For the Firm Foam and Crumbed Foam gloves, increases in the values as a function of drop height occurred almost in parallel with those for the Original ARLI glove, although the values were consistently a little higher.

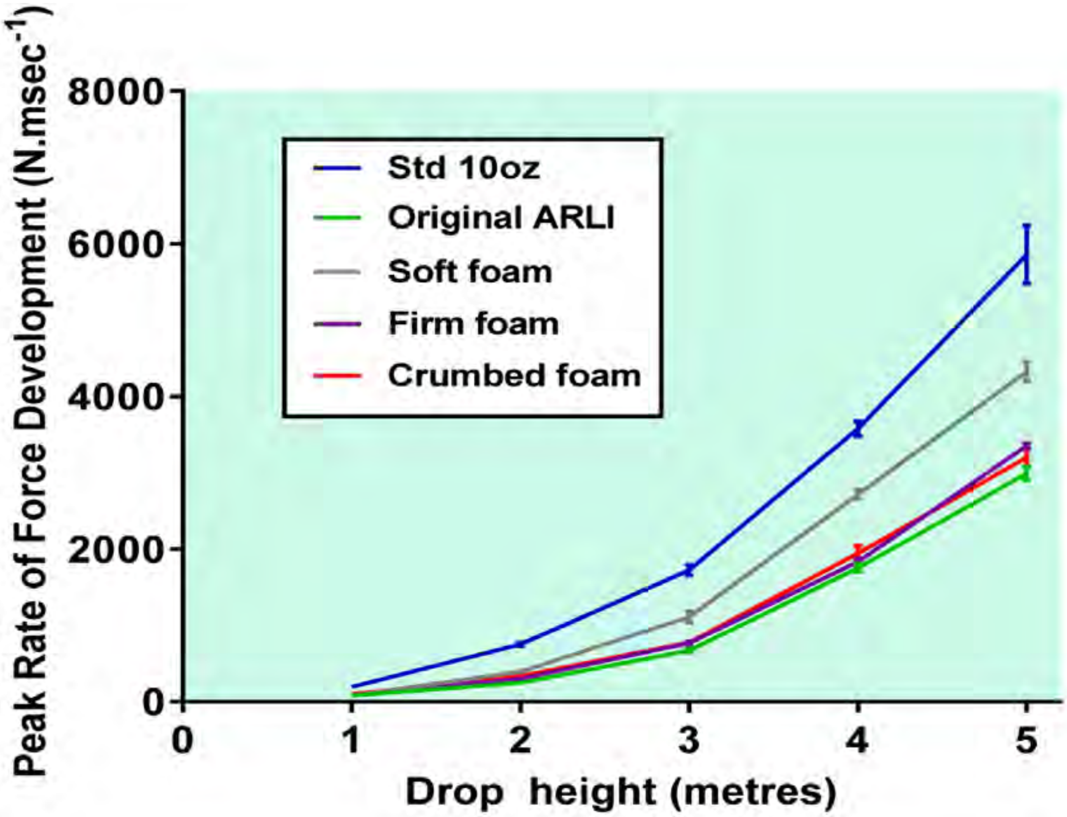

Figure 29: Peak rates of force development for various combinations of glove type and drop height. The curves are based on mean values for five drops that produced the highest five peak impact force readings out of 10 drops. The bars show the standard deviations for the five readings.

In Figure 30, contact times between glove and force plate are presented. At each drop height, contact times for the four prototype low-impact gloves were inversely related to the firmness of foam in the bladder. The fact that the Soft Foam glove always had the longest contact times among the low-impact prototypes, but also produced the highest peak impact forces and peak rates of force development at drop heights of 3 metres and above, indicated that optimization of protective effect depends on more than just maximizing contact time. Use of glove materials that prevent maximum glove compressibility from being approached either too rapidly or too slowly is evidently also important. In our experiment, the performance of the Soft Foam glove appeared to be limited by the latter factor.

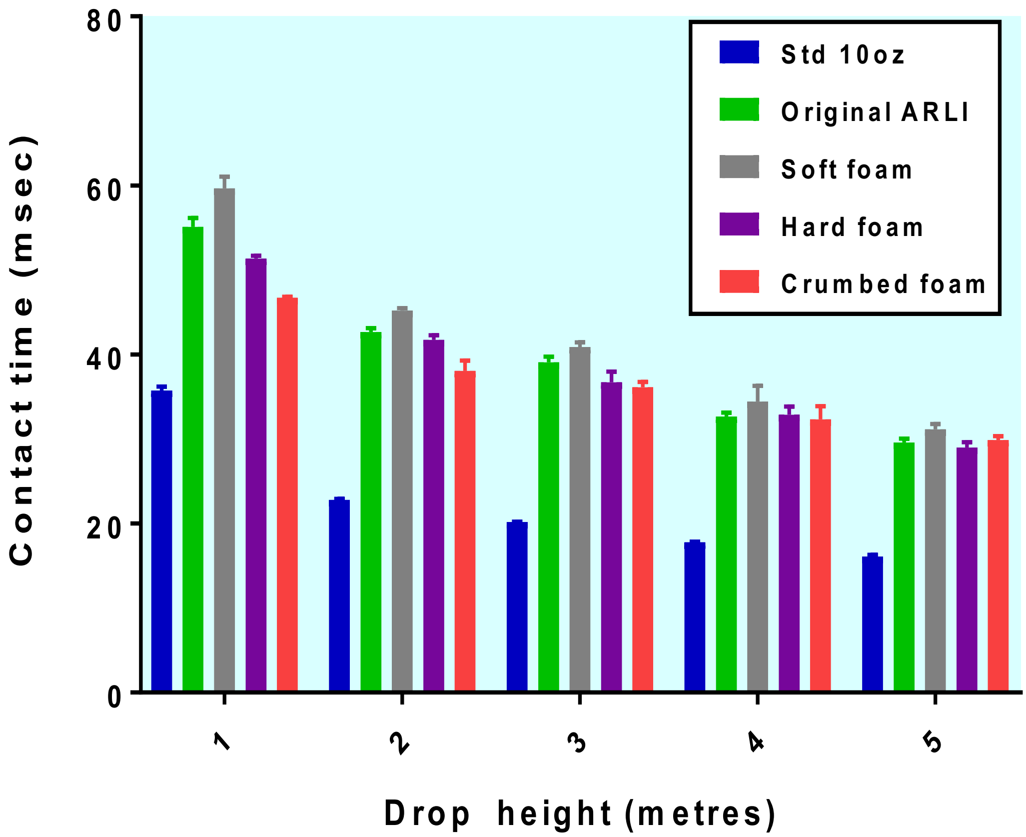

Figure 30: Contact times between glove and force plate for different glove types and drop heights. Each bar represents the mean of five glove drops that produced the highest peak forces within a series of 10 drops under the specified condition. Standard deviations of the five drops are also shown.

On the other hand, the slightly diminished performance of the Firm and Crumbed Foam gloves relative to the Original ARLI glove may have been attributable to their shorter contact times, with the latter likely resulting from difference in the air opening arrangement, a small difference in foam firmness, or both.

Calculated areas under the force-time curves, calculated by the trapezoid method, are shown in Figure 31. Overall, the values for the Std 10oz, Original ARLI and Firm Foam gloves were quite similar. The most striking finding was that the Crumbed Foam and Soft Foam gloves, which had the lowest masses, tended to produce the highest values. The reasons for this are unclear, but it is possible that the lesser amount of material in these gloves reduced their capacity to store some of the impact energy.

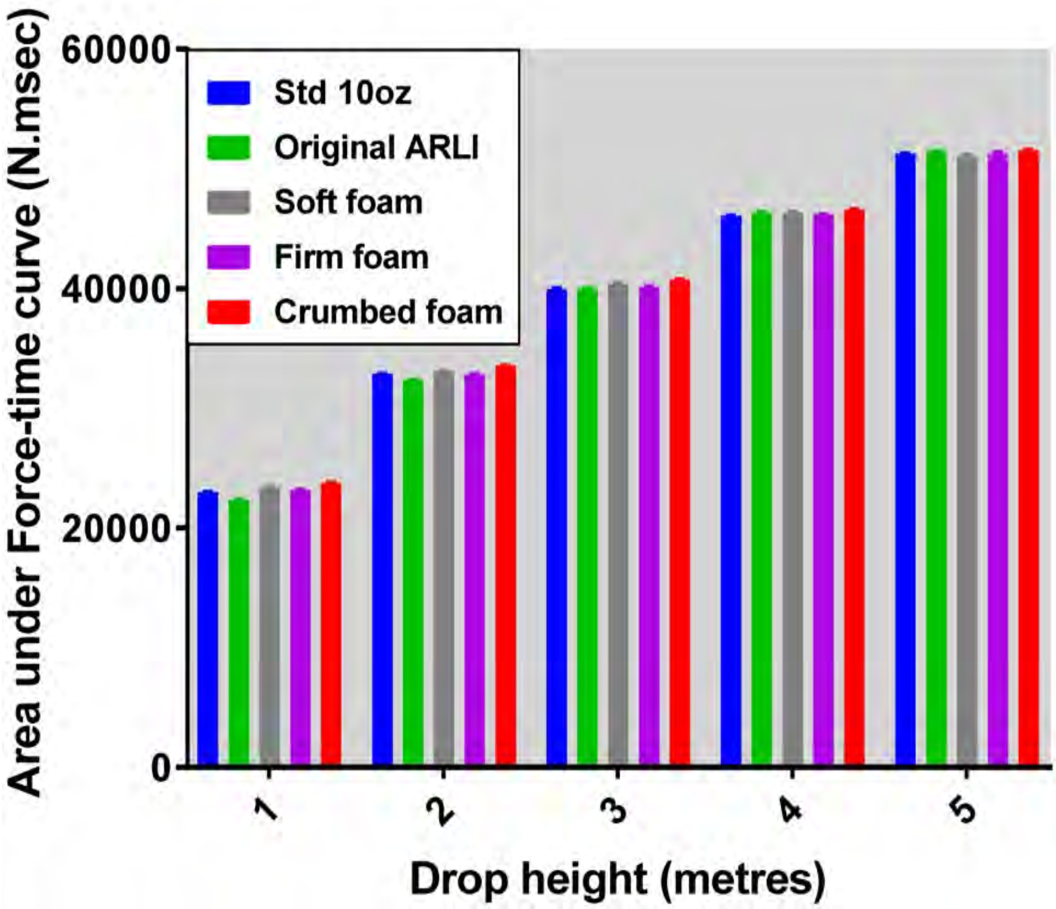

Figure 31: Calculated area under the force-time curve for various conditions of glove type and drop height. The columns indicate means for five glove drops that produced the highest peak force readings within a series of 10 drops. Standard deviations for those five drops are also shown but are so small as to be barely perceptible.

In sum, the findings of the experiment led us to infer that a six-hole system for air ingress and air egress could be incorporated into our pneumatic gloves without substantially compromising protective performance relative to that obtained when a single larger air channel was employed. This was considered important in terms of the aesthetics of a glove product. The experiment also demonstrated a potential for negative consequences from any attempt to use overly soft foam to constitute a glove bladder skeleton intended to reduce the force of initial glove impact.

Finally, it showed that when hole pattern and foam density were held constant, the use of crumbed foam to form the bladder skeleton offered no advantage over the use of a single, custom-shaped foam piece, meaning that any effect of the crumbed foam in increasing the overall air content of the bladder was inconsequential.

8.3.13. Another field trial

In July 2016, a Sydney-based club that had been running a combined boxing and modified boxing (Box'Tag) program for more than a decade and had participated in previous testing and assessment of glove prototypes expressed interest in conducting a field test with the latest low-impact gloves. For this purpose, eight new pairs of ARLI gloves (four red and four blue) were manufactured and provided to the club. Over the following month the gloves, samples of which are shown in Figure 32, were used in a series of sparring sessions, particularly by junior athletes but also by others.

The Head Coach of the club provided us with written and verbal feedback during the trial and with additional verbal comments at its end. He indicated that the club members believed that the gloves looked smart and "worked really well" in terms of impact force reduction but perceived them as feeling "strange" and somewhat uncomfortable. There were specific complaints relating to a tendency for the gloves to rotate around the wrists during impacts and several athletes felt that the fist was too tightly constrained, with consequent inability to obtain even partial relief from the muscular effort required to maintain the fist in a fully clenched fist position. There were two reports of hand cramps after several rounds of sparring. Additionally, the Head Coach intimated that after using the prototype gloves during a couple of sparring sessions, the junior athletes began to request that they be allowed to return to "real gloves".

Figure 32: ARLI gloves of the type provided for the field trial in Sydney.

The major recommendation for improvement of the low-impact gloves was that they should have a separate thumb compartment, since this would both provide an anchor point to prevent glove rotation and decrease the volume of the hand needing to be contained in the main fist compartment. It was also suggested that the width of the gloves should be increased. An encouraging outcome of the exercise was advice from the club that it would be keen to take part in future glove trials.

Throughout the whole process of our development of low-impact glove prototypes, we had quite regularly heard the opinion that a separate thumb compartment was needed, but had resisted it because of statements from medical authorities concerning the potential merits of thumbless gloves as a means for reducing injuries [48,49] and also because incorporation of a thumb compartment would increase the complexity and cost of glove production. In the after-math of the Sydney trial, however, it became clear to us that a positive response to the feedback could be crucial to glove uptake.

8.3.14. Production of a prototype glove with a thumb compartment

In September 2016, our first prototype air-release glove with a thumb compartment was produced (see Figure 33). The location of the thumb compartment relative to the main section of the glove had to be a little different from that typical of conventional gloves, because of the different placement of the remainder of the hand within the glove. Several other new features were also introduced. A horizontal "bar" made of cloth was inserted into the main glove compartment to help guide the hand into the required closed fist position. Instead of leather, a breathable and more flexible webbed material was used to construct the front section of the glove. Combined with the removal of the thumb from the main glove compartment, this was designed to greatly reduce any feelings of constraint of the hand. It also removed the need to incorporate specific air passages into the front section of the glove, since air released from and returning to the glove bladder could easily pass through the webbed material. Visual resemblance to a conventional glove was therefore increased.

Figure 33: Our first prototype ARLI glove with a separate thumb compartment.

Over the following few weeks, we showed the new prototype glove to various members of the local boxing community, and produced some further prototypes embodying adjustments based on their comments and recommendations. The primary adjustments related to ensuring that the thumb could be held in a comfortable, natural and safe position. As we progressed, we received majority feedback that the new glove was a substantial improvement on the previous version.

While the development of the new glove was occurring, we were advised that a consortium of organizations led by Boxing Australia Limited (the entity responsible for administration of amateur boxing in Australia) had obtained a grant to introduce a modified boxing program into a number of schools and other institutions in northern India. The grant included an allocation for manufacture of 60 pairs of low-impact gloves to support the program. We consulted with the Indian partners in the program as to whether thumbed or thumbless gloves should be provided and highlighted the arguments for both options. They expressed a strong preference for the gloves with thumb compartments, on the grounds that similitude to conventional gloves would be likely to facilitate acceptance.

Before initiating a small production run of the new gloves, we needed to ensure that they would be as effective as the prior air-release gloves in providing impact protection.

8.3.15. Laboratory testing of the thumbed glove

Initial laboratory testing of the prototype ARLI glove with the separate thumb compartment was carried out at the University of Canberra in December 2016. The glove was compared with both a Std 10oz glove and a thumbless ARLI glove. Again, a drop testing protocol was employed, with each of the three glove types being dropped on to the force plate 10 times from heights of 1 to 5 metres, with the first drop height being 3 metres, followed by 2, 1, 4 and 5 metres. The thumbed ARLI glove was tested first, then the Std 10oz glove and finally the thumbless ARLI glove. The force plate was covered by a new mat consisting of EVA 75 material with a thickness of 25 mm.

The peak impact forces recorded with the different glove types are shown in Figure 34.

For both low-impact glove prototypes, the peak forces were much lower than those observed with the conventional glove. We calculated a geometric mean peak force for each glove type, an approach entailing inclusion of all readings at all drop heights while minimizing any tendency for readings obtained at the higher drop heights to bias the results. The geometric mean was 5846 N for the Std 10oz glove, 4123 N for the thumbless ARLI glove and 4008 N for the ARLI glove with the thumb compartment. Relative to the Std 10oz glove, the thumb-less ARLI glove therefore reduced the geometric mean peak force by ~29.5% while the thumbed glove reduced it by ~31.5%. We considered this small difference likely due to minor variations in bladder characteristics resulting from our manual construction of the bladders.

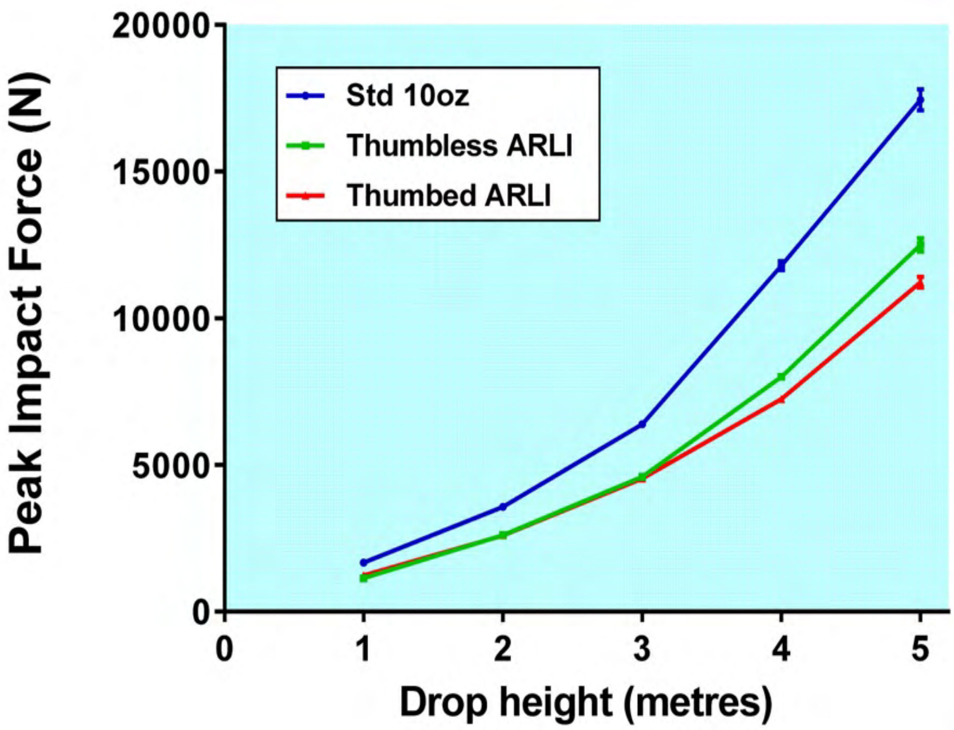

Figure 34: Relationship between peak impact force and drop height for a Std 10oz glove and thumbed and thumbless low-impact glove prototypes. Each data point on the graph represents the mean of the highest five values recorded from 10 glove drops.

Qualitatively similar results were obtained in relation to peak rate of force development. Geometric mean values for all drops across all drop heights were 1606, 741 and 647 N·msec^{-1} for the Std 10oz, thumbless ARLI and thumbed ARLI gloves respectively. Compared to the Std 10oz glove, the reduction in peak rate of force development was ~54% for the thumbless ARLI glove and ~60% for the thumbed ARLI glove.

The above results reinforced our previous findings regarding the ability of ARLI gloves to substantially decrease peak impact forces and indicated that minor changes in glove structure required to include a thumb compartment did not compromise the protective effect. There were, however, some quantitative differences that merited consideration. At drop heights up to and including 3 metres, the peak forces for the thumbless ARLI glove were essentially unchanged from those measured for a glove of the same type six months earlier, but at drop heights of 4 and 5 metres, the peak forces were increased by 16% - 25%. In the case of the Std 10oz glove, the readings at drop heights of 1 - 3 metres were 2% - 12% below those measured six months earlier, whereas the readings at 4 and 5 metres were 17% - 25% higher. Since the calculated area under the force-time curve was very similar for the two series of tests and certainly not higher for the second series (see Figure 35) it seems improbable that the changes were due to alteration of force plate calibration. Instead, the most plausible explanation for the higher peak force readings in December is our introduction of a new mat to cover the force plate.

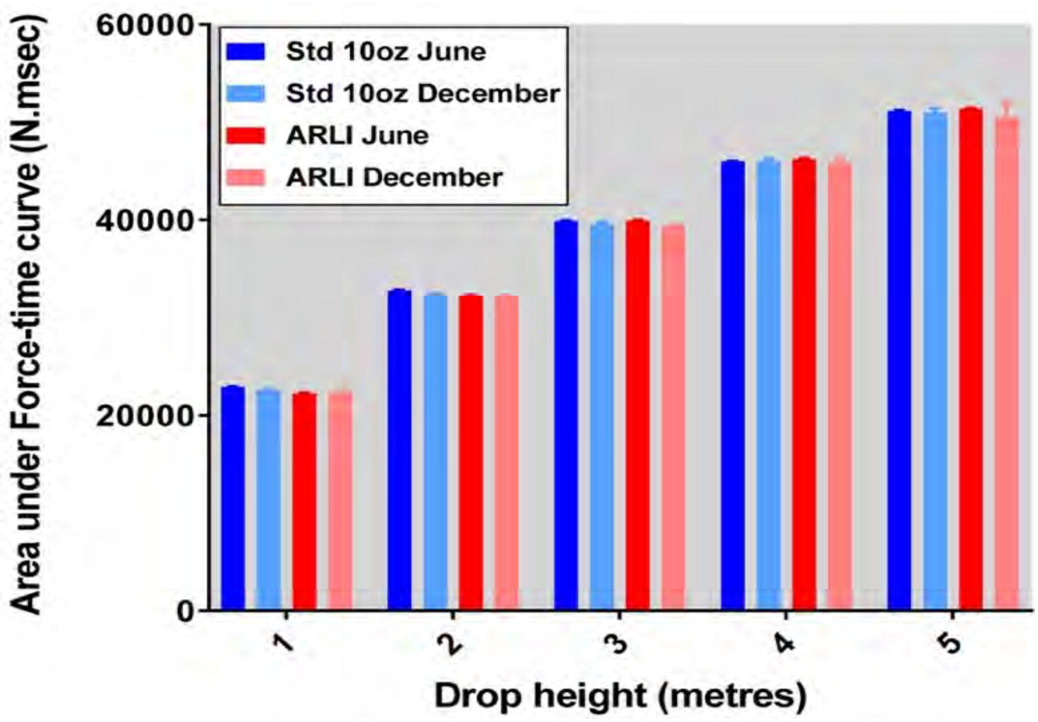

Figure 35: Calculated area under the force-time curve associated with dropping two types of gloves on to a force plate from heights of 1 - 5 metres in June and December 2016. The columns indicate means for five glove drops that produced the highest peak impact forces.

Although the new mat ostensibly consisted of the same material as the old one, and was of the same thickness, batch variability associated with the production of such materials may have caused it to be slightly harder. With the gloves being softer than the target, the effect of target characteristics relative to glove characteristics on peak impact forces could be expected to increase with drop height. The fact that introduction of the new force plate covering was associated with higher peak force readings only at the highest drop heights therefore accords with the notion that the properties of that covering were probably responsible for the change.

The study served partly to highlight the importance of target characteristics in determining the peak impact forces generated by a given level of impact energy as well as the relativity of the peak forces produced by different glove types. There was, however, no change to our observation that ARLI gloves could markedly reduce peak forces across a range of impact energy levels.

Given that the ARLI glove with the separate thumb compartment was at least as effective as our prior prototype in decreasing peak impact forces and rates of force development, we decided to proceed with manufacture of multiple pairs to support the upcoming project in India.

8.3.16. A move to larger-scale production

To cater for the scheduled commencement date of the Indian project, the task of producing 60 pairs of the latest low-impact gloves had to be completed in less than a month. Meeting this requirement entailed overcoming some unforeseen challenges. Obtaining expeditious supply of some glove components proved problematic. Enkay (India) had provided bladders as samples to support our R&D activities but was found to have a quite substantial minimum order quantity when larger numbers of the bladders were required. Since our budget did not permit purchase of the minimum order quantity, we had to pursue negotiations. These were eventually successful, but by then a fortnight had been lost. In addition, we under-estimated the time needed for construction of the gloves through a basic "assembly line" process that was implemented. Nevertheless, 30 pairs of gloves were produced by Stellen Studio and shipped to India before the end of 2016, and the same occurred again during the first three weeks of 2017 (see Figure 36).

Figure 36: The first batch of 30 pairs of ARLI gloves ready for shipment to India.

8.3.17. Initiation of glove production in India

With a view to decreasing the costs of glove production and facilitating supply of low-impact gloves to organizations and individuals participating in the modified boxing program in India, we began investigating possibilities for Indian manufacture of the gloves. Contact was established with Paramount Enterprises, a company based in Dehradun, the capital city of the northern Indian state of Uttarakhand. The company was shown samples of the low-impact gloves and provided with a written and illustrated blueprint for their production. In February 2017, Paramount Enterprises produced its first prototype pair of the gloves and sent them to Australia for evaluation (Figure 37).

Three weeks later, the gloves were tested at the University of Canberra, with a representative of Paramount Enterprises in attendance. The Indian gloves were compared with a similar glove produced in Australia and a Std 10oz glove.

Figure 37: Receipt in Australia of the first pair of ARLI gloves made in India.

The experimental protocol was essentially identical to that employed in our prior drop testing experiments, with each of the gloves being dropped on to the force plate 10 times from each of five heights. The initial drop height was 3 metres, followed successively by 2, 1, 4 and 5 metres. The Std 10oz glove was tested first, followed by the ARLI glove produced in Australia (Aust ARLI), the right-hand glove made in India (Ind ARLI Right), and then the left-hand glove made in India (Ind ARLI Left). The force plate was covered with the same 25 mm thick mat used in the last of the studies described above.

The mass of the Ind ARLI Right glove was 278 g while that of the Ind ARLI Left glove was 274 g. Corresponding figures for the Aust ARLI and the Std 10oz gloves were 318 g and 265 g respectively. The slightly lower mass of the Indian-made gloves relative to the Aust ARLI glove reflected an intention to produce them in a smaller size to allow for the fact that the modified boxing program in India was targeted primarily at 12-16 year-old school students rather than adults.

The peak force readings obtained in the experiment are summarised in Figure 38. For all drop heights, the readings for the three ARLI gloves were well below those for the Std 10oz glove. At drop heights of 1-3 metres, the peak forces for the Aust ARLI glove and the Ind ARLI Right glove were quite similar, but the Aust ARLI glove gave slightly greater protection at drop heights of 4 and 5 metres. The peak forces measured with the Ind ARLI Left glove were always a little higher than those recorded with the other ARLI gloves.

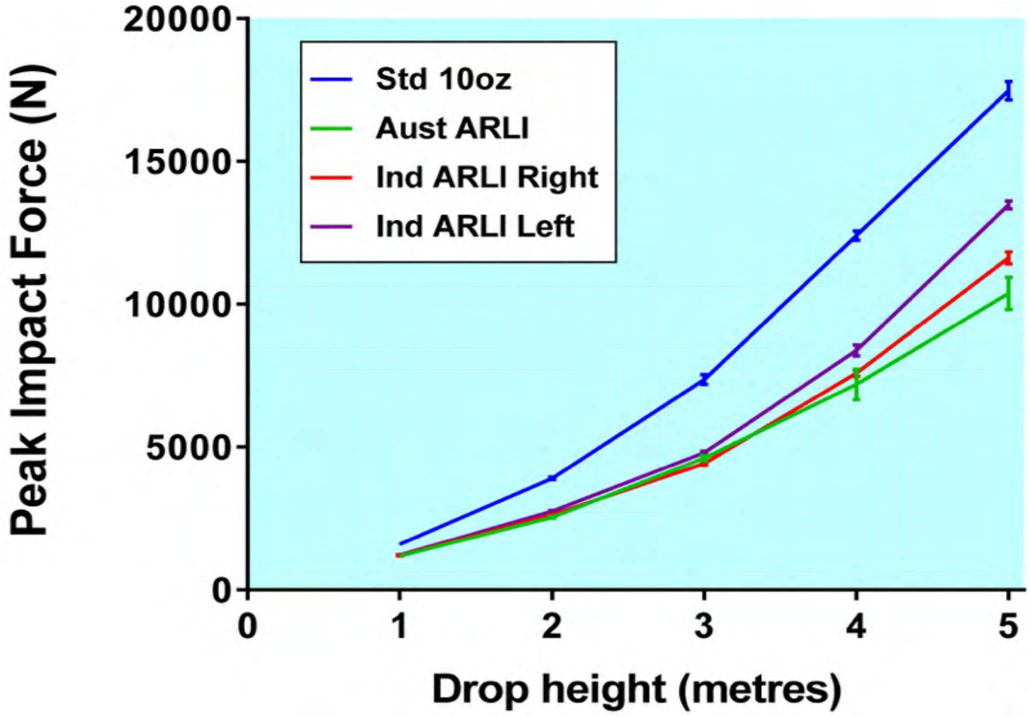

Figure 38: Peak impact forces for a conventional 10 oz glove (Std 10oz) and ARLI gloves produced in Australia (Aust ARLI) and India (Ind ARLI Right and Ind ARLI Left). The curves reflect mean values of the highest five readings recorded from 10 drops. Standard deviations of the five readings are also shown.

The geometric mean peak force, calculated from all drops across all drop heights, was 6135 N for the Std 10 oz glove, 3884 N for the Aust ARLI glove, 4057 N for the Ind ARLI Right glove and 4408 N for the Ind ARLI Left glove. Thus, relative to the Std 10 oz glove, the Aust ARLI glove reduced the overall geometric mean peak force by ~37% and the Ind ARLI Right glove reduced it by ~34%. While the Ind ARLI Left glove was less effective, the overall geometric mean peak force that it produced was still ~31% less than that recorded with the Std 10oz glove.

For peak rate of force development, the geometric means were 1599, 628, 675 and 799 N·msec^{-1} for the Std 10 oz, Aust ARLI, Ind ARLI Right and Ind ARLI Left gloves respectively. Compared to the Std 10 oz glove, the Aust ARLI glove therefore decreased the peak rate of force development by ~61%, while the Ind ARLI Right glove decreased it by ~58% and the Ind ARLI Left glove by ~50%.

Force plate contact times for the Aust ARLI glove tended to be longer than those for the Ind ARLI Right glove, while the times for the latter were slightly longer than those for the Ind ARLI Left glove (except at a drop height of 5 metres). Contact times for the Std 10oz glove were consistently much shorter than for any of the prototype ARLI gloves (Figure 39).

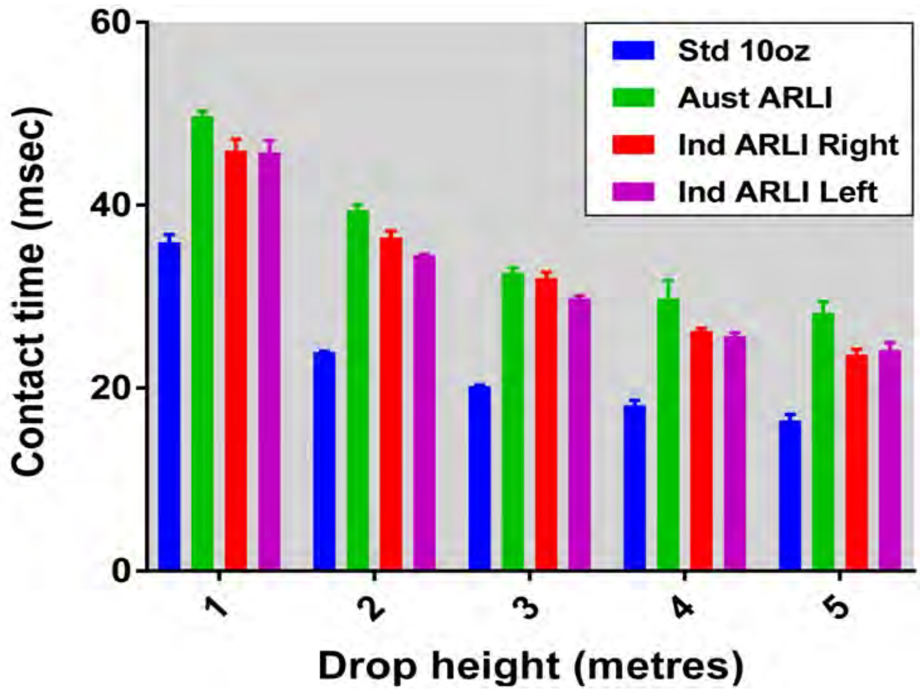

Figure 39: Effect of drop height on force plate contact times for a conventional 10 oz glove and air-release gloves manufactured in Australia and India. The values shown are means for five glove drops that produced the highest peak force readings within a series of 10 drops. Standard deviations for the five drops are also shown.

We plotted the relationship between contact time and peak force for the different gloves and fitted power series regression curves to the data (see Figure 40). The plot showed that for any given contact time, peak force was lowest for the Std 10 oz glove, intermediate for the gloves produced in India, and highest for the Aust ARLI glove.

This indicates that if a given level of impact energy was applied to a target over a specific time period, the Std 10oz glove would be the most effective shield in terms of minimizing the peak impact force. A major ad- vantage of the ARLI gloves appears to be their ability to act more as springs than as shields, with the spring-like attributes prolonging contact times. Provided that the spring-like attributes are appropriately "tuned" to deal with the magnitude of impact energy encountered, the increased contact time allows the energy to be distributed over a longer period and this can outweigh the lesser shield-like traits and enable peak force reduction considerably exceeding that achievable with a conventional glove. Optimizing the capacity and time course of air release and return is crucial to the tuning of the spring characteristics of the air-release gloves.

In Figure 40, the regression curves for the right- and left-hand Indian gloves are essentially identical. We saw this as implying that they had the same material qualities, and that the superior protective effect of the right-hand glove stemmed from better spring tuning (probably relating to the size and/or positioning of the holes in the glove bladder) that enabled slightly longer glove-target contact times.

The most important outcome of the above experiment, though, was demonstration of the viability of manufacture of highly functional ARLI gloves by an independent company.

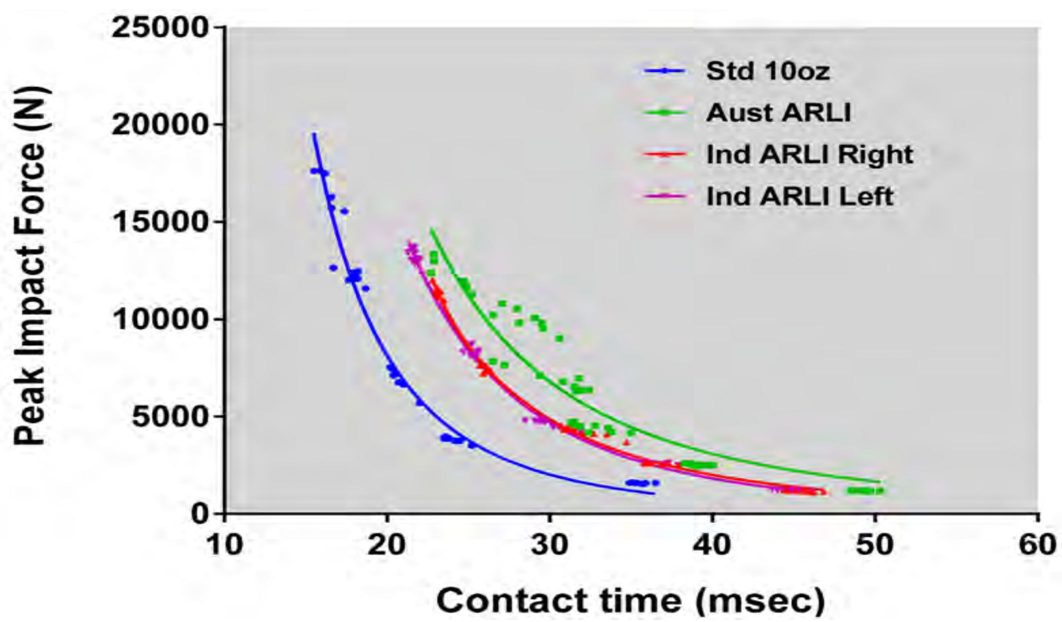

Figure 40: Relationship of peak impact force to contact time for each glove type with calculated power series trend lines shown.

8.3.18. Further feedback on the gloves

We subsequently showed the latest prototype gloves to an internationally renowned boxing coach who has more than 40 years of experience in the sport. After trying them on, he opined that their acceptance by serious boxers remains very unlikely, but did suggest that they could have applications during early learning of boxing skills. The gloves were also shown to the Head Coach of the Sydney club that has run a combined boxing and modified boxing program for many years and has been the site of some of our glove trials. He too put on the gloves (see Figure 41) and commented that they are now visually attractive, comfortable to wear, and highly suitable for use in the modified boxing context.

Figure 41: Head Coach of Sydney club with long history of modified boxing wearing latest ARLI gloves

In May 2017, an Indian colleague who is playing a primary role in implementing and administering the modified boxing program there provided the following written feedback: *"The gloves are being taken very well by the trainees. In fact, it is a matter of pride for them to be able to wear them. Many of them get a chance at it only once a week as the number of gloves given to each school is limited. We have ten schools... Given the availability of only sixty pairs among them, the gloves have taken on an air of exclusivity, which I feel may be also a good thing sometimes, because trainees try harder to perform so that then they get a chance to wear them"*.

8.3.19. More recent progress

In October 2017 Paramount Enterprises in India produced 60 pairs of ARLI gloves to add to the 60 Australian-manufactured pairs already being used in the modified boxing program there. These new gloves have been well-received. ARLI gloves were used in a public performance of modified boxing held in Dehradun towards the end of 2017 (Figure 42).

Based on initial success of the modified boxing program in India, Boxing Australia was able to obtain further funding that now guarantees continuation of the program until the end of September 2018. Encouraged by these developments, Boxing Australia is now seeking to expand modified boxing activities in its domestic domain. In April 2018, it contracted Paramount Enterprises to produce 60 pairs of ARLI gloves for export to Australia to cater for this initiative and the consignment has now been delivered. Stellen Studio continues to manufacture ARLI gloves in small batches each incorporating minor alterations as part of ongoing research efforts aimed at gradual glove improvement. It is envisaged that this will enable regular updating of blueprints provided to Paramount Enterprises for larger scale production.

Figure 42: Use of ARLI gloves during a public performance of modified boxing in India. In this performance, impacts to the head and neck were prohibited and participants worked together to put on an entertaining display of fitness and skill rather than striving for individual victory. Photograph kindly provided by Sumit Kumar Agarwal of Tanjun Associate, India.

8.3.20. Reflection

We have carried out a 5-year design process that has led to the creation of pneumatic boxing gloves that substantially reduce impact forces delivered to an opponent and are now acceptable to at least a niche community engaged in a modified form of boxing that emphasises participant safety. The design process has entailed a need for repeated problem conception, identification of possible solutions that could be achieved within project constraints, consultation with interested parties including several with advanced technical expertise, creation of models and prototypes, and testing of the prototypes in both field and laboratory situations. Evolution of the gloves has been non-linear and has required adoption of directions and techniques that we did not foresee at the outset. To some degree, it has been based on opportunism made possible by initially unplanned access to facilities and partner expertise.

In their present embodiment, the gloves are almost certainly not perfect, but to use a term introduced by Simon [37], they have reached a point of being contextually “satisficing” (i.e. satisfactory and sufficient to fulfil a particular purpose for a particular group). Many aspects of them remain amenable to adjustment. Such adjustment is likely to be necessary to maintain acceptance by existing users and to stimulate wider uptake, but even in their current form, the gloves represent an accumulation of knowledge through design methods.

Available literature shows that boxers can sometimes deliver peak impact forces of more than 5000 N to targets in laboratory and field situations [60-62], and in one study, a hooked punch to the head of a crash test manikin generated a peak impact force of ~8000 N [47]. Research in which force transducers were located in the gloves of professional boxers demonstrated that while most impacts recorded during actual bouts produced peak forces of less than 2000 N readings above 5000 N could be encountered [62]. Based on these findings and allowance of some tolerance to cater for the possibility that forces exceeding those observed in research settings might occasionally occur in field environments, gloves aimed at damping peak impact forces probably need to be effective across a range of standard glove equivalent peak forces extending from below 2000 N to at least 10,000 N. Our current ARLI gloves meet this criterion and, when employed in conjunction with other safety measures, could be expected to reduce the risk and/or severity of boxing injuries [57].

Acknowledgements

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Chapter 9: Pneumatic boxing glove reduces upward drift in peak force and loading rate over a long series of impacts

9.1. Declaration for chapter 9

Declaration by candidate

In the case of Chapter 9, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-authors contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Contributed to the overall design of the study and assisted with data collection, data analysis and manuscript preparation.	No
Alex Jamieson	Assisted with data collection and manuscript preparation.	No
Wayne Spratford	Contributed to data analysis and assisted with manuscript preparation	No
Candidate's Signature		**Date** 22/03/2019.

Declaration by co-authors

The undersigned hereby certify that:

1. the above declaration correctly reflects the nature and extent of the candidate's contribution to this work, and the nature of the contribution of each of the co-authors.
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below: University of Canberra

Signature 1:		25/3/2019
Signature 2:		26/3/2019
Signature 3:		2/4/2019

9.2. Prologue

Having shown that pneumatic gloves produced through the iterative process detailed in Chapter 8 were effective in reducing peak impact forces and peak rates of force development compared to the levels observed with conventional gloves, it became important to assess their robustness when subjected to large numbers of successive impacts, since relatively rapid deterioration in their performance obviously could negate the acute advantages. An experiment was therefore undertaken in which conventional and prototype pneumatic gloves were each dropped on to a force plate more than 250 times. The experiment confirmed the suitability of the gloves for use in the modified boxing environment, as described in a publication that forms the rest of this chapter. The research and the publication contributed to realisation of the following research aims identified in Chapter 1:

- **Aim 5:** To explore and iterate specific technologies seen as having potential to enhance the experience of modified boxing program participants, particularly in terms of safety and program enjoyment.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

9.3. Published paper 8 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Pneumatic boxing glove reduces upward drift in peak force and loading rate over a long series of impacts

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Details of Publication: World Journal of Engineering and Technology 7: 18-53, 2019 (https://file.scirp.org/pdf/WJET_2018121915342054.pdf).

9.3.1. Abstract

A conventional boxing glove and a prototype pneumatic glove were each fitted to a mechanical fist and dropped 253 times from a height of 3 metres on to a force plate covered by an ethylene vinyl acetate (EVA) mat. Impact dynamics were measured and modelled. From the outset, peak impact force and peak loading rate were lower for the pneumatic glove. For both gloves, these variables displayed upward drift during the drop series, but the drift was smaller for the pneumatic glove. Consequently, the magnitude of the protective effect provided by the pneumatic glove increased with the number of impacts. For the conventional glove, change in peak force showed a close inverse relationship to force plate contact time (R^2>0.96) and the time from first contact of the glove with the force plate to attainment of peak force (R^2=0.85). These relationships were much weaker for the pneumatic glove (R^2=0.09 and 0.59 respectively), suggesting the possibility of a more complex impact damping mechanism. Following the 253 drops of the pneumatic glove, the EVA mat covering the force plate was replaced, and another 10 drops then performed. Peak force readings were immediately reduced to an extent suggesting that ~26% of the increase that had occurred over the 253 drops was attributable to impact-induced change in mat properties. This has implications for future experimental designs. Overall, the findings provided further evidence of the potential of pneumatic gloves to enable safer boxing.

Keywords: Boxing safety, Low-impact boxing gloves, Modified boxing, Pneumatic boxing gloves, Protective equipment for boxing, Sport technology, Sport safety.

9.3.2. Introduction

We have recently described experiments showing that, compared to conventional boxing gloves, a pneumatic boxing glove with a bladder capable of air exchange with the external environment can substantially reduce peak impact forces delivered to a target, and provide even greater reduction in peak rate of force development [1], also known as loading rate. This protection is afforded across a wide range of pre-impact glove velocities extending to the average maximum levels observed by Walilko et al. [2] for elite boxers and has been found to exist even when target characteristics are markedly altered [3].

Suitability of the pneumatic gloves for field use will depend not just on their immediate protectiveness but also on their robustness in the face of multiple impacts. Our initial research [1] entailed repeatedly dropping them from heights of 1-5 metres on to a force plate covered by ethylene vinyl acetate (EVA) material, but the maximum number of drops per glove in any one experiment was 90, with 40 of these conducted from drop heights of 2.5 metres or less. We perceived a need to determine whether the gloves could withstand a much larger number of impacts of moderate to high magnitude without occurrence of structural damage and/or significant deterioration in performance.

Our early studies entailed evaluation of two different prototype pneumatic gloves and two conventional gloves that differed in mass. When we combined data from all gloves across all drop heights, we observed a tendency for peak force readings to gradually increase over a series of 10 drops [1]. While we thought this was probably due largely to "bedding down" of gloves on to a mechanical fist inserted into them, it was apparent that progressive glove compression might play a role. This amplified our interest in ascertaining how the gloves might be affected by a large number of impacts under conditions of controlled pre-impact velocity.

Available evidence indicates that professional boxers land an average of ~18 punches to the designated target area of the opponent per 3-minute round [4]. According to data provided by an automated scoring system in which contacts to the target zones were recorded by sensors, accomplished amateur boxers landed an average of ~27 impacts per round [5]. Use of the same automated scoring system in a modified boxing (Box'Tag) context revealed an average of 28 scoring impacts per boxer per round [6], even though the rounds in this context were of shorter duration. In each situation, there would have been additional impacts to non-scoring areas. Given that a single pair of conventional boxing gloves can sometimes remain in frequent use for 2 - 5 years [7,8] for training purposes including sparring, the ability of gloves to maintain integrity and performance over the course of numerous impacts is clearly important.

In light of the above, we compared a prototype pneumatic glove to a conventional glove in terms of changes in measured impact parameters during a long sequence of successive impacts. We aimed to describe and model the changes and to obtain improved understanding of their mechanisms.

9.3.3. Methods

A pneumatic glove incorporating a bladder enabling air release upon impact and subsequent air reuptake (ARLI glove) and a conventional 10 oz boxing glove (Std 10 oz) each underwent

253 consecutive drops on to a Kistler force plate (Kistler, Amherst, MA) from a height of 3 metres. Each glove was placed securely on to a mechanical fist that of itself had a mass of 3.046 kg. The drop testing apparatus is described in detail elsewhere [1]. It consisted of a flanged, low-friction pulley attached to a wall-mounted frame such that the pulley was located at a height of 5.5 metres directly above the centre of the force plate. A cord placed over the pulley allowed gloves to be drawn up to any required drop height. The cord was pulled through an eyelet on a post secured to the laboratory floor. Alignment of markings on the cord with the edge of the eyelet ensured drop height accuracy. The force plate had a surface area of 600 mm × 400 mm and was covered by a mat of EVA 75 material (Ultralon Foam Group, Sydney, Australia) with a thickness of 25 mm and a guaranteed JIS hardness (as measured by an Asker Type C Hardness Tester) of 30 - 35 degrees. The ARLI glove was produced by Stellen Studio (Canberra, Australia) and had a mass of 342 g (12.1 oz). The Std 10 oz glove was made by Sting Sports (Melbourne, Australia) and had a mass of 275 g (9.7 oz). The two gloves are pictured in Figure 1, which shows that they had quite similar dimensions. The height of the Std 10 oz glove was 26.5 cm while that of the ARLI glove was 27.5 cm. The main section of the Std 10 oz glove (the section not including the thumb) had a maximum width of 13.0 cm and a circumference of 43.0 cm. Corresponding measurements for the ARLI glove were 12.5 and 40.0 cm.

Figure 1: The Std 10 oz (blue) and ARLI (red) gloves employed in the study.

It was planned that for each glove 250 drops would be performed in five blocks of 50. In practice, the third block for the Std 10 oz glove was extended to 53 drops, while for the ARLI glove Blocks 4 and 5 consisted of 51 and 52 drops respectively.

This meant that in fact there were 253 drops of each glove. Intervals between the end of one block and the start of the next are shown in Table 1.

Table 1: Intervals between successive blocks of 50 drops in the testing of Std 10oz and ARLI gloves.

	Std 10oz	**ARLI**
Block 1 – Block 2	9 min	13 min
Block 2 – Block 3	10 min	4 min
Block 3 – Block 4	6 min	10 min
Block 4 – Block 5	73 min	71 min

Within each block, there were five sub-blocks of 10 - 12 drops, separated by 2 - 6 minutes. The sub-blocks had durations of 4 - 10 minutes, with an average of 6.4 minutes for the Std 10 oz glove and 6.0 minutes for the ARLI glove.

The intervals were included partly for practical reasons but also in the hope that they would enable insights into the time course of glove recovery after a series of impacts. We attempted to rigorously adhere to a pre-set timetable with a view to making intervals for the Std 10 oz and ARLI gloves identical. Although experimental practicalities prevented this from being fully achieved, variations in the intervals between the two days of testing were minor.

The ARLI glove was tested first, with the testing of the Std 10 oz glove taking place exactly one week later. On both occasions, Kistler Bioware software was used to set force plate parameters and to record force plate data at a sampling rate of 10,000 Hz. The software was run on a standard PC. Known masses were regularly placed on the force plate to check the consistency of readings.

After completion of the 253 drops of the ARLI glove, the EVA 75 mat covering the force plate was replaced with another of the same type and dimensions, and a further 10 drops of the glove were then performed. The intention was to determine whether receipt of multiple impacts by the original mat had altered its properties in a way that affected measured impact dynamics. The first drop of the glove on to the new mat occurred three minutes after the preceding impact. The original and new mats were purchased from the same retailer but several weeks apart. This makes it unlikely that they came from the same production batch. Consequently, their qualities may not have been absolutely identical, although the Ultralon Foam Group carefully controls the manufacturing of its EVA 75 material to meet well-defined specifications [9].

9.3.4. Results

The peak impact forces recorded for the two gloves are shown in Figure 2. Several points are immediately evident. For any given point in the series of drops, readings for the Std 10 oz glove were substantially higher than those for the ARLI glove. There was upward drift in the readings for both glove types, but the extent of this drift was much greater for the Std 10 oz glove, meaning that the difference in peak force between the two glove types tended to increase as a function of the number of glove drops.

For both gloves, the relatively long intervals between successive blocks of 50 - 53 glove drops were generally associated with reduced peak forces readings for the first glove drop after the interval (indicated by the black circles in Figure 2). The longest interval, between Blocks 4 and 5, led to a subsequently much decreased initial reading for the Std 10 oz glove, but the readings then rapidly increased, and although they were generally below the levels recorded in Block 4, they exceeded the levels for Block 3. The long break between Blocks 4 and 5 had little influence on the progression of readings for the ARLI glove.

For both glove types, any influence of the shorter intervals between sub-blocks of glove drops was minor and difficult to detect.

Also apparent in Figure 2 is the fact that toward the end of Block 3, peak force readings for the Std 10 oz glove quite suddenly became elevated beyond a level that could be predicted from the preceding drops, with this elevation continuing through to the end of Block 4.

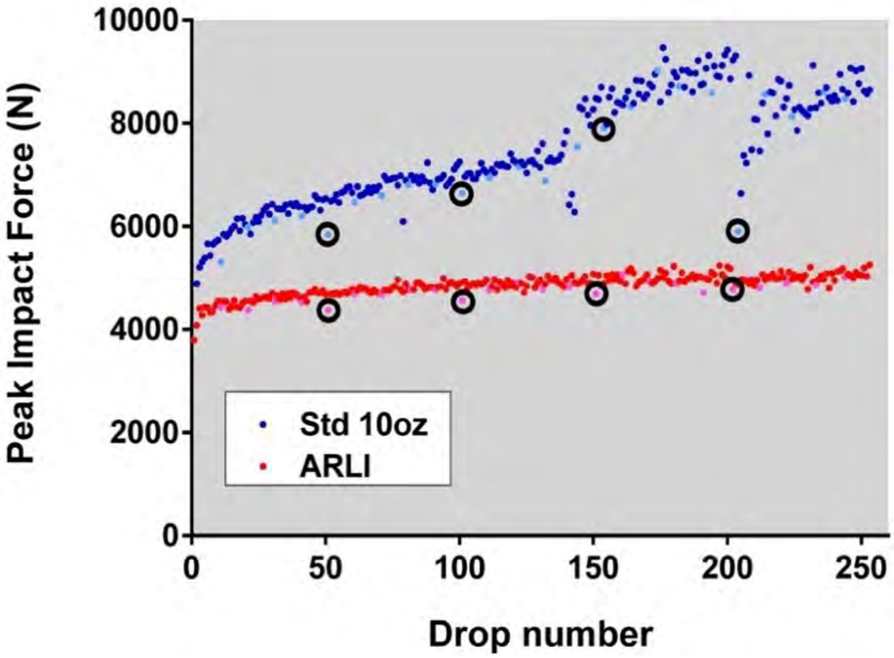

Figure 2: Change in peak impact forces for two different glove types over the course of 253 drops on to a force plate from a height of 3 metres. The first data points of Blocks 2 - 5 are indicated by the black circles, and the first data points of each sub-block of 10 - 12 drops are shown in lighter colours.

In an attempt to identify possible reasons for the sudden change in the peak forces for the Std 10 oz glove, we used the 3D Vector function provided by the Kistler Bioware software to examine the force plate impact profile for every drop of the glove. For completeness, we did likewise for the ARLI glove. Typical profiles for the two gloves are presented in panels A and B of Figure 3, while the profile for the 141st drop of the Std 10 oz glove appears in panel C.

For the 141st drop of the Std 10 oz glove, the initial point of contact was relatively close to the front edge (left side in the schematic) of the force plate, and the subsequent propagation of force extended beyond the force plate boundary. Drops 117 and 230 of the Std 10 oz glove produced somewhat similar outcomes, as did drops 67, 114, 117, 191 and 208 of the ARLI glove, but in none of these cases was the effect so pronounced (see Figure 4).

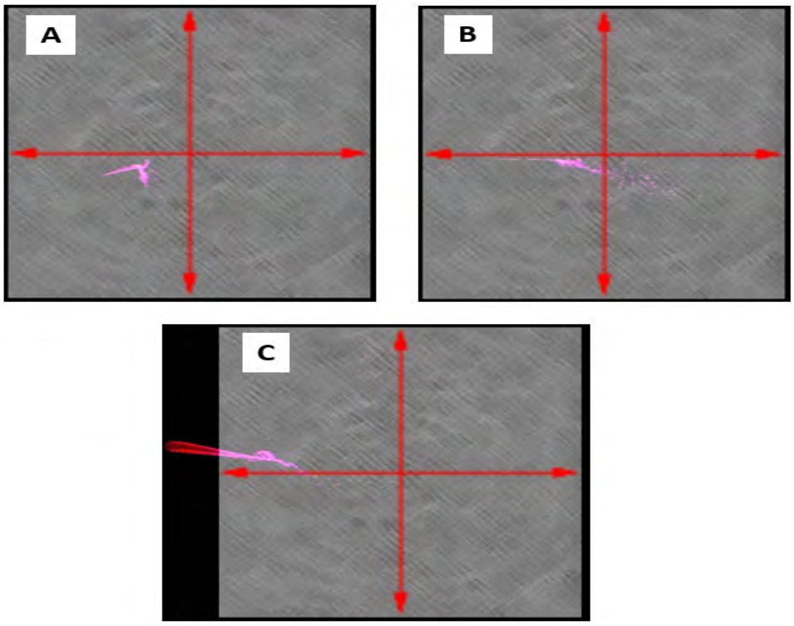

Figure 3: Force plate profiles associated with impacts resulting from dropping of Std 10 oz and ARLI gloves. Panel A = representative profile for Std 10 oz glove, Panel B = representative profile for ARLI glove, Panel C = 141st drop of Std 10 oz glove.

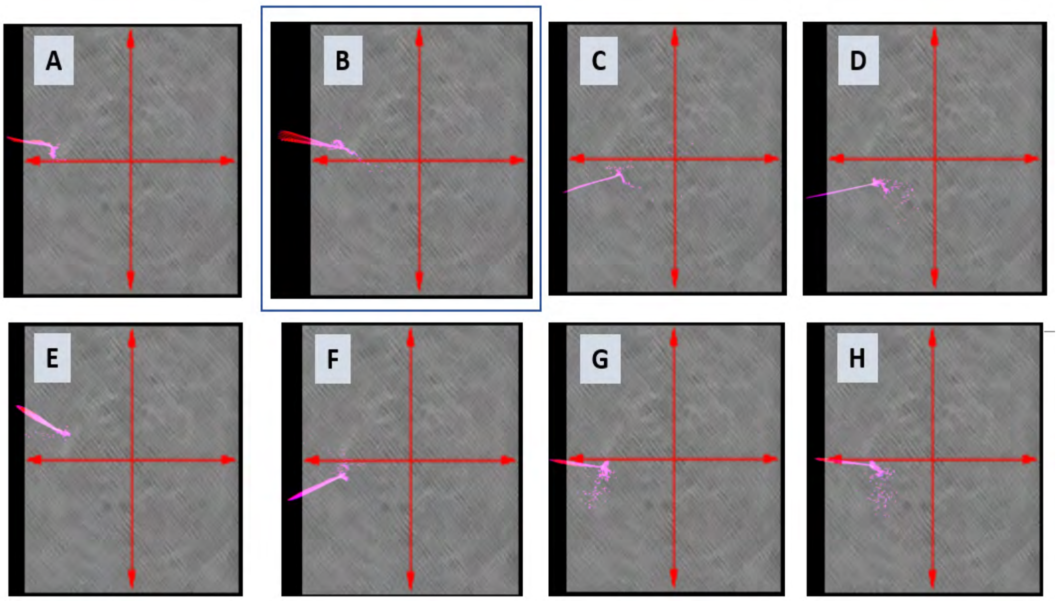

Figure 4: Force plate profiles for each of eight glove drops in which force propagation extended beyond the force plate boundary. A = Drop 117 with Std 10oz glove, B = Drop 141 with Std 10oz glove, C = Drop 230 with Std 10oz glove, D = Drop 67 with ARLI glove, E = Drop 114 with ARLI glove, F = Drop 117 with ARLI glove, G = Drop 191 with ARLI glove, H = Drop 208 with ARLI glove.

Although the problem was confined to just ~1.5% of all glove drops, we sought to ascertain the reasons for its occurrence. We determined the force plate impact locations for every glove drop with both glove types. Using Kistler Bioware schematics such as those shown above, and with the aid of colour coding and moving displays of force propagation provided by the Bioware software, we identified and marked the centre point of each impact. A transparent 20 × 20 grid was then electronically superimposed on to the schematic to facilitate identification of X and Y co-ordinates for the mark. For example, the coordinates for the glove drop represented in Figure 5 were deemed to be X = −22 and Y = −11.

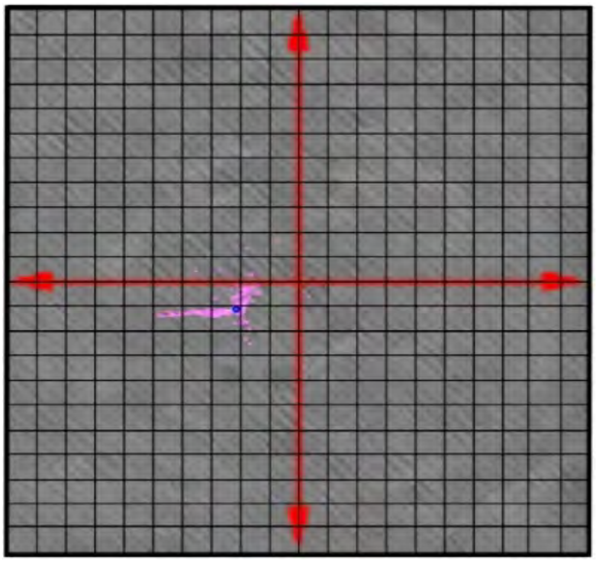

Figure 5: Force plate profiles for each of eight glove drops in which force propagation extended beyond the force plate boundary. A = Drop 117 with Std 10oz glove, B = Drop 141 with Std 10oz glove, C = Drop 230 with Std 10oz glove, D = Drop 67 with ARLI glove, E = Drop 114 with ARLI glove, F = Drop 117 with ARLI glove, G = Drop 191 with ARLI glove, H = Drop 208 with ARLI glove.

The impact locations so identified are presented in Figure 6, which reveals that there was an overall tendency for the gloves to land forward of the centre of the force plate. This was despite our preparatory use of a plumb line to ensure that the pulley used to raise the gloves to the required drop height was positioned directly over the centre point. The white circles in the Figure denote the above-mentioned problematic impacts and highlight the fact that the most forward landings were the most likely to cause failure of containment of force propagation within the force plate boundaries, although impact location was not the sole determinant of such failure.

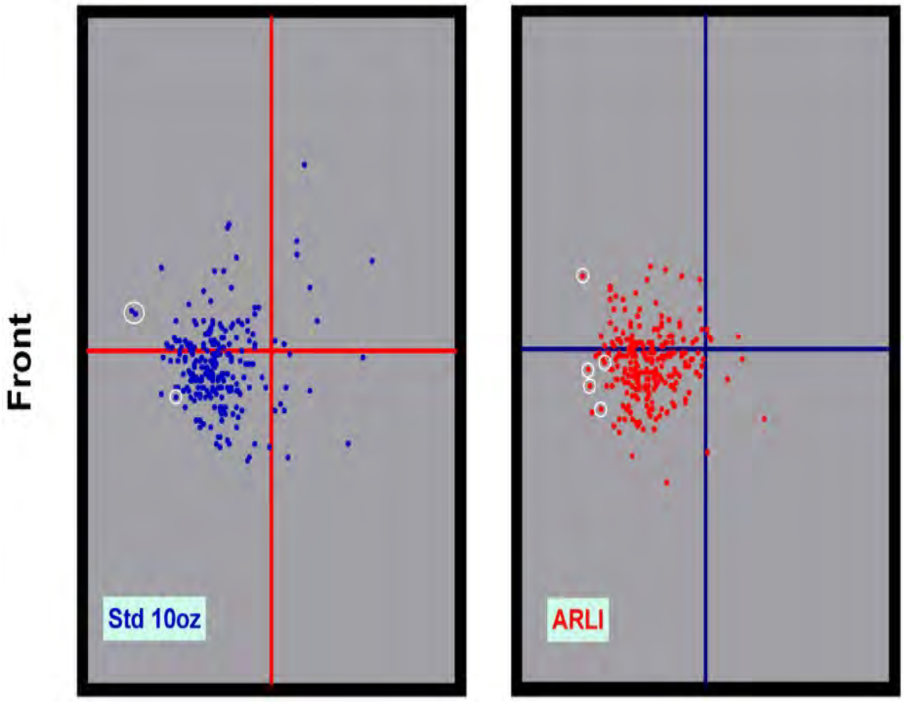

Figure 6: Centres of impact for 253 drops of Std 10 oz (left panel) and ARLI (right panel) gloves on to a force plate from a height of 3 metres. The white circles identify glove drops in which force propagation extended beyond the boundaries of the force plate.

Seven of the eight glove drops that resulted in impact forces traversing the boundaries of the force plate had no discernible or lasting effect on the progression of peak forces withsubsequent drops, but such an effect was evident in the case of the 141st drop of the Std 10 oz glove. Accordingly, we decided that for data modelling purposes analysis of the response of the Std 10 oz glove to repeated impacts should be limited to the first 140 glove drops, whereas analysis of the performance of the ARLI glove could be based on all 253 drops. For both glove types data obtained from the problematic drops were removed, after which there were 139 valid observations for the Std 10 oz glove and 248 valid observations for the ARLI glove.

Since the increase in peak force over the series of glove drops was curvilinear for both glove types, with a rapid early increase followed by slower subsequent rise (see Figure 2), we plotted the logarithm of peak force against the logarithm of drop number, which made the relationship more linear. We then applied linear regression analysis to the logarithmic data and used the results to develop power equations that fitted the data.

Each power equation was determined as the antilogarithm of the intercept provided by the linear regression analysis multiplied by the drop number raised to the power of the slope provided by the linear regression analysis. Because we wanted to compare predictive models for the two glove types, it was necessary to evaluate the possible effects of using different numbers of observations to develop the models. Consequently, for the ARLI glove, we produced two separate models, one based on all 248 valid observations and the other just on the first 140 glove drops, of which 137 were valid.

Key results of the linear regression analysis conducted to determine relationships between peak force and drop number are presented in Table 2.

Table 2: Results of statistical analysis used to develop a power regression model relating peak force to drop number for two different glove types, with the model for the Std 10 oz glove derived from 139 glove drops (140 minus one problematic), one model for the ARLI glove derived from 137 drops (140 minus three problematic), and another model for the ARLI glove derived from 248 drops (253 minus five problematic).

	Std 10oz (139)	**ARLI (137)**	**ARLI (248)**
Linear regression equation based on logarithmic values	Y = 0.09222*X + 3.661	Y = 0.04106*X + 3.604	Y = 0.04217*X + 3.602
R^2	0.9206	0.8334	0.8244
Probability that true slope is zero	P<0.0001	P<0.0001	P<0.0001
Power equation	$Y=4581.9*X^{0.09222}$	$Y=4017.9*X^{0.04106}$	$Y=3999.5*X^{0.04217}$
Standard deviation of residuals (Sy.x) for power curve	168.63	80.15	90.86
Sy.x as % of highest & lowest observed values	2.1, 3.7	1.0, 2.1	1.7, 2.4

For each of the three models, the linear regression equations revealed that more than 80% of the variance in the logarithm of peak force could be explained by variance in the logarithm of drop number, and in each case the slope of the line obtained from the linear regression analysis was significantly different from zero.

Subsequent one-way analysis of variance (ANOVA) showed that the slope for the Std 10 oz glove was significantly greater than that associated with either of the models for the ARLI glove ($P < 0.0001$).

The slopes for the two ARLI models were not significantly different from each other ($P = 0.9432$). The standard deviations of the differences between peak force values predicted from the derived power equations and the raw observed values were small, representing 2.1% and 3.7% of the highest and lowest readings respectively for the Std 10 oz glove and being even smaller for the ARLI glove. This indicates good fit of the models to the data on which they were based.

In Figure 7, peak forces calculated by using the above power regression models are shown for a series of 250 glove drops. It can be seen that the two different models for the ARLI glove produced essentially identical results. For the Std 10oz glove, the peak impact force for drop 250 is 1.66 times that determined for Drop 1. For the ARLI glove the corresponding figure is 1.25-1.26.

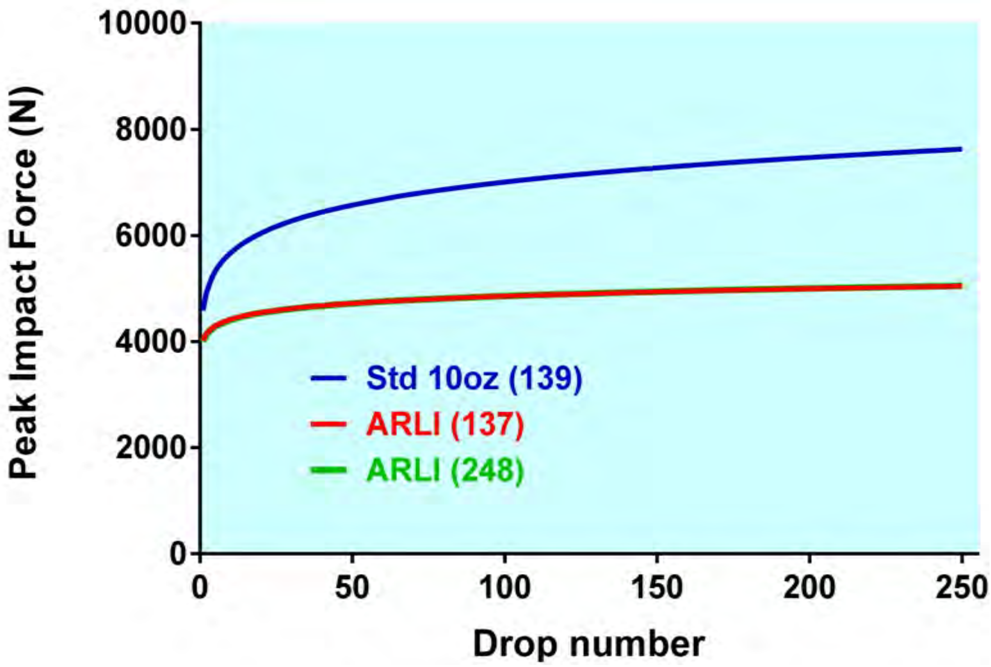

Figure 7: Peak impact forces for Std 10 oz and ARLI gloves, as indicated by regression models derived from 139 valid observations for the Std 10 oz glove, the first 137 valid observations for the ARLI glove, and all 248 valid observations for the ARLI glove. The line for the model based on 248 drops of the ARLI glove is drawn thicker than the others to make it visible.

Figure 8 shows how the number of drops influences the reduction in force afforded by the ARLI glove relative to the Std 10 oz glove, based on the data above. The modelling indicates that for Drop 1 the protective effect of the ARLI glove is ~12.5%, but that by Drop 10 it has already risen to more than 22%. Thereafter, it keeps gradually rising, reaching ~34% by Drop 250. Accordingly, it is clear that the magnitude of the protective effect is dependent on the point of its determination within a drop series.

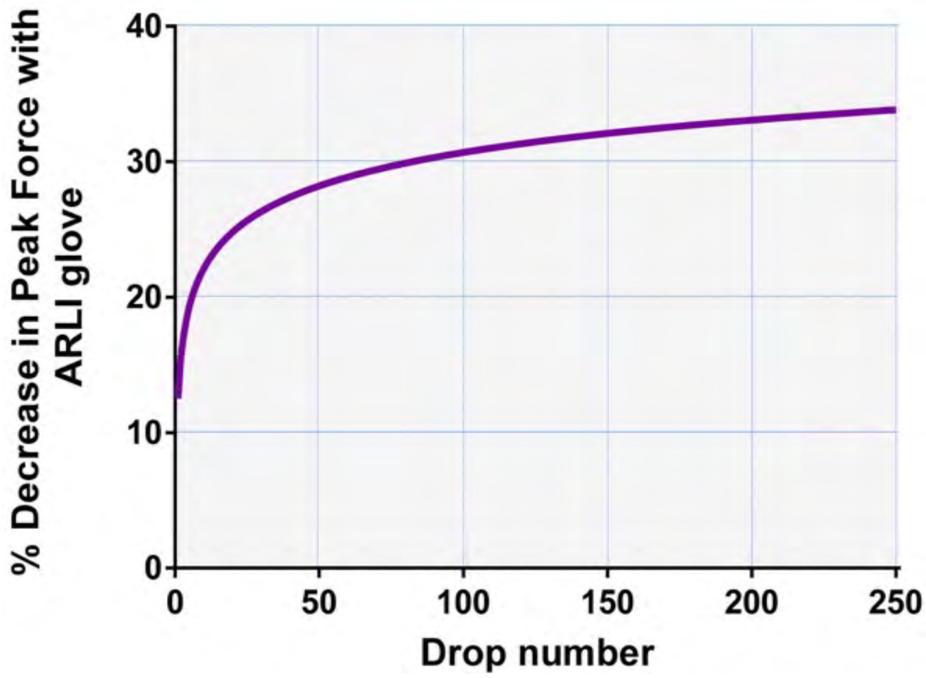

Figure 8: Percentage reduction in peak impact force provided by ARLI glove relative to Std 10 oz glove over a series of 250 glove drops on to a force plate from a height of 3 metres, as indicated by application of power regression models derived from real laboratory observations. Data from two different models determined for the ARLI glove are combined by averaging, since the models produced essentially identical results.

We applied the above method of analysis to all measured impact parameters, since in each case linear regression analysis of logarithmic values provided better fitting of the data than similar analysis of raw values.

Raw data for peak rate of force development are shown in Figure 9. Rate of force development was calculated as the change in force over successive running periods of 0.5 msec, with each result then multiplied by two to provide a reading in $N{\cdot}msec^{-1}$.

Again, disruption in the progression of readings for the Std 10 oz glove from Drop 141 onwards is evident, justifying our decision to use only the first 140 drops of that glove for data modelling. Even within this limitation, it is apparent that the variability of readings was larger for the Std 10 oz glove than the ARLI glove.

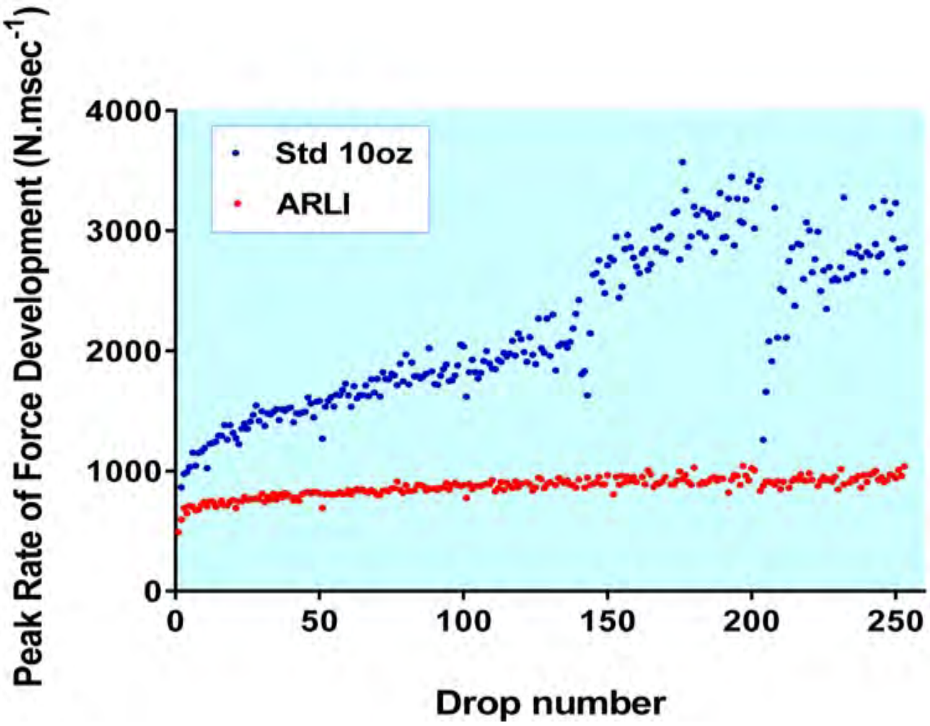

Figure 9: Raw data showing change in peak rate of force development for two different gloves over 253 drops on to a force plate from a height of 3 metres.

Outcomes of statistical analysis are presented in Table 3 and are qualitatively similar to those obtained for peak impact force. All three logarithmic linear regression equations had a positive slope that was significantly different from zero. One-way ANOVA revealed that the slope for the Std 10oz glove was significantly ($P<0.0001$) steeper than that for either of the ARLI glove models, which were not significantly different from each other ($P=0.9797$). For each of the models, the R^2 value indicated that more than 80% of the variation in the logarithm of the peak rate of force development was explicable in terms of change in the logarithm of drop number. In the case of the Std 10oz glove, the standard deviation of residuals associated with fitting of the power equation shown in Table 3 to the raw data was relatively high, reflecting the greater variability of the raw scores.

Table 3: Results of linear regression analysis relating the logarithm of peak rate of force development to the logarithm of drop number for two different glove types, with the model for the Std 10oz glove derived from 139 glove drops, one model for the ARLI glove derived from 137 drops, and another model for the ARLI glove derived from 248 drops.

	Std 10oz (139)	**ARLI (137)**	**ARLI (248)**
Linear regression equation based on logarithmic values	Y = 0.2104*X + 2.852	Y = 0.09353*X + 2.751	Y = 0.09453*X + 2.75
R^2	0.9166	0.8547	0.8262
Probability that true slope is zero	P<0.0001	P<0.0001	P<0.0001
Power equation	$Y=711.2*X^{0.2104}$	$Y=563.6*X^{0.0935}$	$Y=562.3*X^{0.0945}$
Standard deviation of residuals (Sy.x) for power curve	105.00	28.34	36.42
Sy.x as % of highest & lowest observed values	4.3, 14.0	3.0, 5.8	3.5, 7.4

Changes in peak rate of force development as a function of number of glove drops, as determined from the power regression equations, appear in Figure 10, with values generated by the ARLI model based on 137 valid drops effectively indistinguishable from those produced by the model derived from 248 drops. For the Std 10 oz glove, the peak rate of force development for Drop 250 is higher than that for Drop 1 by a factor of 3.20, whereas for the ARLI glove this factor is 1.68.

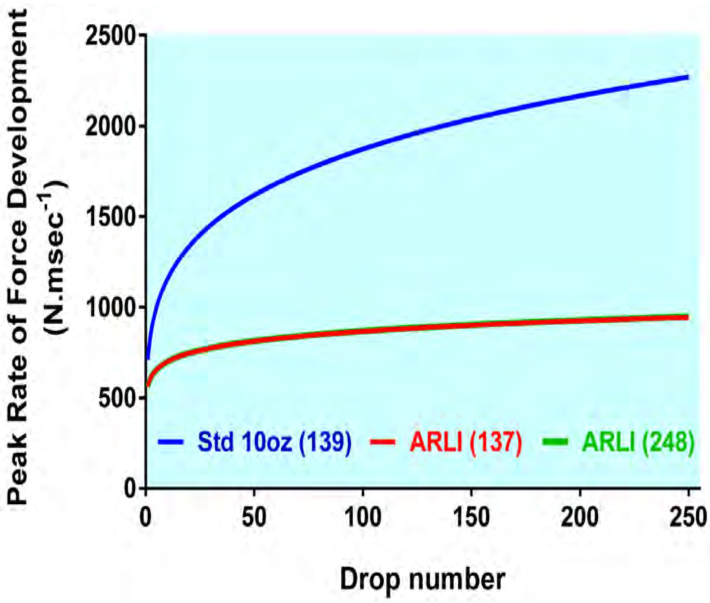

Figure 10: Peak rates of force development for Std 10 oz and ARLI gloves, as indicated by power regression models derived from 139 valid observations for the Std 10 oz glove, the first 137 valid observations for the ARLI glove, and all 248 valid observations for the ARLI glove.

Figure 11 shows that the relative protective effect of the ARLI glove increased with drop number, being ~21% for Drop 1, rising to ~39% by Drop 10 and reaching ~58% by Drop 250.

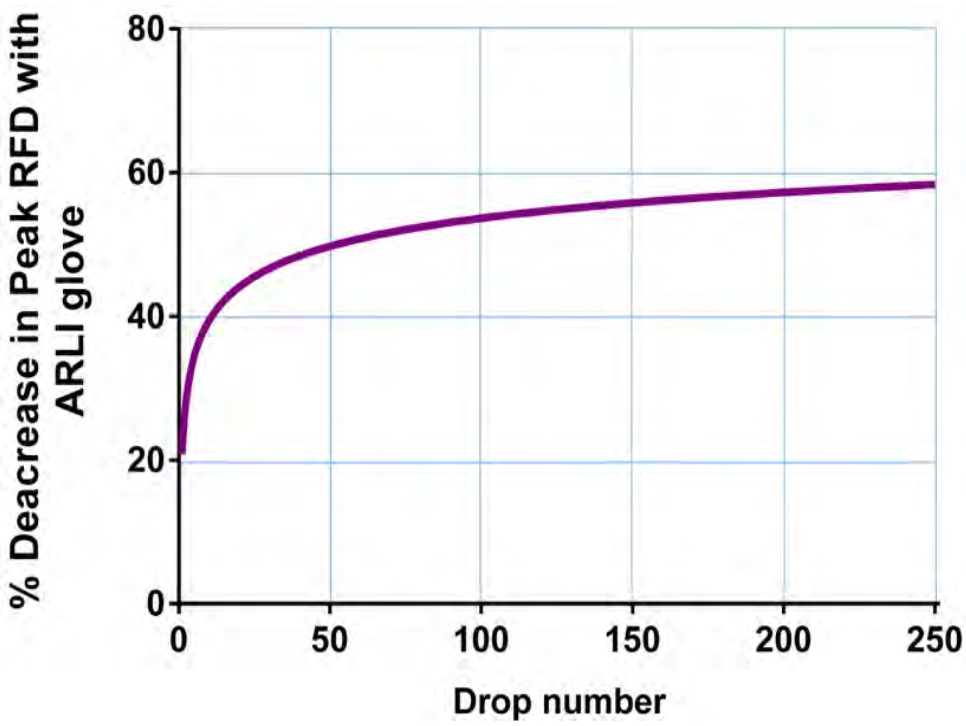

Figure 11: Percentage reduction in peak rate of force development provided by ARLI glove relative to Std 10 oz glove over a series of 250 glove drops on to a force plate from a height of 3 metres, as indicated by application of power regression models derived from real laboratory observations.

Measured contact times between glove and force plate are presented in Figure 12. The contact time was defined as the period between first occurrence of a force exceeding 10 N in the ascending phase of the force curve and a return to a force less than 10 N in the descending phase. The definition was adopted in consequence of prior observations that the baseline electrical "noise" in the force plate was consistently below 10 N. For both gloves, the force plate contact time showed a downward trend. In contrast to the findings for peak impact force and peak rate of force development, variability in the progression of contact time readings was less for the Std 10 oz glove than for the ARLI glove. Indeed, the progression for the Std 10 oz glove was very smooth up to and including Drop 140.

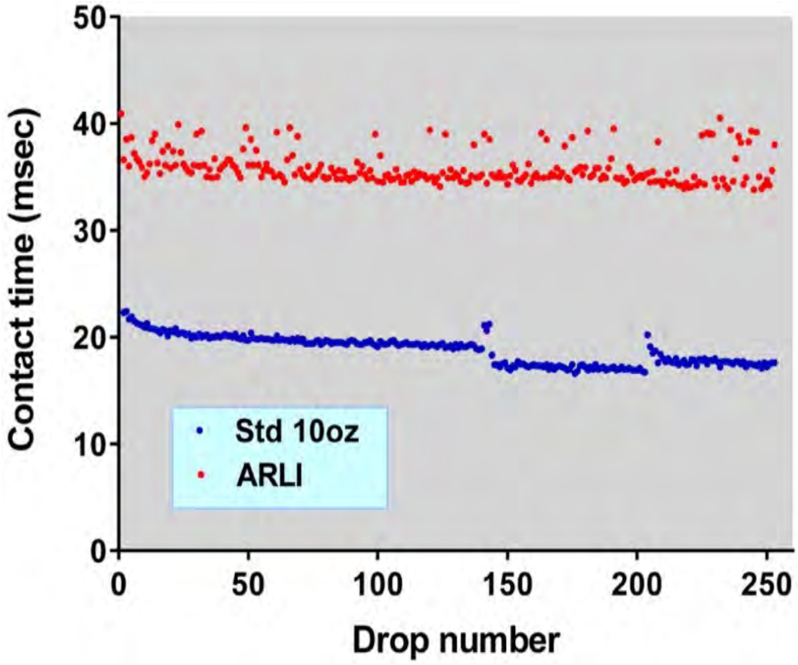

Figure 12: Raw data showing change in contact times between glove and force plate for two different gloves each dropped on to the force plate 253 times from a height of 3 metres.

Results of statistical analysis relating to force plate contact time are presented in Table 4. All linear regression models based on logarithmic data had a statistically significant negative slope. One-way ANOVA showed that the magnitude of this slope was significantly larger ($P \leq 0.0001$) for the Std 10oz glove than for the ARLI glove models, which were not statistically different from each other ($P=0.2690$). For the Std 10oz glove, over 94% of the variation in the logarithm of contact time could be explained by progression of drop number. This percentage was much lower for the two ARLI glove models but because the R^2 values were significant with an uncertainty equal to or less than 1 in 10,000 calculation of power equations was still considered justified. The standard deviation of differences between raw readings and values determined from the regression model was less than 1% of even the lowest raw reading in the case of the Std 10oz glove, providing a further indication of excellent model fit. The corresponding figures for the ARLI models were in the range of 3.7 to 4.3%, implying that the fit was reasonable.

Curves generated from the power regression equations for contact time appear in Figure 13, which shows that the departure from parallel, while statistically significant, is quite small. The model for the Std 10oz glove indicates a reduction in contact time of 1.8 msec from Drop 1 to Drop 10, and a further 2.3 msec from Drop 10 to Drop 250, making a total decrease of

4.1 msec. Aggregated values from the two ARLI models show a reduction of 1.4 msec from Drop 1 to Drop 10, and a further 1.9 msec from Drop 10 to Drop 250, yielding a total decrease of 3.3 msec. The difference between the two gloves becomes greater when expressed in relative terms, with total decreases in contact time being equivalent to 18.0% and 8.6% of the Drop 1 values for the Std 10z glove and ARLI gloves respectively.

Table 4: Results of linear regression analysis relating force plate contact time to drop number for two different glove types, with the curve for the Std 10oz glove derived from 139 glove drops, one model for the ARLI glove derived from 137 drops and another model for the ARLI glove derived from 248 drops.

	Std 10oz (139)	**ARLI (137)**	**ARLI (248)**
Linear regression equation based on logarithmic values	Y = -0.0359*X + 1.359	Y = -0.0190*X + 1.588	Y = -0.0134*X + 1.58
R^2	0.9418	0.2201	0.0994
Probability that true slope is zero	P<0.0001	P<0.0001	P<0.0001
Power equation	$Y=22.86*X^{-0.0359}$	$Y=38.73*X^{-0.0190}$	$Y=38.02*X^{-0.0134}$
Standard deviation of residuals (Sy.x) for power curve	0.168	1.250	1.437
Sy.x as % of highest & lowest observed values	0.7, 0.9	3.1, 3.7	3.5, 4.3

Curves generated from the power regression equations for contact time appear in Figure 13, which shows that the departure from parallel, while statistically significant, is quite small. The model for the Std 10oz glove indicates a reduction in contact time of 1.8 msec from Drop 1 to Drop 10, and a further 2.3 msec from Drop 10 to Drop 250, making a total decrease of 4.1 msec. Aggregated values from the two ARLI models show a reduction of 1.4 msec from Drop 1 to Drop 10, and a further 1.9 msec from Drop 10 to Drop 250, yielding a total decrease of 3.3 msec. The difference between the two gloves becomes greater when expressed in relative terms, with total decreases in contact time being equivalent to 18.0% and 8.6% of the Drop 1 values for the Std 10z glove and ARLI gloves respectively.

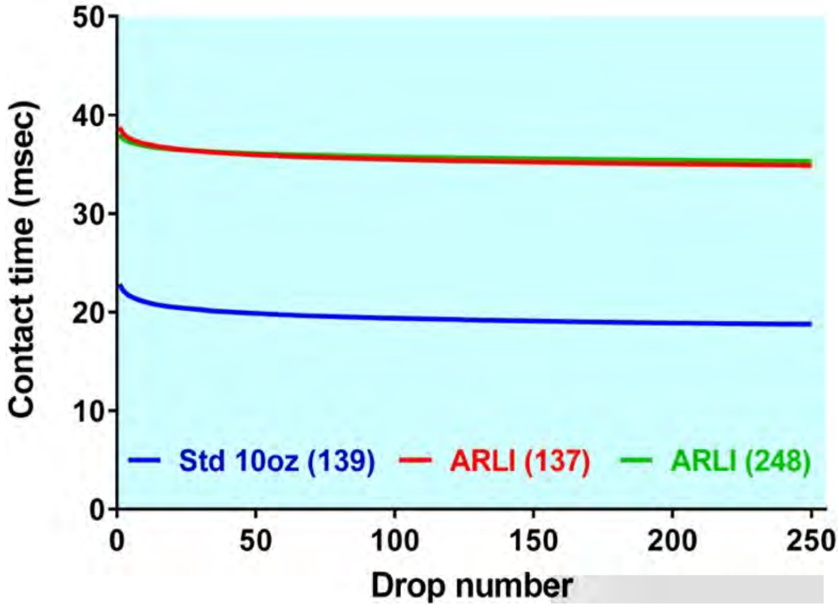

Figure 13: Force plate contact times for Std 10 oz and ARLI gloves, as indicated by regression models derived from 139 valid observations for the Std 10 oz glove, the first 137 valid observations for the ARLI glove, and all 248 valid observations for the ARLI glove.

Figure 14 shows how variation in force plate contact time related to variation in peak impact force for the two glove types. Two separate graphs are included for the Std 10oz glove – one based on 139 glove drops (the first 140 less one problematic) and the other on 250 drops (253 less three problematics). In both graphs, a strong linear relationship is evident, with reduced contact times associated with increases in peak force. While correlation does not necessarily imply causation, it is pertinent that following the problematic drop 141, which presumably affected the characteristics of the Std 10oz glove, sudden changes in contact time and peak impact force occurred in almost perfect synchrony, such that when 250 drops of the glove were included in the analysis, more than 96% of the variance in peak impact force could be explained by variance in contact time. For the ARLI glove, the relationship was of the same direction but, despite reaching statistical significance, it was not nearly as strong, with variance in contact time explaining only ~9% of the variance in peak force.

Results similar to the above were obtained for the relationship between contact time and peak rate of force development, with linear regression analysis incorporating 139 drops of the Std 10oz, 250 drops of that glove and 248 drops of the ARLI glove yielding R^2 values of 0.8861, 0.9457 and 0.0885 respectively.

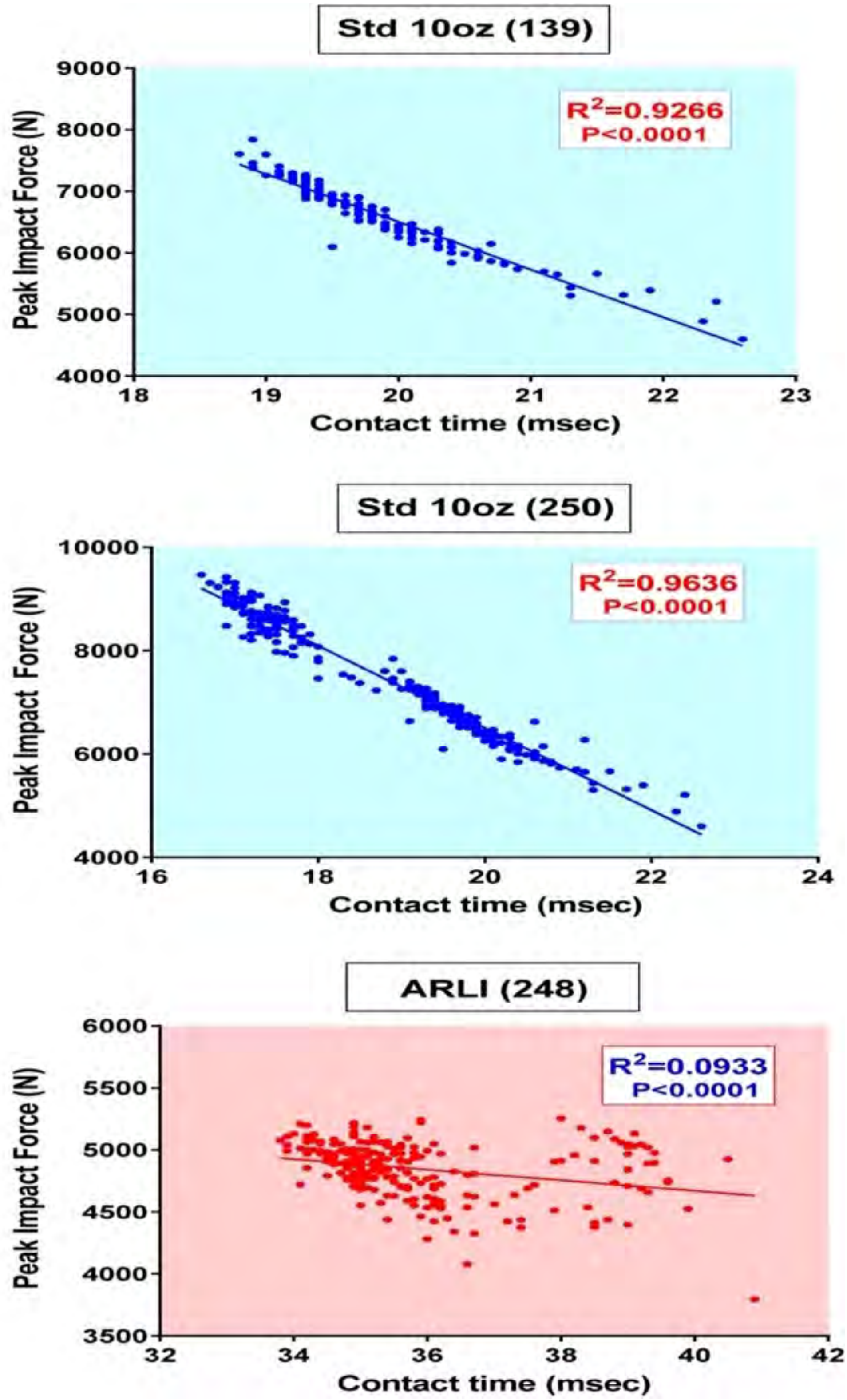

Figure 14: Relationship between force plate contact time and peak impact force for two different glove types. The top panel is based on 139 drops of the Std 10 oz glove, the second panel on 250 drops of that glove, and the bottom panel on 248 drops of the ARLI glove.

We wondered whether the lesser predictive value of contact time in the case of the ARLI glove might be due to lower reliability in contact time measurement. It seemed conceivable that 'softer' impact produced by that glove could diminish ability to precisely discern points of impact initiation and cessation. Accordingly, we decided that in addition to examining contact time it might be instructive to consider the time from the beginning of force plate contact to the attainment of peak force, since the latter would be likely to have a more definitive end-point.

Figure 15 shows change in the time from glove contact to attainment of peak force as a function of the number of drops for the two glove types. The disruption to readings for the Std 10oz glove following Drop 140 is clear. Readings for the ARLI glove progressed within a proportionally narrower band than was the case for total contact time, particularly after the first 20 glove drops.

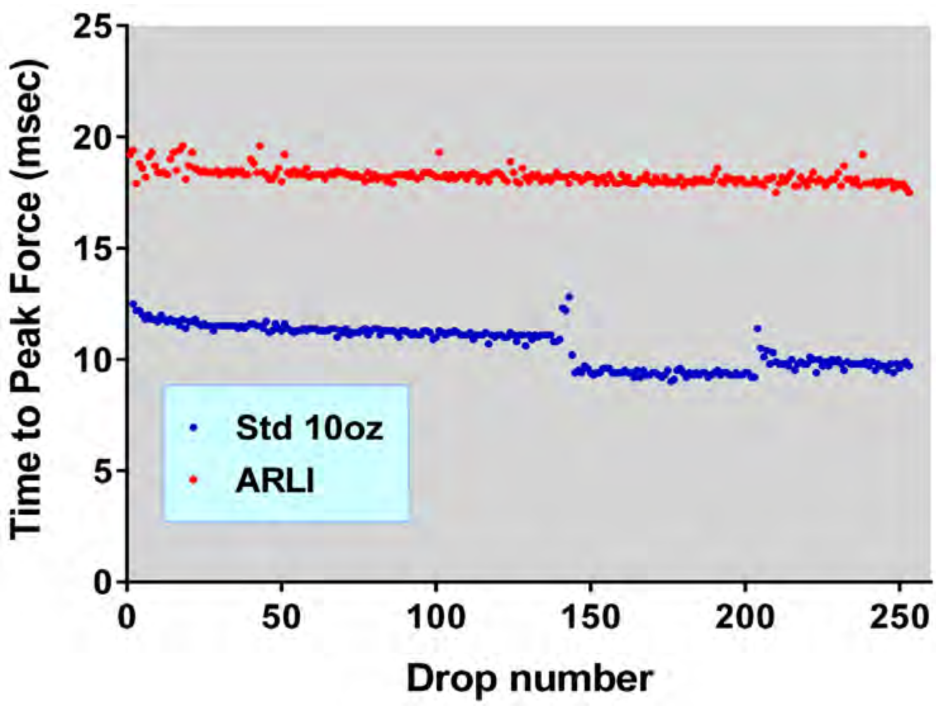

Figure 15: Raw data indicating time from glove contact to peak force for two gloves each dropped 253 times on to a force plate from a height of 3 metres.

Major statistical findings concerning the change in time to peak force are presented in Table 5. The slopes of all three linear regression models based on logarithmic values were negative and significantly different from zero. The negative slope of for the Std 10oz glove was found to be significantly steeper (P<0.0001) than that for either of the two ARLI glove models, while the slopes for the latter were not significantly different from each other (P=0.9277). For the Std 10oz glove, almost 85% of the variance in the logarithm of time to peak force was explicable in terms of the logarithm of drop number. The percentages were lower for the ARLI glove models, but still exceeded 41% for model derived from 248 valid readings and 26% for the model obtained from 137 valid readings. Values provided by power equations generated from the logarithmic models were generally close to observed values, as demonstrated by the fact that the standard deviation of the residuals was between 1.1 and 1.6% of the lowest observed value in each instance.

Table 5: Results of linear regression analysis relating time to peak force to drop number for two different glove types, with the curve for the Std 10oz glove derived from 139 glove drops, one model for the ARLI glove derived from 137 drops and another model for the ARLI glove derived from 248 drops.

	Std 10oz (139)	**ARLI (137)**	**ARLI (248)**
Linear regression equation based on logarithmic values	Y = -0.0268*X + 1.101	Y = -0.0099*X + 1.282	Y = -0.0123*X + 1.285
R^2	0.8473	0.2646	0.4145
Probability that true slope is zero	P<0.0001	P<0.0001	P<0.0001
Power equation	$Y=12.62*X^{-0.0268}$	$Y=19.14*X^{-0.0099}$	$Y=19.28*X^{-0.0123}$
Standard deviation of residuals (Sy.x) for power curve	0.121	0.294	0.263
Sy.x as % of highest & lowest observed values	1.0, 1.1	1.5, 1.6	1.3, 1.5

Curves derived from the power equations for time to peak force appear in Figure 16. The equation for the Std 10oz glove indicated a reduction of 0.7 msec from Drop 1 to Drop 10, and a further 1.0 msec from Drop 10 to Drop 250, with the total decease therefore being 1.7

msec (13.5% of the Drop 1 value). Averaging of data from the two ARLI models showed a reduction of 0.5 msec from Drop 1 to Drop 10 and another 0.6 msec from Drop 10 to Drop 250, giving a total decrease of 1.1 msec (5.7% of the Drop 1 value).

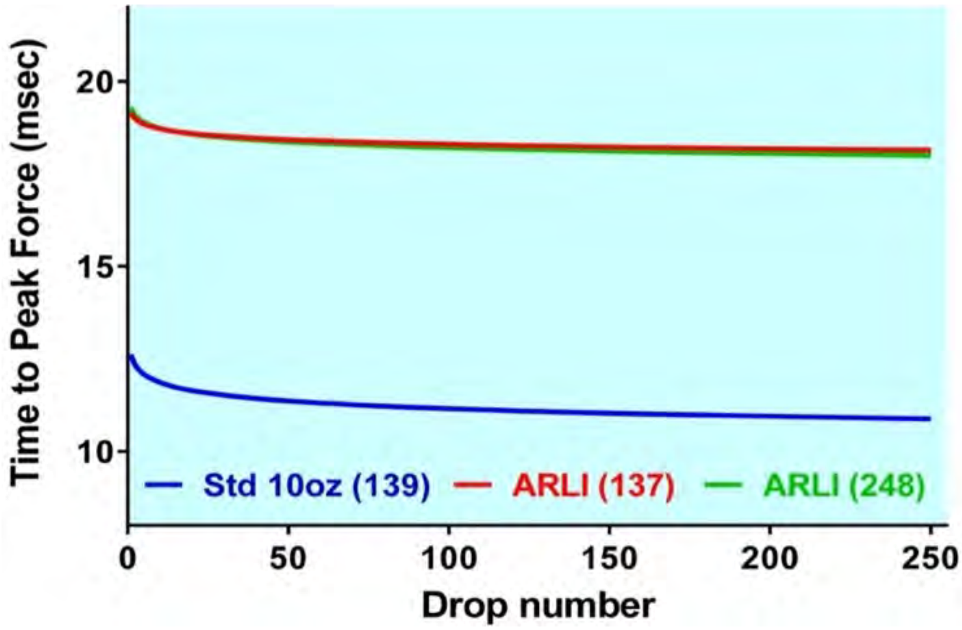

Figure 16: Time from force plate contact to attainment of peak force for Std 10 oz and ARLI gloves, as indicated by regression models derived from 139 valid observations for the Std 10 oz glove, the first 137 valid observations for the ARLI glove, and all 248 valid observations for the ARLI glove.

The modelling showed that time to peak force accounted for a higher percentage of total contact time for the Std 10oz glove than for the ARLI glove (55-58% vs 49-52%).
The relationship of time to peak force to magnitude of peak force for the two glove types is presented in Figure 17. For the Std 10oz glove, the predictive effect of time to peak force was almost as good as that of total contact time. When 250 drops of this glove (including 111 drops following the problematic Drop 141) were included in linear regression analysis, ~92% of the variance in peak force was explicable by variance in time to peak force. For the ARLI glove, time to peak force was superior to total contact time as a predictor of peak force magnitude, being able to explain ~59% of the variance.

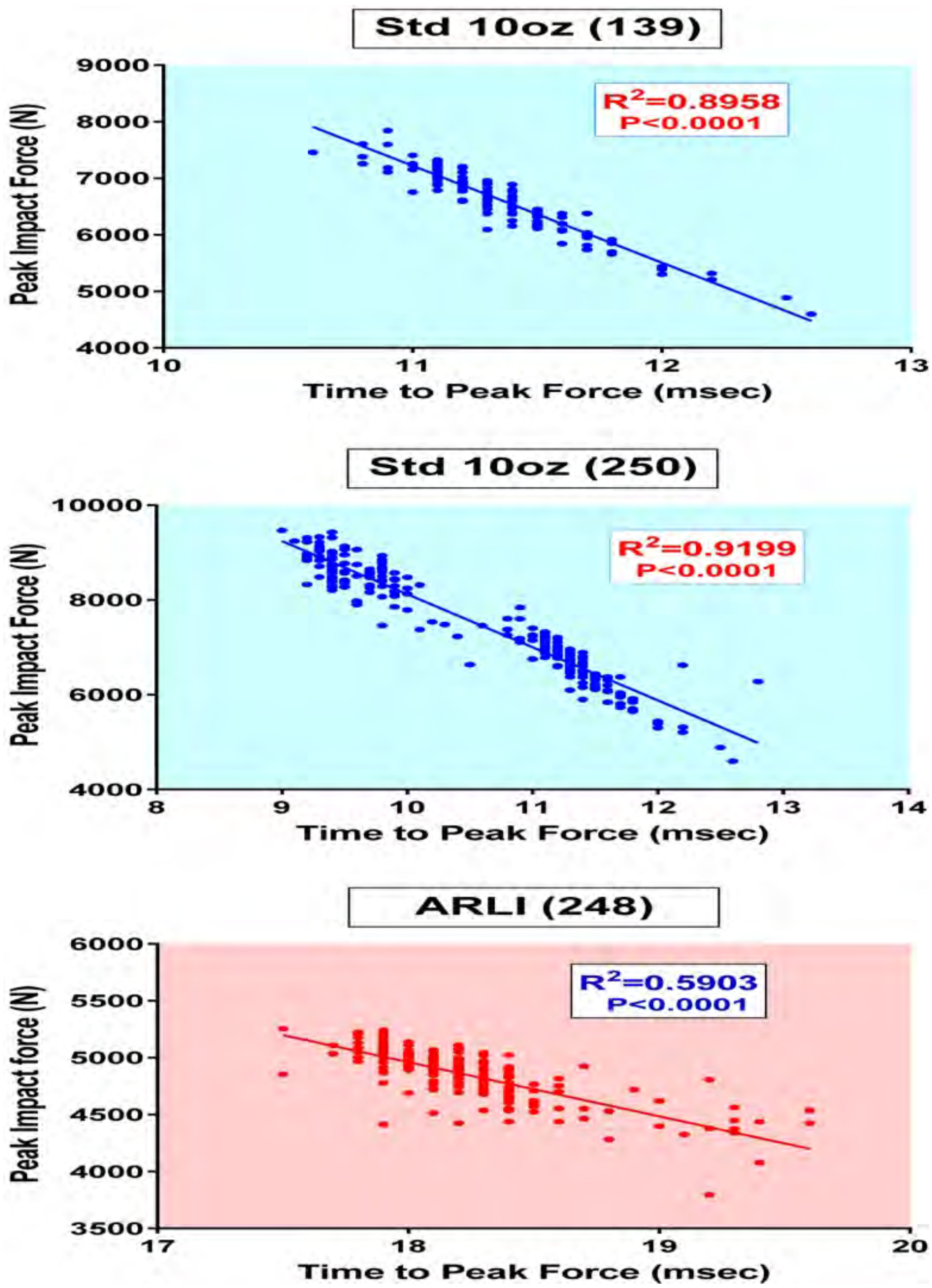

Figure 17: Relationship between force plate contact time and peak impact force for two different glove types. The top panel is based on 139 drops of the Std 10 oz glove, the second panel on 250 drops of that glove, and the bottom panel on 248 drops of the ARLI glove.

Time to peak force was also a good a predictor of the instantaneous peak rate of force development, with the R^2 value being 0.8815 for the linear regression equation derived from

139 drops of the Std 10oz glove, 0.9141 for the equation derived from 250 drops of that glove, and 0.5653 for the equation based on 248 drops of the ARLI glove.

To further explore relationships between temporal aspects of collisions and changes in force generation over a long series of repeated glove drops, we examined individual force-time curves for both glove types. Observed curves for drops 10, 50, 100, 140, 150, 200 and 250 in the laboratory experiments are presented in Figure 18. For the ARLI glove, the curves clearly consisted of a slow phase during which they essentially traced over one another, and a fast phase during which some separation as a function of drop number eventually became evident. This was true also for the Std 10oz glove up to and including Drop 140. The problematic Drop 141 seemed to cause the slow phase of the curve to become shorter and less distinct, making the curve for Drop 150 quite different from the earlier drops depicted in Figure 18. Drops 150, 200 and 250, however, displayed substantial similarity, varying primarily just in height.

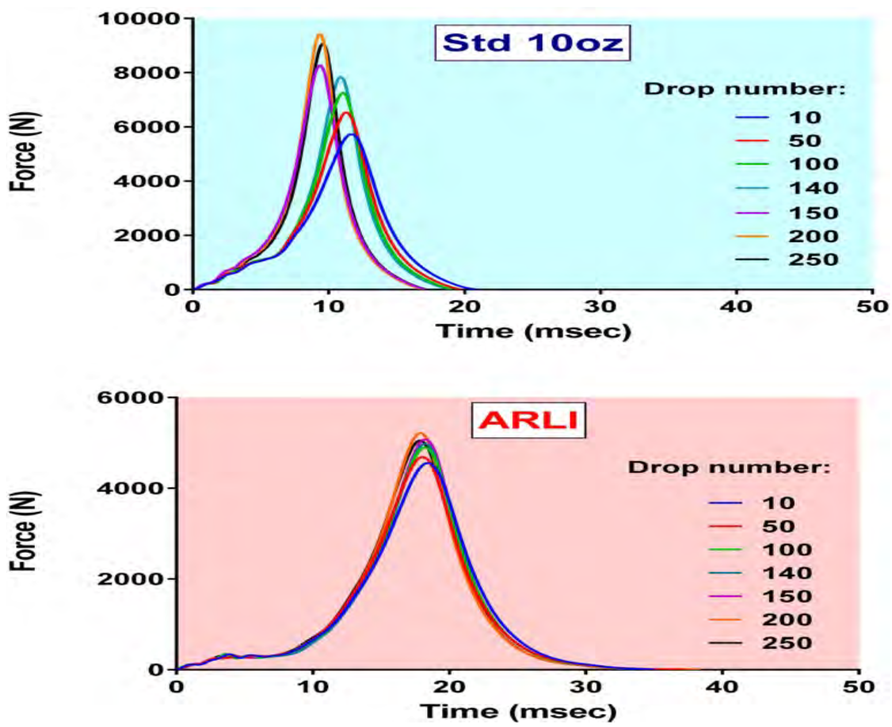

Figure 18: Force-time curves for Std 10 oz and ARLI boxing gloves as a function of number of drops. Note that the scales on the Y-axis differ between the two panels.

Figure 19 provides data for Drops 10, 50, 100, 140, 150, 200 and 250 with respect to time course of change in rate of force development. Key features resemble those observed for impact force.

For the Std 10oz glove, there was no early separation of curves up to and including Drop 140. Earlier separation did occur in the aftermath of the probably glove-altering Drop 141. The curves for Drops 10, 50, 100 and 140 of the Std 10oz glove essentially traced over one another for the first 6-7 msec. In the case of the ARLI glove, changes in rate of force development as a function of drop number were not apparent until ~13 msec.

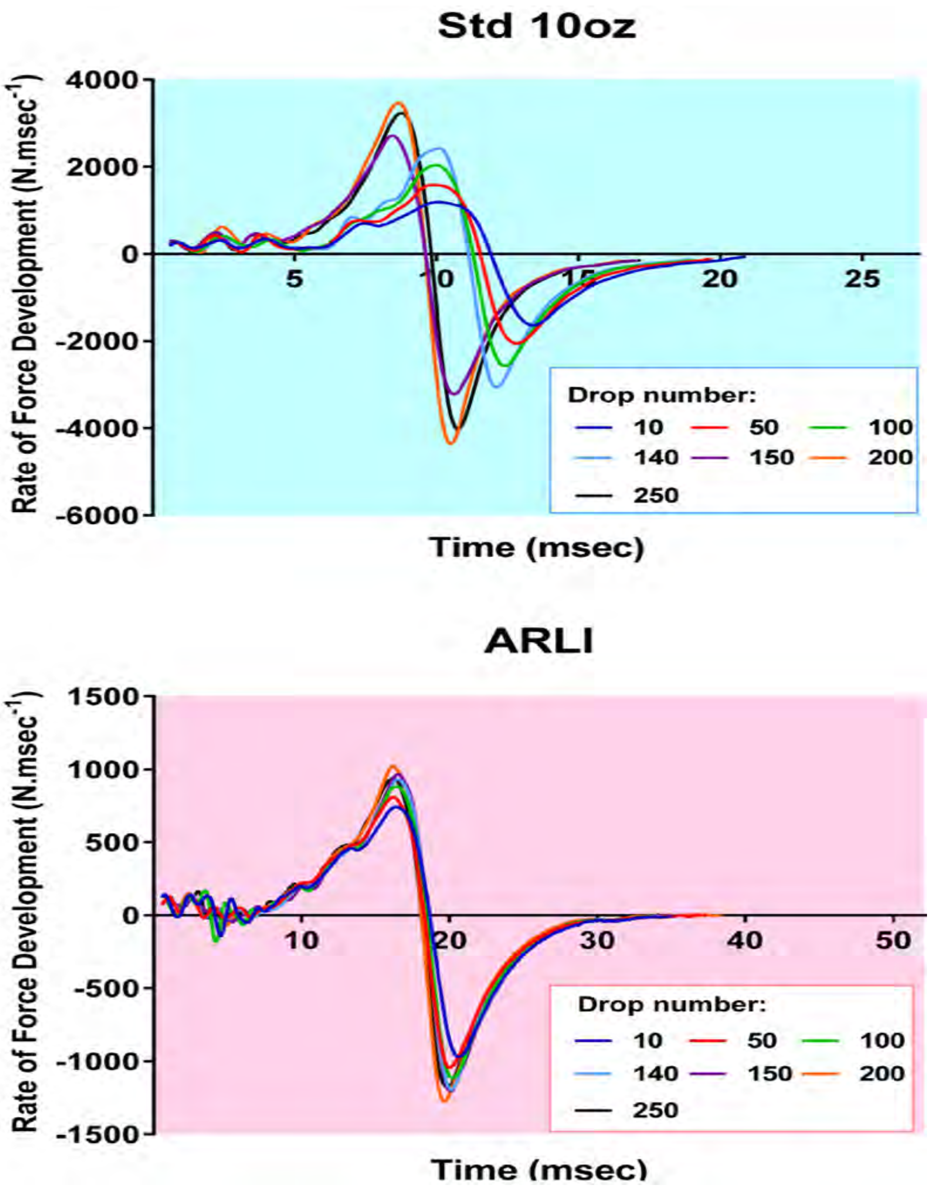

Figure 19: Curves showing relationship of rate of force development to time over a long series of glove drops for Std 10 oz and ARLI boxing gloves. Note that the scales on both axes differ between the two panels.

The finding that the ARLI glove, when compared to the Std 10oz glove, produced lower peak forces and peak rates of force development, increased contact time with the target and the time to peak force, and diminished drift in the various parameters over a long series of repeated glove drops, was not due to reduction of the impulse of impact. We estimated the latter by using the trapezoid method to calculate area under the force-time curve (AUC) for every glove drop. The results are shown in Figure 20. AUC was lower for the Std 10oz glove than the ARLI glove, probably because the former was lower in mass, but rose more rapidly with repeated glove drops. Change in the progression of AUC for the Std 10oz glove after the problematic Drop 141 was detectable but less dramatic than that observed for other impact parameters.

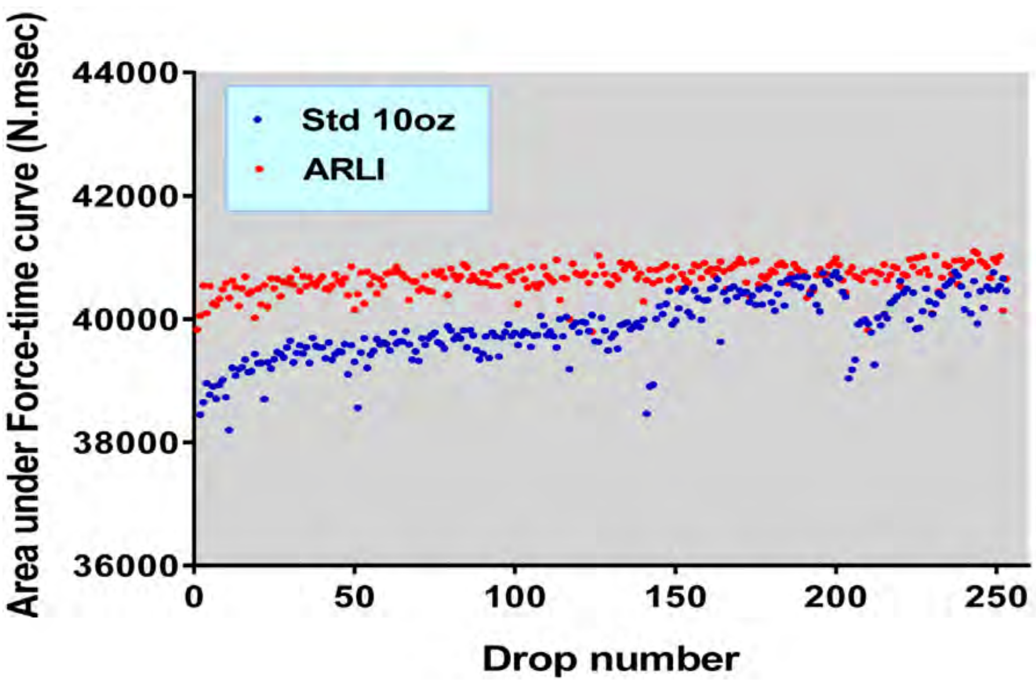

Figure 20: Raw data indicating change in area under the force-time curve for two different gloves over a series of 253 drops on to a force plate from a height of 3 metres.

Outcomes of statistical analysis of the AUC data appear in Table 6. For the Std 10oz glove, ~71% of the variance in the logarithm of AUC was explicable in terms of change in the logarithm of drop number. For the ARLI glove models this figure was in the range of ~30-32%. For each of the logarithmic linear regression models, the relationship between predicted and observed AUC values was statistically significant.

The slope of the line for Std 10oz glove was significantly larger than that for either of the ARLI models ($P<0.0001$), while no statistical difference between the slopes for the two ARLI models could be discerned ($P=0.9794$). Power equations generated from the logarithmic linear models provided a good fit with laboratory data, as evidenced by the fact that the standard deviation of the residuals was never more than 0.5% of the lowest observed value.

Table 6: Results of linear regression analysis relating area under the force-time curve to number of glove drops for two different glove types, with the model for the Std 10oz glove derived from 139 glove drops, one model for the ARLI glove derived from 137 drops, and another model for the ARLI glove derived from 248 drops.

	Std 10oz (139)	**ARLI (137)**	**ARLI (248)**
Linear regression equation based on logarithmic values	Y = 0.008029*X + 4.583	Y = 0.00315*X + 4.603	Y = 0.003053*X + 4.603
R^2	0.7121	0.3241	0.2990
Probability that true slope is zero	P<0.0001	P<0.0001	P<0.0001
Power equation	$Y=38282*X^{0.0080}$	$Y=40087*X^{0.0032}$	$Y=40087*X^{0.0031}$
Standard deviation of residuals (Sy.x) for power curve	189.1	174.6	183.4
Sy.x as % of highest & lowest observed values	0.45, 0.50	0.43, 0.44	0.45-0.46

Curves developed from the AUC power equations are presented in Figure 21. The upward trend of the curves is notable given that the impact energy resulting from dropping an object of specific mass from a controlled height is theoretically constant.

One possible reason for the rise in AUC with repeated glove drops is a gradual reduction in the ability of the colliding objects to store some of the impact energy. Such storage could occur, for example, through deformation of a glove and/or the EVA mat covering the force plate. With successive glove drops, there could be diminishing capacity for further deformation, causing more of the impact energy to be transferred to the force plate. This could affect a range of impact metrics, including peak force.

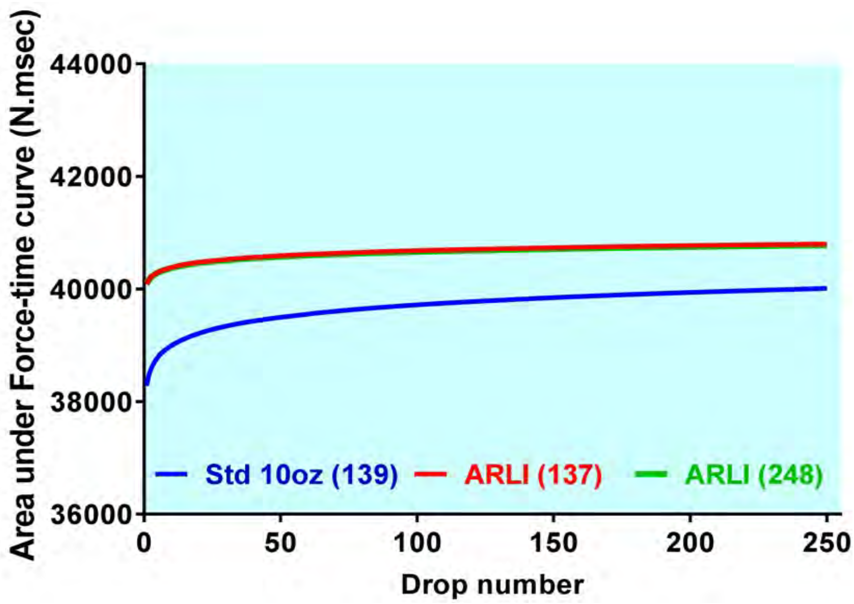

Figure 21: Area under the force-time curve for Std 10 oz and ARLI gloves, as indicated by regression models derived from 139 valid observations for the Std 10oz glove, the first 137 valid observations for the ARLI glove, and all 248 valid observations for the ARLI glove.

Figure 22 shows relationship between AUC and peak force for the two different glove types included in our experiment. For the Std 10oz glove, the relationship was strong, with a linear regression model derived from 250 points able to explain almost 84% of the variance in peak force based on variance in AUC. The corresponding figure for the ARLI glove was markedly lower at ~47%, although the association between peak force and AUC was still statistically significant.

Comparable results were obtained for the relationship of AUC to peak rate of force development, but here the relationship was better described by a power regression model than by linear regression. The power models yielded R^2 values of 0.7616, 0.8298 and 0.4395 for 139 drops of the Std 10 oz glove, 250 drops of the Std 10oz glove and 248 drops of the ARLI glove respectively. In each case, the probability of a zero relationship was less than 0.0001.

AUC, force plate contact time and time from initial force plate contact to attainment of peak force could not be considered independent predictors of peak force or peak rate of force development since they co-varied, as shown in Table 7. The extent of co-variation was much less for the ARLI glove than for the Std 10oz glove.

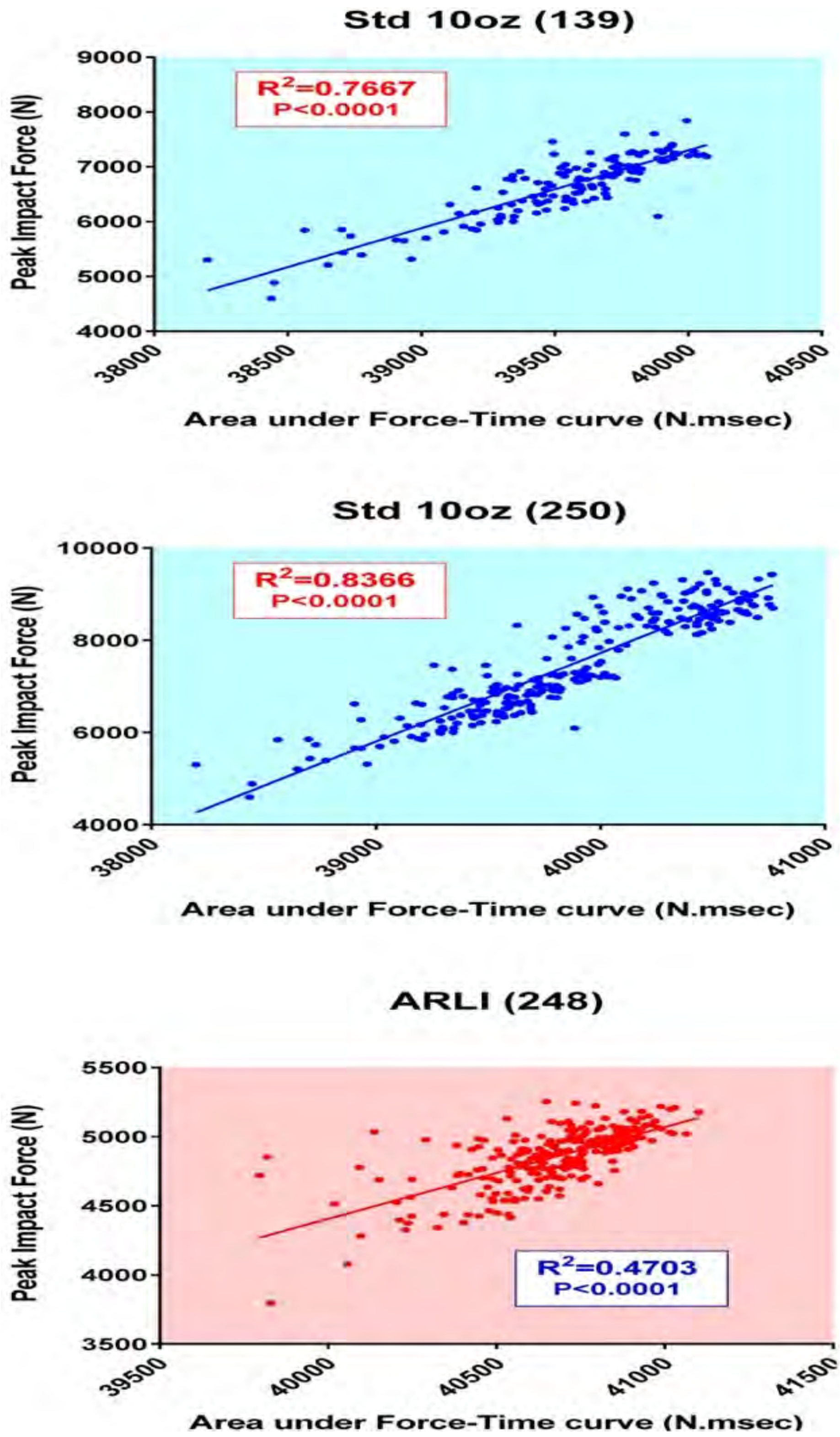

Figure 22: Relationship between area-under the force-time curve and peak impact force for two different glove types. The top panel is based on 139 drops of the Std 10oz glove, the second panel on 250 drops of that glove, and the bottom panel on 248 drops of the ARLI glove.

Table 7: Matrix showing inter-relationships between selected impact metrics. R^2 values determined through linear regression are given together with the associated probability that the true relationship could be zero. The R^2 values are based on 250 observations for the Std 10oz glove and 248 for the ARLI glove.

	Std 10oz	**ARLI**
AUC vs Contact Time	0.8153 (P<0.0001)	0.0259 (P=0.0112)
AUC vs Time to Peak Force	0.7297 (P<0.0001)	0.2082 (P<0.0001)
Contact Time vs Time to Peak Force	0.9638 (P<0.0001)	0.0612 (P<0.0001)

Overall, force plate contact time was the best single predictor of peak force rate of force development for the Std 10oz glove, while time from initial force plate contact to attainment of peak force was the best predictor for the ARLI glove. The performance of the Std 10oz glove could be predicted with greater accuracy.

Figure 23 shows what happened to peak impact force when, after 253 drops of the ARLI glove, the EVA 75 mat covering the force plate was replaced with a new one, and the glove was then dropped a further 10 times. We reasoned that if drift in peak force over the 253 drops was wholly due to impact-induced changes in the properties of the mat, introduction of a new mat should produce readings resembling those obtained at the outset of the 253-drop series. Conversely, if drift in peak force was entirely attributable to changes in glove properties, readings following replacement of the mat would be much the same as those recorded for the last few of the of 253 drops. The data revealed that introduction of the new mat reduced peak forces to a level that was ~74% of the way between the means of the highest five values for the first and last 10 of the 253 drops. This suggested that about a quarter of the upward drift in peak force during the long sequence of impacts was due to mat alteration, while about three-quarters of it was due to glove alteration. In absolute terms, however, the mean value of the highest five peak force readings from the 10 drops performed after introduction of the new mat was only ~3.5% below the corresponding value for the last 10 drops of the original mat. A difference of this magnitude conceivably could be explained by batch variation in mat manufacture.

Accordingly, the only inference that can be drawn with a high level of certainly is that most of the upward drift in peak force over the 253-drop series was due to changes to the glove.

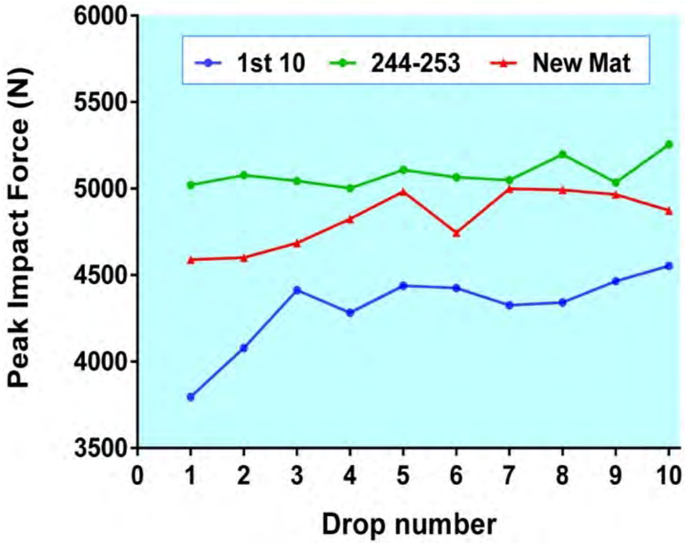

Figure 23: Effect of replacing the EVA 75 mat covering the force plate on peak impact forces measured when the ARLI glove was dropped on to the plate from a height of 3 metres. 1st 10= first 10 drops of the 253-drop sequence, 244-253= last 10 drops of that sequence, New Mat= 10 drops performed after a new EVA 75 mat was introduced.

There could be some relevant information, however, in the shapes of curves describing changes in peak impact forces over sub-blocks of 10-12 drops. For the first sub-block of the 253-block series, a power curve provided the best fit to the data, with an R^2 value of 0.7836. The third sub-block of the series was the only other one for which fitting of a power curve yielded an R^2 value exceeding 0.7, but this was seen again for the 10 drops on to the new mat. Additionally, application of linear regression analysis to successive groups of 10-12 drops revealed that the steepness of the slope for the drops on to the new mat was second only to that for the very first sub-block of 10 drops. The fact that mat replacement moved not just peak forces but also the pattern of their rise over 10 glove drops toward those that initially characterised the original mat supports the notion that the properties of the latter may have undergone some alteration over the course of receiving 253 impacts.

At the end of each of the two days of our experiment, we carried out a visual examination of the glove that undergone testing. We detected no evidence of change to the ARLI glove.

As shown in Figure 24, the Std 10oz glove padding showed some sign of deformation in the area close to the wrist.

Figure 24: Deformation near wrist region of Std 10 oz glove after 253 drops on to a force plate. The area of deformation is indicated by the white ellipse. A glove with which the dropped glove formed a pair is shown for comparison.

9.3.5. Discussion

We set out to quantify the progression of impact variables for Std 10 oz and ARLI boxing gloves over a series of 250 drops on to a force plate from a height of 3 metres. In the case of the ARLI glove, we were able to analyse 248 data points to develop statistical models. Since these data points spanned 253 glove drops (of which five were excluded for technical reasons), the resultant models were of an interpolative nature. By contrast, a technical problem that occurred on the 141st drop of the Std 10 oz glove had a lasting effect on subsequent impact dynamics and meant that only the first 140 drops (one of which was technically invalid) could be used for model development. Quantification of the effects of 250 glove drops therefore depended on extrapolation of trends observed over a lesser number of drops. Through development of two different models for the ARLI glove, one based on 248 glove drops and the other based on the first 140, we were able to demonstrate that the interpolative and extrapolative approaches produced essentially identical results for all impact variables examined.

This made it clear that for the ARLI glove 140 observations were sufficient to enable establishment of models that could be accurately extrapolated out to 250 glove drops. It seems reasonable to expect that the same would be true for the Std 10 oz glove and that our findings concerning changes in impact variables for the two glove types over the course of 250 drops are realistic.

A key finding of our research is that for both glove types all measured impact variables showed progressive change and did not reach a plateau even after as many as 250 drops. Also important is the fact that the rate of change in the variables over the course of 250 drops was always greater for the Std 10 oz glove than the ARLI glove. Our previous studies have shown that, compared to a Std 10 oz glove, the ARLI glove provides acute reduction of the peak force and peak rate of force development associated with standardized impacts of a magnitude that can be encountered by boxers. This information is now supplemented by the observation that under our experimental conditions it also damps cumulative change in these parameters over a long series of ostensibly identical impacts. An implication of the new observation is that the relative degree of protection provided by the ARLI glove becomes greater as the number of impacts increases.

Only a few other studies have examined change in impact damping performance of boxing gloves over a long series of impacts. In 1985, Smith and Hamill [10] reported a study in which they dropped a conventional boxing glove on to a force plate 50 times from a height that produced a pre-impact glove velocity of 2.0 $m \cdot sec^{-1}$. Data were recorded for Drops 1 and 5, and for every fifth drop thereafter. The peak impact force increased from 1484 N at the outset to 2914 N at the end, a rise of 96%. Much of the change occurred early in the series, with the peak force already over 2150 N by Drop 5 and over 2450 N by Drop 10. There were smaller rises up to Drop 35, after which the readings stabilized. The time from initial force plate contact to attainment of peak force decreased from 19 msec on Drop 1 to 15 msec on Drop 5 and 14 msec on Drop 15, before remaining constant for the rest of the series. The area under the force-time curve increased sharply over the first 20 drops. It then fluctuated in an inconsistent manner but was always higher than the value recorded for Drop 1. Overall, the findings were qualitatively similar to those presented in this paper. Smith and Hamill [10] considered that the increase in peak force over the series was likely due to the decreased glove contact time caused by compression of the glove padding. They saw distribution of the impulse over a shorter contact time as the reason for the higher forces.

The composition of the glove padding (a layer of hair sandwiched between two layers of open cell foam contained within a leather sheath) was regarded as sub-optimal since a karate glove with customised molded foam padding demonstrated a much smaller (27%) increase in peak force across a series of 50 drops. Over recent years, there has been substantial change in the manufacture of boxing gloves, with a range of new materials employed [11,12]. This has produced a need for research akin to that conducted by Smith and Hamill [10] but entailing evaluation of contemporary gloves.

Lee and McGill [11] used a mechanized device to deliver 10,000 impacts of a conventional 16 oz glove - of the type typically used by boxers for sparring [13] - to a "pancake" force transducer. The impacts were delivered at a rate of one every 1.8 seconds for 5 hours. Force-time characteristics were sampled from 20 impacts at the outset and 20 at the end of each 30-minute period. Data from the 20 impacts were averaged to produce representative force-time curves for each sampling point. The mean peak force was 532 N at the start of the trial and 747 N at its end, with the increase therefore amounting to ~40%. Most of the increase took place over the first 2000 impacts, after which the peak impact force already exceeded 700 N. The upward drift in peak force was associated with progressive reductions in contact time and the time to peak force, with the magnitude of shifts following a similar course. Although the peak forces were quite low compared to those reportedly generated by boxers [2,14-18], the glove showed visible signs of wear and material deterioration after ~2000 impacts. It is interesting that its performance then exhibited very little further decrement over the course of another 8000 impacts. The early rise in peak force was ascribed to a "breaking in" period characterised by some degradation of padding materials, after which performance became relatively consistent. It was suggested that the breaking in period was probably characterised by increasing glove stiffness resulting from deformation, with the increased stiffness resulting in less energy loss upon impact and therefore greater peak force.

Recently, Chadli et al. [12] carried out a cross-sectional study of the effects of numerous impacts on the performance of boxing gloves by comparing three new gloves with three that had been extensively used by elite boxers. All the gloves were of the conventional type and had been manufactured to meet a specification that they should have a mass of 10 oz. A rotary mechanism incorporating torsion springs was employed to deliver nine impacts of each glove to a target that had lower inertial mass than the striking device and therefore moved away from it shortly after contact.

The nine impacts were arranged into three sets of three with impact energy levels of 4, 18 and 44 J to simulate punches of different magnitudes. At each impact energy level, peak angular velocity and peak acceleration of the target were substantially greater for the used gloves than for the new ones. Calculated peak impact forces were 128, 540 and 1540 N for the best-performed new glove, compared to 589, 2060 and 3960 N for the worst-performed used glove. The latter values were therefore 2.6 - 4.6 times greater than the former. At the low and medium impact energy levels, the new gloves compressed much less than the used gloves, but at the highest energy level, the difference in compression was slight. Consequently, the much-reduced impact damping effects of the used gloves at the highest impact energy level could not be attributed to greater glove compression. Instead, the findings were seen to imply that the foam padding of the used gloves had undergone significant chemical and physical alteration. It can be imagined that repeated collisions could damage the walls of the cells that constitute foam structures, thereby changing the properties of the foam and making it subject to more rapid compression. The time shift might be more important than the extent of maximum compression in explaining deterioration in the protective performance of a glove as a function of repeated impacts.

Our current study augments the work of preceding researchers in several ways. It represents the first evaluation of the performance of a pneumatic boxing glove over a long series of impacts. It also incorporates use of much higher levels of impact energy than has characterized any of the prior research into effects of numerous impacts on glove performance. The previous highest was the 44 J employed by Chadli et al. [12], who produced that level by combining a glove velocity of ~6.4 m·sec^{-1} and a striker mass of ~2.0 kg. We used a glove drop height of 3 metres to generate a pre-impact glove velocity of ~7.6 m·sec^{-1}. With an effective impact mass of ~3.3 kg, our impact energy level was therefore ~99 J. Walilko et al. [2] reported that for seven elite boxers who delivered maximal straight punches to the head of a Hybrid III manikin the peak pre-impact glove velocity averaged 9.14 m·sec^{-1} and the effective mass averaged 2.9 kg. This equates to an impact energy level of 121 J. Hooked punches, however, have been found to produce greater pre-impact velocities, with average readings of ~11.0 m·sec^{-1} reported in two different studies [19,20]. Even if it is assumed that hooked punches have only the same effective mass as straight punches, it appears that impact energy levels as high as 176 J are realistic. By comparison, the level generated in our experiment can be considered moderate.

The impact forces to which gloves are subject are influenced, however, not just by the impact energy level but also by the target characteristics. Under the conditions of our experiment, the peak impact forces for the Std 10 oz glove over the first five drops were in the range of 4500 to 5400 N. In an earlier paper [1], we summarized available data on the peak impact forces produced by boxers and noted that values in the range of 4000 - 8000 N have been recorded in studies involving delivery of punches to the heads of crash test manikins designed for maximum biofidelity [2,13]. Additionally, research involving the use of instrumented gloves during six professional boxing matches showed that while the great majority of peak impact forces were below 2000 N values exceeding 5000 N did occur [15]. On this basis it is evident that our study entailed assessment of change in glove performance with repeated heavy impacts whereas previous research (where the initial peak forces varied from 532 to ~1500 N) was focused on much lighter impacts.

An interesting finding of our research was that upward drift in peak impact force over a series of 253 glove drops was apparently not wholly due to alteration of glove properties, but also reflected impact-induced alteration of the target. To protect our force plate from risk of damage caused by high impact forces, we covered it with a 25 mm thick mat consisting of a closed cell, thermoplastic co- polymer of ethylene and vinyl acetate. This material is recognised as well-suited to vibration and impact absorption, and as flexible, resilient and able to recover quickly from compression [21]. We therefore considered it ideal for our purpose. Nevertheless, when we replaced a mat that had received 253 glove drops with a new one of the same composition and then performed another 10 drops with the same ARLI glove, we observed an immediate reduction in peak impact forces, to an extent suggesting that one-quarter to one-third of the change that had occurred over the course of the 253 drops was likely attributable to target modification. The actual effect might have been somewhat larger or smaller, since manufacturing variations could have caused a small difference in the baseline properties of our two mats, but the fact that mat replacement shifted not just peak forces but also the pattern of their rise over 10 glove drops toward those that were initially observed with the original mat strongly supports the inference that the properties of the latter had undergone some alteration.

We did not conduct a corresponding mat change experiment following 253 drops of the Std 10 oz glove, because of a potential confounding effect of changes in impact dynamics that occurred following Drop 141.

Consequently, we cannot exclude the possibility that the proportional effect of target modification on the upward drift in peak impact force for this glove was somewhat different from that seen with the ARLI glove. A larger effect, however, could only have resulted from greater target alteration, an outcome which would still serve to emphasise the ability of the ARLI glove to provide superior target protection in the context of repeated impacts.

It is possible that target modification was associated with storage of potential energy in the mat, with scope for additional storage lessening as the series of drops progressed, thereby accounting for the gradual upward trends in the impulse of impact (as indicated by area under the force-time curve) that occurred with both the ARLI and Std 10 oz gloves. Greater mat compression due to higher impact forces produced by the Std 10 oz glove may have increased the return of potential energy to kinetic energy during breaks between blocks of glove drops, thereby contributing to more substantial recovery of that glove between blocks of glove drops, particularly in the long break of more than 70 minutes between Blocks 4 and 5. If this was the case, however, it would be necessary to surmise that the mat was less resistant to recompression following recovery, since peak impact force and peak rate of force development regained quite high levels within the first 10 drops of Block 5.

Our data are consistent with the notion that the time over which a change in target momentum is distributed is a principal determinant of peak impact force. For the Std 10 oz glove, primacy of this mechanism is strongly suggested by the very high inverse correlation between force plate contact time and peak force ($R^2 > 0.96$ for 250 glove drops). Although the correlation was much lower for the ARLI glove, this might have been due to noise in the contact time data resulting from an effect of slower rise and decline in forces making the points of contact initiation and release less distinct. Such an explanation is supported by the fact that when time to peak force was used in place of contact time as a descriptor of the temporal nature of ARLI glove impacts, thus providing a more precisely identifiable endpoint, the correlation with peak force was substantially improved. Even so, the observation that the R^2 value was still only 0.59 offers grounds for conjecture that, for the ARLI glove, a variable other than contact time might also have exerted a major influence on peak force. It is conceivable that in the case of the Std 10 oz glove, progressive increases in peak force may have been due very largely to reduction in time taken to reach a given level of glove compression and stiffness limited by the material properties of the foam padding, while the pneumatic impact-damping mechanism of the ARLI glove allowed a gradual increase in glove stiffness to take place concomitant with decrease in contact time. It can be imagined that the ARLI glove eventually could become dynamically stiffer during impact in concert with a need for more rapid expulsion of air from its bladder through a fixed aperture, a situation obviously not applying to the Std 10 oz glove.

We can only speculate on what might have happened to the Std 10 oz glove in consequence of its off-target landing on Drop 141. As can be discerned from Figure 2 and Figure 12, the two immediately following drops produced considerably lower peak force measurements and longer contact times compared to Drop 140. Then, after a short break, markedly elevated peak force readings and reduced contact times were observed, with the force-time curve shifted decidedly leftward (see Figure 18). These changes persisted for ~60 drops, before a 73-minute break between Blocks 4 and 5 of the experimental sequence was associated with some recovery, although force-time curves generally remained well to the left of those recorded for the first 140 drops. To us, the most plausible explanation for this pattern is that:

1. The off-target landing caused a marked change in both the shape of the glove and the resistance of its padding to compression.
2. The altered shape caused an increase in the contact surface area of the following two impacts, with the distribution of the impact energy over this larger area reducing peak forces.
3. During a break of 4.5 minutes before commencement of the next sub-block of glove drops, there was substantial reversion of the glove toward its original shape as potential energy stored through its deformation was converted back to kinetic energy.
4. The change in the qualities of the glove padding then became the predominant influence on glove performance, reducing the time taken for it to reach a given level of compression, with attendant increase in the rate of change of momentum producing higher peak forces and peak rates of force development.
5. During the 73-minute interval between Blocks 4 and 5 of the drop testing experiment, there was partial recovery of the qualities of the glove padding, but not enough to restore it to the level of performance that it demonstrated prior to Drop 141.

There is some evidence to support the notion of an increased contact surface area for Drops 142 and 143, since the force plate impact profiles provided by the Kistler Bioware software for these drops were "thicker" than those for drops performed beforehand and afterwards.

While our direct observations may well be open to other interpretations, it can be stated with certainty that 140 drops of the Std 10 oz glove under the conditions of our experiment produced changes in glove performance that were quite minor compared to those inducible by more traumatic impact.

Our findings have important practical implications. Experimental designs for future research entailing glove comparisons will need to exclude potential order effects created by change in the material properties of any coverings used to protect force-measuring instruments. It now seems that such change can occur even in circumstances where the baseline properties of the covering seem close to ideal, and that in situations where two identically performing gloves are consecutively assessed it may cause the glove tested second to seem inferior. Although this potential order effect appears to be quite small relative to the differences in performance between Std 10 oz and ARLI gloves, it could affect the quantification of those differences, and confound comparison of different prototypes of a specific glove type. Modelling of changes of glove performance with repeated impacts, as accomplished through this study, offers a prospect for mathematical correction of order effects, but we have so far developed models only for two glove types and a single drop height, and have not explored interactions that might arise from variations in experimental protocols. For example, it is possible that testing of an ARLI glove could have relatively little influence on the results of subsequent testing of a Std 10 oz glove, but that the reverse might not be true. Much more extensive and complex modelling would be needed to ensure precision of mathematical corrections.

It may be preferable to either seek a more impact-resistant protective material or to interweave the testing of gloves so that each is subject to only a few impacts before being replaced and then reinstated. The latter approach would have the disadvantage of increasing likelihood of error caused by continual "reseating" of gloves on the impacting device, and determination of the extent of this error relative to that produced by an order effect therefore would be necessary.

It is noteworthy that many devices used to measure impact forces produced by boxers have incorporated protective padding [16,17,22,23]. This has been thought essential to safeguard not only the devices but also the hands of the boxers [16]. Our results suggest that whenever padding is included consideration must be given to the possibility that the measurements might be influenced by changes to properties of the padding over the course of a series of impacts. Multiple calibrations of the measurement system throughout each testing session might be needed to ensure the integrity of the data. Additionally, it is entirely possible that padded protective equipment used by boxers (and participants in other combat sports) might become progressively less effective within the confines of a sparring session or a bout, and/or with employment in several contests during a day. The padding in such equipment often includes EVA foam [21].

The most salient outcome of our study, however, is reinforcement of the case for use of pneumatic gloves to enable safer boxing.

We have now demonstrated that in their current iteration these gloves acutely diminish peak impact forces and rates of force development, decrease upward drift in these variables with exposure to numerous high-energy impacts, and have a high level of structural robustness. We recognise that intervals between successive impacts were longer in our experiment than often occurs in the real world, where two or more punches may be delivered within a second. The comparative abilities of conventional and pneumatic gloves to effectively damp all impacts in such a rapid sequence remain to be determined. If it can be proven that pneumatic gloves are not inferior in this regard, there will be a strong rationale for their further development and the conduct of extensive field trials.

We have previously published a review of arguments for and against boxing [24]. There is no doubt that the sport exposes participants to risk of serious injury. Between 1890 and 2007, more than 1200 boxers died either in the ring or within a few days after leaving it, with subdural hematoma being the most common cause [25]. Amateur boxers accounted for almost a quarter of the fatalities. From 1990 to 2008, there was average of almost 2000 presentations per year to United States Emergency Departments for head or neck injuries sustained in boxing [26], raising concerns about possible sequalae, since neurological damage can lead to debilitating functional deficits later in life [27-29]. Occurrence of rib fractures, pneumothorax, myocardial contusion, spleen rupture and injury to other abdominal organs is also well-documented [30-34]. In their current form, pneumatic boxing gloves do not reduce peak impact forces or peak rates of force development enough to eliminate the injury risks, but they do have potential to reduce overall injury incidence and severity.

Our primary aim, though, is to support ongoing evolution of modified versions of boxing in which risk of serious injury is minimal and lifelong participation is therefore facilitated.

Such versions presently exist in a fledgling state [35], with prohibition of impacts to the head and neck among their fundamental characteristics, but their long-term viability will likely require progressive refinement of highly effectual protective equipment, establishment of new rules, customised education programs for coaches and athletes, specialised teaching of skills and perhaps even creation of novel models of competition. Pursuit of this diverse array of tasks constitutes a substantial challenge that will be met only if a sufficiently broad, expert and focused collaborative effort emerges. Even so, the advances being made in the iterative development and evaluation of pneumatic gloves represent a major step toward realising the objective.

9.3.6. Conclusion

Pneumatic boxing gloves of the type used in our experiment show considerable promise as one means to enable safer boxing. Their effectiveness in damping impacts exceeds that of conventional gloves. They retain structural integrity after a long series of high-energy impacts. Although they do not prevent some upward drift of peak impact forces and peak rates of force development in response to numerous impacts, the drift is less than that seen with conventional gloves. A strong case exists for continuing exploration of the practical utility of pneumatic gloves and their potential influence on rates and types of boxing injury. In particular, the gloves could prove to be a fillip for emergence of modified forms of boxing designed to emphasise safety.

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Chapter 10: Factors Underpinning at Least Three Years of Participant Adherence to a Community-Focused Modified Boxing Program

10.1. Declaration for chapter 10

Declaration by candidate

In the case of Chapter 10, the nature and extent of my contribution to the work was the following:

Nature of contribution	Extent of contribution (%)
Study design, data collection, data analysis and preparation of manuscript.	80%

The following co-author contributed to the work.

Name	Nature of contribution	Is contributor also a student at UC?
Allan Hahn	Assisted with data analysis and manuscript preparation.	No
Candidate's Signature		**Date** 22/03/2019.

Declaration by co-author

The undersigned hereby acknowledge that:

1. the above declaration is correctly reflects the nature and context of the candidate's contribution to this work, and the nature of the contribution of each co-author;
2. they meet the criteria for authorship in that they have participated in the conception, execution, or interpretation, of at least that part of the publication in their field of expertise;
3. they take public responsibility for their part of the publication, except for the responsible author who accepts overall responsibility for the publication;
4. there are no other authors of the publication according to these criteria;
5. potential conflicts of interest have been disclosed to (a) granting bodies, (b) the editor or publisher of journals or other publications, and (c) the head of the responsible academic unit; and
6. the original data are stored at the following location(s) and will be held for at least five years from the date indicated below:

University of Canberra

Signature 1: Allan Hahn.	25/3/2019

10.2. Prologue

In 2016, the modified boxing program at the Canberra PCYC closed. This ended an almost five-year period during which I had constant access to a dynamic field research environment that allowed me to continually experiment with program emphasis, content and equipment, and to obtain immediate feedback from participants. That environment had proven critical to the evolution of a locally attractive form of modified boxing and to rapid iteration of specialised pneumatic boxing gloves for use in the program context. It had been made even more special by its formal recognition as a joint field research centre of the Canberra PCYC and the University of Canberra, and the consequent awareness of the modified boxing participants that they were essentially co-developers of a new initiative. It would have been ideal to maintain the situation, but circumstances made this impractical. The Canberra PCYC changed its strategic direction and wanted the floor space for other purposes. At the same time, I was offered part-time employment with Boxing Australia. I saw this as an opportunity to promulgate the concept of modified boxing more widely, but accepting the new role also reduced my availability for my previous work.

Upon cessation of the Canberra PCYC modified boxing program, the club surveyed the existing participants to obtain final feedback. A substantial proportion of the participants had sustained their involvement for three or more years. I was permitted to access their feedback in order to ascertain which aspects of program made the most lasting impressions on them. A paper outlining the research methods and results was subsequently published and served to supplement the findings reported in Chapters 3 and 4. To my mind, this paper brings together the various strands of my PhD research by highlighting their overall effects on intended beneficiaries and identifying key characteristics of the program that was created. The paper is reproduced below. It was instrumental in meeting three of the six research aims identified in Chapter 1 of this thesis, as follows:

- **Aim 3:** To investigate the need and want for a modified and safer form of boxing.
- **Aim 4:** To implement a modified boxing program in a community setting and liaise with participants through everyday conversation, formal interviews and written surveys, thereby developing deep understanding of their perceptions of the program and enabling program refinement.
- **Aim 6:** To comprehensively document the implemented modified boxing program and the research surrounding it, so providing useful resources to facilitate possible design and introduction of modified boxing programs in other settings.

10.3. Published paper 9 (The remainder of this chapter is a reproduction of a published manuscript, with formatting adjusted to meet the requirements of the thesis).

Factors Underpinning at Least Three Years of Participant Adherence to a Community-Focused Modified Boxing Program

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10.3.1. Abstract

In Australia, a modified form of boxing aimed at maximising participant safety and enjoyment has existed since 2006. Known as Box'Tag, it precludes impacts to the head and neck, in accordance with recommendations of medical and other experts. It also makes use of automated scoring technology. From 2012-2016, a Box'Tag program was run at a Police Community Youth Club (PCYC) in Canberra, Australia, with the first author of this paper as the coach. It rapidly grew to include more than 100 regular participants, which was ten times the number involved in a conventional boxing program that it replaced. During its term, it gradually evolved to increasingly take on characteristics that seemed to be valued by participants. Upon its closure, participants were asked to complete a Program Evaluation Form as part of standard PCYC procedure. Among participants who met this request, there were 38 (18 F, 20 M) who had been involved in the program for at least three years. We subsequently carried out thematic analysis of their written feedback to identify which aspects of the program had attracted them and were primarily responsible for their prolonged participation. Four major themes emerged, covering the program environment, the underlying concept, the timetable and the characteristics and outcomes of the training itself. Specifically, the environment was considered friendly, welcoming and supportive. The concept was seen to have extended beyond a sport program to encompass the establishment of a dynamic community brought together by a common interest. The program timetable was regarded as accommodating and flexible, and the training itself was described as safe, fun and beneficial in multiple respects. Overall, the participants expressed deep affection for the program. Our findings accord with those of other researchers who have sought to discern factors influencing adherence to sport and exercise programs and who now suggest that traditional, highly instructional approaches to the operation of such programs might contribute to participant dropout. Prolonged involvement in the Canberra PCYC Box'Tag program is explicable in terms of self-determination theory, in that the program seems to have provided conditions that supported participant growth in autonomy, competence and relatedness. A strong case exists for replication of these conditions in other settings.

Keywords: Box'Tag, Community Sport, Modified Boxing, ModBox, Sport Design, Sport for all, Sport Participation, Self-Determination Theory

10.3.2. Introduction

Over the past five years, we have been part of a small team that has sought to determine whether it is possible to develop a modified, low-risk form of boxing capable of attracting large-scale community participation and involvement of population segments not well-reached by mainstream sports.

The first author of this paper has a background that makes him well-suited for such a project. He has been involved with boxing almost continuously since 1978, initially as an athlete and then as a coach. In the latter role, he has worked at all levels of the sport from novice to international and has received the highest level of accreditation offered by the International Boxing Association (the organisation which oversees the administration of world amateur boxing). In 2009, he was appointed to a position as a boxing coach at the Australian Institute of Sport (AIS) in Canberra. In this setting, he was exposed to the development of a modified form of boxing aimed at maximising the safety and enjoyment of participants.

Known as Box'Tag, the modified form was designed to add a new dimension to boxing by catering for people who were attracted by the fitness and skill aspects of the sport but who did not wish to take part in conventional boxing due to risk of injury [1]. The need for such a new dimension was suggested by low rates of participation in conventional boxing relative to community interest in the sport [2]. In keeping with recommendations from various medical and other experts [3-8], the rules of Box'Tag preclude impacts to the head or neck. Instead, the target zone is confined to the front of the torso and small areas on the upper arms. Even then, any impacts above a moderate level of force are prohibited, and as an additional safety measure, contestants are required to employ various items of protective equipment, including head guards and mouth guards. Scoring of Box'Tag contests is achieved through use of automated scoring technology that was initially developed by the AIS in conjunction with the Cooperative Research Centre for Microtechnology, and later improved through scientific and technical inputs from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) and a small engineering company, Superinteractive Pty Ltd. [1,2,9]. The system is shown in Figure 1. It consists of specialised instrumented vests and boxing gloves incorporating sensor fabrics. The vests have thin stripes of silver nylon yarn that form a circuit when connected to a transceiver located in a pocket on the upper back. The transceiver directs a low-level electrical current through the circuit. Electrically conductive patches are positioned on the surfaces of the gloves. When a patch bridges two vest stripes, a change in the electrical resistance of the vest occurs and is detected by the transceiver, which sends the data by wireless mechanisms to a ringside computer. A customised algorithm is then applied to determine whether a score should be registered. Scores can be displayed in real time [10,11]. The novel scoring technology has been regarded as one of the major attractions of Box'Tag [2,9].

Figure 1: Components of the automated scoring system used in Box'Tag. The image shows an instrumented vest and a conductive patch on a glove. Wires connecting vest to transceiver also can be seen. When connected, the transceiver sits in a pocket on the up- per back. Photograph provided by Kris Arnold Photography, Canberra, Australia.

Toward the end of 2010, the AIS Boxing program was closed and the first author of this paper moved to a new position as Head Coach for Boxing at the Canberra Police Community Youth Club (PCYC). As a key aspect of the position he was required to substantially broaden participation in PCYC Boxing. He therefore decided to establish a Box'Tag program at the club. Exemplar programs already existed in Sydney and Melbourne, but were operating in commercial boxing and fitness centres. The introduction of Box'Tag at a not-for-profit, community-focused club similar to the one where the first author began his own boxing journey represented a unique challenge that he was keen to undertake.

The Canberra PCYC Box'Tag program was officially launched in January 2012 as a community engagement initiative. As it began to take shape, there was a realisation that it could provide a setting for research and development (R&D) activities to support the ongoing refinement of Box'Tag - activities that previously had been performed largely in the context of the AIS Boxing program and the club hosting the Sydney Box'Tag program. After the successful completion of several small projects, a series of discussions between management of the Canberra PCYC and personnel from the University of Canberra resulted in the PCYC being formally recognised as a joint Field R&D Centre of the two organisations (Figure 2).

Figure 2. Outside view of the Canberra PCYC with one of three prominent signs displaying the partnership between the PCYC and the University of Canberra.

The establishment of the R&D Centre at the club coincided with progressive growth of the Box'Tag program to a point where it became the Canberra PCYC's most popular afternoon/evening activity, with over 100 regular participants - a 10-fold increase in participation compared to the conventional boxing program that it replaced. Many of the participants subsequently continued their engagement in the program for several years. It seemed important to understand the reasons for this high rate of uptake and adherence so as to provide a basis for successful implementation of similar programs elsewhere [12]. The present study was therefore undertaken in an attempt to identify which specific elements of the Canberra PCYC Box'Tag program were most influential in the attraction and retention of participants.

10.3.3. Approach to Investigation

We followed the examples of Bloor & Macintosh [13], McLaughlin & Ritchie [14] and Kirschbaum & Knafl [15] by re-using existing data to tease out new understandings about a situation. Arguments in favour of this approach can be found in Hinds, Vogel & Clarke-Steffen [16], Sandelowski [17], Szabo & Strang [18], Thorne [19], Fielding [20] and Law [21]. These authors contend that secondary analysis of existing data can be used to generate new knowledge, new hypotheses, or support existing theories [16]; reduce the burden placed on respondents by negating the need to recruit further subjects [17]; provide an improved benefit/cost ratio for vulnerable groups who may be at risk from repeated data-gathering intrusions [19]; and allow for wider use of data from atypical or inaccessible respondents [20] [21].

In the context of the present study, a secondary analysis was made of data collected as part of normal operational procedures carried out by the Canberra PCYC to evaluate program effectiveness. The use of this approach was considered justified on the following three grounds:

- **Compatibility of the primary data with secondary analysis**
  Thorn [19] notes that the "fit" between the purpose of the analysis and the nature and quality of the original data is an important factor when determining whether to use secondary analysis. As the data were originally collected for the purpose of program assessment, and this was the purpose also of the secondary analysis, a high level of compatibility exists.
- **Position of the secondary analyst**
  Fielding [20] believes that the value of re-using qualitative data is maximised when extensive context is provided about the primary study. Silva [22] and Moore [23] also emphasise the importance of knowing the context of the fieldwork practices and note that without this knowledge, there is the potential for the data to be de-contextualised. The present study attempted to ensure that the context and meaning of the data were not lost by using the person originally responsible for the primary data collection to conduct the secondary analysis.

- **Ethical issues**
  Growing interest in re-using data makes it imperative that researchers in general consider obtaining consent to cover the possibility of conducting secondary analysis [24]. This was the case for the participants in the Canberra PCYC Box'Tag program, all of whom signed consent forms granting permission for the collected data to be used in additional projects.

10.3.3.1. Philosophical Assumptions

The study was framed by an epistemological constructivist understanding that knowledge is socially co-constructed and generated from various perspectives [25], and guided by an ontological point-of-view that participants would construct different versions of the reality [26] that when analysed would create a detailed understanding of the experience [27].

10.3.3.2. Ethical Approval

Ethical approval for the study was obtained from the University of Canberra Human Research Ethics Committee and permission to re-use organisational data was provided by the Acting General Manager of Canberra PCYC.

10.3.3.3. Data Generation

Data for the present study were generated from the responses of 38 program participants (Table 1) who had at least 3 years of continuous involvement in the Box'Tag program and who had completed a final Program Evaluation Form upon closure of the program at the end of an almost 5-year term. The closure was due to restructuring of Canberra PCYC operational priorities and the appointment of the coach to a new position with another organisation.

The Program Evaluation Form consisted of three parts. The first was designed to obtain general demographic information. The second required participants to use a 5-point Likert scale to rate specific aspects of the program, including the extent to which it met their expectations, the suitability of the venue, the structure and format of training sessions, the exercises and activities employed, and the characteristics of the coach in terms of knowledge, methods and enthusiasm.

The third part of the form posed eight open-ended questions, as follows:

1. Are the any additional exercises/training drills you would add to the program?
2. Were there enough training sessions?
3. Were the training times suitable?
4. As a result of participating in this modified form of boxing, would you be likely to compete in and/or train for conventional boxing?
5. Can you please describe the best features of the program?
6. Are there any aspects of the program that you think could have been improved, changed or deleted?
7. Has your participation in this program been beneficial? If yes, please explain how.
8. Can you please share your experience of the program?

Table 1. Details of the purposeful sample used to obtain varying first-hand accounts of the experience.

Age Groups	**Gender Breakdown**	**Number of training sessions attended per week**
12-15 yrs	2 females, 4 males	2 male and both female athletes attended 3 sessions per week. The other 2 males attended 2 sessions per week.
16-19 yrs	5 females, 4 males	All athletes attended 3 sessions per week.
20-24 yrs	2 males	Both athletes attended 3 sessions per week.
25-30 yrs	2 females, 2 males	All athletes attended 2 sessions per week.
31-39 yrs	4 females	3 athletes attended 2 sessions per week. 1 athlete attended 3 sessions per week.
40-49 yrs	5 females, 3 males	3 female and 3 male athletes attended 3 sessions per week. 2 female athletes attended 2 sessions per week.
50+ yrs	5 males	2 athletes attended 3 sessions per week. 3 athletes attended 2 sessions per week.
Age range (12-60 yrs)	**Total** 18 females 20 males	**53.0%** of athletes attended 3 training sessions per week (13 males and 11 females). **47.0%** of athletes attended 2 training sessions per week (7 males and 7 females).

10.3.3.4. Data Analysis

In an attempt to ensure that the research objectives were met, responses from the evaluation forms underwent a 6-step analysis procedure (Table 2) that was consistent with the guidelines outlined by Braun & Clarke [28] for the organisation, identification and interpretation of qualitative data.

Table 2. The steps by which data were analysed. Following this process enabled interpretation of each individual account and the development of integrated themes.

Steps	Purpose	Methods used in present study
1. Become familiar with the data.	Getting a sense of the participants' experience	Evaluation forms were rigorously explored one at a time and notes were made to log early impressions.
2. Generate initial codes	Start organising the data in a meaningful and systematic way.	Data were organised into small "chunks" of information by highlighting any passage or word that seemed relevant to the research question. This process is known as open-coding.
3. Search for themes	Capturing the patterns in the text that were specific to the research question.	Themes were initially developed by grouping the related codes together based on their overall significance to the research question and theoretical similarities.
4. Review themes	Reviewing, modifying and developing the preliminary themes into meaningful and authentic units.	This process involved combining some of the existing themes and eliminating any that did not appear to fit in with the emerging structure. The aim here was to ensure that the themes accurately reflected what was evident in the data and that when connected they would provide a richer account of the overall experience.
5. Define themes	Identifying the essence of each theme – Braun & Clarke [28].	Consideration was given to the naming of each theme so that an immediate indication of a particular theme's essence could be clearly conveyed to the reader.
6. Writing up	Reporting the findings.	Words, extracts and comments from the original evaluation forms were chosen to help illustrate and exemplify elements of each theme.

10.3.4. Results

The analytical process outlined above revealed four major themes that together summarised the participants' feedback.

There was some overlap between the themes but Fielden et al. [29] have noted that this should be viewed as reflecting good interpretation rather than repetition as themes hardly ever emerge in isolation and are nearly always related to each other.

The themes were as follows (with the figures subsequently shown in parentheses indicating the total number of participants who noted underpinning sub-themes):

- **The environment:** It was friendly, welcoming and supportive.
- **The concept:** It was more than a sport program - we were a community.
- **The timetable:** It was accommodating and flexible.
- **The training:** It was safe, fun and beneficial.

10.3.4.1. Theme 1. The Environment: It Was Friendly, Welcoming and Supportive

Stemming mostly from responses to Question 5 (Can you please describe the best features of the program?), the environment emerged as a significant factor for the participants' uptake of the Canberra PCYC Box'Tag program and sustained involvement with it. The environment was seen as a *"positive"* (19), *"friendly"* (24), and *"supportive"* (27) place that promoted *" whole family participation"* (14) and was always *"welcoming"* (21) and *"encouraging"* (17). Two pertinent and representative comments were as follows: *"I have been to quite a few other gyms but have never seen a more family-friendly one or one that makes you feel so comfortable and welcomed. The place quickly becomes an extension of your life and going there used to be the highlight of my day"* **- (Female participant, 43 yrs old)**. *"The success of this program was largely due to the charismatic way in which it was delivered. A positive, welcoming and supportive atmosphere encouraged repeated participation and made it easy to commit to on a weekly basis"* **– (Male participant, 51 yrs old)**.

For some participants (7 males and 11 females, aged 12 - 49 yrs), the training environment was a place where they felt *"valued"* (13) and *"respected"* (15) and where they were able to express themselves without fear of being *"belittled"* (11), *"judged"* (16) or *"bullied"* (7). These participants attributed this to the supportive nature of the environment, as can be seen from the following examples: *"Knowing that I wasn't going to be ridiculed or bullied for not being good enough was one of the main reasons why I loved the program as much as I did* *and why I kept coming for as long as I did"* **- (Female participant, 16 yrs old)**. *"One of the best things about the program was that nobody judged you if you couldn't do something very well. There was always someone willing to help and plenty of encouragement"* **- (Male participant, 14 yrs old)**. *"Initially I felt very self-conscious about being in a training environment while I was overweight, and my lack of experience participating in a boxing-specific activity added to my insecurities. Within a relatively short amount of time, though, I stopped feeling self-conscious on both counts and was able to really enjoy the training.*

I believe this change was the result of regularly being in a positive, supportive and non-judgmental environment" **- (Female participant, 46 yrs old)**. *"Even though there was a wide range of ages and abilities at the training sessions everyone was considered important and given the same degree of commitment and enthusiasm and encouraged only through positive and supportive feedback rather than criticism"* **- (Female participant, 35 yrs old)**.

10.3.4.2. Theme 2. The Concept: We Were More than a Sport Program - We Were a Community

The emergence of the second theme suggests that one of the main aims of the program - encouragement of community engagement - was achieved. Fifteen females and fourteen males aged 13 - 60 years (and comprising 76% of the study sample) spontaneously indicated that "a sense of community" was a contributing factor to their prolonged participation in the program.

The importance of *"community"* for the participants is clearly demonstrated in the following extracts: *"I think the best feature of the program was the sense of community which was always welcoming and inviting"* **- (Male participant, 15 yrs old)**. *"I really enjoyed the sense of community at the program, and the welcoming nature of the coach and the other participants. Overall, I loved the whole experience and hope another program starts up soon"* **- (Female participant, 17 yrs old)**. *"The program is built around people, from the coach through to the participants. It gave me the opportunity to become a part of a very special community and I have made a lot of good friends"* **- (Female participant, 37 yrs old)** . *"The sense of community you got made the program really special. Everyone got on really well and we all tried to inspire each other to be the best that we could be"* **- (Male participant, 17 yrs old)**. *"I enjoyed the training a lot, but for me it is was all about the people and being part of a special community that made it so appealing"* **- (Female**

participant, 33 yrs old). *"Our whole family has been involved with and benefited from this program. We loved the community feel that you got as soon as you walked in the doors and the feeling of being a part of something really special"* - **(Female participant, 42 yrs old)**. *"The participants were from a wide range of abilities and age groups making it a particularly family-friendly environment and an effective community building activity"* - **(Male participant, 51 yrs old)**. *"The nature of the program as well as the coach's style fostered a positive and supportive community/team culture"* - **(Female participant, 35 yrs old)**.

10.3.4.3. Theme 3. The Timetable: It Was Accommodating and Flexible

Participants who had to juggle work and family commitments with their commitment to training (8 males and 7 females, aged 25 - 53 yrs) made it clear from their responses to Questions 2 and 3 (Were there enough training sessions? and Were the training times suitable?) that having different training sessions to choose from (Table 3) was *"essential"* (9) and *"vital"* (7) to their uptake of the program and sustained participation in it, as is evident from the examples below.

"The program provided flexibility when necessary and I really appreciated the two time options that were available. I often had to work late, so having the later session meant I never missed out on training" - **(Male participant, 53 yrs old)**. *"The flexible training times and a variety of different sessions encouraged repeated participation and made it easy to commit"* – **(Male participant, 51 yrs old)**. *"The training times and amount of sessions available were excellent. I primarily trained at the 6.30pm sessions on Monday, Wednesday and Thursday but on occasion, due to other commitments, I was able to train at the earlier time of 5.30pm and when needed I could also train on one of the other days"* - **(Female participant, 46 yrs old)**. *"I thought the overall of structure of the program and the variety of the training (technical and more fitness-orientated classes) was excellent. It was great back when I was able to do three sessions a week. However, even after I moved to the other side of Canberra, I still managed to attend two sessions a week because of the amount of sessions that were available"* - **(Female participant, 28 yrs old)**.

Table 3. An overview of the training structure that was considered by some study participants to be a contributing factor to their uptake and sustained involvement with the program. Examples of the different exercises, training drills and game-based activities used to develop and enhance the physical qualities and sport-specific skills of the participants can be accessed through a free online resource [30].

Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Sport-specific circuit training	Skill development	Punch bag training	Skill development	High -intensity interval training
Session times 17:30-18:30 18:30-19:30	**Session times** 17:30-18:30 18:30-19:30	**Session times** 17:30-18:30 18:30-19:30	**Session times** 17:30-18:30 18:30-19:30	**Session times** 17:30-18:30 18:30-19:30
Targeting Muscle endurance Aerobic conditioning Power repeatability	**Targeting** Box'Tag specific-skills through the use of constrained game activities	**Targeting** Muscle endurance Aerobic conditioning Technique	**Targeting** Box'Tag specific-skills through the use of constrained game activities	**Targeting** Muscle endurance Speed endurance Aerobic conditioning

10.3.4.4. Theme 4. The Training: It Was Safe, Fun and Beneficial

There was a strong consensus amongst the participants (13 males and 16 females aged 13 - 60 yrs, constituting 76% of the study sample) that an emphasis on safety was an important feature of the program and a significant motivator for their involvement (see, for example, Figure 3). For instance, when responding to Question 4 (As a result of participating in this modified form of boxing would you be likely to compete in and/or train for conventional boxing?) one of the male participants answered: *"No! This program taught a much safer form of boxing in a very friendly and inclusive training environment that was available to people of all ages and levels of ability, which made it very unique and much more appealing than normal boxing"* **- (Male participant, 27 yrs old)**.

Figure 3. Two of the male study participants who identified a focus on safety as a significant motivator for their involvement in the Box'Tag program. In this photo they are practising their sport-specific skills with specially constructed impact-damping boxing gloves that were developed by members of the research team as a means of improving participant safety and enjoyment. The gloves have been shown to significantly reduce peak impact forces [31]. Permission to use this image with the associated wording was provided by the people depicted.

Similar responses were provided by some of the other participants who compared their experiences with the Box'Tag program to previous experiences with conventional boxing: *"The best feature of the program was the novel and safe approach to the training. It incorporated the latest in research by examining and developing new "better" ways of getting results. This prescient mentality and the focus on safety is what distinguished this program from the rest. The coach avoided the old school "macho" mentality, which is pervasive amongst the other established boxing gyms that I have trained in"* **- (Male participant, 28 yrs old)**. *"As a long-term martial artist with some prior boxing experience, I think our program was a way of emphasising the most beneficial and positive aspects of boxing (athleticism, technique and skill) while avoiding some of the aspects which tend to discourage broader participation (risk of head injury, overly aggressive/macho culture).*

This made the training not only very appealing but also very safe" **- (Female participant, 35 yrs old)**.

The perceived importance of participating in a modified form of boxing that emphasised participant safety and enjoyment is also indicated by the following extracts: *"I enjoyed the non-threatening atmosphere of this program as opposed to the boxing gym my friend and I tried before coming here. They weren't as friendly or as welcoming and the training was nowhere near as much fun or as safe"* **- (Female participant, 17 yrs old)**. *"Having had a head injury in the past, I was very cautious about training again but after attending a few sessions here I quickly realised that Box'Tag is a really safe option and a great way to get fit and have a good time"* **- (Male participant, 28 yrs old)**. *"My parents don't like boxing - they think it is cruel and dangerous. That's the reason why my brother and I started training here"* **- (Male participant, 20 yrs old)**.

Having fun while training emerged as another factor that enhanced the participants' experience of the Canberra PCYC Box'Tag program. For some of the participants (9 males and 11 females, aged 12 - 60 yrs), having fun included training with friends. The participants used descriptions such as *"It was the best, it made the training much more fun and enjoying"* and *"training with my besties was the coolest thing about the program"* to express their feelings.

Participating in game-based activities (see, for example, Figure 4) at the Tuesday and Thursday skill-specific training sessions was also highly regarded with 12 male and 14 female participants across all age groups indicating that this aspect of the training also contributed to their sustained involvement.

For one of the younger participants the specially designed games were *"heaps fun to do and a great way to get fit"* **- (Male participant, 13 yrs old)**, while one of the female participants thought this type of training was *"a safe and fun way to learn the concepts of boxing while getting fitter and stronger"* **- (Female participant, 36 yrs old)**.

Figure 4. Participants playing a game called "peg boxing" at one of the program's skill-specific training sessions. In this activity, each partner attempts to snatch clothes pegs affixed to the other's vest. The game encourages development of tactical and movement skills resembling those required in Box'Tag. Permission to use this image with the associated wording was provided by the people depicted.

In addition to the above, a vast majority of the participants (17 males and 16 females across all age groups, amounting to 87% of the study sample) believed that the training was beneficial for accomplishment of personal, health and/or sport-specific outcomes (Figures 5-7), as exemplified by the following extracts: *"The training was excellent. I'm a lot fitter, stronger and more confident now and I really enjoy feeling this way"* – **(Female participant, 15 yrs old)**. *"Every aspect of the training was excellent. The coordination drills were really challenging and required a lot of concentration. The boxing games enhanced my learning and skill levels and the conditioning training led to growth in strength, speed and endurance"* **- (Female participant, 34 yrs old)**. *"I do the program as strength and conditioning training for rugby league and rugby union and my confidence, determination and skills have all improved as a result of my participation with this program"* **- (Male participant, 13 yrs old)**.

"Watching my son grow and develop as a person as a result of his participation with the program has been a real highlight for me. Training here has taught him to be respectful and kind to others, to always do your best and the meaning of discipline and commitment" - **(Male participant, 55 yrs old)**. *"This program has changed how I tackle physical activity. Prior to my involvement in this program I was tentative about what I was physically capable of and lacked the confidence to try. This program has increased my confidence in my ability to face physical challenges. I enjoy the challenge that each training session brings and, most importantly, I want to train"* - **(Female participant, 37 yrs old)**. *"The sessions were always mentally and physically challenging, which produced a sense of accomplishment afterwards. I found the mindset I started to develop during the training sessions really beneficial and started to adopt a similar mindset to situations and environments outside of the program"* - **(Female participant, 46 yrs old)**.

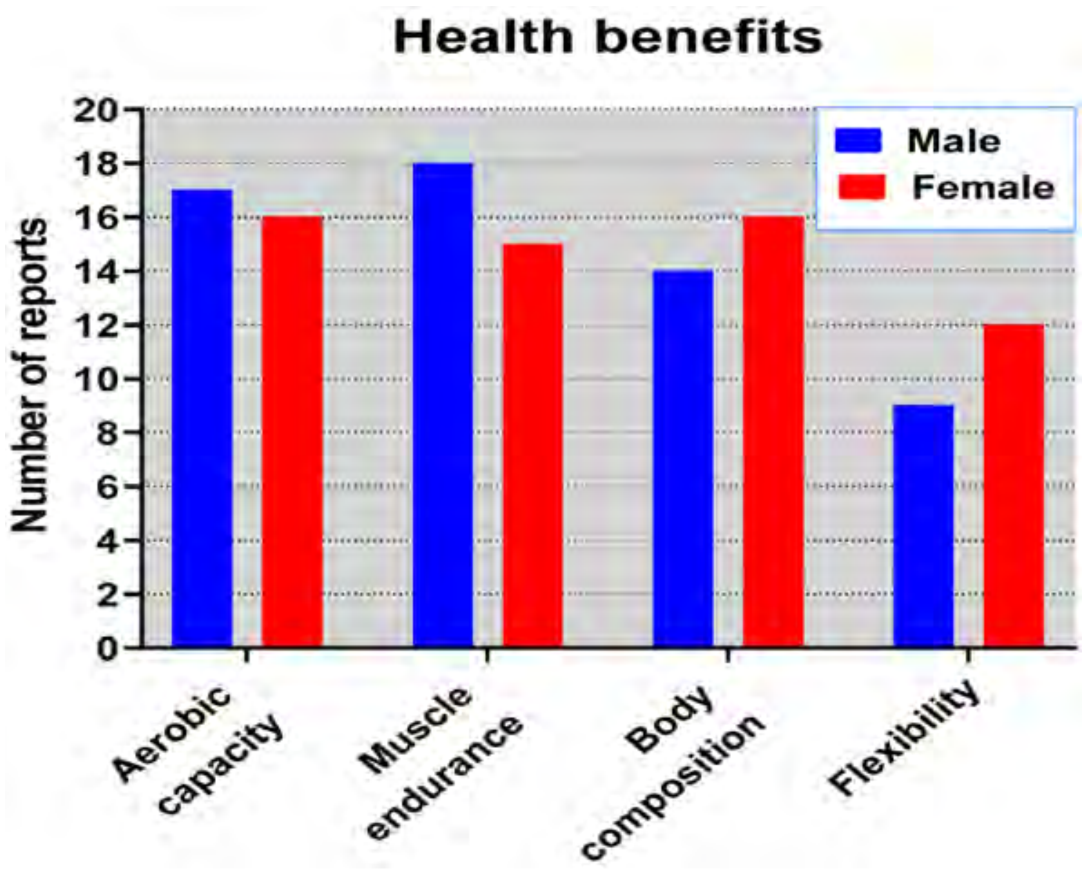

Figure 5. Number of study participants reporting specific health benefits that they attributed to their sustained involvement with the Canberra PCYC Box'Tag program.

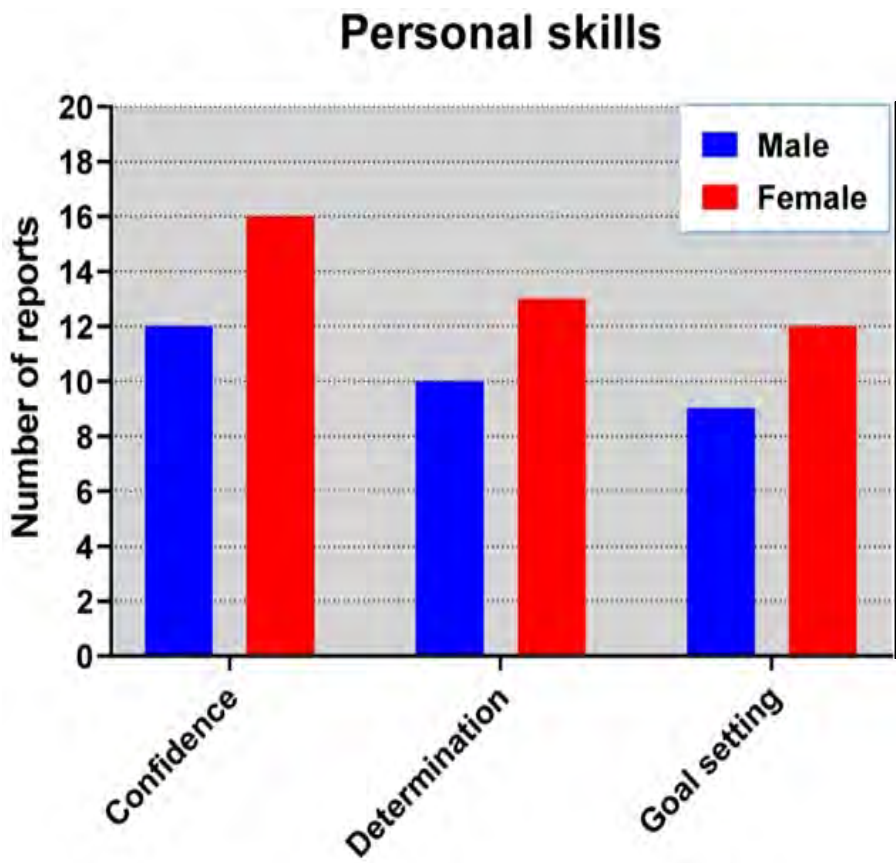

Figure 6. Number of study participants attributing improvement of specific personal attributes to their long-term participation in the Box'Tag program.

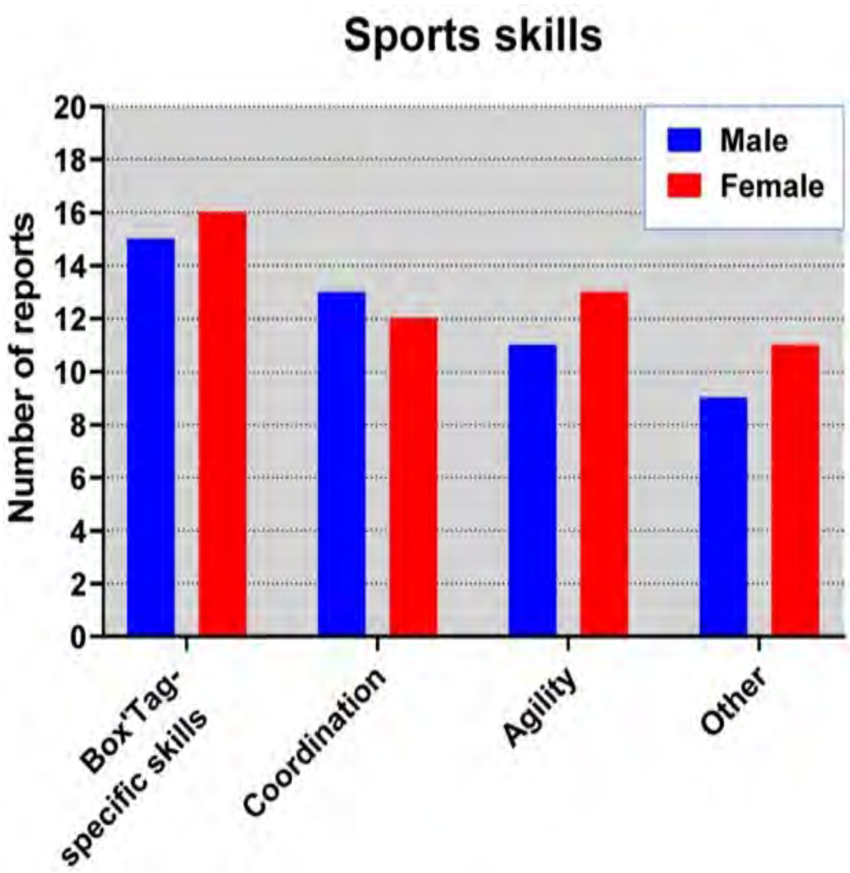

Figure 7. Number of study participants reporting improvement of specific sporting skills as a result of sustained participation in the Canberra PCYC Box'Tag program. Box'Tag-specific skills include footwork, movement patterns and attacking and defensive actions. The "Other" category includes weightlifting, running, jumping, skipping, throwing and catching.

10.3.5. Discussion

The present study set out to identify, interpret and report the key factors that encouraged participants to enrol in the Canberra PCYC Box'Tag program and maintain active involvement in it for at least three years. The results suggest that a perception of the training environment as friendly, welcoming, supportive and free of judgement was one such key factor.

This finding is consistent with the observations of other researchers. For example, a longitudinal investigation conducted by Casey et al. [32] showed that the participation of adolescent girls in sports clubs is influenced by their perceptions of the club environments. In the study [32], female students from 17 metropolitan and 14 non-metropolitan secondary schools in Australia took part in three annual surveys that recorded their current or past membership of sports clubs and the underlying motivations. For ~80% of respondents, the friendliness of the club, knowing someone at the club and the friendliness of the coach were the predominant factors affecting their sport club participation.

The emergence of the first theme is also compatible with the literature on 'psychological safety'—the degree to which individuals feel comfortable taking positive interpersonal risks (such as trying something new) [33]. According to Edmondson & Lei [34] and Merritt et al. [35], welcoming and supportive environments often promote a sense of psychological safety for participants by encouraging them to engage in authentic ways that align with personal motivations, which in turn, enables the co-construction of meaningful and productive experiences. When nurtured, these experiences can lead to participants feeling a sense of empowerment within their environments [33-35]. For example, research [33-36] shows that when individuals feel a sense of psychological safety, they are more likely to demonstrate such self-regulated strategies as engaging in learning opportunities, admitting and learning from mistakes, providing feedback to others, sharing suggestions and helping others. It would appear that the environment at the Canberra PCYC was sufficiently positive, supportive, welcoming and non-judgmental to promote a feeling of psychological safety and a sense of empowerment for many of the participants, which in turn resulted in the development of some the self-regulated strategies described above and contributed to sustained participation in the program.

Participants in the present study made it clear that belonging to a special community was another key motivator for the longevity of their involvement in the Canberra PCYC Box'Tag program. This finding is consistent with research showing that people are more likely to stay involved in a community initiative when they feel they belong to that community, and when that community makes them feel valued and accepted [37-39]. This transfer of feelings and emotions is referred to as a Sense of Community (SoC) [40-42].

A number of scholars [40-45] have noted that sport is ideally positioned to promote, develop and enhance a SoC since it represents a social institution that offers a collective social experience for participants. In fact, it has been suggested that sport is one of the few remaining domains where this type of collective experience is promoted and experienced [43]. Warner and colleagues (Warner & Dixon [44]; Warner, Dixon, & Chalip [45]) used a grounded theory approach to examine the specific features that lead to a SoC among recreational and elite athletes in a collegiate sport context. Their research revealed that certain community features are required for development of SoC in such settings and yielded a seven-factor theoretical model outlining those requirements (Table 4).

Table 4. A summary of the seven mechanisms identified by Warner et al. [45] as contributors to a sense of community for participants within a sport setting.

Factor	Definition
Administrative consideration	The level and intentionality of genuine care and concern expressed by administrators for the safety and well-being of participants.
Common interest	Strong and positive group dynamics, social networks, and meaningful friendship groups that form as a result of individuals being brought together by a common interest.
Competition	Opportunities to excel against both internal and external rivalries.
Equity of administrative decisions	Decisions and actions demonstrating that all members are treated equally.
Leadership opportunities	Opportunities to guide and direct others in the community.
Social spaces	A common area or facility in which athletes are able to interact with one another.
Voluntary action	Self-fulfilling and self-determining activities resulting from little to no external incentive.

The emergence of an accommodating and flexible timetable as a theme demonstrates that the administrators of the Box'Tag program were at least partially successful in attempting to address one of the known barriers to sport participation by providing a range of options in relation to training times. In Australia, for example, it has been reported that many people find it difficult to be involved in organised sport because of the rigid structure of training and competition times and the resultant impact on family life [46]. This inflexibility has led to a significant shift toward less structured forms of exercise such as bushwalking, recreational cycling, gym training and park runs, and traditional sports are now in direct competition with these activities as vehicles for meeting the physical activity needs of the Australian public [46].

Research undertaken by the Australian Sports Commission (recently renamed as Sport Australia) in consultation with GfK Blue Moon provided an overview of challenges associated with Australian club-based sport participation. The research [47] was aimed at identifying motivators and barriers that influence decisions and behaviours of Australians in relation to club-level sport participation. Through use of a specifically developed needs-based, consumer-centric market segmentation model targeting sports participants and non-participants, the study concluded that club membership is being negatively influenced by the fact that Australians:

- Are increasingly time poor.
- Have limited budgets and are being inundated by new forms of entertainment.
- Have new preferences towards fun and fitness.
- Are increasingly favouring more flexible, non-organised forms of physical activity.
- Are developing new tastes as the population becomes more culturally diverse.
- Are sometimes self-conscious and embarrassed by their lack of sporting ability, with this applying especially to adolescents.

Further analysis of the results of the above study enabled grouping of identified barriers to adult sport participation into two categories - practical barriers and perceptual barriers (Table 5). The Canberra PCYC Box'Tag program was deliberately designed to address not only the issue concerning flexibility of training times but also many of the other issues, and the responses recorded by participants indicate that this was instrumental in their uptake of the program and their long-term adherence to it.

For sport to keep pace with the changing needs of the public, there may be a need for the development and implementation of more community-focused programs based on contemporary knowledge of participation barriers.

Table 5. The practical and perceptual barriers to adult sport participation in Australia, as reported in the Australian Sport Commission Market Segmentation Report for Adults [47]. For many of the study participants, the overriding perception was that they were not the "type of participant" that would interest the clubs.

Practical barriers	Perceptual barriers
Lack of time, meaning other commitments or interests took priority over sport or physical activity.	A dislike of the assumed competitive nature of sport.
A lack of information about how to get involved.	Self-consciousness and a general dislike of certain sports.
Costs—both purely financial and in relation to perceptions of value for money.	Perception that club members are cliquey, exclusive, single-minded and often highly judgmental of non-participants or those with less ability.
Location and convenience, including the inflexibility of club schedules.	Belief that sport clubs only operate an "open door" policy to those with sufficient ability and commitment, and a feeling of lacking the level of skill needed to achieve success.
The commitment required as well as other conflicting commitments.	Lack of confidence in being able to break into the club social scene, or inability/unwillingness to make the required commitment.
Club structures, "in-house politics" and organisation.	Belief that a highly competitive nature is a pre-requisite for club participation.

The fourth and final theme that emerged from our analysis of feedback provided by participants in the Canberra PCYC Box'Tag program was focused on characteristics and effects of the training. It incorporated three sub-themes that are discussed below.

The training was safe: The emergence of safety as a sub-theme is consistent with previous research undertaken by members of our team who performed an analytical interpretation of data collected from in-depth interviews of participants who had at least two years of involvement in the Canberra PCYC Box'Tag program [48].

Participants in that study (three females aged 27 - 44 yrs) considered *"not being able to hit to the head"*, *"using specially developed impact absorbing gloves"* and *"not intentionally harming anyone"* as *"vital"* for their involvement with the program and noted that the risks involved with conventional boxing were *"unnecessary"*, *"inappropriate"* and *"completely avoidable"*.

There is unequivocal evidence that participation in conventional boxing entails serious risk of harm, including neurological damage [49-52] and facial disfigurement [53]. Between 1990 and 2008, there were more than 37,000 presentations to United States Emergency Departments for head or neck injuries caused by boxing [54]. Boxing-related injuries were also responsible for a total of 437 British Army medical unit admissions from 1969 to 1980 [55]. Head trauma accounted for ~ 68 % of these injuries, but there were also 20 admissions for trunk injuries including rib and vertebral fractures, and 13 for kidney and pelvic organ injuries that required an average hospitalisation time of 6.2 days [55]. Medical studies have detected a relatively high incidence of electro-encephalographic (EEG) abnormalities and deficits in cognitive function amongst boxers [56-59], and several studies have shown structural pathology in the brains of boxers including changes resembling those associated with Alzheimer's disease [60-63]. Although the incidence of chronic traumatic brain injury is higher in professional than amateur boxing because of the longer duration of professional contests, magnetic resonance imaging reportedly shows discernible structural anomalies in the brains of ~11 % of amateur boxers [64]. Between 1890 and 2007, more than 1200 boxers, including 293 amateurs, died in the aftermath of contests [65].

The present study demonstrates that it is possible to modify rules, equipment and sub-culture to produce a form of boxing that is much safer while also able to attract and retain considerable numbers of participants. A notable finding of our research is that following its establishment the Canberra PCYC Box'Tag program rapidly drew a number of participants that was ~10 times greater than the level associated with a pre-existing conventional boxing program operating at the same venue. Even allowing for the fact that in general the Box'Tag participants trained less frequently and for slightly less time per session than the conventional boxers, overall use of the training venue had an approximate four-fold increase. It is also salient that the Box'Tag program attracted participants from outside the conventional boxing community, with its perceived safety being crucial in this regard, as summarised by one of the older male participants who wrote: *"The whole concept of this program is to encourage participation in a safer form of boxing, learn new skills and create a sense of community. This is a program that should be greatly encouraged because it works and it is needed. However, it should not lose its prime objective of a community experience that is available to everyone"* **- (Male participant, 60 yrs old)**.

Nevertheless, uncertainty remains concerning the extent to which modifications such as those introduced at the Canberra PCYC would ever be accepted by the wider boxing community [66], since it is believed that the cultural, visual and emotional appeal of the sport to that community is closely tied to the inherent risks [67]. A primary effect of the modifications may be an ability to substantially broaden the historical boxing demographic.

The training was fun: For the participants in the present study having fun while training was perceived as *"essential"* to their sustained involvement in the Box'Tag program, with 29 of the 38 survey respondents spontaneously mentioning this aspect (see, for example, Figure 8).

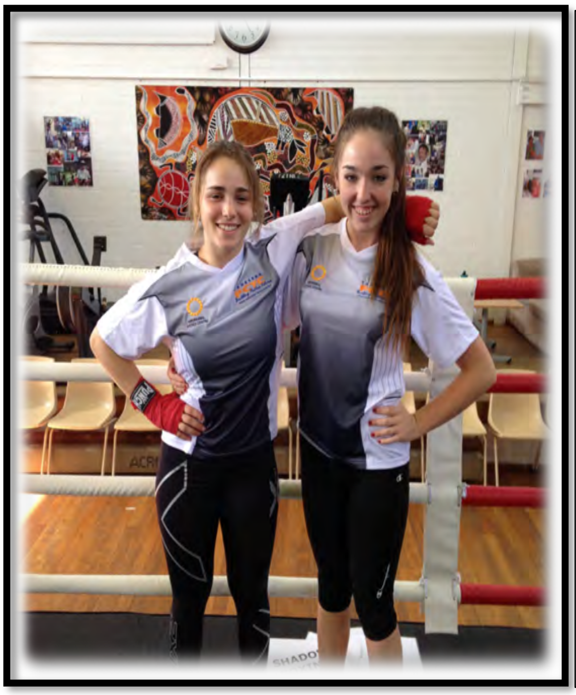

Figure 8. Two of the younger female study participants who considered training with friends and the achievement of high skill levels through use of novel, constrained games as a lot of *"fun"* and important motivators for their sustained involvement in the Canberra PCYC Box'Tag program. Permission to use this image with the associated wording was provided by the people depicted.

This finding is consistent with literature showing that two sources of fun are important for achieving long-term sport participation [68].

1. Situational influences such as positive and meaningful social interactions [69]; supportive relationships [70]; the challenges involved with learning the activities and training drills [71]; and extrinsic rewards such as praise from coaches and peers [72].
2. Individual characteristics including high perceptions of sporting competence [72] and achievement of high skill level [73].

Interestingly, it appears that the perception of fun depends less on winning than on simply performing well and achieving a desired outcome when there is something at stake [74].

In the present context, the participant perceptions of fun consisted mostly of training with friends (a situational influence) and the use of constrained games [75,76] for the development of sport-specific skills (a situational and individual characteristic).

The use of the constrained games at the program enabled participants to develop their tactical appreciations of Box'Tag and acquire the skills necessary for displays of competency by providing them with opportunities to explore and discuss the tactical aspects of the activities [77,78] in an encouraging, supportive, inclusive and non-judgmental training/learning environment. This approach to skill development is in stark contrast to the more traditional and highly structured "skill-drill" methods that focus on the individual technical elements of a sport separate from the context in which they are to be applied, and generally prior to any actual participation [79-81]. The latter methods provide little scope for the development of tactical knowledge [82] and are contradictive of the specificity of motor learning and the fundamental principles of skill transfer [83].

Learning and development of skills are seen as essential elements of sports participation [72], and our data suggest that encouraging friends to train together while developing their skills through the use of constrained games enhanced the participants' experience and contributed to their sustained program engagement.

The training was beneficial: Another important finding of our research was that 33 of the 38 athletes who completed the Program Evaluation Form suggested that participation in the Canberra PCYC Box'Tag program was beneficial to development of health, personal and/or broader sporting outcomes (see, for example, Figure 9).

Figure 9. Some of the study participants taking part in a strength and conditioning training session that formed part of the Box'Tag program. Permission to use this image with the associated wording was provided by the people depicted.

A perception that the training was beneficial for improving the physical qualities of participants is not surprising considering the length of time they spent with the program and available data suggesting that boxing training is an excellent activity for the development of physical fitness [84]. National male amateur boxing squads from England, France and Germany have recorded average maximum oxygen uptakes in the vicinity of 60 - 65 $ml{\cdot}kg{\cdot}min^{-1}$ [85,86], which far exceeds the 42 - 46 $ml{\cdot}kg{\cdot}min^{-1}$ considered "good" for 20 - 29 year old males [87]. Results from a study that investigated the punch forces of senior male English amateur boxers also helps to demonstrate the effectiveness of boxing training [88].

The study was conducted in a laboratory situation and revealed punch forces reflecting extraordinary neuromuscular capability [88].

Boxing training is also a highly efficient way to exercise. This is evident from a study that compared the energy expenditure of boxing-specific training with treadmill running [89]. Eight adult males with experience in boxing training completed the following three sessions:

1. A one-hour boxing-specific workout in a laboratory.
2. A one-hour boxing-specific workout in a gym.
3. A one-hour incremental run on a treadmill

The subjects were found to have an average energy expenditure of 671 calories (2807 kilojoules) in the laboratory and 599 calories (2506 kilojoules) in the gym when performing the boxing training. To achieve similar energy expenditure on the treadmill, the participants had to run approximately 9 km during the one-hour session. The researchers considered the energy expenditure high for all three tests but concluded that the boxing workouts were more anaerobic and required greater overall body power than the treadmill running [89].

Participant perceptions that involvement with the Box'Tag program was beneficial for the development of a number of personal attributes may be a reflection of their long-term program engagement, since it has been reported that prolonged sport adherence is crucial not just for the development of sporting skills, but also for the changing of attitudes and behaviour as a consequence of sports experience [90].

There is considerable debate, however, as to whether sports participation in general has any character-building effects, and instances of athletes using prohibited performance-enhancing drugs, cheating, abusing officials and committing crimes outside of the sporting arena are sometime cited as evidence to the contrary [91].

Current expert opinion is that sport does not inherently build character but can do so if the experience is structured in a way that places an imperative on specific behaviours, provides appropriate role models and rewards demonstration of positive behavioural traits [92,93]. In the context of the Canberra PCYC Box'Tag program, a focus on "whole-person" development (rather than just athletic development) by encouraging, modelling and rewarding such desirable values as fair play, cooperation, responsibility, determination, empathy and continuous learning appears to have been recognised and favourably regarded by participants and to have contributed significantly to their lasting involvement (see, for example, Figure 10).

Figure 10: A young female study participant who reported that her long-term involvement in the Box'Tag program was responsible for the development of important personal attributes such as determination, goal setting, leadership skills, and improved self-confidence and self-image. Permission to use this image with the associated wording was provided by the person depicted.

Participants indicated that their long-term engagement with the Canberra PCYC Box'Tag program was also motivated by their perceived development of Box'Tag-specific skills, as well as a range of other more fundamental movement and physical literacy skills such as coordination, agility, skipping, hopping, jumping, throwing and catching (see, for example, Figure 11).

The emergence of this sub-theme is consistent with the literature on exercise motivation from the perspective of self-determination theorists [94,95], who contend that a lack of motivation toward sport and/or exercise can be broadly explained by two factors.

Firstly, some people do not wish to participate in sport due to competing demands on their time (from such external sources as school/education commitments, family interests and career obligations), or do not place enough value on the outcomes potentially achievable through such participation to justify making sport and/or regular exercise a priority in their lives [95,96]. The second factor is that some people perceive that they are not physically fit or skilled enough to take part in a sporting or recreational activity of their choice, which in turn, presents a significant barrier to participation [95,97]. These factors are among those reported also by the Australian Sports Commission [47], as presented earlier in this paper.

It has been reported that some individuals express high levels of personal motivation to exercise regularly and/or commit to a sporting program, but then go on to display behaviours to the contrary, reflecting little follow-through and a lack of genuine commitment [98,99]. Of particular concern is that a significant number of people exercise or participate in sport only because of such externally controlled motivations as improving appearance or gaining a positive reward. For example, participation in recreational activities like going to the gym or running regularly is often based on a feeling of “this is something I have to do” rather than “this is something I truly want to do” [100,101].

The above highlights that many individuals are either unmotivated or not sufficiently motivated to be physically active or are motivated by externally-driven considerations that generally do not lead to sustained participation. This demonstrates a need for further investigation of the self-regulatory factors associated with regular sport participation and other forms of physical activity [100]. Based on self-determination theory [94-97], it has been argued that the stability of an individual’s motivation is partially dependent on the degree of perceived autonomy. The implication is that self-endorsement for an activity and a willingness to improve that is driven by self-approval should result in greater levels of persistence and longer involvement [100,101]. This suggests that the use of utilitarian approaches and over-prescriptive instructional coaching methods to promote exercise and sport participation, as often prevalent in group exercise classes and sport settings where exercises and training drills are externally prescribed, could actually be partially responsible for the high dropout rates observed in such settings, and accordingly could be ill-suited for the promotion of sustained sport participation [101-104].

The Canberra PCYC Box'Tag program provided its members with an autonomy-supportive training environment in which their participation was voluntary, their opinions were valued and sharing of their ideas was encouraged. This may have fostered high levels of self-endorsement for the various training activities and led to involvement in the program being mostly self-driven by a desire and willingness to improve, with such intrinsic motivation externally reinforced by a program philosophy of continuous learning. It seems likely that resultant feelings of satisfaction contributed to the prolonged engagement of the participants with the program, which in turn provided the time necessary for the development of sport-specific and other more fundamental movement and physical literacy skills, and for formation and consolidation of social relationships.

The program environment therefore may have supported participant experiences of autonomy, competence and relatedness. Self-determination theory suggests that conditions providing for meeting of these basic psychological needs are associated not only with persistence, but also with enhanced performance and creativity [97-101]. Perceptions of competence and relatedness were very clearly communicated in the written feedback from Canberra PCYC Box'Tag program participants.

Figure 11: One of the older male study participants who indicated that his long-term involvement in the program was motivated by his development of Box'Tag-specific and other more general fundamental movement and physical literacy skills. This participant was blind, which demonstrates the importance of maintaining a "sport-for-all" concept so that people of all ages can enjoy the social, health and personal benefits associated with sport participation regardless of their gender, cultural background or levels of functionality. Permission to use this image with the associated wording was provided by the person depicted.

An interesting and somewhat surprising finding arising from the present study is that the participants made no mention of the automated scoring technology, which up to now has often been considered one of the major attractions of Box'Tag and an integral part of the concept [2,9,105]. The lack of mention occurred even though the program participants had regular exposure to the technology, which for a considerable period was made available weekly for use in Box'Tag sparring. Although the nature of the present study precludes formation of definitive conclusions as to why access to the scoring technology was less highly regarded than other program characteristics, the finding suggests that most members of the Canberra PCYC Box'Tag program were choosing to participate for reasons other than competing. This suggestion is compatible with the AusPlay participation data collected by the Australian Sports Commission between October 2015 and September 2016 [46]. The data show that only 5% of ~20,000 survey respondents aged 15 yrs and older identified competition as the key motivator for their participation. In contrast, the top three motivators for sport participation during the above period were:

1. Improving physical health and/or fitness (63%).
2. Having fun (55%).
3. Gaining social benefits (32%).

The automated scoring technology has been a key component of the Sydney Box'Tag program, which has operated since 2006, staging regular Box'Tag competitions for its members. Conducted similar to conventional boxing tournaments, these events provide an opportunity for club participants to demonstrate their skill levels, and to experience the thrill of competition in encouraging and supportive environments.

We have assisted with setting up and running the technology at the Sydney events and have seen at first hand that the objectivity of the scoring and the excitement generated by dynamic, real-time display of scores (Figure 12) is almost always favourably received by participants and audiences alike.

Given that there appears to be more of a desire for the scoring technology at the Sydney club, a case could be made for the development of two different forms of modified boxing, especially since the Sydney program is more geared toward preparing athletes for traditional boxing and sometimes uses Box'Tag as an entry-point to help prepare athletes for formal competition within the amateur boxing ranks.

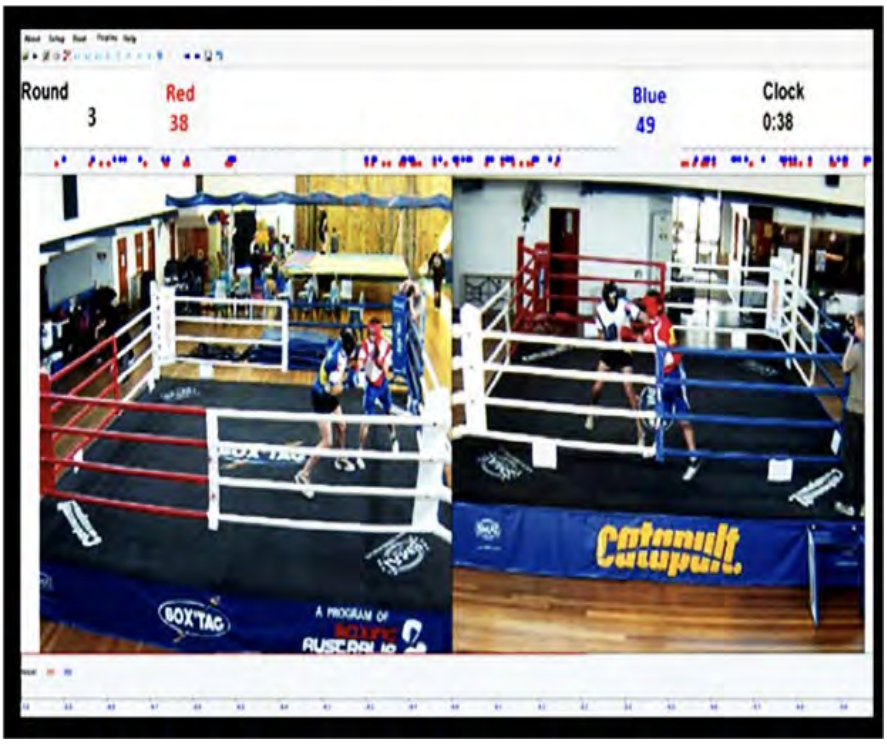

Figure 12. Real-time displays of scores in a Box'Tag contest through the use of the automated scoring technology.

Promoting at least two different forms of modified boxing has the potential to enable greater uptake of the modified boxing concept by aligning individual motivational characteristics to additional participation opportunities, which in turn would increase the possibility of greater community engagement. For example, Bailey et al. [106] propose that involvement with sport occurs for a number of reasons and, in keeping with the findings derived from the AusPlay participation data of the Australian Sports Commission [46], they note that for many people competing and/or winning is not a significant motivator for their participation. Instead, Bailey et al. [106] contend that there are three different categories of sport participation, which are summarised in Table 6. Also included in Table 6 are suggestions as to how these categories could be developed into a modified boxing implementation framework, designed specifically to be compatible with the views of Collins [107], who described sport development as: *"a process of effective opportunities, systems and structures that are set up to enable people in all or particular groups and areas to take part in sport and recreation or to improve their performance to whatever level they desire"*.

To differentiate modified boxing programs with a predominant sport-for-development focus from those placing greater emphasis on competition between athletes, introduction of distinct program names might be helpful. Accordingly, we have begun to refer to programs resembling that which evolved at the Canberra PCYC as "ModBox", while continuing to call programs modelled on the one at the Sydney club Box'Tag. Over the past two years, with support from the Australian Department of Foreign Affairs and Trade, ModBox programs have been implemented as a sport-for-development initiative at 16 schools and a substance abuse rehabilitation centre in northern India. An overview of that initiative is available in a free online document [108].

Table 6. A summary of the different categories of sport participation as reported by Bailey et al. [106] and their possible applications to establishment of a modified boxing implementation framework incorporating modified boxing programs with different primary emphases.

Categories of sport participation	Definition	Most suitable program
Participation for Personal Wellbeing (PPW)	Participants take part in sport for personal wellbeing reasons including the social and health benefits associated with participation.	A sport-for-development initiative modelled on the Canberra PCYC program would aim to use sport as a vehicle to assist the positive growth and development of the participants and to help build happier and healthier communities.
Personally Referenced Excellence (PRE)	Participants gain enjoyment from skill development and the challenge of surpassing their previous performances.	The above sport-for-development initiative and the existing Box'Tag program operating at the Sydney club would both be suitable for this category of sport participation, since participants within this category tend to gain enjoyment from learning skills and the challenge associated with bettering their previous best efforts.
Elite Referenced Excellence (ERE)	Participants engage with sport for the purpose of winning at the highest possible level and generally measure success by win/loss ratios.	The Box'Tag model operating at the Sydney club would be much better suited to try and engage with this category of sport participant, particularly with its focus on preparing athletes for amateur boxing competition.

Apart from the automated scoring technology, several other aspects of the Canberra PCYC Box'Tag program that we had thought attractive to participants elicited little or no comment on the Program Evaluation Forms. Included here was the positioning of the Canberra PCYC as a Field R&D Centre through which the participants effectively became co-developers of the Box'Tag program and associated equipment through engagement in field trials and provision of both formal and informal feedback. Also, throughout the duration of the program some notable visitors attended sessions to see the program in action. Among these were the Chief Executive Officer (CEO) and Board members of Boxing Australia Limited, the Australian Head Coach for Boxing, a former CEO of the Australian Sports Commission, scientists from the Australian Institute of Sport, the Queensland Chief Scientist (who was also a former CEO of CSIRO, Australia's premier Government-funded research agency), a senior officer of the Queensland Academy of Sport, the Vice-Chancellor of the University of Canberra and academics from that institution, representatives of Australian sport technology companies and a former school principal who had an ongoing interest in youth education.

The visits repeatedly caused program participants to verbally express some pride that the activities at their club had captured the attention of such people, but this sentiment was not recorded in the data that we analysed. It is possible that the Field R&D Centre concept, the visits from luminaries and the availability of the automated scoring technology contributed in some way to the recorded participant perceptions that the Canberra PCYC Box'Tag program was "special" even though these factors were clearly not at the forefront of participant recollections of their experience with the program.

We recognise that the documents from which we extracted overarching themes had limitations that may have influenced our findings. For instance, the fact that the Program Evaluation Form contained a specific question about the suitability of the training times obviously brought this matter to the direct attention of the respondents and increased the probability that the flexibility of the training schedule would emerge as a theme. It is noteworthy, however, that the other three themes were derived largely from questions that were not leading. It therefore seems likely that, overall, the themes that we have identified provide a good representation of the program characteristics that the participants most valued.

Interestingly, when participants were invited to be critical of the program by responding to Question 6 (Are there any aspects of the program that you think could have been improved, changed or deleted?), there were only four comments that could be construed as being in any way negative. Two female participants aged 16 and 17 yrs suggested that the cool-down component at the end of training sessions could possibly have been more structured, while one female aged 28 yrs and one male aged 16 yrs noted that the popularity of the program sometimes resulted in a lack of floor space and suggested that a larger training area would have enhanced their experience. On the other hand, 89% of the study sample responded to the question either by indicating that it was "not applicable" (3 males and 5 females aged 12 - 55 yrs) or taking the opportunity to supplement and reinforce the positive answers that they had provided to other questions (with 13 females and 13 males aged 14 - 60 yrs adopting the latter approach). This confirms that the program was highly valued by the participants, and provides further confidence that the themes identified through our analysis are truly reflective of the participants' recalled experience of the Canberra PCYC Box'Tag program.

10.3.6. Conclusion

We have demonstrated that a community-focused modified boxing program can achieve substantial participation and adherence, while also reaching beyond the traditional boxing demographic. The structure, primary focus and philosophical underpinnings of the program appear to have been critical to its popularity. The inclusion of elements that required participants to learn increasingly complex skills added to the attraction of the program and differentiated it from programs focused solely on use of boxing-related activities to build physical fitness. The design and deployment of various constrained games as a means for skill development contributed to participant enjoyment. A key attraction of the program was that it enabled participants to experience a strong sense of community. Diversity in the age, physical fitness and functionality of participants was seen by the participants as a major program strength, as was a general emphasis on co-operation rather than competition between program members. A notion that everyone should strive for continuous personal improvement rather than within-group superiority was broadly endorsed. The program was regarded as female-friendly and suitable for whole family involvement. Perceived equality in the treatment of group members was instrumental in building strong participant affection for the program. The attraction of the program can be explained within the framework of self-determination theory, with the program environment affording participants opportunities for growth in personal autonomy, competence and relatedness.

The success of the modified boxing program that evolved at the Canberra PCYC suggests that there may be merit in introducing similar programs elsewhere, perhaps complementing the original Box'Tag concept. Although our research has been carried out within the context of modified boxing, the findings are clearly applicable to other sport and physical activity domains.

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Chapter 11: Overview of current status

Thank you Allan.

"At times, our own light goes out and is rekindled by a spark from another person. Each of us has cause to think with deep gratitude of those who have lighted the flame within us"

– Albert Schweitzer.

11.1. Summary of research project

The research reported in this thesis was motivated by a desire to determine whether a form of boxing modified to provide greater participant safety could achieve significant community uptake. The investigation was initially centred on a specific version of modified boxing called Box'Tag. Essentially, a non-linear design process was then used to introduce progressive refinements based on participant feedback. The design process entailed not only formal studies incorporating participant interviews and surveys, but also my daily interaction with participants in my role as coach of a modified boxing program at the Canberra PCYC over a period of almost five years. It led to the evolution of a version of modified boxing that differed in concept from that employed at the outset. Initial emphasis on competition supported by use of automated scoring technology gradually disappeared, and the focus turned to cooperation between participants, building of a sense of community, and development of skills through employment of constrained games that were widely perceived as fun. A concept of preparing for public performances - rather than for tournaments - emerged, with the preparation being a communal endeavour. Because feedback from participants clearly showed that they placed high value on safety, efforts at safety enhancement were continually made. In particular, gloves capable of reducing peak impact forces were designed, produced, tested and iteratively improved, with this becoming a major element of the research.

Because the modified boxing program at the Canberra PCYC was shaped by participant feedback, it is unsurprising that the participants came to perceive it as highly effective in meeting their needs. The fact that the program attracted far more people than a prior conventional boxing program, and that many of those people maintained their involvement for three or more years, clearly demonstrates that in certain circumstances substantial community uptake of a modified form of boxing can be achieved. This offers no guarantee, however, that the program emerging from the Canberra PCYC would necessarily be successful elsewhere. A fundamental tenet of design theory is that a product that fulfils a need for one community might not do so for others [1].

Nevertheless, there is some evidence to suggest that programs incorporating the key features of that refined at the Canberra PCYC could be popular in other settings. In 2017, I was part of a team that introduced such a program (titled 'ModBox') into northern India as part of a sport diplomacy project supported by the Australian Department of Foreign Affairs and Trade (DFAT). I developed a course for training of ModBox Community Coaches and had it accredited through the Australian Sports Commission. I also prepared the supporting course materials and learning resources. I then travelled to India and delivered the course to 33 Indian trainees (including 17 females) over a 6-day intensive period (Figure 1).

Figure 1: Overview of the ModBox Community Coach Course that was conducted over a 6-day period at Tanjun Associate Livelihood Skills Training & Research Centre, Uttar Pradesh, northern India.

I remained in India for seven weeks to provide ongoing support to the coaches and to directly assist in the early stages of program implementation. Within less than six months, the program was running in 10 schools and a substance abuse rehabilitation centre, enabling over 300 young people from some of the most disadvantaged sectors of the Indian population to become regular ModBox participants. Feedback was highly positive and included reports that some young people who had not been attending school returned simply to be part of the ModBox community.

The Indian program was initially funded for one year, but due to its early success DFAT provided a supplementary grant that enabled continuation through to the end of September 2018. By then, a total of 16 schools had been reached by the program. Even following exhaustion of the funding, ModBox programs have been sustained in several locations. Moves are currently being made toward one of the schools taking on a role as a ModBox Exemplar Centre.

There has been some local adaptation of the program since its introduction into India. Most notably, public performances have taken on dimensions never envisaged in Australia. In October 2017, one of the Indian schools hosted what it billed as “the world’s first multi-school public performance of ModBox”. I was again in India at that time, so was able to attend, along with my Principal PhD supervisor. The event was held outdoors on a dirt surface in the school quadrangle with drapes on one side and seating for participants and spectators on the other sides. The participants had used painted stones to form a large ModBox logo on one side of the quadrangle (Figure 2).

The performance incorporated choreographed and well-rehearsed warm-up routines, training activities and skill drills, all performed to music. This was followed by several “bouts” in which participants worked together to display the skills that they had learnt, rather than competing against each other. No winners or losers were declared. Afterwards, there were some coach-led activities that again had strong musical and dance elements. The event lasted for ~2 hours and was visually spectacular (see Figure 3). A total of ~110 young people from five schools took part with great joy. Standard societal divisions based on ethnicity, caste and religion were wonderfully transcended.

Figure 2: The world’s first multi-school public performance of ModBox. Staged at the Moravian Institute in Uttarakhand, northern India, the event involved the participation of young people from some of the most disadvantaged sectors of Indian society.

Figure 3: The multi-school public performance was not only visually spectacular, it also promoted the development of bridging capital - the connections that are formed through experiences shared between individuals who are dissimilar with respect to socioeconomic and other characteristics such as race, class, and/or religion [2].

Recently, PCYC NSW (an umbrella organisation representing all 64 PCYCs in New South Wales) initiated a process aimed at eventually establishing a ModBox program at each of its centres. As part of this process, more than 150 Police Officers have undergone training to become ModBox Community Coaches, and arrangements have been made for still more to do so.

In addition, the Northern Territory Institute of Sport has expressed interest in running ModBox programs in three indigenous communities and has suggested that these programs should conform closely to the model that has been pursued in India.

On the other hand, some barriers to the wider roll-out of ModBox have been encountered. Stigma associated with boxing [3] can cause difficulty in gaining acceptance even for a form tailored to address primary objections to the sport. This problem might diminish with establishment of more ModBox programs and resultant increased public visibility of their characteristics. There have been suggestions that the focus of ModBox on cooperation rather than competition between participants means that it cannot be considered as belonging within the sport domain. Competition is widely considered integral to the concept of sport, along with physical exertion and institutionalised activity [4]. It has been pointed out, however, that the concept of sport is a social construction and therefore subject to change [5]. The predominant existing concept is largely a product of western industrialism and is currently being challenged by development of new social norms in many parts of the world. The emergence of e-sports is among a range of trends stimulating reassessment of conventional ideas as to what constitutes sport [4]. There may well be increasing acceptance of a notion that individuals constantly striving to better their own previous performances are in fact engaged in a form of competition. As long ago as 1975, McBride [5] warned that attempts to define sport through setting of rigorous criteria are logically futile and at risk of becoming prescriptive. Accordingly, Jonasson has reportedly suggested that sport should be defined only as what the sports world considers to be sport [4]. It seems reasonable to imagine that an activity in which participants engage several times weekly with the aim of improving their skills, physical qualities and movement aesthetics might be able to achieve such consideration.

The novelty of ModBox has been questioned. Along with my fellow researchers, I have repeatedly been asked to explain how ModBox differs from 'boxercise' and other boxing-related fitness programs that have been popular since the early 1990s, or from initiatives like

‘Fight for Peace’ [6] and ‘Boxgirls’ [7] that use boxing and other forms of martial arts as a means of social outreach. I believe that ModBox is unusual in combining fitness and social outreach objectives with a focus on use of constrained games to develop skills required for a modified form of boxing that places high value on participant safety, and in its incorporation of the concept of public performances. Novelty, however, has not been the fundamental aim of the research. Rather, the focus has been directed toward building a program that is effective in meeting the needs of a specific community of which I have been part. I have sought to provide a rich description of my experience in the hope that it might be of value to people working in similar situations. I do not claim that the ModBox program developed at the Canberra PCYC is revolutionary, universally applicable and/or superior to any prior initiative in the field.

Reactions of the existing boxing community to ModBox have been mixed. Some members of that community have vigorously opined that the whole notion of modified boxing is silly, unnecessary, distracting and threatening to the essence of the sport. Others regard it as having potential to recruit new people into the sport and set them on a path toward conventional boxing. Only a few have embraced it as something that could exist parallel to conventional boxing and for an entirely different purpose. Those few, however, have been quite enthusiastic about the possibilities. Boxing Australia (the organisation responsible for national oversight of amateur boxing) is actively promoting ModBox, and several current and former boxers have become advocates. In general, though, there appears to be more support for the ModBox concept outside the boxing community than within it, with organisations concerned with social welfare showing most interest. This probably reflects the fact that ModBox entails employment of boxing as a vehicle for a social initiative, as opposed to use of a social initiative to aid the development of boxing (see Figure 4 below).

I have frequently been quizzed about the commercial viability of ModBox. The program at the Canberra PCYC was run in a not-for-profit environment. Much of the necessary equipment was provided by the club. Although I was employed part-time by the club for most of the program duration, I also volunteered a great deal of unpaid time, and for the final year my input was entirely voluntary. Where clientele is drawn primarily from less affluent sections of the population, it seems unlikely that the program could successfully operate on a standalone, user-pays basis. Its immediate future, therefore, may well depend largely on contributions of time and expertise from staff already employed by host institutions, substantial volunteerism, grants from research or social welfare agencies and/or philanthropic contributions. There may be some circumstances in which the program could be run for profit, with the profit then used to subsidise availability of the program to people of more restricted means, but this is presently a distant prospect.

Figure 4: Some of the participants from the Indian ModBox program that is being used as a mechanism to assist with the personal growth and development of people from various backgrounds and to encourage community engagement.

In the context of minimising costs, groups interested in establishing ModBox programs have enquired as to whether the program could be run without use of the specialised impact-damping gloves. At present, the ModBox research team strongly recommends use of the gloves in all situations where impacts to another person can occur, but it is certainly important to consider the cost to benefit ratio. Currently, pneumatic gloves manufactured in India can be provided to Australian organisations for ~AUD 90 per pair, which obviously would represent a significant expense if standard gloves already owned by clubs or purchasable for less than AUD 50 per pair could be employed. In my view, however, the benefits of using the pneumatic gloves far outweigh the greater initial cost. Research reported in this thesis shows that surveyed ModBox participants place very high value on safety and that the pneumatic gloves provide an important means for safety enhancement by reducing peak impact forces and peak rates of force development associated with any given pre-impact glove velocity. While mandating use of the gloves is not in itself a sufficient safety measure, it helps to convey a message to participants that safety is seen as paramount, and likely increases their receptiveness to other vital measures such as education concerning the risks inherent in forceful strikes, removal of the head and neck from the target area, teaching the skill of striking lightly and use of additional protective equipment such as head guards and body protectors. Effective occupational health and safety procedures typically incorporate a 'hierarchy of controls', with initial risk identification followed sequentially by hazard elimination where possible, diminution of remaining hazards, worker education and training and the use of personal protective equipment [8]. Maximising the safety of ModBox participants demands that they should be subject to a similar system of controls, with no element omitted. It is noteworthy that research by others has shown that standard gloves kept in club settings and used repeatedly over long periods can have greatly decreased impact-damping qualities even compared to new gloves of the same type [9]. Due diligence demands that the ModBox research team should not waver from vigorously recommending the use of gloves that it has found to be the best currently available for protection of ModBox participants.

There is little doubt that the pneumatic gloves could be further improved through continuing iteration. Scope exists also for other technological developments to increase the appeal of ModBox. Together with my Principal PhD supervisor, I have conceived a design for a protective vest that I think could be an improvement of on any such item currently on the market. Beyond just the progression of personal protective equipment for ModBox participants, there may be great potential for deployment of technology to augment the 'fun' element of training that is so critical to the ModBox concept. For example, wall-mounted units with padding capable of air release upon impact could be developed and could provide not only for impact counting but also for different musical notes to be played according to the area of the unit struck. The possibilities seem infinite and I hope I might have opportunity to explore them over the coming years.

I entered into my PhD studies with an extensive background in coaching, yet my experience in running the modified boxing program at the Canberra PCYC (and then initiating a similar program in India) has given me a new perspective on this role. I have found that coaching successfully in a community environment requires a skill set different from the one that I had developed in high-performance settings. Some aspects proved to be transferable, with the ModBox participants enjoying being treated as serious athletes and appreciating detailed planning of the overall program and the individual training sessions. There was, however, a need to cater for much larger numbers of simultaneously active participants, to guide participants rather than instructing them, and to help participants gain a sense of physical and psychological safety. Deliberate attention had to be given to methods for building community spirit. To promote learning of skills, greater use had to be made of 'feed-forward' (as opposed to traditional feedback) methods [10]. There was more requirement for individual nurturing and pastoral care. The reading that I was conducting as part of my studies helped me to understand and adapt to the differences, and eventually to conclude that traditional approaches to training and accreditation of coaches might not be optimal for preparing them to work at community level. The success of a program incorporating specific content and philosophies depends greatly on the abilities, behaviours, attitudes and demeanour of the coach who delivers it [11]. This realisation motivated me to produce the 'ModBox Community Coach Reference Guide' [12] and to establish social media platforms aimed at continuous coach education. I retain a major passion for the development of community coaches through more informal methods of learning, similar to the coach education and training program that was undertaken in India (Figure 5).

Figure 5: The ModBox Community Coach Course in India utilised a face-to-face delivery model that was supportive of the principles of adult learning and competency-based assessment, and that led to accreditation of 33 community-minded individuals who all had an interest in the holistic personal development of young people and in community-building through sport.

11.2. Concluding thoughts

My PhD project was undertaken primarily to address a specific question as to whether a modified, low-risk form of boxing could achieve significant community uptake. The research reported in this thesis indicates that the answer is unequivocally affirmative, a point that is perhaps made most evident by participant feedback outlined in Chapter 10. It is important to emphasise, however, that the form of modified boxing that proved popular at the Canberra PCYC was evolved through research and design processes in which participants were directly involved, and it and took on characteristics not foreseen at the outset. It is probably not the case that 'one form of modified boxing fits all'. Indeed, a major theme arising from my research is a need to progressively tailor and adapt programs to meet the needs of specific target populations.

I began with six underpinning research aims, as outlined in Chapter 1, and all were eventually achieved. Two related to developing a comprehensive understanding of contemporary arguments for and against boxing and of the ways in which they might influence acceptance of modified boxing. This understanding was developed through the scoping review provided in Chapter 2. A further two aims were focused on assessing the need and want for modified boxing and implementing a community-based modified boxing program that could provide a vehicle for that assessment and for interacting with participants to guide program iteration. The realisation of these aims is clearly demonstrated in Chapters 3, 4, 8 and 10. A fifth aim was to explore and develop technologies thought to have potential to enhance the safety and enjoyment of modified boxing participants. This aim was met through evaluation and enhancement of automated scoring technology, as described in Chapter 5, and through the design, use, evaluation and continual refinement of specialised impact-damping boxing gloves, as outlined in Chapters 6, 7, 8 and 9. The final aim was to comprehensively document the implemented modified boxing program and the research surrounding it, and this has been accomplished through a series of publications in the peer-reviewed literature and the preparation of this thesis.

I also hoped that my research might provide a basis for development of a nationally accredited course for training of modified boxing coaches, and this goal too has been attained.

I am now almost at the end of my PhD journey, and what a journey it has been! Like many PhD students, I encountered a few moments when the road ahead seemed too long and uncertain, but development of ability to push through these moments has been part of the learning process, and in total my experience has been overwhelmingly positive. I have read widely, and this has opened a whole new world to me. I have become familiar with both quantitative and qualitative research methods, design theory and a range of philosophical and ethical considerations that previously had not occurred to me.

This has hugely influenced my world view. I have developed increased understanding of both the value and the limitations of the scientific method, and of the fact that its pursuit can be a powerful stimulus for creative thought. I have been introduced to deductive, inductive and abductive logic. I have gained an appreciation of the benefits of empirical knowledge accumulation. Perhaps most importantly of all, I have met many extraordinary people along the way.

From my personal perspective, the journey has therefore been highly worthwhile, but it is natural that I should now reflect also on whether it has achieved wider outcomes. Apart from facilitating the development of modified boxing programs perceived by participants as enjoyable and positive, my research has produced extensive documentation of that process and a thorough description of the iterative development of pneumatic boxing gloves. I hope that this has added to the foundations of available knowledge and experience upon which future researchers can build. My published papers have attracted substantial international interest. One has received over 7,000 downloads, placing it in the top three most downloaded papers from 473 published by that journal over its 7-year history. Three others have received between 2,400 and 3,300 downloads. A paper published as recently as 28th February 2019 has already been downloaded more than 850 times. Each of my papers published in a journal that monitors download numbers has been the most popular within the issue. Four have been the most popular for their year and another the second most popular. The capacity of my work to consistently gain the attention of others does constitute a form of impact.

Throughout my PhD enrolment I have undertaken only part-time paid employment, and for the past three months I have concentrated fully on my studies. I will now need to return as soon as possible to full-time employment, and I am unsure what that will entail. I would dearly love to find a position that would allow me focus intensively on continuing the work described in this thesis. If that proves impractical, I will aim to further the work in my spare time. My PhD studies have caused me to become captivated by the excitement inherent in well-planned research activities. I still identify strongly as a coach, but now even more so as a researcher.

11.3. Final remarks

I want to finish by conveying my special thanks to the University of Canberra for accepting me into its postgraduate program based on my life experience and despite my lack of the usual academic prerequisites. This was a bold move and one of which I have never lost sight. I hope I have at least begun to repay the faith.

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