Hip and knee joints biomechanics of karate players during training and competition style kicks

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1- Hip and knee joints biomechanics of karate players during training and competition style kicks

By

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Riyadh Alsaeed

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Abstract

There is an oddity in the long-term practice of Karate as traditionally it has been an activity that can last a lifetime, but there are many people who suffer from various chronic complaints of the lower limbs. Much research has looked at acute injuries in Karate but for the most part these injuries are not to the parts of the body that suffer the chronic problems, from this it would seem likely that chronic injuries are due to repetitive training or from minor non-contact injuries repeated intermittently.

The purpose of study is to analyse the main five karate kicks (Front kick, Roundhouse kick, Side kick, Hook kick and Back kick) in three modes (Training, Competition and Competition step). 3D motion capture system (VICON) with 2 force plate has been used to measure angles and moments at the hip and knee joints for both the kicking leg and support leg. 28 healthy high level of Karate players volunteered to be part of this study. In addition, two case studies of Taekwondo players who had injuries in different joints, case one had lower back pain and case two had a left knee injury, both with more than 6-months rehabilitation were carried out. The aim of this PhD study will be to establish joint loading at the hips and knees of kicking practices in both a basic fashion and a competition type fashion. This will be performed on a wide range of adult karateka from the age range where most competitors come from. Motion and force analysis along with inverse dynamics will be performed to examine the load on the body at specific joints and comparisons made between the basic and competition modes of technique. It is hypothesised that the competition modes of training will have higher loading to the joints and thus could be more injurious if the karateka is not suitably conditioned. Highest joints loading of karate kicks were: Highest moment for the **support hip** (left) about the Y axis was 1.8 N.m/kg during front kick, competition mode. The next highest moment was about the X axis at 1.7 N.m/kg during front kick, competition mode and roundhouse kick, step mode. The third highest moment was about the Z axis at 1.7 N.m/kg during hook kick, step mode. Highest moment for the **support knee** (left) about the X axis was 1.8 N.m/kg during the front kick, step mode. Next highest moment was about the Y axis at 0.8 N.m/kg during side kick, competition and step modes. The highest moment about the Z axis was 0.4 N.m/kg during roundhouse kick, training mode. Highest moment for the **kicking hip** (right) about the X axis was 1.2 N.m/kg during the front kick, step mode. Highest moment about the Y axis was 0.9 N.m/kg during the front kick, step mode. Highest moment about the Z axis was 0.3 N.m/kg during the front kick, step mode and

the roundhouse kick, step mode. Highest moment for the **kicking knee** about the X axis was 1.0 N.m/kg during the front kick, step mode. Highest moment about the Y axis was 0.3 N.m/kg during the roundhouse kick, step mode, side kick, step mode, and hook kick, step mode. Highest moment about the Z axis was 0.6 N.m/kg during front kick, competition mode.

Support leg has the highest joint loading moments, from this information analysed, coaches and players should focus on the supporting leg more than the kicking leg to lessen the risk of injuries and at the same time perform the kick with the kicking leg the best way.

The novelty of this study is creating a 3D motion analysis database of kinematics and kinetics of healthy karate players performing the five main kicks in three different modes with analysis of both the kicking and support legs.

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Chapter 1

1. Introduction

Over many years oriental martial arts such as Karate, Taekwondo, Judo and Jujitsu have spread and taken root in a large number of countries worldwide. There has been a steady increase in the number of participants involved for a variety of reasons such as for competition, as a hobby, for self-defence, and for health. There are now over 200 million participating in the martial arts, and around 100 million in Karate (Antonio Espinós, 2014) with both sexes and various ages participating in the martial arts. Over the years there have been many studies into martial arts across the range of sports science disciplines (Biomechanical, Psychological and Physiological). As might be expected from a combat sport derived from self-defence and martial combat origins there has been a perception that there are a lot of injuries associated with martial arts as sports. Hence, much of the research has focussed on the epidemiology of injuries that happen in both training and competition and many minor, major and acute injuries are reported in Karate, Taekwondo and other martial arts. These most commonly include contusions to all parts of the body and limbs, a fracture to feet, hands and legs and strains and sprains to the ankles and knees (McPherson & Pickett, 2010a; Nandi, Sarkar, Mondal, & Banerjee, 2014; Willy Pieter, Fife, & O'Sullivan, 2012). A lot of work has gone into making Karate and Taekwondo safer and more spectator friendly over the decades and developments have been steadily and sometimes rapidly implemented.

1.1. The Asian martial arts (Karate and Taekwondo) spread internationally

The modern martial arts developed in countries in the Far East especially Japan, Korea, China and Thailand. Each area has its own martial arts philosophy, how to fight using arms and legs without weapons as a self-defence from different enemies, either human or animal. Japan created Karate, and Jiu-Jitsu, Korea created Taekwondo, China created Kung-Fu and Thailand created Muay-Thai. There are other martial arts, including western ones, but this thesis will focus on two of them, Karate and Taekwondo because both are considered as Olympic martial arts and have the larger number of participants, outside of China, and higher injury rates. In the past martial arts were used for self-defence not as a sport but when many masters of martial arts moved from Eastern countries around the world and spread their arts as self-defence Karate and Taekwondo developed heavily into sports variations with many kinds of competitions. Taekwondo became an Olympic Games sport after many changes in the rules to be as safe as possible, since 2000 in Sydney Australia, Karate was announced as Olympics Games sport in 2016 and will take part in Tokyo, Japan by 2020 (YoungIl, 2016).

1.1.1. Karate as a martial art and Olympic sport

This Asian martial art started with only local competitions in Japan, mainly within and sometimes between Karate styles, for example Shotokan, Chito-Ryu, Shito-Ryu, Wado-Ryu, Goju-Ryu, and Kyokushin. After karate spread internationally, people interested in these martial arts created federations to manage the competitions and develop rules that allowed many styles to compete together to become a sport with the World Karate Federation (WKF) being recognised by the International Olympic Committee (W. K. Federation, 2017a, 2017b). Many of the changes to competitions rules have been done to reduce the injuries and allow more freedom of techniques for the player to use in safe ways. This has led to the creation and development of safety gear for the head, mouth, chest, hands, body, groin, shin and foot guards, which the players must wear (all these guards are now compulsory in WKF fights and before the start of the matches the referee checks them). There have also been changes to the rules promoting more head kicks, takedowns and complex techniques and more and harsher penalties for excessive contact and causing injury.

Although a popular martial art the International Olympic Committee only recently awarded Karate a place in the Olympic Games for 2020 as in the past they considered Karate one of the more dangerous sports. After these changes through the years, and research studies that reviewed Karate injuries, it was documented that there were reduced injuries, especially to the head, upper limbs and chest (Arriaza & Leyes, 2005; Arriaza, Leyes, Zaeimkohan, & Arriaza, 2009; Destombe et al., 2006; W. Pieter, 2010; S Sterkowicz, 2013; Zetaruk, Violan, Zurakowski, & Micheli, 2000). Finally the WKF was successful in 2016 where Karate was announced as an Olympic Games sport by 2020 in Tokyo, Japan (W. K. Federation, 2017a, 2017b; Japan Olympic Games Committee, 2016; Warnock, 2015). Recently WKF decided to use modern technology of high definition and high-speed video cameras at different angles to help the referees repeatedly view the quick kick, punch or any other Karate skills within competition in slow motion when the coach asks under an appeal to see it. At the same time, it allows the provision to all Karate federations, coaches and players high-quality videos of matches and competition to study and review to develop their techniques and compete within the rules. This also aids judging practice and means broadcasting the event on TV is easier, also WKF made a rule to present the best karate match placed the referee, judges and players placements Figure 1, Figure 2 and Figure 3. A free for reproduction and use adapted from K photos-WKF.

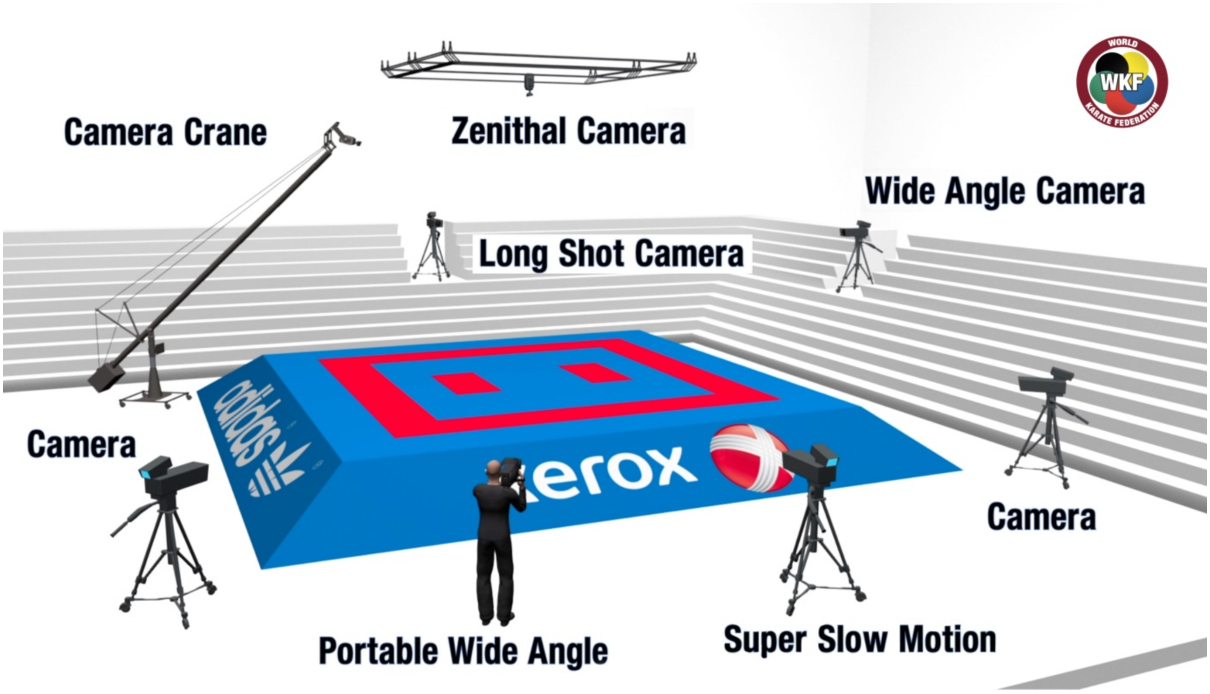

Figure 1 Media technology for new rules

(WKF-fightnetwork, 2013)

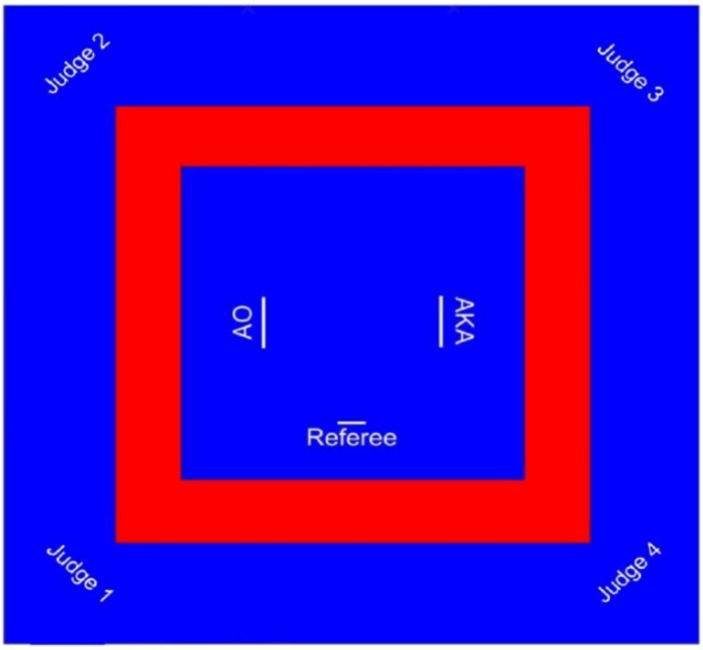

Figure 2 Karate referee, judges and players location

(KARATE-BUJIN-DO-KAN, 2012)

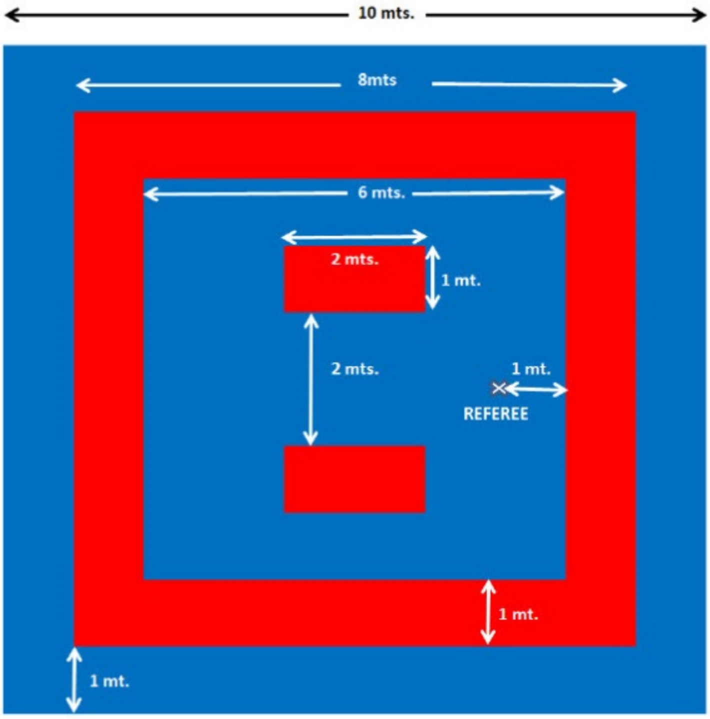

Figure 3 Karate tatami dimension

(SHOTOKAN-KARATE-DO, 2014)

1.1.2. Taekwondo as martial arts sport

The Korean people created Taekwondo from their philosophy of fighting in which they think legs are stronger faster and have greater reach than the arms so they made their style about 80% kicking and 20% punching. Competition rules give kicks more points than punching and that made Taekwondo look like it only uses kicks, which is very clear in World Taekwondo Federation rules (WTF). Mat area rules in the competition allow one referee, three judges, 2 coaches and the two players to be in this area (W. T. Federation, 2015; W. T. Federation & Rules, 2015; Rules, 2017; World Taekwondo Federation, 2017) Figure 4.

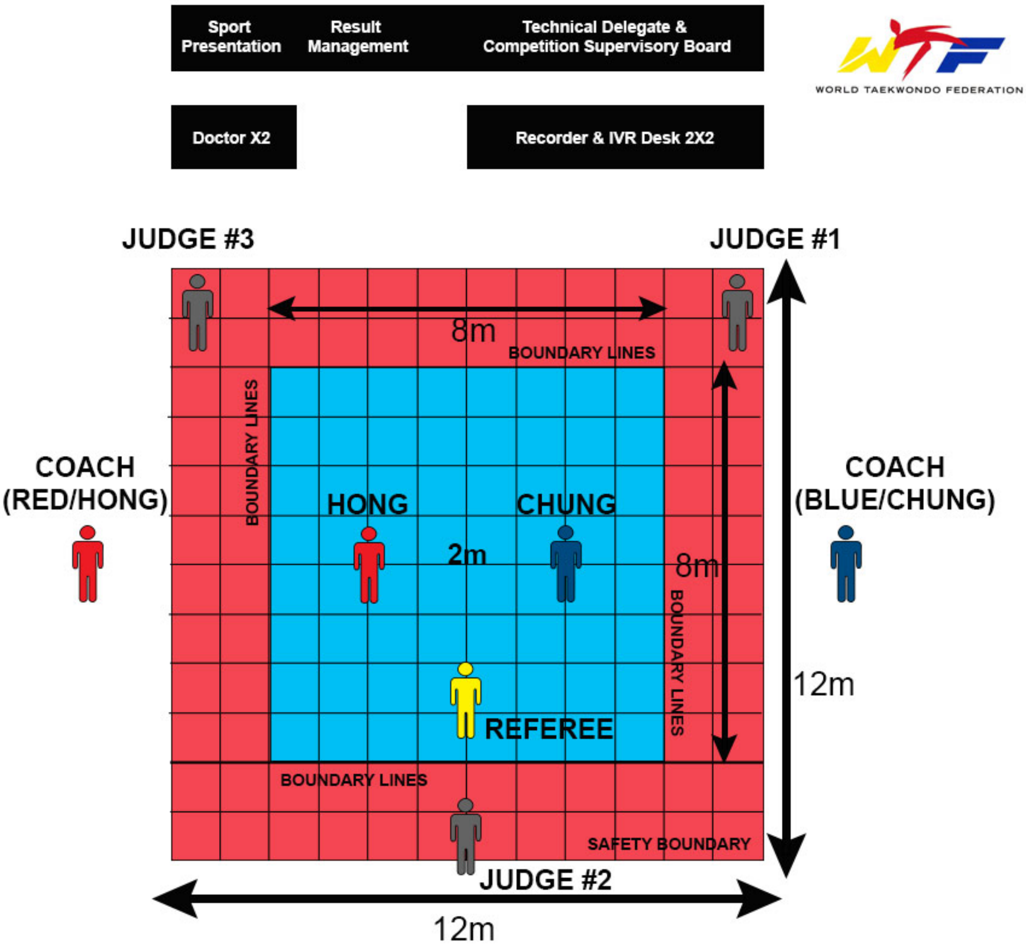

Figure 4 WTF Tournament Point System | Taekwondo Preschool

(WTF, 2017)

1.2. Purpose of study

There is an oddity in the long-term practice of Karate as traditionally it has been an activity that can last a lifetime, but there are many people who suffer from various chronic complaints of the lower limbs, and within the UK a large number of older karateka (people who do Karate) have undergone hip and knee replacements and suffer from serious knee pain. However, there are many esteemed practitioners and teachers in their late 60s, 70s and even 80s who are still highly active and kicking. Much research has looked at acute injuries in Karate but for the most part these injuries are not to the parts of the body that suffer the chronic problems (see literature review). From this it would seem likely that chronic injuries are due to repetitive training or from minor non-contact injuries repeated intermittently. For example, in 2014 Mariconda et al. looked at femoral acetabular impingement in the Brazilian martial arts (Capoeira) players. Capoeira requires extreme movements of the hip to perform jumps and kicks but has little contact or competition with contact, in its modern form, and few acute injuries. Mariconda et al. (2014) used radiographic assessments to find out the impact of these motions on hip health. There were 24 subjects (10 women and 14 men) all of whom had a lot of experience in Capoeira. Of the 24 subjects 4 had hip pain and 44 of the 48 hips had signs of impingement, and they suggested doing more research about martial arts hip problems.(Mariconda et al., 2014)

Previous work by the Loughborough Sports Biomechanics group has shown that during competition type stress, and reduced time frames available for action, the technique of martial artists can break down and riskier versions of the technique are executed (Roosen, 2007). Is it the case that the more competition based training kicks are more of an injury risk in terms of loading and poor performance leading to higher more potentially injurious loads?

The aim of this PhD study will be to establish joint loading at the hips and knees of kicking practices in both a basic fashion and a competition type fashion. This will be performed on a wide range of adult karateka from the age range where the majority of competitors come from. Motion and force analysis along with inverse dynamics will be performed to examine the load on the body at specific joints and comparisons made between the basic and competition mode of technique. It is hypothesised that the competition mode of training will have higher loading to the joints and thus could be more injurious if the karateka is not suitably conditioned.

1.3. Research questions and Objectives

Q1. What are the differences among karate kick performance modes in terms of joint moments and peak angles of the hip and knee for both the kicking and support legs?

Karate kicks can be performed in different ways such as: training, competition and competition step modes, and it is expected that there will be some differences between them. All these modes aim to reach the target in the best way, but the criteria can differ. Training mode follows the classical path of the kick which is meant to maximise impact and direction of impact. Competition mode aims to get there quickly under control with enough good form to be given a score. Competition step mode is the same but with a drive, or advancing forwards a long way during the kicking action to chase the opponent down. The players use all modes but in the competition they choose the mode they think is the best mode in each case depend on each match environment such as the opponent height, weight and the way the opponent fights. It has not been quantified how different these modes are in terms of hip and knee joint actions and if some versions are more strenuous on the joints than others.

Q2. How are hip and knee joint moments and peak angles affected by kicking with the right or left side?

Each Karateka has preferred, dominant, side to kick or punch and Karateka train very hard to be good on both sides, so they have the option to apply more techniques any time during the match. It would be expected that there would still be differences between sides despite training and it may be that the competition type kicks have greater differences between the left and right sides as they tend to follow more individual specific preferences for how to kick.

Q3. Can the methods and analyses developed be used to study two injured elite athletes?

Two elite Taekwondo players that had two different injuries: one had hypermobility of the left knee and case two had lower back issues, which affected their performance, were assessed as case studies. Hip, knee and trunk joint moments and angles were measured for a range of kicks and analysed using insight gained from the study of the healthy Karateka's kicks.

Q4. Is it useful to make a database of karateka's kicks for the main five kicks?

There is very limited quantitative data of the limb motions and joint loads during the five main kicks and none for all five kicks by the same people. It could be very useful to make a limited database as a reference for future studies or for rehabilitation and physiotherapy staff, coaches and players.

1.4. Study novelty

The novelty of this study is creating a 3D motion analysis database of kinematics and kinetics of healthy karate players performing the five main kicks in three different modes with analysis of both the kicking and support legs.

Chapter 2

2. Literature review

The literature review is in three main parts. First, injuries in martial arts are reviewed regarding incidents, epidemiology and injured areas, and indicates the acute injury locations do not tend to match the chronic injury locations. Then some background on joint loading and function for the knee and hip is covered in terms of basic function. Finally, a short review of studies that have looked at either joint kinematics or inverse dynamics analysis of martial arts kicks is presented, which also typifies the limited kick types and kicks/subject numbers that have been looked at.

2.1. Literature review of acute injuries

This first literature review focusses on injuries to different parts of the body, such as the head and neck, upper limbs "shoulder and elbow", lower limbs "knee and ankle" and torso mainly sustained during competition.

This review involved 13 international research papers and studies in martial arts that looked at common injuries published from 2000 to 2013. All these studies were collected from international databases available from Loughborough University online library, Science Direct, EBSCO HOST, The Knee, Taylor & Francis Social Science and Humanities Library, Science and Sport, Journal of Sports Science and Medicine, Accident Analysis and Prevention, World Applied Sciences Journal, Journal of Combat Sports and Martial Arts, aspects of sports medicine, BMC Public Health and Google Scholar. Keywords used were (Martial arts injuries, Karate injuries, common martial arts injuries in the shoulder, hip, knee and ankle injuries in martial arts.

The definitions of minor and major (serious) injuries in karate are that the minor injuries tend to be abrasions, contusions, epistaxis and minor strains and are common to the head, face, neck, and torso. The major serious injuries are mostly severe sprains, lacerations, luxation and fractures and mainly occur in the joints for example hip, knee, shoulder and ankle. A quantitative summary of the main findings is presented, and a descriptive summary of the key points is presented below, Table 1.

Table 1 Karate and other martial arts injuries

Karate and Martial arts injures						
Author	year	Study Population	Injured athletes %	Number of injuries	location of injury	Type of injury Sprain, Laceration Luxation and Fracture
1- Pieter, Fife, & O'Sullivan	2012	1000 Athletes	14.5%	145	Head and neck	Most them minor injuries and Sprain, Laceration, Luxation and Fractures
This study is review of most common injuries in martial arts studies					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
2- S Sterkowicz	2013	497 players	12.9%	385	Head and neck	Most them minor injuries and Sprain, Laceration, Luxation and Fractures
This study is review of most common injuries in martial arts studies					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
3- Pieter	2010	302	35.76%	108	Head and neck	Fractures and laceration
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
4- Macan, Bundalo-Vrbanac, & Romić, 2006	2006	1997 = 887 Fighters 2002 = 1604 Fighters	23.44% 15.83%	208 254	Head and neck	1997= 5 Fractures 2002= 2 Fractures
					Upper limbs (Elbow + Shoulder)	1997= 3 Fractures and Luxation 2002= 1 Fractures and Luxation
					Lower limbs (Knee + Ankle) + Torso	1997 and 2002 Sprain, Laceration and Fracture
5- Destombe et al.	2006	186	44.62%	83	Head and neck	Fractures
					Upper limbs (Elbow + Shoulder)	Fractures and Laceration
					Lower limbs (Knee + Ankle) + Torso	Laceration and Sprains
6- Arriaza & Leyes	2005	2837 Matches	15.7%	891	Head and neck	796 minor injuries and Sprain, Laceration, Luxation and Fractures
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
7- Halabchi, Ziaee, & Lotfian	2007	1019	18.25%	186	Head and neck	Most them minor injuries and Fracture 3, Luxation 3 and Laceration 28
					Upper limbs (Elbow + Shoulder)	
					Lower limbs	

					(Knee + Ankle) + Torso	
8- Zetaruk, Violan, Zurakowski, & Micheli	2000	68	27.94%	19	Head and neck	minor injuries
					Upper limbs (Elbow + Shoulder)	Sprain
					Lower limbs (Knee + Ankle) + Torso	Sprain and minor injuries
9- Arriaza, Leyes, Zaeimkohan, & Arriaza	2009	2762	17.99%	497	Head and neck	Lacerations and fractures
					Upper limbs (Elbow + Shoulder)	Luxation 2
					Lower limbs (Knee + Ankle) + Torso	Sprain and Lacerations
10- Peeri, Boostani, Boostani, Kohanpur, & Mirsepasi	2011	40	82.5%	33	Head and neck	Most them minor injuries and Sprain Fracture Luxation and Laceration
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
11- Boostani	2012	462 Competitions	-------	177	Head and neck	Most them minor injuries and Sprain and Laceration
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
12- Brusovanik et al.	2010	232	23.7%	55	Head and neck	Most them minor injuries and 4 Sprains 4 Fractures 28 Lacerations 1 Luxation
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) + Torso	
13- McPherson & Pickett	2010	1845	49.86% (12.79% Series injuries)	920 (236 Series injuries)	Head and neck	Most them minor injuries and Sprains Fractures
					Upper limbs (Elbow + Shoulder)	
					Lower limbs (Knee + Ankle) Torso	

2.2. Karate and Martial Arts injuries in competition

Two studies W. Pieter and S Sterkowicz showed that the most common injuries in martial arts were minor injuries, especially to the head and neck, with some serious sprains, laceration, luxation and fractures in the upper limbs and lower limbs. The first study in 2012 (W. Pieter, Fife, & O'Sullivan, 2012) took taekwondo players during competitive as a sample to find out methods to reduce the serious injuries in taekwondo competition. Another study in 2013 (S Sterkowicz, 2013) took karateka as a sample; their goal was to find out the common injuries and classified them by male and female, age, competition rules and injuries type and location. The results of both studies were similar with the overall percentage of injuries 14.5% and 12.9% respectively depend on gender, age, the level of sports skills, type and location of the injury. The final finding of the first study was they should take concrete steps to reduce the severity of injuries. For the 2nd study by Sterkowicz they found just the major injuries were decreased, about four–times from the first study, these studies cover a period of about 35 years (Sterkowicz, 2013). That lead to the goal for minor injuries to be decreased in the future like the major injuries had been. Both studies provided useful information about martial arts injuries, but the 2nd study was practically more useful because it showed which type of injuries had decreased, that helps encourages researchers to focus on the areas that did not decrease such as the pelvis, upper limbs and lower limbs.

W. Pieter (2010) found there was no difference between young males and females in injuries. The serious injuries were fractures and laceration to the upper limbs and lower limbs. He found the majority of injuries were minor to the head and neck. This study did not present the full reality of injuries in martial arts, because of its focus on young karate player, as they do not do the higher-level karate techniques. More importantly the new rules of World Karate Federation "WKF" in 2000, made the young karate player much safer than adults, for example there is no contact to the face, punches and kicks must be controlled to be sure it will not cause any injuries to the opponent. Techniques must be stopped before contacting the opponent`s body, all opponents must wear karate helmet. Just the correct techniques to the head or body are recorded, the punches or kicks must have strength, speed, accuracy, control, shape and strong and balance stance but not make contact. At the same time if there are uncontrolled punches or kicks the referees will give the competitor a penalty and the referees are very strict about enforcing these rules in addition to the new equipment requirements for juniors. (Macan, Bundalo-

Vrbanac, & Romić, 2006) made an evaluation and comparison of the injuries before and after the new rules of WKF were applied. They found a real decrease in injuries in 2002 compared with 1997 especially in the young karate players. The result of this study was that stringent judges and strong punishment could reduce the number of injuries. This study provided proof for how the new rules forced players to improve their skills regarding controlled techniques. In addition, the WKF provided an increased number of courses for referees and coaches in order to spread the new rules to all karate staff who in turn could teach their players these rules.

Destombe et al., (2006) to define the danger factors in karate injuries devised a questionnaire, and the karate players had to answer all questions in the list about injuries they had, such as type, location, medical care and how many days they had to stop training. The main result was that the lower limbs injuries were worse than upper limbs injuries and included fractures, laceration and sprains, however, the majority of injuries were minor injuries and most injuries occurred in training not in competitions. Questionnaire studies have limitations though and it is not always sensible to rely solely on the accuracy of these studies to give the complete picture of what is happening. Sometimes respondents do not give the full information (especially if it will have a potentially negative effect on their selection for teams) and these studies depend on how much the sample remembers, their view of injuries and how honest they are.

Arriaza and Leyes (2005) made an archive of karate injuries in three successive world karate championships (WKC) 1996, 1998 and 2000, where they took a huge number of matches, 2837 matches (some players had more than one match) were recorded and from them about 891 injury cases were reported during the three competitions, which is around 15.7% from the population of study. The researchers found most injuries were to the hands, head and face but also some to the lower limbs were of the type which the considered as short-term injuries. With these injuries the players came back to training or competitions after one or two weeks. Moreover, with more serious injuries such as lacerations, luxation and fractures the players cannot come back to training or competitions after a short time; they need more than 6 weeks or sometimes months. Even if they return to play after an extended time some did not return to the same level where they were before the injury. In addition, they will not develop properly as their colleagues and it could be some of them cannot continue their sport at all.

Halabchi, Ziaee, and Lotfian (2007) studied the injuries of women doing karate in Iran. The study population was 1019 females, the athlete's number of injuries was 186 which is 18.25% of all athletes, and the researchers recorded type, location and reason for the injuries. The results of this study were that most injuries were to the face and head, upper limbs, lower limbs and trunk, in descending order of the number of injuries. There were 37 severe injuries which it about 20% of all injuries in the study, such as injuries that needed a visit to the hospital to get treatment, which includes some that needed surgery or injuries that needed weeks of rest and rehabilitation. This means the players will miss some weeks training for these severe injuries. Also, the study showed that the lower limbs suffered few injuries but there were some severe injuries to the lower limbs. Reducing these are a very important focus for future studies as severe lower limb injuries more severely limit training and return to training than upper limb or torso injuries. This is one of the main reasons the current research will focus on the pelvis and lower limbs.

Zetaruk, Violan, Zurakowski, and Micheli, (2000), looked at 68 subjects to study how to determine the risk factors for injuries in order to try to improve safety methods for children in karate. The percentage of injuries was 27.9%, 19 subjects. The result of this study was the injury numbers rose with increases in weekly hours training more than expected if a linear relationship. It was surmised that the children are not capable of training for a long time five or seven day a week like some adults do in competition periods. Therefore they suggested three hours per week is good enough to reduce children's injuries. This study showed the useful relationship between these two variables the training hours and injuries have a positive relationship, if one increases the other will increase. However, from practical experience of karate training and generally accepted views of coaches three hours a week is not enough to develop the children's karate skills for competition level karate and four to six hours a week is needed.

Arriaza et al. (2009) completed their second study to archive serious injuries in karate (sprains, lacerations, luxation and fractures) in another three World Karate Championships (WKC) competitions, 2002, 2004 and 2006. From 2762 matches there were 497 injured cases, 18% from all matches. Next, they made a comparison between the numbers of serious injuries from their previous study published in 2005 with data from before the new rules with their new data from after the new rules which came into place in 2000. The result was that they found there was a difference in male competitions, with the rules have reduced the number of serious injuries (the injuries needing to go to the hospital and maybe need surgery after that needs a long time for rehabilitation. But there was no real difference in the number of female's serious injuries but there was a big change was in minor injuries (scratch, bruise and scrape). This was a very useful study as it showed how the new rules had made changes to the number of serious injuries.

Peeri et al. (2011) used a questionnaire application to find out: parts, type, time and number of injuries from 40 Iranian elite karate players who participated in WKC 2010. They found most injuries happened during training time compared with the number of injuries in competitions. Most of the injuries were in the head and neck 49 cases (32.4%) from 151 total injuries that were considered as minor injuries) with some additional serious injuries to the knee and torso. This information clearly showed that the serious injuries still happened during both training and competition. The Iranian elite karate players' injuries have been evaluated by Boostani (2012) They followed Iranian elite karate team players for 462 matches and the number of injuries was 178. The result was most injuries were minor injuries to the head and neck. Most injuries happened in the competition, not like the previous study of Peeri et al. In 2011, and moreover there were very few serious injuries. In this study the effect of the new rules and equipment to reduce injuries clearly appeared.

Brusovanik et al. (2010) collected information about Mixed Martial Arts (MMA) players' injury, the population of this study was 232 subjects; there were 55 injury cases, 23.7% of all the study population. They followed them over 7 years, 1999-2006 from the MMA organisation and compared this information with information from other contact sport (Karate, Boxing and Taekwondo). They found MMA players did not have the highest number of injuries when looking at the number of injuries per exposure (single participation) which he found to be: MMA (0.237), Karate (0.31), boxing (0.25) and taekwondo (0.0629). It was not only the number of injuries in other sports were higher but serious injuries in these other sports were also more common.

McPherson and Pickett (2010) got their information from recorded martial arts injuries by hospitals in Canada for very long period of about 14 years, 1993 to 2006. The population of this study was 920 karate and other martial arts players (Taekwondo, Judo, Kickboxing, Jujitsu, Aikido, Kung Fu, Tai Chi and other) the hospital recorded 188000 cases but for martial arts was just 920 injury cases. 236 cases about (12.79%) of cases were serious injuries (sprains and fractures). However, the highest number, 634 cases of injuries was minor injuries in head and neck, 68.9% of all injury cases. Their results showed that Karate had the highest number of injuries 299 (33%) but at the same time the percentage of serious injuries in karate was 25%. This percentage less than other martial arts sports and some of them were much higher. That, because the participating of serious injuries other martial arts was not very close. For example, Taekwondo 129 (14%) and serious injuries were 28%, Judo 99 (12%) injured cases, (27%) of them serious injuries and kickboxing 60 (7%) injured cases, (25%) of them serious injuries. Also, the lower limbs recorded the highest number of injuries, especially fractures. This study is different from most other studies and could mean injuries are region dependent or there may have been a period of abnormal injury and this study needs further investigation. Cases of injuries the players can get first aid in the competition or training time did not record as it did not need a hospital treatment.

The key finding of these studies were that Karate has less major, or serious, injuries than Taekwondo and MMA. The new karate rules and new equipment reduced about 80% of head, face and upper limbs injuries, but serious injuries are still present and there is still a need to focus on reducing them.

2.3. Literature review chronic injuries

This literature review will focus on international papers and studies in martial arts and other sports. These studies are a focus on chronic and potential cases which it differs from the previous studies. The research looks at force, biomechanics, rehabilitation and techniques and possible relationships to hip and knee joints injuries for the period from 1982 till 2017. All these studies were collected from international databases available from Loughborough University online library, Science Direct, EBSCO HOST, The Knee, Taylor & Francis Social Science and Humanities Library, Science and Sport, Journal of Sports Science and Medicine, Accident Analysis and Prevention, World Applied Sciences Journal, Journal of Combat Sports and Martial Arts, aspects of sports medicine, BMC Public Health and Google Scholar. The keywords were used by the researcher are (1- Arthritis of knee and hip, 2- Long-term Knee and hip injuries. 3- Force on the knee and hip joints. 4- Biomechanics of knee and hip joints. 5- Rehabilitation of Knee and Hip. 6- Martial arts techniques can reduce injuries). This literature review has been classified into different parts. This is to cover all areas that have a relationship with biomechanics and rehabilitation in martial arts Table 2, Table 3, Table 4 and Table 5.

Table 2 Arthritis of knee and hip

Arthritis of knee and hip					
Author(s)	**year**	**Study Population**	**Injured athletes % (Karate or Martial arts)**	**Number of injuries**	**Type of injury**
14- Klontzas, Akoumianakis, Vagios, & Karantanas	2013	632	%3	17	knee Arthritis
15- Dauty, Menu, Fouasson-Chailloux, & Dubois	2013	39	%15	6	knee (Arthritis) anterior cruciate ligament reconstruction revision
16- (Jones, Bartlett, & McCormack,	1995	13	%15	2	Knee(Arthritis) osteochondral fracture and meniscal
Long-term Knee and hip injuries					
Author(s)	**year**	**Study Population**	**Injured athletes % (Karate or Martial arts)**	**Number of injuries**	**Type of injury**
17- Holder-Powell, Di Matteo, & Rutherford	2001	36	58%	21	Long-term knee injuries
18- x x x x					
19- Parolie & Bergfeld	1986	25	100%	25	Long-term knee injuries
20- Dehaven, Lohrer, & Lovelock	1991	30	100%	30	Long-term knee injuries
21- (Kettunen, Kvist, Alanen, & Kujala	2002	36	55%	20	jumper's knee

2.4. Arthritis of the knee and hip

Arthritis is a chronic injury that affects the joints, and there are different types of arthritis but the most common one is osteoarthritis. There are some popular reasons for the cause of osteoarthritis (the age, infection of the joint, or trauma to the joint). (VanItallie, 2010). Three studies were found that related to knee injuries and arthritis in martial artists, the treatment and the period needs to return to their sport were reviewed.

1st Klontzas et al. (2013) looked at 632 subjects in their study but the athlete injury percentage for just Karate and other martial arts was 3% which is 17 chronic injury cases and all these injuries were arthritis in the knee. (They are just 17 martial arts players).

2nd (Dauty, Menu, Fouasson-Chailloux, & Dubois, 2013) They tested 39 players presented various sports (Soccer, handball, running skiing, judo, karate, other martial arts, and volleyball) they found that 6 players had injured their knee because they have arthritis (anterior cruciate ligament reconstruction revision) therefore, these 6 about 15% of the study population.

3rd Jones, Bartlett, and McCormack (1995) The researchers examined 13 athletes as subjects all of them doing karate or other martial arts, they found 2 of these athletes have an injury (Knee Arthritis) osteochondral fracture and meniscal) which it about 15% of all their population.

The result of these three studies that the researcher reviewed is that many athletes still have pain after knee surgery. They are also very careful when they undertake rehabilitation to get the best result, and that it takes a long time to return athletes to the previous level in their sport, especially karate and others martial arts. Klontzas et al. and Duty et al. both used MRI (Magnetic Resonance Imaging) exams to be sure the diagnoses was highly accurate and this easy to do nowadays, but Jones did not use MRI because this it was difficult to get this technology, or it was not available for him at that time 1994. Both Dauty and Jones have the same percentage of martial arts injuries 15% (6 of 39) and (2 of 13) even though there are 19 years between these studies.

These studies can inform players and coaches that players have a risk of developing longer term chronic injuries and that most of them that get surgery from acute injuries with no guaranty they can back to previous level and many do not.

2.5. Long-term Knee and hip injuries

Long-term knee and hip injuries are very important to look at it to find out the best way to make an exercise as a treatment or to create new exercises if the patients need it. Here four studies focussing on the relationship between long-term injuries and the effect of rehabilitation on knee injuries are reviewed.

1st Holder-Powell, Di Matteo, and Rutherford (2001). The population of this study was 36 athletes all of them had unilateral knee injuries, 21 athletes (58%) had injuries to the dominant limbs and 15 athletes (42%) to the non-dominant limbs and they found a significant difference between them. After all subjects took rehabilitation course the result was 12 of them returned to their sport to the same level. 4 players returned to their sport but lower than the previous level. On the other hand, they found 13 cases did not return to their preferred sport (Karate, other Martial arts, rugby basketball, skiing and football) but they are still practising sports. The remaining 7 players did not participate in any sports. All subjects have long-term knee injuries and they took a long course of rehabilitation.

2nd Parolie and Bergfeld (1986). They tested 25 football players in their study. They all had knee injuries for a long-time side by side with rehabilitation. The researchers followed up 21 patients, 17 of them returned to their preferred sport, 13 returned to the same level and 4 to lower levels than before. The researcher said that some of the athletes with knee injuries could return to their sport at the same level without surgery.

3rd Dehaven, Lohrer, and Lovelock (1991). They followed up 30 patients as a population of their study for about 11 years, all patients had knee injuries. After long-term treatment and rehabilitation there were about 80% of patients returned to their sport but not really at their previous level.

4- Kettunen et al. (2002) followed up 36 athlete patients (20 with jumper's knee and 16 control subjects) for more than 15 years all of 36 patients they have long-term knee injuries. The results were more than 50% (20 from 36) of patients returned to their sports career. 9 of jumper's knee athletes said that they had quit their sports job because of the pain in the knee and Just 1 of the control subjects said that he had quit his sports job. That main the result is the same as with the previous studies. The players generally were not at the same level as before the knee injuries. This study shows that it clears the subjective symptoms better than the subject with jumper's knee because the last one still has knee pain after treatment.

A long time follow-up of patients by Helito et al. (2015), 27.3 months on average, for 9 patients (8 male and 1 female) with 2 males doing martial arts, had been injured in their knee. All the 9 patients must get surgery, 5 of them got back to their level before the injury but 4 of them returned to a lower level than before the injury and just 1 back to a very low level.

From these studies it seems that players who have long term injuries have more chance of getting back to their sport at the same level, or slightly lower, if they get good rehabilitation exercises and rehabilitate over a long time and this can be beneficial in cases even without surgery and the risks involved with it.

2.6. Literature review of force and biomechanics of the knee joint

Presenting 9 literature reviews, 4 of them focus on the force on the knee joints and 5 focuses on the biomechanics of knee joints.

2.7. Force on the knee joint

The force or the loading on the knee joint has a very strong relationship to knee joint injuries and these four-examined forces on the joints and its relationship with injuries. These studies used computer simulations.

1st. There are three bones (tibia, femur and patella) which make up the knee joint, in addition to articular cartilage, ligaments and muscles surround the knee. develop 3D model of the knee joint, they said that the muscles make various forces when its work on the knee joint and they used 3 different muscle forces 30 N, 137 N and 411 N on knee joint throughout the knee flexion in different angles (0 – 90) degrees (Mesfar & Shirazi-Adl, 2005). The result was the force on the patellofemoral surface clearly rose throughout the joint flexion and it reduced when it was in extension. They suggested its better if the patients or players did not do large exertion of quadriceps at close to full extension angles.

2nd Shirazi-Adl and Mesfar (2007) used different forces 205.5 N and 411 N in different knee angles of the knee joint, the knee flexion angles were (15 - 120) degrees. The result was the force on the patellofemoral contact was reduced at smaller angles. Also, the maximum contact stress increased at 90 degrees, but it decreased at full extension. The study conclusion was the range of changes depends on the elevation volume came from the model created, the angles of joint flexion and the loading.

3rd Shalhoub and Maletsky (2014) In this study 14 cadaver knees were used and they loaded the muscles using static weight and motors attached to the muscle tendons Figure 5.

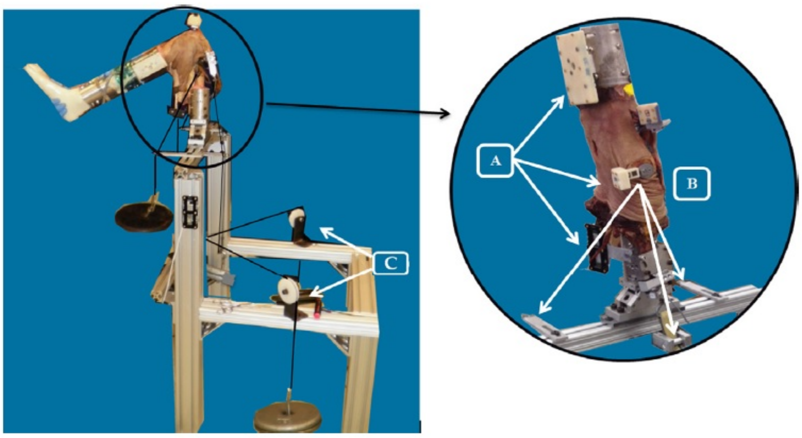

Figure 5 Muscle loading by static weight and motor attached to the muscle-tendon

(Shalhoub & Maletsky, 2014)

They used forces of 30 N and 70 N on the knee joint with the knee flexion angles 0, 30, 60, and 90 degrees. The result of this study was the loading on the knee joint by the extensor muscles can influence patellofemoral (PT) kinematics “The quadriceps muscle loading configuration can have a large influence on PF kinematics during full extension but less in deeper flexion” in addition, the weakness in the both of vastus medialis and the vastus lateral muscles might make change in PF and that will lead to pain and patellar dislocation.

4th. Bei and Fregly (2004) created a computer model “A commercial Multibody dynamic simulation of knee” (dynamic simulation of an artificial knee model) using a simulation program and they made a comparison with the experimental measurement for 16 experimental cases using a cadaver knee. They used forces higher than other studies of 750 N, 1500 N, 2250 N, and 3000 N with flexion angles of 0, 30, 60, and 90 degrees, and they found that there a linear model was a match to the average force data.

The relationship between force on the knee joint and the risk for knee injury was a positive relationship. Being at full extension was more risky comparing with full flexion to get a knee injury. Knee joint can tolerate large forces at different angle in linear flexion and extension.

Table 3 Force and biomechanics of knee and hip

Pressure on the knee and hip joints					
Author(s)	**year**		**joint angles degree**	**Forces or Loads (N)**	
22- Mesfar & Shirazi-Adl	2005		0 - 90	3, 137, and 411 N	
23- Shirazi-Adl & Mesa	2007		0 - 90	411 N or 205.5 N	
24- Shalhoub & Maletsky	2014		15 - 120	70 N and 30 N	
25- Bei & Fregly	2004		0, 30, 60 and 90	750, 1500, 2250 and 3000 N	

Biomechanics of knee and hip joints					
26- Kecskemethy	2011			Knee and Hip Joints	3D biomechanical simulation
27- Malone, Dowd, & Saifuddin	2006			Knee and Hip joints	Biomechanical understanding
28- Ward, Terk, & Powers	2004			Patella alta on knee	compare the knee extensor mechanics
29- Peña, Calvo, Martinez, & Doblaré	2005			Knee joint	3D biomechanical simulation
30- John P. Goldblatt, MD, and John C. Richmond	2003			Knee joint	Biomechanics

2.8. Biomechanics of knee and joint

The biomechanics of joints is important subject researchers have studied to understand how the joint work (mechanical side) and their environment, and moreover, what the variables affect them. In this part of the review these studies focused on the biomechanical structure of the hip and knee joints were looked at.

Ward, Terk, and Powers (2005) focussed on patella alta in the knee joint and they made a comparison of knee extensor mechanism with and without patella alta. They used different angles (0, 20, 40, and 60) degrees of knee flexion and by taking a measurement of quadriceps force ratio in various moments; they found out there was no significant difference, the only one between the 2 groups participated in this study was at 60 degrees of knee flexion. The population was 27 patients 13 with patella alta and 14 without patellar (25 females and 2 males).

Peña et al. (2006) made a 3D (three-dimensional) model of the healthy human knee including the mean components of joint such as bones, muscles and ligaments, and they analysed all these components throughout load transmission to know the main structures of the knee joint under a physiological external load. The result was under tibia load of 134 N plus the force load of 150 N, the anterior cruciate ligament support three times 75% more than the medial collateral ligament 25%.

The studies found that there is no significant difference between the force on the knee joint with and without patella alta, also the cruciate ligament provides the most support of the knee joint, about 3/4 of the force on the knee.

2.9 Literature review of Rehabilitation and using martial arts as treatments.

6 literature reviews have been presented, 4 literature reviews about rehabilitation and two talking about using martial arts to reduce injuries.

Table 4 Rehabilitation and Martial arts techniques can reduce knee and hip injuries

Rehabilitation of Knee and Hip

Author(s)	year	Study Population	Injured athletes %	Number of injuries	location of injury	Notes
31- Laboute et al	2010	540	%53	289	Knee	undergone ACL surgery via patellar or hamstring tendon
32- Giphart, Stull, LaPrade, Wahoff, & Philippon	2012	10			Hip	Using 13 Hip Rehabilitation Exercises and (EMG)
33- Dargel, Michael, Feiser, Ivo, & Koebke	2011	60			Knee	The differences in the anatomy of male and female knee joints
34- Wilk, Andrews, & Clancy	1996	Literatures review			Knee	REHABILITATION OF THE COLLATERAL LIGAMENTS OF THE KNEE

Martial arts techniques can reduce injuries

Author(s)	year	Study Population	Injured athletes %	Number of injuries	location of injury	Notes
35- Groen, Weerdesteyn, & Duysens	2007	6			Hip	Martial arts fall techniques can reduce hip impact force, during sideways falling
36- Weerdesteyn, Groen, van Swigchem, & Duysens	2008	14			Hip	Martial arts fall techniques reduce hip impact forces in naive subjects after a brief period of training, and use EMG

2.10. Rehabilitation of Knee and Hip

Rehabilitation of the knee and hip joint is one of the important treatments for athletes to return to their sport at the same level or close to their previous level, and be as active as they were before injuries and is highlighted in the following four studies.

1st Laboute et al. (2010) followed up 540 athletes (twenty-five sports, one of them a martial art) who had anterior cruciate ligament surgery in 2003 and 2004 and found successful rehabilitation depends on time because the relationship between time and risk is a positive relationship. The results were some of them return to their sport with the same level and some other lower than the previous level. The time was one of the important elements they took to return was one month to seven months with considered the type of treatment, the level of injuries and the person response were all sport the same outcome.

2nd Wilk, Andrews, and Clancy (1996) indicated the medial collateral ligament and medial capsular structures as one of the most common sports injuries (knee injuries). Successful rehabilitation used the sports exercises as part of treatment especially for the knee joint. The researchers focussed on the positive rehabilitation using the sports exercises with some weights and they took care of the knee flexion and extension ranges. They found out that rehabilitation is not good when focusing on wide ranges of motion in the very early drills/exercises because the capsular structures naturally are weak and the stabilisation of lateral aspect of the knee is not good enough.

3rd Giphart et al. (2012) looked at 10 healthy peoples' hips. They tested them by doing 13 hip rehabilitation exercises and they were measured with an electromyography (EMG) system during hip flexion exercise. They found that the pectineus and piriformis became much more activated through the training, which led to hip-stabilization. Also, they said training the pectineus and piriformis may help players if they get injuries or after surgery, because the pectineus was strongly working through hip flexion exercises and hip rotation for stabilization. In addition, the piriformis was highly worked through the static external rotation.

2.11. Martial arts techniques can reduce injuries

Only two scientific papers which focus on and discuss the relationship between martial arts techniques and possibility of reducing injuries were found.

1st Groen, Weerdesteyn, and Duysens (2007) studied 6 subjects who were high level, experienced Judo players. The researchers examined them to know the impact of hand, velocity and trunk orientation to reduce the hip impact and the result was there was no significant difference between the two groups of techniques (using hand and without using hand to do the techniques).

2nd Weerdesteyn et al. (2008)studied 15 subjects (10 of them untrained and 5 of them trained) after half an hour training session in one judo technique sideways break fall "A sideways MA fall technique is characterized by trunk lateral flexion and rotation and shoulder protraction in order to enable rolling on after impact" and used EMG to analyse the differences. The data collected showed that was no significant difference between the 2 groups, so they implied that the short time training can reduce the hip injuries group who do not have any experience got to benefit from the technique quickly.

The outcomes of these studies show there is the possibility to use martial arts as treatment to avoid injures and at the same time martial arts exercises and movements techniques could use to reduce the longer-term effects of injury.

2.12. The philosophy of all karate schools in competition version

The philosophy of all karate schools, in competition version or other versions use about fifty percent kicks and fifty percent punches. They use their kicks to get high scoring points (two points for the body kicks and three points for head kicks). For these points the players try to do different karate kicking techniques and from different positions, different angles (sometimes very odd angles) Moreover, these techniques are done at high speed. Some of these techniques are complicated techniques with consideration of balance, control and the accuracy, plus they need to limit the contact with the other competitor and be responsive to the other competitor's reaction, there are a lot of opportunities to get injured. The more complex techniques are usually used by the players in training and competition, to get the highest score to win the matches as quickly as possible. Other players use these techniques at the end of the match as a plan to win or if they are behind on the score and want to quickly reduce the difference between the players' scores. Despite their knowledge of that the chance of more serious injury is greater than the rest of the skills; the increased number of points attracts them to do it. From the foregoing reasons, the strength and importance of these techniques and the risk of them led to the plan to study the biomechanics of these techniques. The aim is to gain enough knowledge about hip and knee joint loads in different versions of the basic kicks that insight into the kicks can be gained to help provide information to avoid injuries or reduce the rate of occurrence

2.13. Literature review of karate kicks performance

There are only a few studies that focus on the biomechanical assessment of the performance of karate, or martial arts kicks and most studies have only looked at once or variants of the same kick type at a time from the same player. In most cases few subjects have been used and some of these have been single-subject studies. There are studies that have looked at force onto a target, or reaction time but the review is limited to the following articles which represent published papers and conference abstracts that have looked at martial arts kicks regarding joint kinematics and kinetics Table 5. Apart from (Sørensen, Zacho, Simonsen, Dyhre-Poulsen, & Klausen, 1996) and (Robertson, Fernando, Hart, & Beaulieu, 2002) all the studies used automatic motion analysis systems and can provide 3D inverse dynamics data, at least for the kicking leg. Details for each such studies are summarised in Table 5 and discussed below.

(Sørensen et al., 1996) used high-speed video and only performed 2D inverse dynamics of the kicking leg; however, they had 17 Taekwondo subjects and performed a detailed analysis to determine various contributions to the front kick and the timing of the joint extensions. They found peak hip moments of around 500 N.m, which is very high value for a low load dynamic movement and peak knee joint moments of around 200 N.m. They concluded the action was not a whip-like action despite sequencing but flail like where the knee extension slowed the thigh rather than the thigh whipping the lower leg out. (Robertson et al., 2002) was a two-subject study in a conference presentation and looked at the front kick from an elite Taekwondo player and karate player to look at angular velocity, moment and power at the knee and hip for flexion-extension. They found peak hip moments of 300 N.m flexion and 150 N.m extension. Peak knee moments of about 150 N.m was found but in these kicks the knee moment for extension was low and it was a braking moment that was high indicating the knee was not actively accelerating as in the Sorensen paper. It is expected that forceful knee extension is seen in a karate front kick as that is how the fundamental kick is trained.

VICON motion analysis was used to measure roundhouse kicks, speed and timing of the action, both the kicking and support legs for 14 skilled karate players split into two groups based on their training time by Pecoraioli and Merni (2009). The karateka performed two roundhouse kicks modes the traditional karate version and the NEW version agreed with the rules changed by WKF in 2000. They found some differences between the two groups in reaction time and take-off leg position and that peak angular velocity was better for the traditional mode.

Cabral, Veloso, & Moniz-Pereira (2011) attempted to look at skill level on kick performance using three karatekas of different skill levels, low, medium and high, when performing roundhouse kicks to choose the best four performances. Automatic motion analysis but no force plates were used so only the kicking leg was measured and variables calculated in 3D. Peak joint moments at the ankle, hip and knee were reported in N.m/kg, and were between 1 and 4 N.m/kg at the hip and knee with the hip being generally higher (mean mass 67 kg). Peak moments were to decelerate the limb and the study concluded that hip flexion-extension and internal-external rotation moments play a major role.

In 2013 Quinzi et al. examined the lower limb karate skills of six elite karate players and six amateurs kicking to the air, as is common in traditional training, and to a target (Quinzi, Camomilla, Felici, Di Mario, & Sbriccoli, 2013). They examined neuromuscular activation with electromyography (EMG) and the kinematics between these two groups at three joints, hip, knee and ankle of the kicking leg. They found there was an effect of karate player group on kicking with higher knee and hip angular velocities, co-activation of hip movements and knee flexion.

Fourteen high skilled karate players (age of 24 ± 7 years, height of 171 ± 7, weight of 72 ± 19 kg) were studied by Tan (2014) performing front kick (Mae-Geri) and were compared to 16 students of sports sciences non-karate skilled (age of 23 ± 6, height of 179 ± 6, mass of 73 ± 10 kg) to a fixed target. The main result was a similarity in kick pattern, but the karateka had greater accuracy, but also covered larger distances with the kick and had larger joint angles and moments.

Saxby & Robertson (2016) examed a single subject study on the circular or round kick with 3D inverse dynamics from an automated motion analysis system. A total of 15 circular kick were performed by one elite-level player. Two force plates were also used which would allow full inverse dynamics of the kicking and support legs but only the kicking leg results were reported. Knee and hip moments had peak flexion extension moments of around 150 N.m and the peak hip abduction/adduction moment was also close to 150 N.m. They summarised, that this kick was very different from soccer and front kicks not only in terms of abduction-adduction but in terms of hip extension-flexion timing and magnitude.

Although different styles teach and execute kicks with some differences comparison of kick between styles is not that common but three kinds of martial arts, Karate, Taekwondo and Muay Thai were compared for their performance of a roundhouse kick by Gavagan & Sayers (2017). Eight subjects from each style had their kicks analysed with a Qualisys Motion Capture System and an instrumented impact pad. Joint moments were not reported but the Taekwondo performances and joint ranges were more similar to each other than to the Muay Thai. This makes sense as the Muay Thai kick is often delivered to carry on through the target whereas the other styles snap them back to recover balance and remain forward facing in guard after the kick.

Petri et al. (2017) tested four healthy elite Karate from the Shotokan style, from Germany (age of 16-31 years height of 1.75-1.87 m with a mass of 73-87 kg) when performing roundhouse kicks (Mawashi Geri). They performed 10 repeated kicks from their own start and another 10 with reaction time to an external stimulus and measured the distance covered by the attacks using a Vicon motion system. They found that there were no individual differences between conditions.

The studies showed that there are few studies that have looked at martial arts kicks from the biomechanics side, especially Karate kicks. The studies normally examined one or two kicks with a low number of subjects, sometimes only one subject. They used 2D and 3D motion capture system such as VICON and Qualisys to analyse the data and only some used force plates to measure the force generated by joints. This gives a limited view of the different kicks across people and it was rare for the supporting leg to be analysed despite it being a basic technical point.

Table 5 Karate kick performances

Karate kicks performances				
Author(s)	year	Participants No.	Kick name	Kick analysed at one time
David Saxby and 2 D. Gordon E. Robertson	2016	1	Circular kick	1
Colin J. Gavagan, Mark G. L. Sayers	2017	24 (8 karate, 8 taekwondo and 8 mauy thai)	Roundhouse kick	1
D. Gordon E. Robertson, Carlos Fernando, Michael Hart and François Beaulieu	2002	2	Front kick	1
Silvia Cabral, António P. Veloso and Vera Moniz-Pereira	2011	3	Roundhouse kick	1
Sørensen , Zacho, Simonsen, Dyhre-Poulsen, & Klausen	1996	17	Front kick	1
Katharina Petri, Marvin Lichtenstein, Nicole Bandow, Sebastian Campe, Marcus Wechselberger, Dominik Sprenger, Felix Kaczmarek, Peter Emmermacher & Kerstin Witte	2017	4	Roundhouse kick	1
Tan, Kevin Siah-Yeow	2014	14	Front kick	1
Fabrizio Pecoraioli and Franco Merni	2009	14	Roundhouse kick	1
Quinzi, F., Camomilla, V., Felici, F., Di Mario, A., & Sbriccoli, P.	2013	12	Roundhouse kick	1

Chapter 3

3. Methods

3.1. Pilot studies

The five main Karate kicks (Front kick, Roundhouse kick, Side kick, Hook kick and Back kick) are fast movements that cover a wide range of motion in all three planes, especially at the hip. The ranges of motion seen are similar to those seen in dance and gymnastics, but the kicks generally have higher peak joint angular velocities. To look at the five main kicks careful equipment set up is required to obtain good, complete marker trajectories. This involved a lot of pilot testing to develop suitable experimental protocols and equipment set up to allow a single data collection session to accurately record all 5 kicks with the subject remaining comfortable. In competition and in training although the kicks themselves are directed in different directions relative to the body they are nearly always aimed at an opponent, real or imaginary, in front of the player. This can involve set up movements including 180° spins, or 90° twists and counter rotations of the upper and lower body. This can make marking tracking difficult and marker occlusion can occur, especially as the kicks tend to tuck into the body before being extended towards the target and high kicks have to pass by the hands that are in guard. Repeated kicking requires considerable effort and players will sweat which makes marker loss likely when combined with high-velocity movements with rapid acceleration changes. In fact, some kicks are taught with the expression, imagine you are flicking something of the end of your foot. Several large, and some smaller, pilot studies were undertaken to optimise data collection for the main study and, to also help decide on kicks, how many and what variants to use.

3.1.1. First major pilot study

The target of the first experiment was to become familiar with the laboratory equipment and devices (9 camera T20 Vicon system and 2 Kistler 600x900 force plates), identify the preparing time to run the VICON system and the cameras set up, markers types and sticky tape types, the time required to put the markers on the subject`s bodies, markers placements and markers numbers needed to obtain clear data on karate techniques.

A full body marker set was chosen to start with and a range of markers sizes were tested Table 6, Figure 6 and Figure 7. Different marker sizes were tested as although larger markers suffer from occlusion less they are also more likely to get knocked off by other limbs moving or fly off during the kick due to their inertia, Figure 8 shows markers type and sizes of 9mm for lower legs and 19mm for the pelvis.

Table 6 Markers labels, position and descrption

Marker Label	**Marker Position**	**Description**
Finger (R/L)	End of $3^{rd.}$ distal phalanx (finger)	Tip of middle finger
5MCP (R/L)	Dorsal aspect of the head of the 5^{th} metacarpal	Medial and lateral projections of the MCP joint centre (mid-point of these two markers is the MCP joint centre)
2MCP (R/L)	Dorsal aspect of the head of the 2^{nd} metacarpal	
US (R/L)	Lateral aspect of the styloid process of the ulna	Medial and lateral projections of the wrist joint centre (mid-point of these two markers is the wrist joint centre)
RS (R/L)	Lateral aspect of the styloid process of the radius	
LE (R/L)	Lateral aspect of the lateral humeral epicondyle	Medial and lateral projections of the elbow joint centre (mid-point of these two markers is the elbow joint centre)
ME (R/L)	Lateral aspect of the medial humeral epicondyle	
Acromion (R/L)	Superior tip of the Acromion process	
Shoulder (R/L)	Estimated lateral projection of the glenohumeral joint centre when the arm is elevated	Approximately the belly of the posterior Deltoid when the arm is elevated
Anterior Shoulder (R/L)	Estimated anterior projection of the glenohumeral joint centre when in the anatomical position	Mid-point of these two markers is the shoulder joint centre (only used for static trials)
Posterior Shoulder (R/L)	Estimated posterior projection of the glenohumeral joint centre when in the anatomical position	
R_Scapula	Middle of right scapula	Used only for identification of right side
Sternum	Superior tip of the manubrium of the sternum	Suprasternal notch at top of sternum
Xiphoid	Centre of the xiphoid process of the sternum	Inferior tip of sternum
C7	7^{th} cervical vertebra	Prominence at base of neck when the neck is flexed
T10	10^{th} thoracic vertebra	Count up from L1 (moving the skin over the spinous
L1	1^{st} Lumbar vertebra	Find L5 between right and left PSIS and count

L_Hip	Superior border of left iliac crest	Used only for identification of left side
Marker Label	Marker Position	Description
ASIS (R/L)	Anterior superior iliac spine, in line with hip joint	Bony landmark on the front of the pelvis (level with your belt)
PSIS (R/L)	Posterior superior iliac spine	Dimple in the skin at the back of the pelvis (a little lower
Left_iliac	Superior and lateral tip of the left iliac crest	Used for identification of the left side
Hip (R/L)	Greater trochanter of the femur	
MK (R/L)	Lateral aspect of the medial femoral epicondyle	Medial and lateral projections of the knee joint centre (mid-
LK (R/L)	Lateral aspect of the lateral femoral epicondyle	
LM (R/L)	Lateral aspect of the lateral malleolus of the	Medial and lateral projections of the ankle joint centre (mid-
MM (R/L)	Inferior tip of the medial malleolus of the fibula	
1MTP (R/L)	Head of the 1st metatarsal	Medial and lateral projections of the MTP joint centre (mid-
5MTP (R/L)	Head of the 5th metatarsal	
Toe (R/L)	End of 1st distal phalanx	Tip of big toe
Head Band	Four markers placed at front right/left and back left/right of the head	

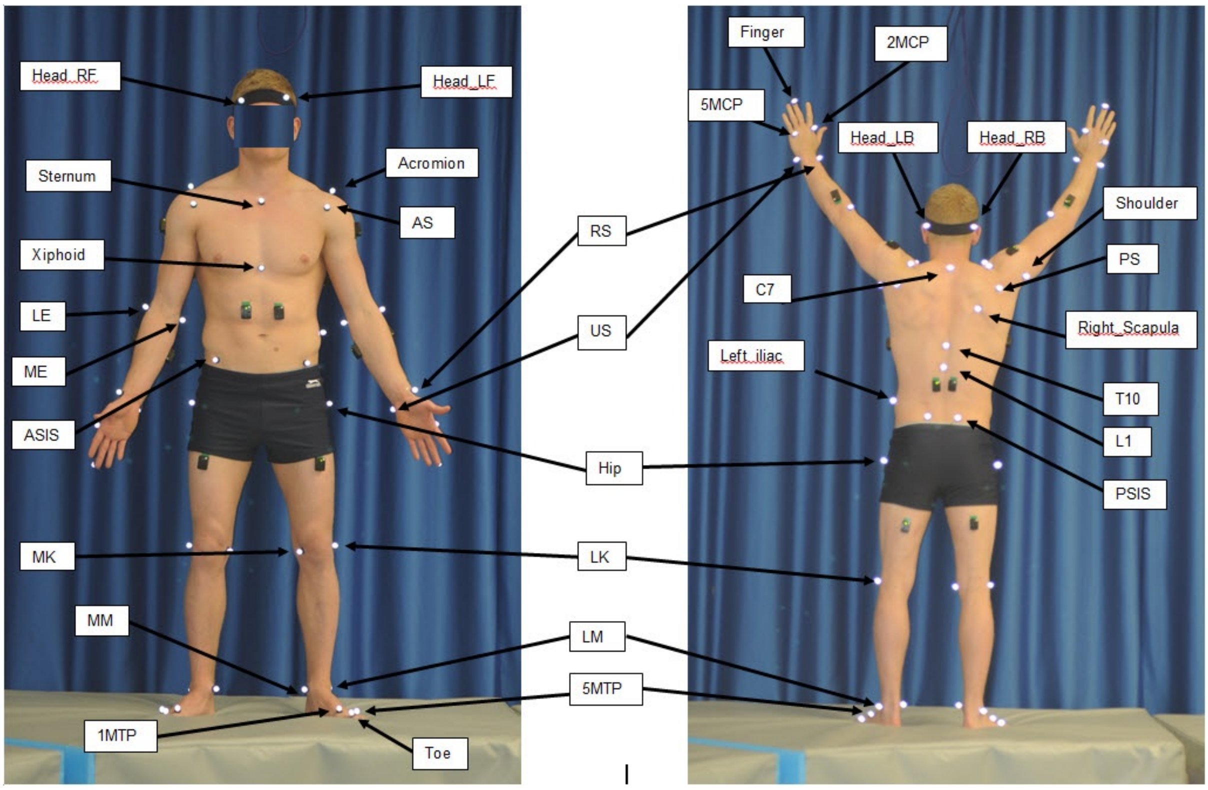

Figure 6 Marker names and placements on the body

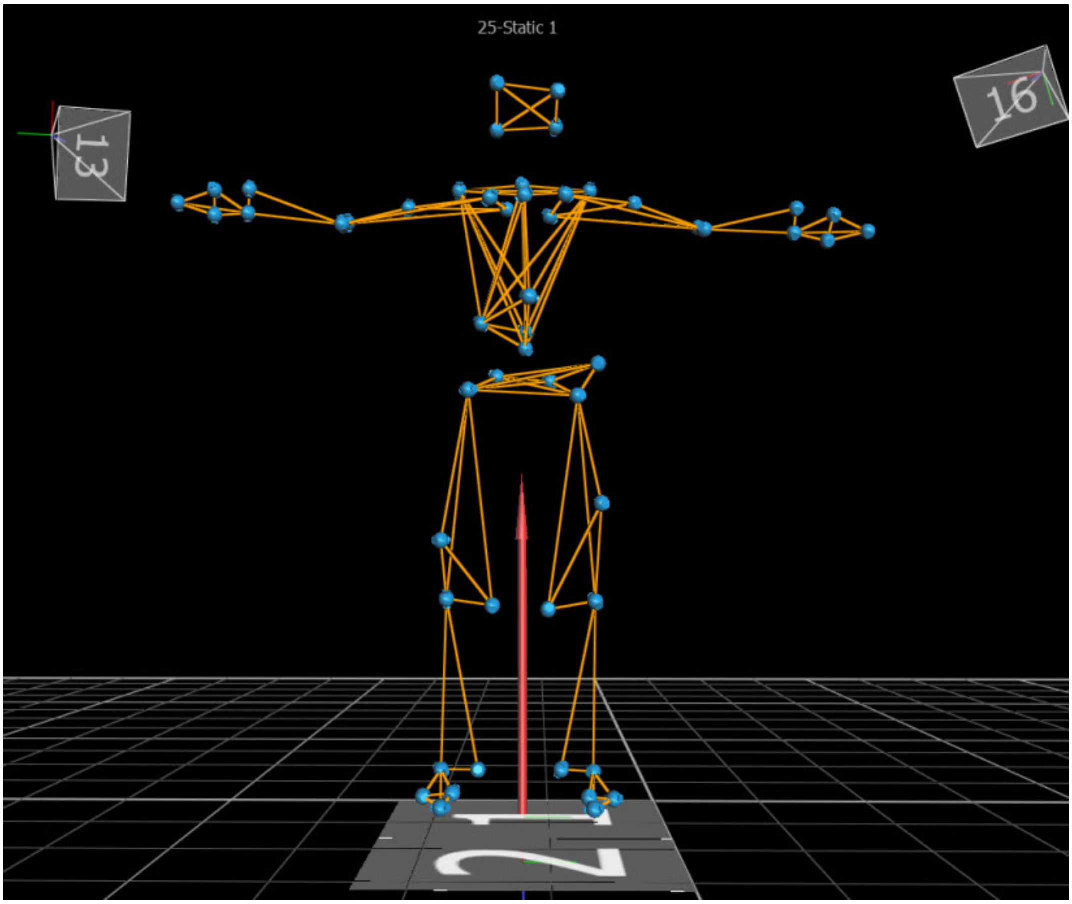

Figure 7 Marker placement reconstructed in Vicon

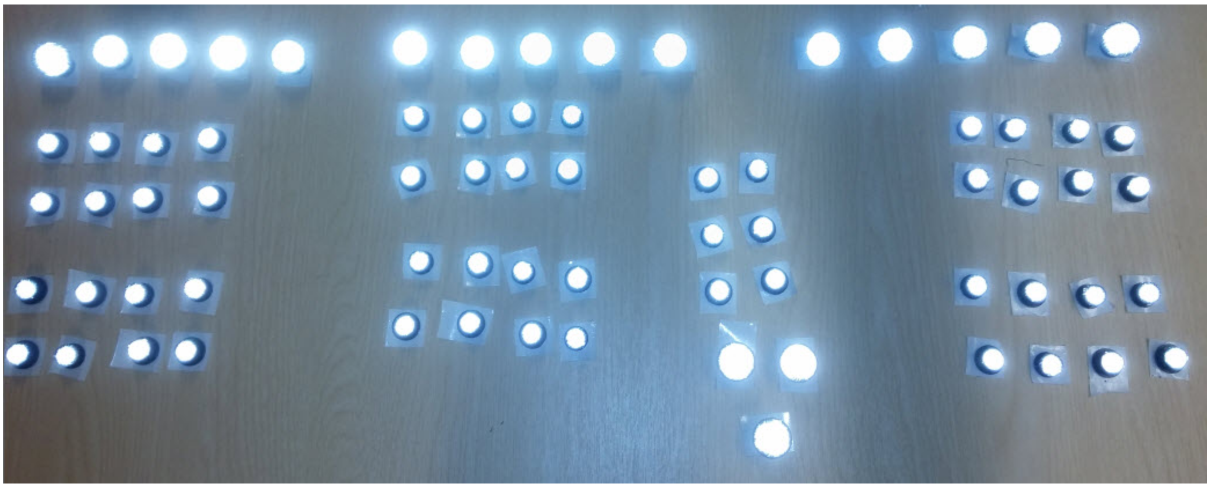

Figure 8 Markers type and sizes

Three subjects of different sizes performed all the main kicks in various different ways with the setup, marker attachment and recording undertaken by one person. With only one person it was taking a long to prepare the laboratory equipment, such as camera placement, masking to remove noise, and calibrating. There was a high percentage of camera errors and some cameras did not finish calibrating. The volume was based on two force plates, but the required volume was much larger than this to allow full leg extension in all planes. This meant that within the camera rig set up a 5 x 5 x 4 m rig fixed to the walls, for the 9 cameras available, edges of the required calibration volume were poorly covered. A large part of this was from some cameras being too close to a well-focused image of some markers.

There were also large issues with the time it took to put on the whole-body marker set, that markers would regularly fly off the feet or lower leg, mainly during front, roundhouse and hook kicks, and that upper body markers were crossing paths with lower limb markers. The upper body markers also extended the range within the volume that markers had to be seen in focus at the same time. This resulted in a lot of incomplete marker tracking and very noisy data as long set up time. Due to markers coming off it also meant that data collection time was extended. Performing up to 10 repetitions of each kick was attempted in one recording but marker loss often stopped this and was resulting in the subject having to spend a lot of time not kicking or actively resting but being re-marketed and the set being started again. The many kicks per recording with the poor camera conditions also led to many gaps that made trajectory reconstruction very time-consuming.

3.1.2. Second major pilot study

Based on the previous pilot study and steady developments in use of Vicon the issues were all addressed. Camera locations were moved, to higher points on the rig and some of the rig onto tripods to increase volume area. Cameras were set up, so they could get good coverage of the markers on the lower leg from the floor to the end of the kicks. Lenses were checked, and cameras swapped to make the best use of the different fixed lengths. Some reflective surfaces were covered, and sunlight completely removed from the room by taping and tucking curtains tightly into place. This allowed good calibrations to be obtained and the full body marker set could be recorded with minimal marker loss Figure 9.

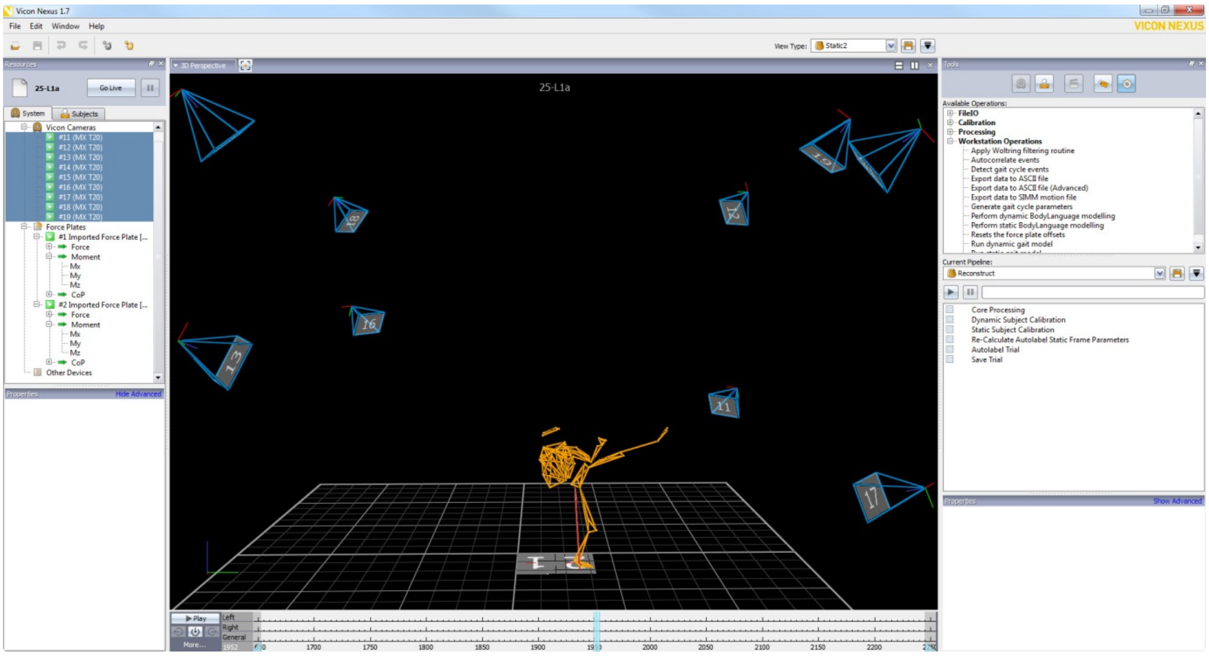

Figure 9 Good cameras position and set volume origin

Four types of tape were tried, Figure 10 and Figure 11. A super sticky double-sided tape was found that when a lot was used with 14 mm markers stayed on for most kicks. This super sticky tape was used for markers below the knee and the normal double-sided tape was used for other markers, 3rd tape in Figure 10. There were still problems with the time it took to prepare a subject and the time it took to process the marker data, gap filling and marker crossover, especially when performing 10 repetitions of the kick in a single recording. The 10 repetitions of kicks in a single recording were used to assess the repeatability, variability of kicks and there was very little variation per subject within a kicking mode compared to between modes. Mean and standard deviation of the 10 repeated kicks flexion – extension angles were: Front kick (right): Kicking hip 81°±3°, kicking knee 169°±2.4°, support hip 16°±1.9° and support knee 130°±2.1°. Roundhouse kick (right): Kicking hip 59°±2.5, Kicking knee 130°±3.2°, Support hip 51°±3.1° and support knee 176°±2.3°. Roundhouse kick (right) 60°±3.3°, kicking knee 156°±3.2°, support hip 60°±3.1° and support knee 163°±2.6°.

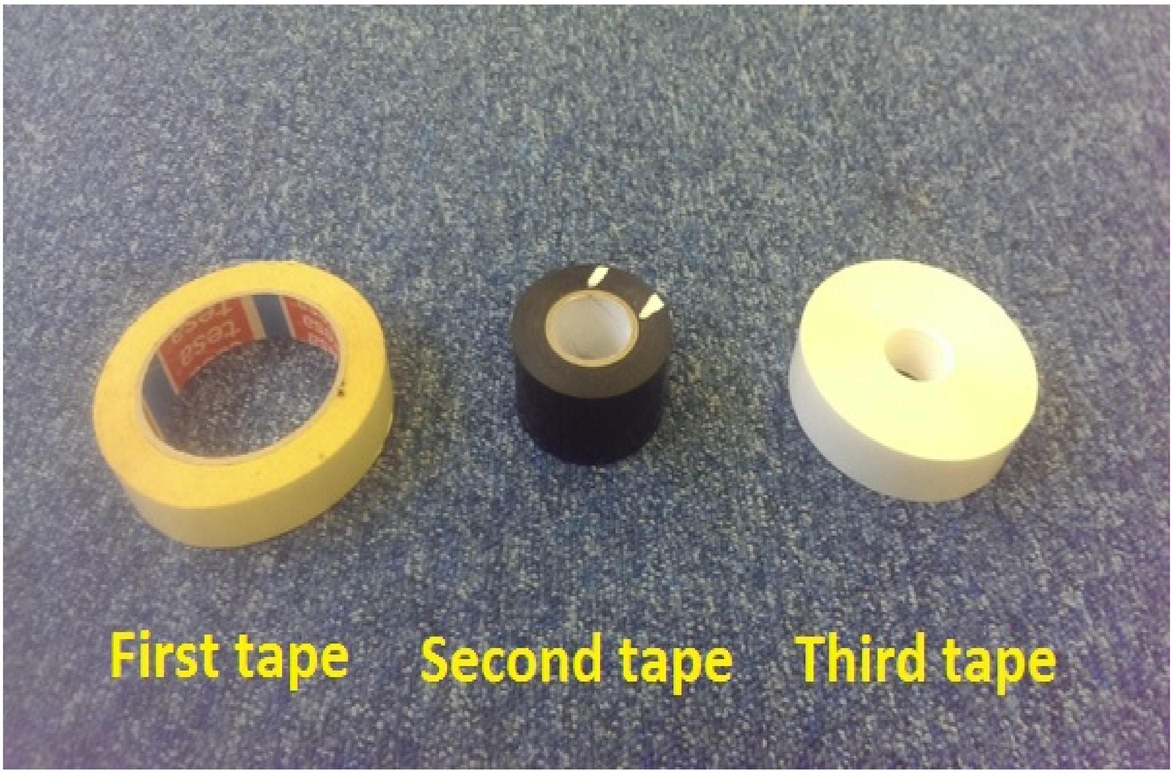

Figure 10 The three types of tape tried

Figure 11 The 4th tape type, super sticky tape

3.1.3. Third pilot study

Now it was possible to collect good data of the kicks with the camera set up and tape it was still taking too long for the subjects to remain warmed up and flexible, which is needed to not only get good kick performance but also to reduce the chance of injury. A lower body marker set was tried instead of a whole-body marker set on a group of 3 subjects. This was just the lower limb and pelvis markers of the whole-body marker set. This reduced the number of markers to 21 and not only greatly reduced the markers set up time and the comfort of the subject it improved the overall data quality by allowing the capture volume to be slightly smaller. This meant fewer gaps, crossing trajectories and so fewer data processing time to get clean useable trajectories. Some further minor camera adjustments were made and then camera details were recorded as the cameras were used by others who needed them in different locations in the room.

The actual kick choices, number of modes of performing them and the repetitions per kick were also refined at this stage. The five main kicks were all able to be recorded in one session and each kick could be done in 3 ways, Training, Competition and Step. This gave 30 trials for each subject for kicks, 15 for each side plus 1 static position for a total of 31 trials per subject. They repeated attempts of each kick after warm-up, they kick until one good rep for each kick in each mode was obtained. A good kick was one that the supporting leg was on the force plate all time through the kick when the support leg was on the floor, no markers were lost and the researcher, an international coach and competitor, deemed it a qualitatively technically correct and of speed seen in the warm-ups and practice.

The third experiment was aimed to improve data collection skills and make some necessary changes in the setup. Type of the tape has been changed to double side tape stronger than the first tape on the first experiment. Changing the cameras placements to focus on the very low markers and very odd angles has been done. Renaming the markers and create the body segments for each trial took less time almost reduced to the half by reduced the markers on the body to cover just segments under the study (Pelvis and lower limbs). So, the markers became just 21 markers that are led to fewer gaps and the filling gaps became easier and faster. 5 kicks each kick 3 ways (Training, competition and step) will become 30 trials for each subject, 15 for each side plus 1 static position to be 31 trail overall Table 7and Figure 12.

Note: Subjects participated in the previous pilot did not participate in the main experiment.

Table 7 List of Karate kicks Japanese and English names

No.	Japanese name	English name
1	Static position	Open arms up
2	Mae Geri training	Front kick
3	Mae Geri competition	Front kick
4	Mae Geri step	Front kick
5	Mawashi Geri training	Roundhouse kick
6	Mawashi Geri competition	Roundhouse kick
7	Mawashi Geri step	Roundhouse kick
8	Kekomi Geri Training	Thrust kick
9	Kekomi Geri competition	Thrust kick
10	Kekomi Geri step	Thrust kick
11	Ura Mawashi Geri training	Hook kick
12	Ura Mawashi Geri competition	Hook kick
13	Ura Mawashi Geri step	Hook kick
14	Ushiro Geri training	Back kick
15	Ushiro Geri competition	Back kick
16	Ushiro Geri step	Back kick

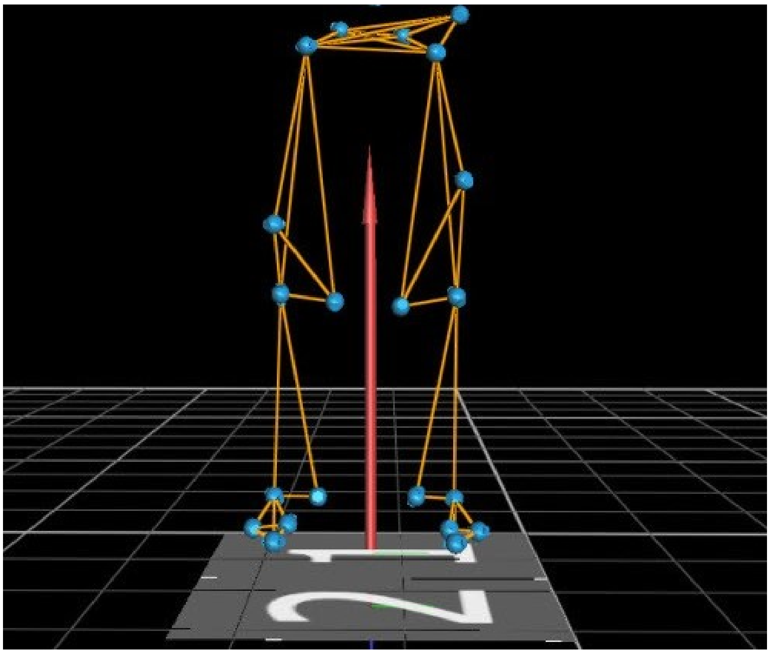

Figure 12 New marker set up

3.2. Main Study Overview

Following ethical approval 28 black belt karate players (20 men and 8 women, mean ± SD; age: 26 ± 7.2 years, height: 177.7 ± 7.0 cm, mass: 78 ± 9.4 kg and years training: 14 ± 6.2 years Table 8) with no injuries to their knees or hips volunteered for this study.

Table 8 Individual subject details

Healthy Subject	Sex	Age	Height (cm)	Mass (kg)
KAR1	*Female*	19	165	60
KAR2	*Female*	21	163	58
KAR3	*Female*	22	168	65
KAR4	*Female*	23	167	71
KAR5	*Female*	35	166	61
KAR6	*Female*	30	164	72
KAR7	*Female*	27	168	67
KAR8	*Female*	18	166	68
KAR9	*Male*	21	180	85
KAR10	*Male*	19	175	75
KAR11	*Male*	18	170	88
KAR12	*Male*	18	179	87
KAR13	*Male*	21	177	67
KAR14	*Male*	20	170	74
KAR15	*Male*	20	182	67
KAR16	*Male*	23	172	71

KAR17	*Male*	25	183	80
KAR18	*Male*	29	175	62
KAR19	*Male*	20	178	73
KAR20	*Male*	30	171	79
KAR21	*Male*	35	175	90
KAR22	*Male*	40	183	83
KAR23	*Male*	21	180	76
KAR24	*Male*	19	182	71
KAR25	*Male*	18	184	93
KAR26	*Male*	43	168	76
KAR27	*Male*	33	179	81
KAR28	*Male*	37	176	77
Mean		26.0	177.7	78.1
SD		**7.2**	**7.0**	**9.4**

Players height and mass were recorded and after a personal warm up, each karate player performed the main 5 kicks in three different ways for both legs right and left, training, competition and step modes. Training Karate rules, norms and practices come from Japanese culture where it was invented, so from that philosophy they prefer to use the right leg rather than left leg as main leg or dominant leg, even if people are left leg dominate. They believe that the right leg is stronger, faster and can make more impact (Hsieh, Huang, & Huang, 2012; Pędzich, Mastalerz, & Urbanik, 2006; Sidthilaw, 1996). In competitions people are free to use either leg as they prefer but basic training drills and the Kata (defined forms of movement for practice) are right side biased. This standard training practices force karateka to train both legs but there is bias to using right side. The kicks were qualitatively checked as per the 3rd pilot study by the researcher who has been an international coach and competitor. For each kick mode the players started stationary, they did not take a deliberate extra step into the kick or actively jump with the kick but foot slide and foot rotation during the kick necessitated two force plates and the support foot was not stopped from leaving the floor if this occurred as part of the kick. They kicked the air at a point of their choosing with the only constraint being that they kept their supporting foot on the force plates or in the air. The training kick was as executed as in standard training in their style with ‘speed and power’ and the competition kick was also executed with ‘speed and power’ but with their own greater emphasis on speed at the expense of traditional form of execution as they would in the competition.

There was no other constraint on how the experienced karate players performed the modes of the kicks.

For each kick the following sequence of events was followed by the subject, sides changed for left kicks. Subject took a ready stance: left leg in front with about 90° flexion, right leg behind with a small amount of knee flexion, hands to the upfront with about 90° elbow angles, chest almost 45° to the right and the head should be facing to the front, note: each subject has his own ready stance, but they are all slight variations of this standard stance. Researcher started recording and informed the subject they could perform the kick from this point on in their own time. Subject performed the kick on their own volition; no rush to the reaction was required. Data were reconstructed, and kick validity checked. If markers came off they were replaced with new ones and the trial repeated. There was no dedicated rest time beyond that needed for data acquisition steps. Motion and force data were collected with a nine T20 camera VICON motion analysis system (VICON, Oxford Metrics Group, UK) set to 250 Hz and two 0.6x0.4 m Kistler type 9281EA force plates (Kistler Instruments AG, Winterthur, Switzerland) set to 1000 Hz. Twenty-one 14 mm retro-reflective markers were put on the player's bodies. Five on the foot (1 on the big toe, 2 on the foot, medial and lateral sides of the MTP joint on the top surface , 2 on the medial and lateral sides of ankle joint); 2 on the knee joint (medial and lateral sides of knee joint), 1 on the thigh; 5 on the pelvis (2 on the bony protrusion of the right and left anterior super iliac, two on the dimples created by the right and left posterior super iliac and 1 on the left iliac this just to check right and left sides) Figure 12.

Data were reconstructed and processed in VICON Nexus and then exported to Visual3D (C-motion, Germantown, MD, USA) to calculate 3D joint motion and joint moments about the hip and knee of both the support leg and kicking leg for all kicks (moment normalised to body mass). Time was normalised to kicking duration from a common start point and common end (actual kicking time was between 1-2 second). For example, the actual times for front kick training mode is 0.71s ± 0.1s to full extension, time for competition mode is 0.63s ± 0.1s to full extension and time for step mode is 0.54s ± 0.1s to full extension. The actual times for roundhouse kick training mode is 0.78s ± 0.1s to full extension, time for competition mode is 0.69s ± 0.1s to full extension and time for step mode is 0.56s ± to full extension. The actual time for side kick were: Time for Training mode is 0.65s ± 0.1s to full extension, Time for competition mode is 0.63s ± 0.1s to full extension and time for step mode is 0.83s ± 0.1s to full extension. The actual time for hook kick were: Time for Training mode is 0.74s ± 0.1s to full extension, time for competition time is 0.71s ± 0.1s to full extension and time for step mode is 0.63s ± 0.1s to full extension. The actual time for back kick were: Time for training mode is 0.81s ± 0.1s to full extension, time for competition mode is 0.71s ± 0.1s to full extension and time for step mode is 0.73s + - 0.1s to full extension. Maximum joint angle and maximum joint moment during the kick (when the foot left the force plate and before the foot landing the ground) were calculated and pooled across all 28 karate players for each of the three joint axes of the hip and knee. The X-axis is flexion-extension, the Y-axis is abduction-adduction and Z axis is an internal-external rotation. To achieve the above setup of VICON and the force plates there were many steps and procedures refined through the pilot studies. The experimental setup, data collection, data processing within Vicon and then Visual3D are presented below.

As it is well known and accepted that the different kicks have very different ranges of motion about different joint axes and different loading patterns statistical comparisons were only made between the modes and comparisons were subject by subject. After processing the data through VICON and Visual3D data were reorganised in Excel to transfer into SPSS software to do one-way repeated ANOVAs. Cohen`s D for effect size for post hoc tests were considered as: small effect if it is less than 0.20, medium effect if it is 0.20 to 0.50 and large effect if it is more than 0.50.

3.2.1. Data Collection using the VICON system in the laboratory has been done by the following steps:

1- Laboratory environment, this was set up appropriately for each session to ensure that no external lighting was coming in, that may affect the cameras and areas were clear and free of slip hazards.

2- Cameras location and angles: Location of the cameras was chosen according to the number of cameras, the size of the laboratory, the location of the force plates. Cameras positions and angles were chosen according to what was found from the pilot studies and these were recorded so they could be repositioned when moved Figure 13.

3- Camera set up: Cameras were moved if needed back to their optimal positions for this study and focused depending on the distance between the camera and the subject to obtain clearly defined marker images.

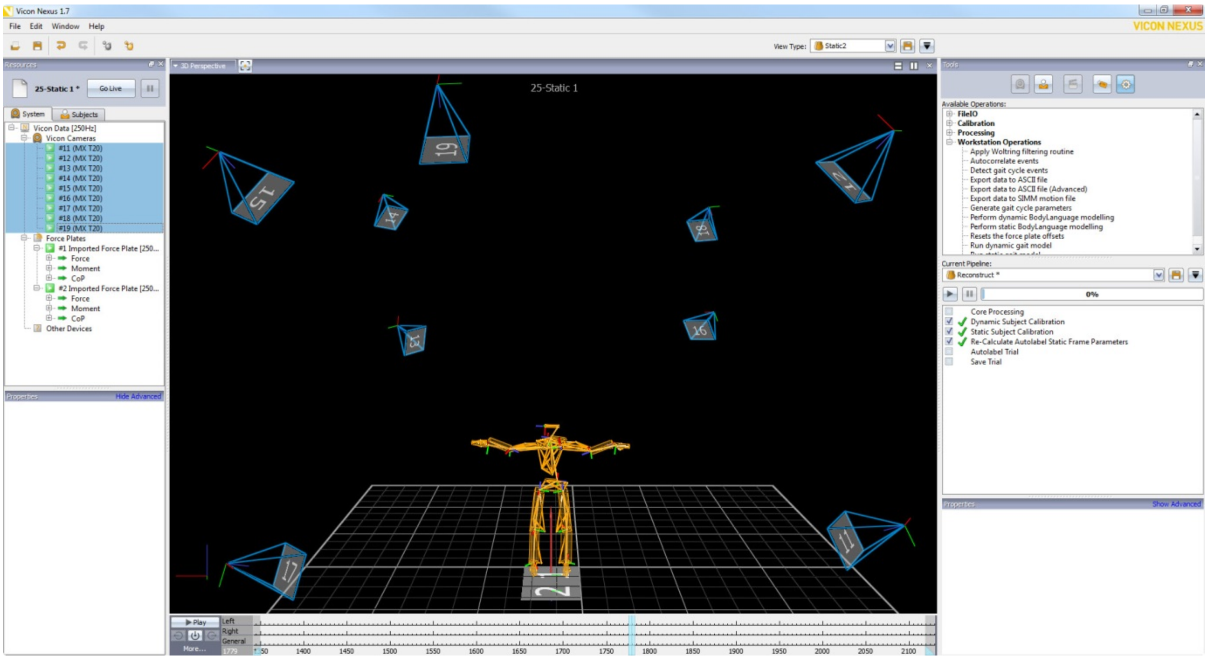

Figure 13 Camera placement

4- VICON Nexus v.1.8 software, with Eclipse database management, data collection. Settings were determined from pilot studies and recorded, at the same settings used each time Figure 14.

a. Camera settings: Strobe Intensity =1, Threshold = 0.5 and Grayscale = Auto Figure 14.

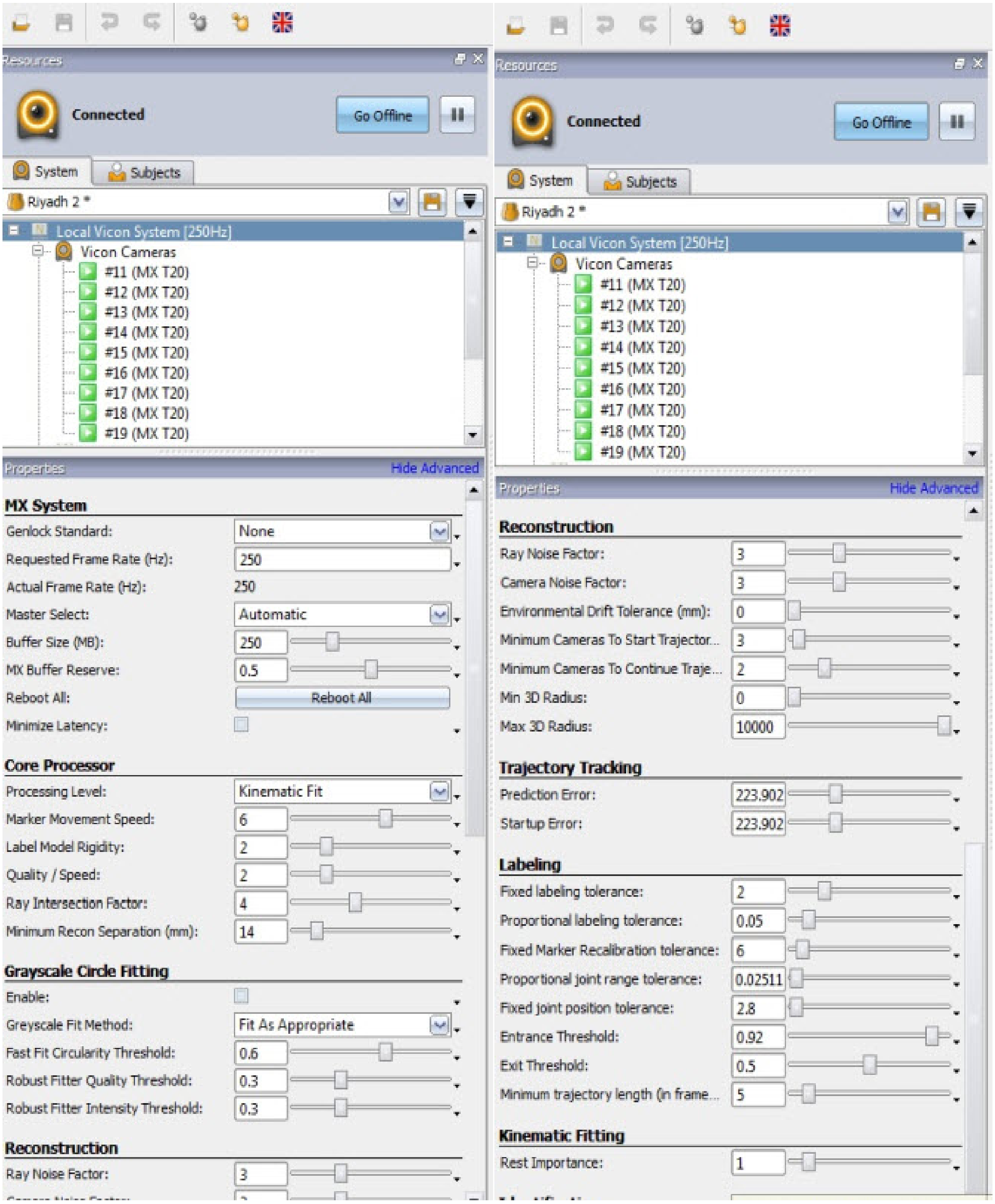

Figure 14 Cameras setting

b. Adding camera mask: It was important to add camera masks to cover noise still appearing in each camera window, and other camera strobes to get clean and neat data Figure 15.

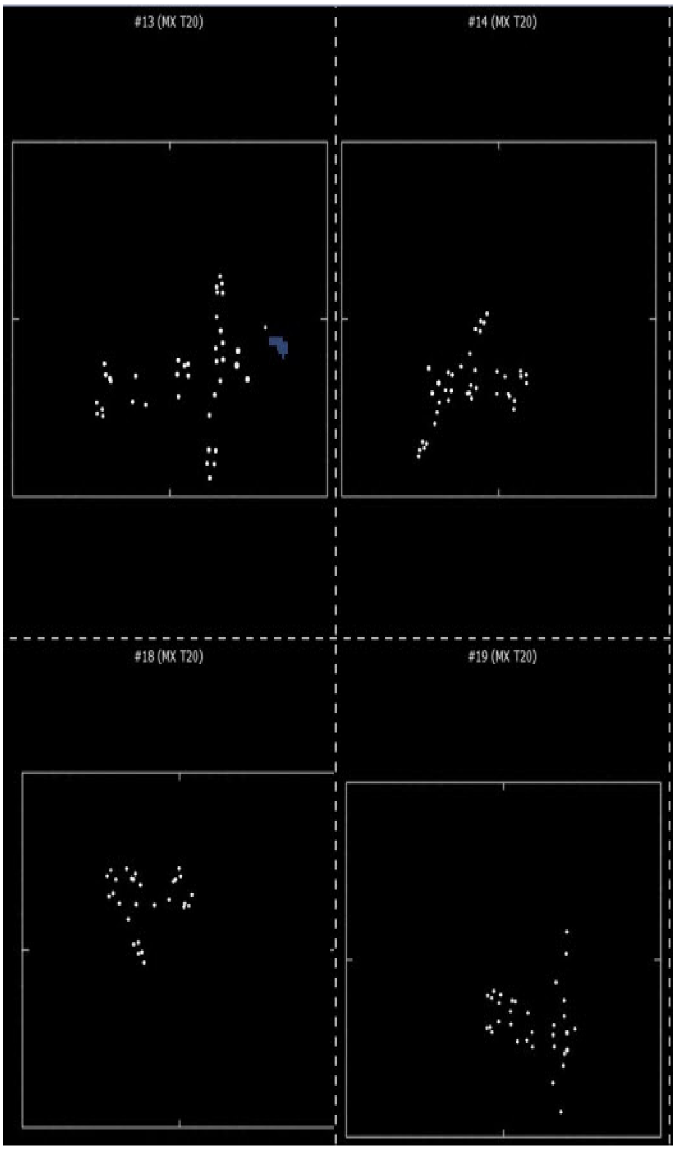

Figure 15 Camera mask, Calibration, Volume origin and Image error

c. Calibration cameras and Volume origin: T wand required before start calibration to focus the calibration just on the area the motion will be. Ensure the calibration has been selected is full calibration and the camera calibrating all MX cameras also the refrainment frames are 1000 and finally auto stop has been selected.
d. Calibration was repeated for each session until an image error of less than 0.3mm on each camera was obtained.
e. T-wand was placed in the centre the corner of the left force plate before clicking start twice to set up the volume origin and orientation of the capture volume.

f. Force plate set up: The force plates were connected and synchronised with motion data from cameras through the Vicon software digital force plate interface. Before trials the force plates were manually zeroed, the force plate was highlighted and appeared on the live view with the real-time force arrows.
g. Static position of each subject was recorded.
h. Kicking trials were then recorded manually.

3. Vicon Nexus data processing
    a. Marker reconstruction: Saved trial data recorded previously were opened from Eclipse and after it loaded to Nexus software was used to reconstruct it Figure 16.

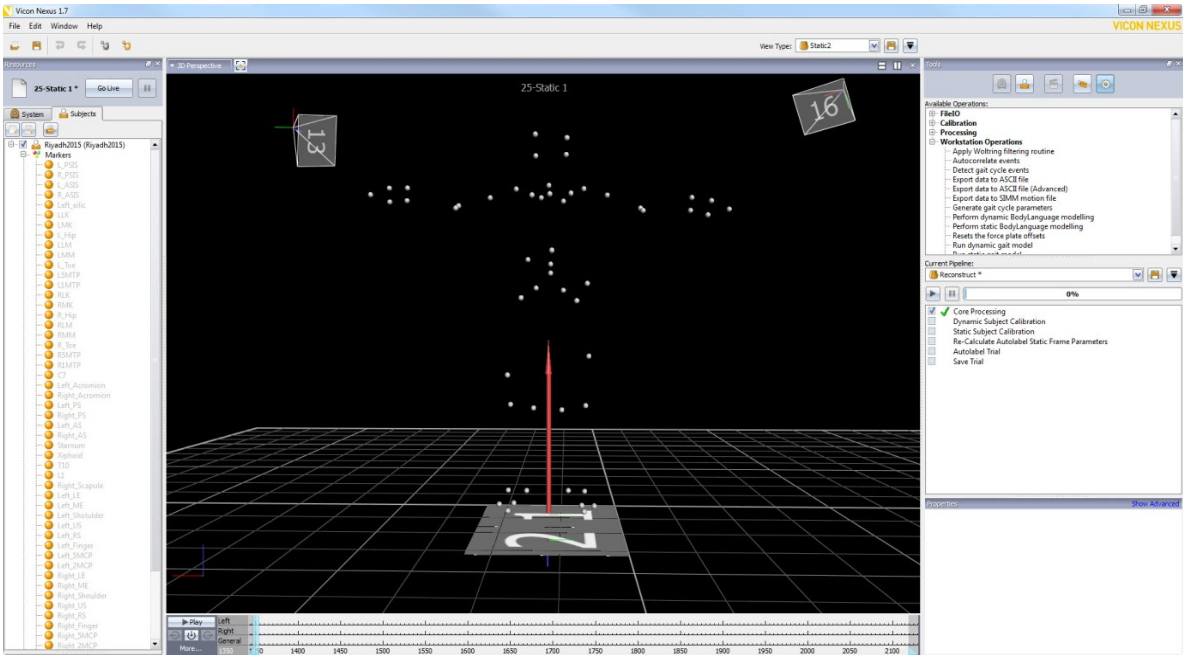

Figure 16 Markers Reconstruction

    b. Minimum cameras to start trajectory: 2 cameras were chosen to reconstruct due to the limited camera views for large periods of the kicks.
    c. two screens were used in Nexus to view the 3D perspective view of marker trajectory and graph view to track total marker trajectories when dealing with gap filling.
    d. Creating marker model: Segments were created in order (pelvis, left thigh, left shank, left foot, right thigh, right shank and right foot Figure 17.

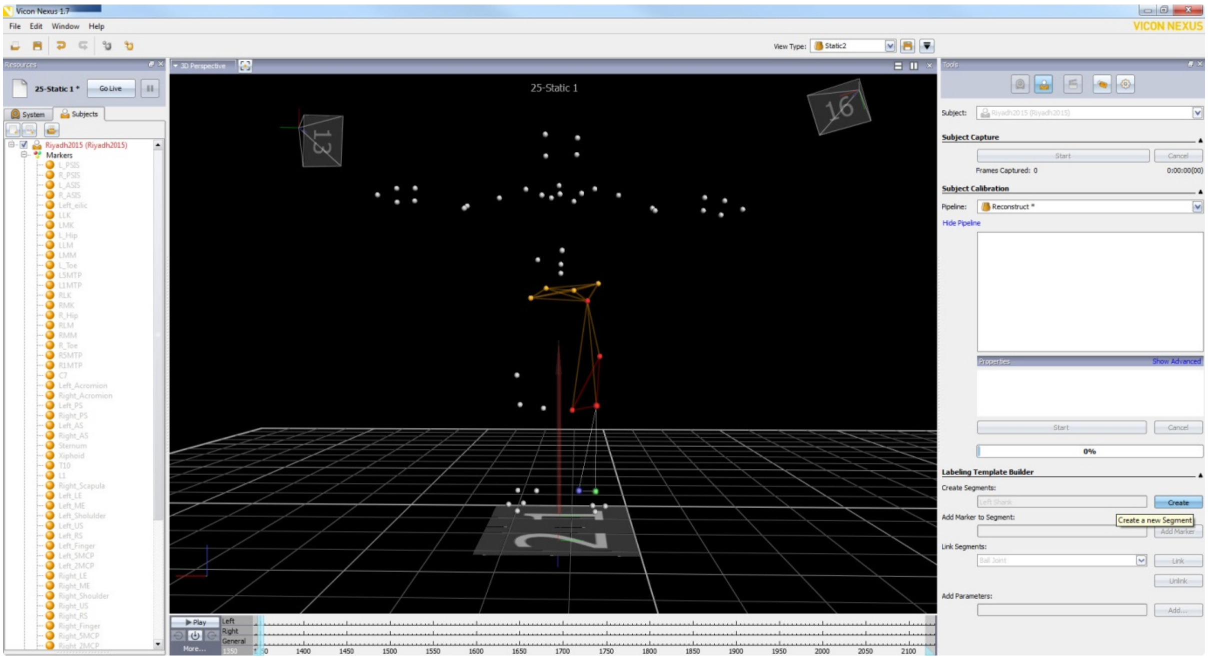

Figure 17 Renaming the markers and creating the body segments

e. Linking segments: when the segments were created the root segment was chosen as the Pelvis. Segments were linked in the following manner (Pelvis-Left thigh, Left Thigh-Left shank, Left Shank-Left foot, Pelvis-Right thigh, Right Thigh-Right shank and Right Shank-Right foot) Figure 18.

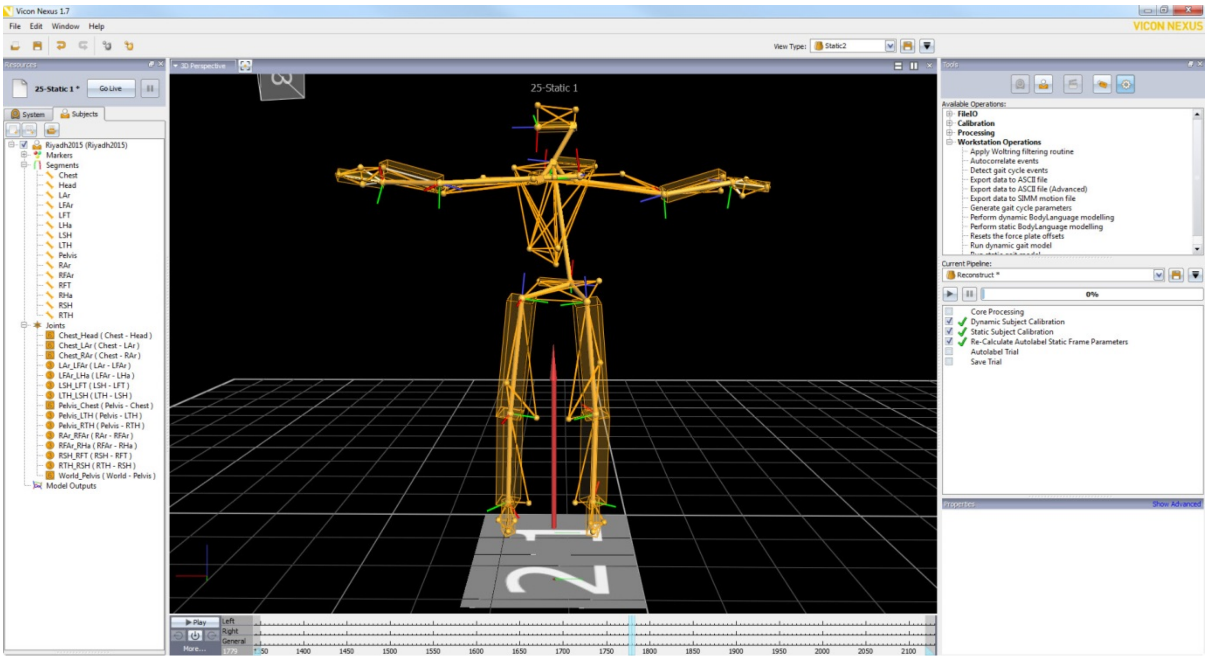

Figure 18 Segment and joint linking

f. Naming markers: Whenever segments have been created markers can be renamed (labelled) and stored in the Vicon Skeleton (VSK) and Vicon Skeleton Template (VST) files were generated and saved. A VSK file is considered as a generic model that can be used by many subjects and VST file it is a specific file for one session or one subject.
g. Filling gaps: ones' marker trajectories were labelled and ghost markers were deleted then gap filling was carried out. Of the two ways for filling the gas "Spline Fill" and "Pattern Fill", pattern fill was mostly used Figure 19.

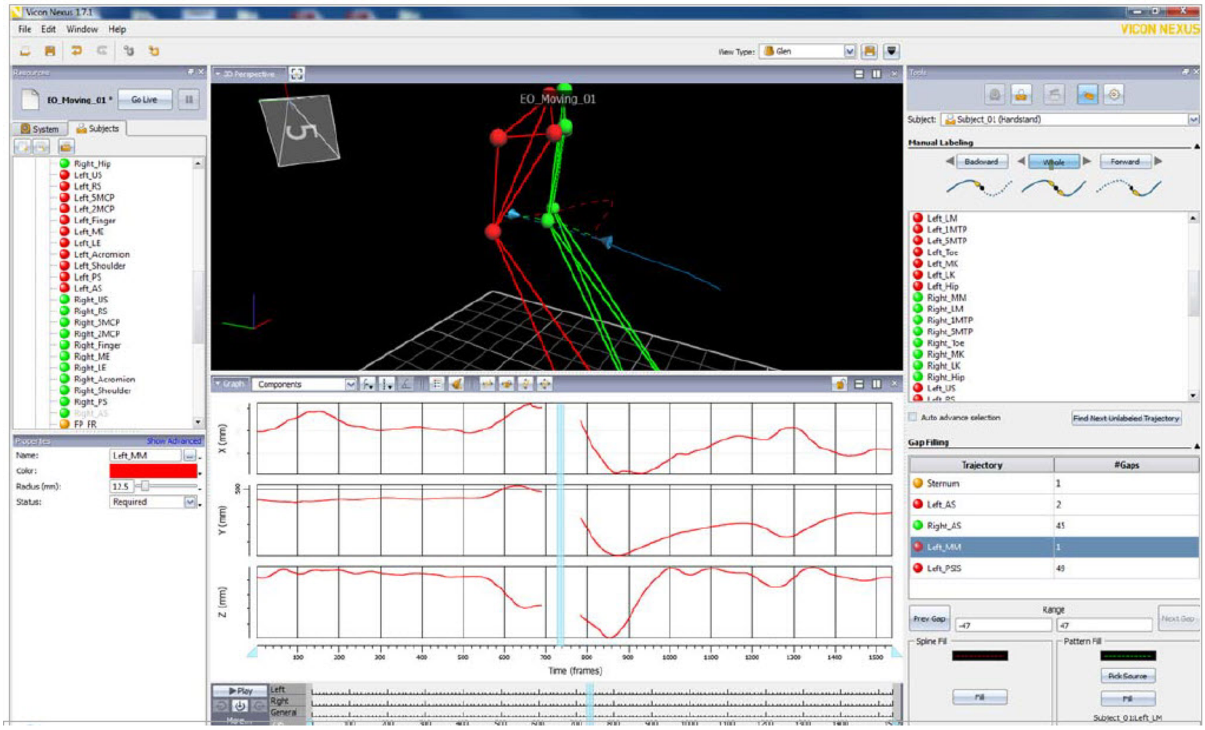

Figure 19 Gap filling

h. Saving and exporting data: The final steps were saving data which can be in several formats, Excel and c3d were used in this study. C3d files were exported to Visual3D to calculate angle and moments of the hips and knees.

3.2.2. Subject model creation in Visual 3D:

The inertial parameters for each subject were the V3D default values based on mass and certain lengths.

a. First a static trial was loaded into the Visual3D software Figure 20.

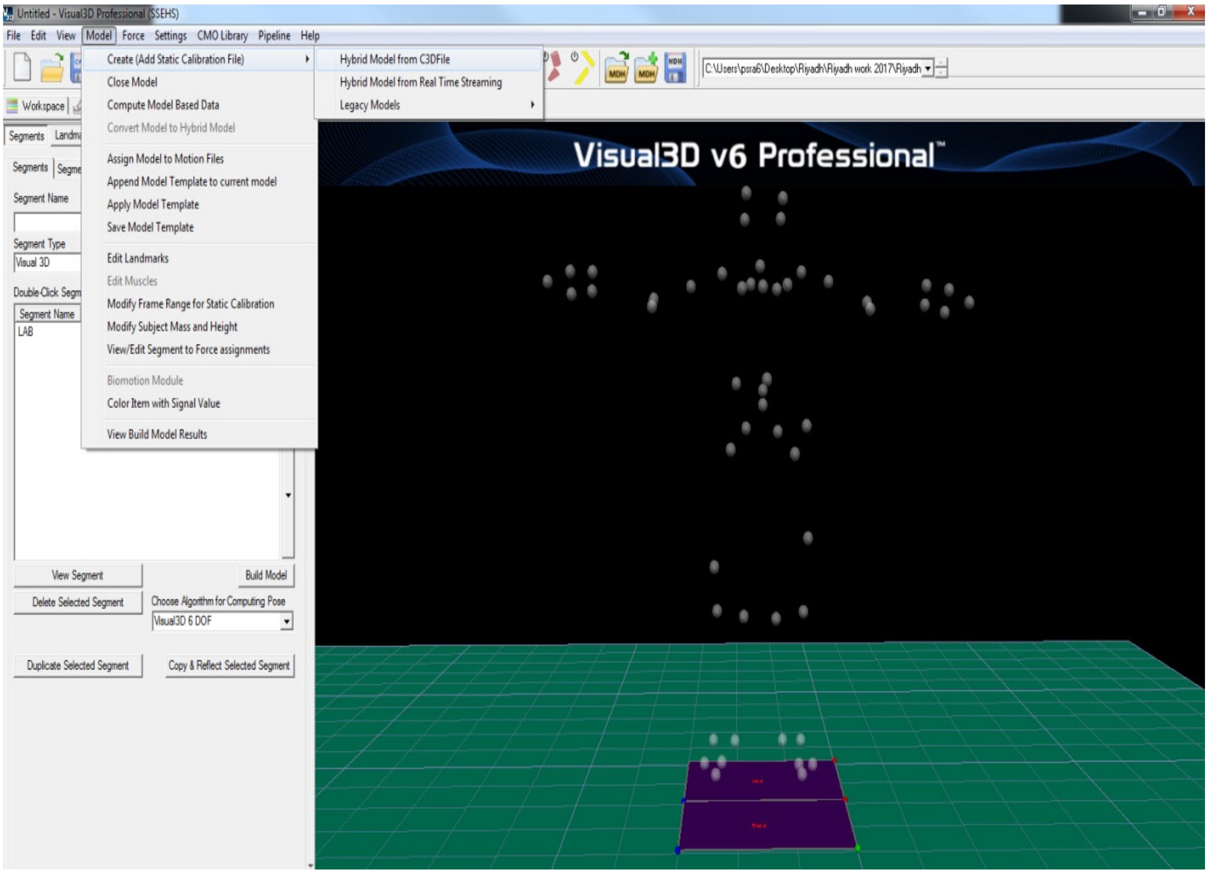

Figure 20 Static file loaded

b. Right and left hips joints centres were created within pelvis segment using 5 markers (Right_PSIS, Left_PSIS, Right_ASIS and Left_ASIS with Left_iliac), right knee joint centre (Right_LK and Right_MK), Right ankle joint centre (Right_LM and Right_MK), Left knee joint centre (Left_LK and Left_MK) and Left ankle joint centre (Left_LM and Left_MM) were created due to being needed to create the body segments Figure 21.

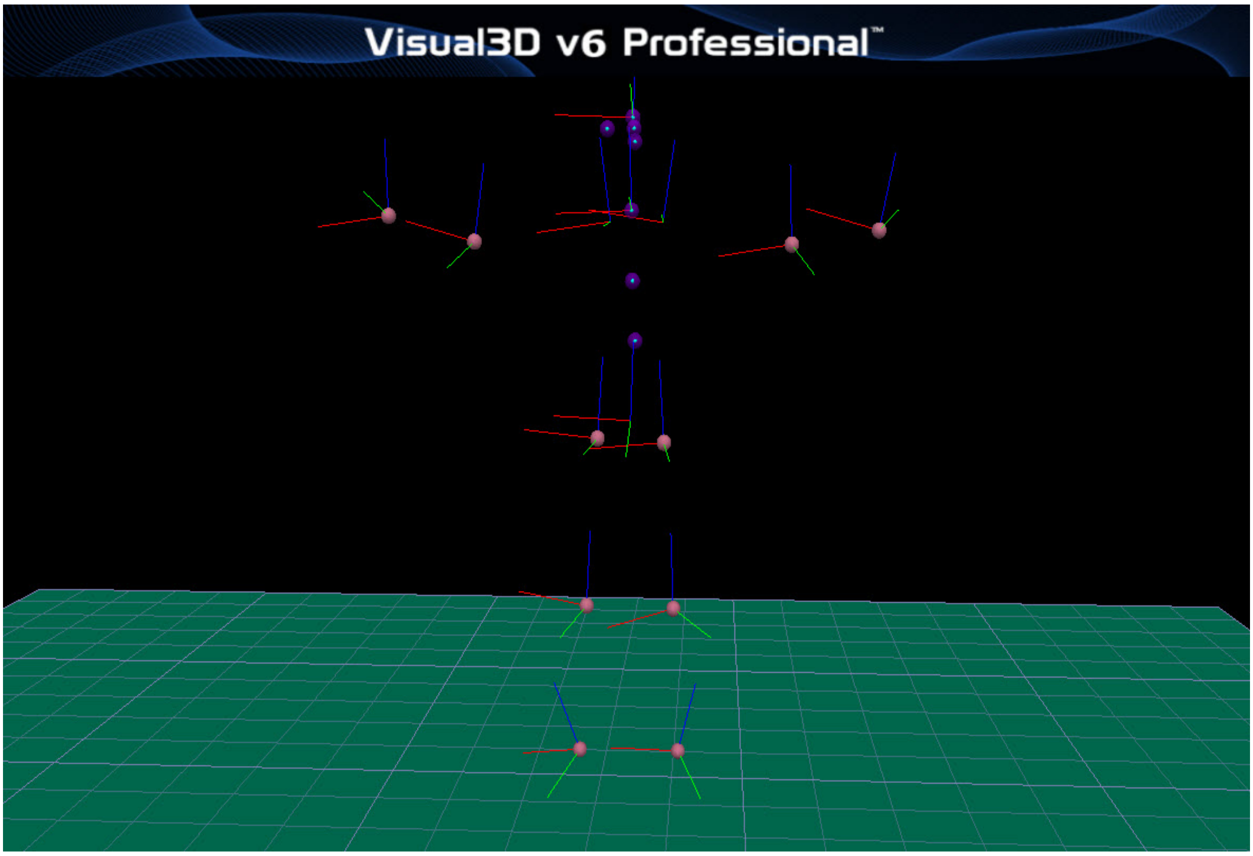

Figure 21 Knee and ankle joint centres created

a. In order to create the segments body mass (kg) and height (m) were required. The right thigh, right knee, right shank, left thigh, left shank and left foot was created, Figure 22 and Figure 23 (these show a whole body set up used for a Taekwondo player in later chapters)

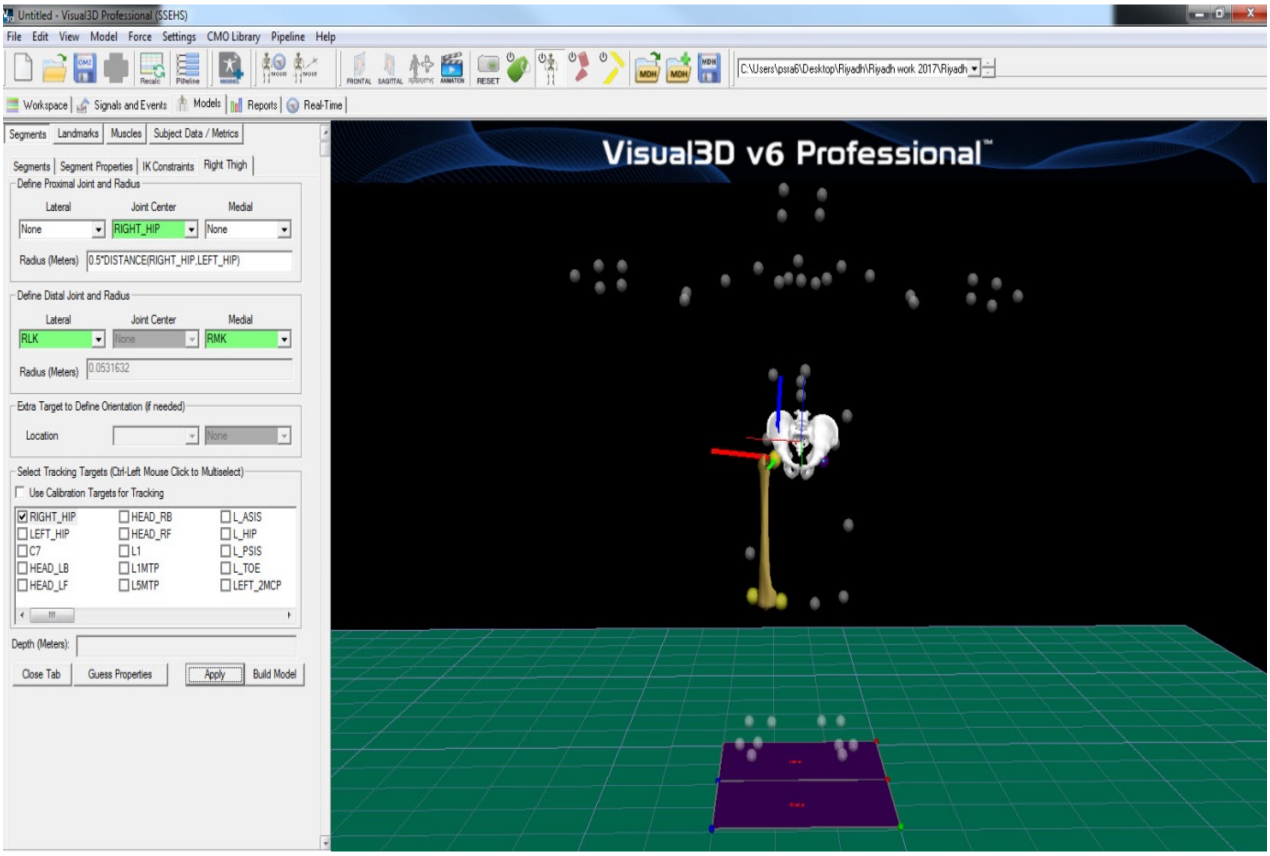

Figure 22 The centre point of the ankle, knee and pelvis

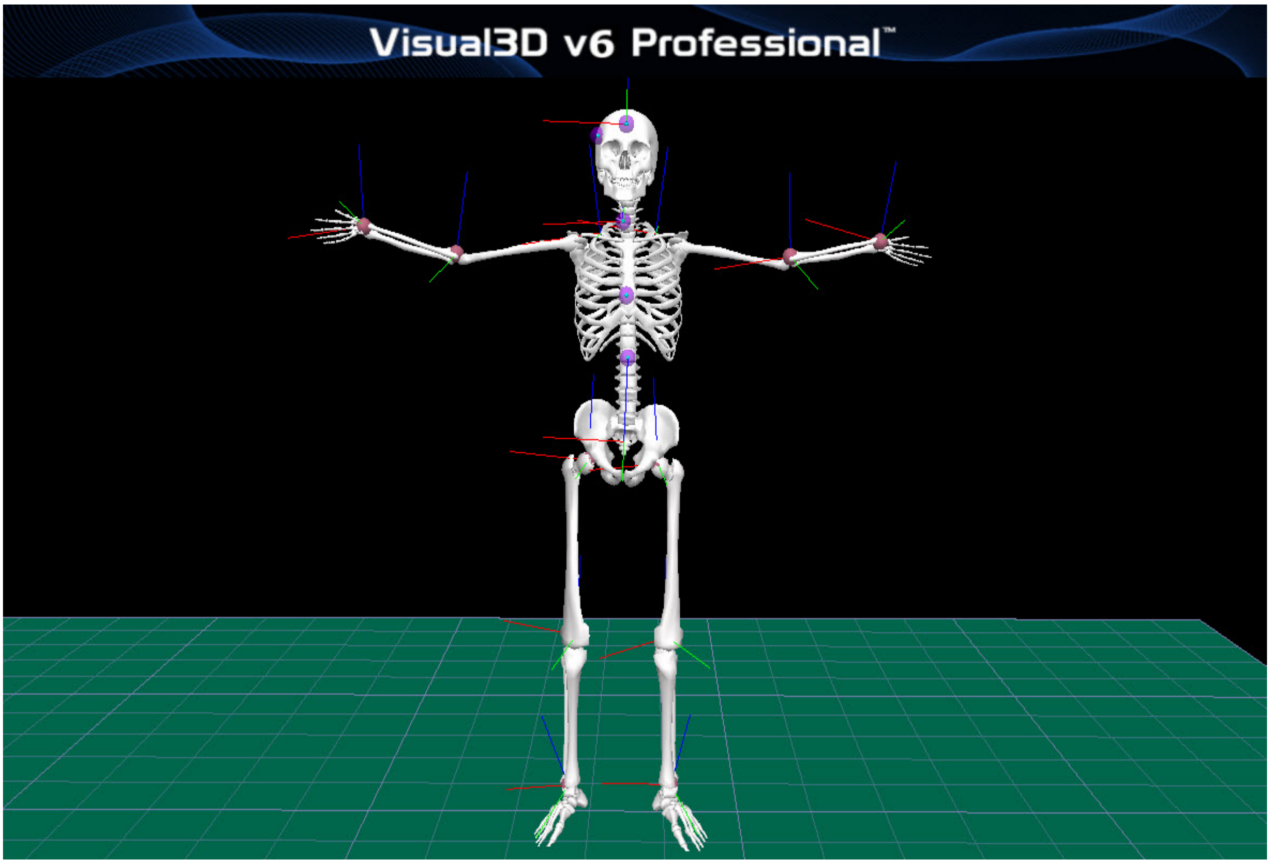

Figure 23 The segments as skeleton (Static)

b. The model template file (MDH) was saved and was created for each subject and applied to the dynamic trial processing.
c. Dynamics trials were loaded for a subject.
d. The model was assigned to the motion files.
e. All processed work was saved as CMO/CMZ files to be loaded more quickly in the future as one file.
f. Joint angles and moments were then calculated using the command Compute_Model_Based_Data in order of: right knee angle, right hip angle, left hip angle and left knee angle, also right knee moment, right hip moment, left hip moment and left knee moment.
g. A low pass filter was used to filter data to make the data smoother as in the figures, the frequency Cut-off = 6 hz. Cut-off = 12 Hz and 16 Hz had many sharp spikes in the graphs. 10 Hz and 8 Hz were generally smoother and had peak values similar to 6 Hz. A 6Hz cut off was chosen as some kicks had a lot of marker wobble and needed this low value and it didn't alter the peak values, Figure 24.

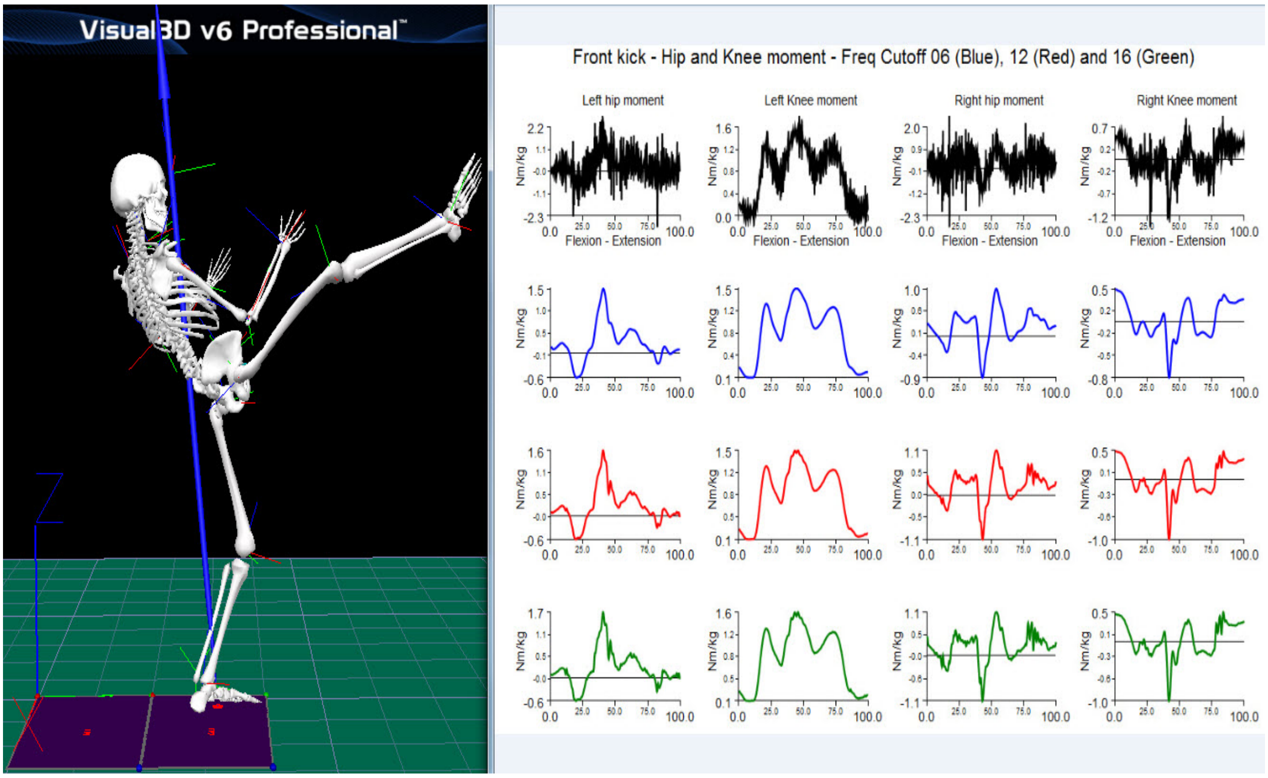

Figure 24 Frequency cut-off

h. Metrics of Maximum, Minimum, Mean and events sequence were recorded.
i. Angle and moment data were exported as Excel files
j. The final step was to save all data again after calculating as CMO/CMZ files.

k. Note: All previous steps were carried out using a pipeline of the same commands Figure 25.
l. The pipeline file was saved to use it in the future.
m. Add new file tag command was used to create kicks file tag which was required to make a comparison between 2 or more kicks.
n. A report file was created for all comparison angle and moments among the 3 kicks modes (Training, Competition and Step) also for right and left kicking leg and support leg joints Figure 26.

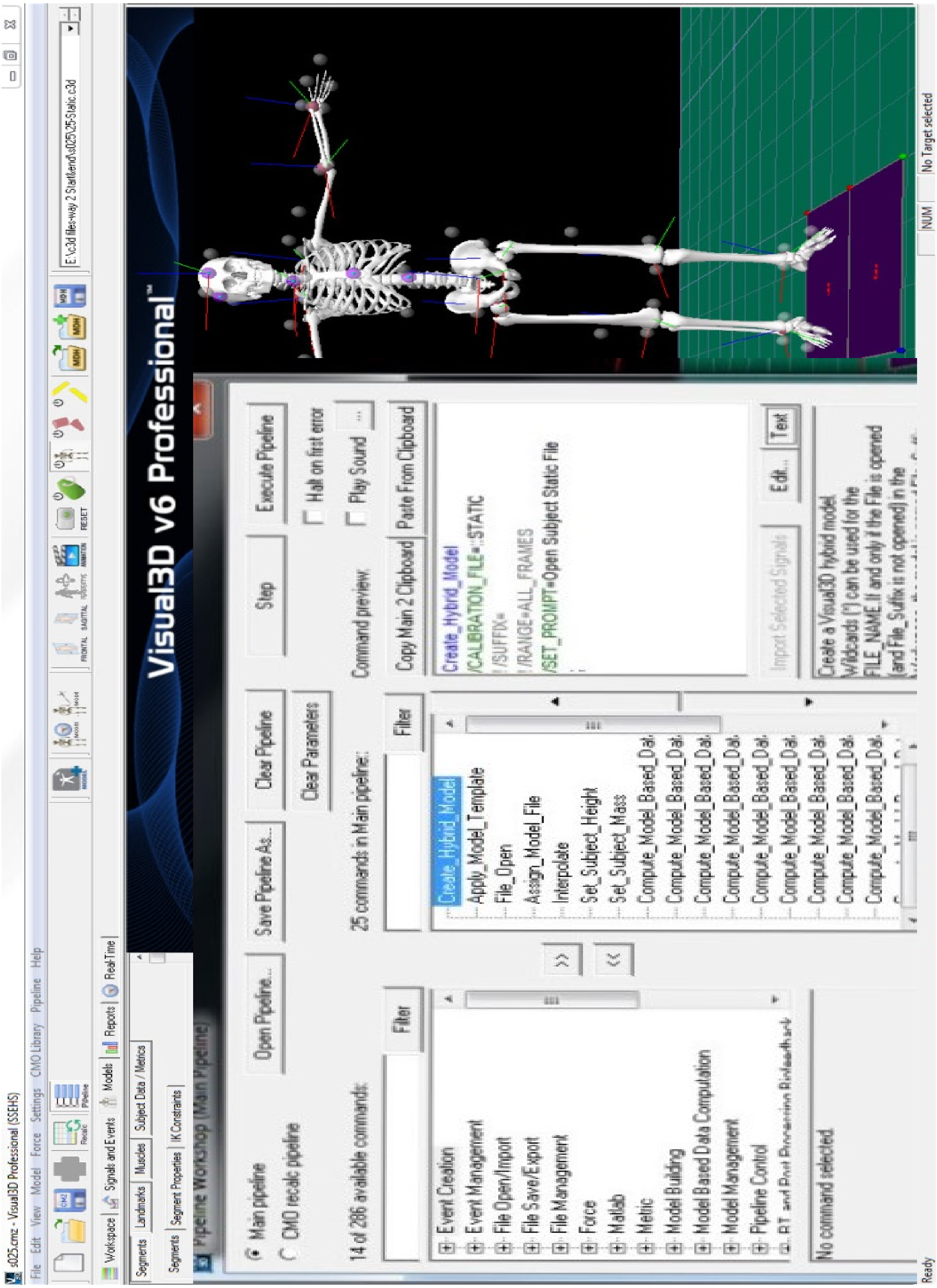

Figure 25 Pipeline Commands

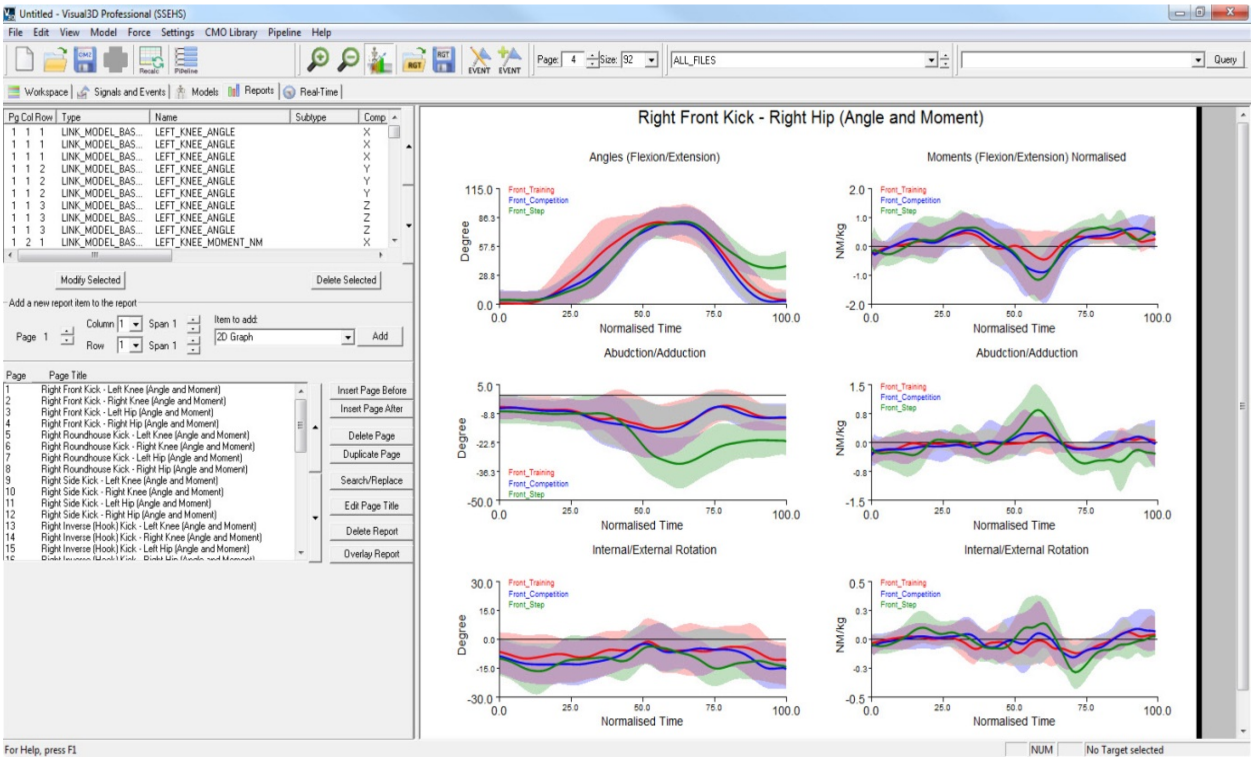

Figure 26 Report file of mean and Standard Deviation

3.3 Statistical Analysis

One-way ANOVA (repeated) of the 3 modes of the kick was carried out for each kick for the peak joint angles and peak joint moments for each joint angle using SPSS (version 21, SPSS Inc., Chicago, Illinois, USA). Peak joint angles were chosen because it is important to know if the hip and knee angles go over the normal range and into what could be considered as hyperextension. Peak moments indicate the load on the joints and are more commonly reported than joint forces as internal loading is not accurate from just these net loads. Measures for risk and load are normally correlated ones not mechanical values and both measures here are common in the literature for many activities to allow comparison of the results. Comparisons between the joints, hip and knee, and between kicks, front, side, round, back and reverse round, were not carried out as joint actions and loads are known to be different between kicks. An uncorrected significance level of 0.05 was chosen. Normal distribution was checked for all parameters using a Shapiro-Wilk test of normality using SPSS (version 21, SPSS Inc., Chicago, Illinois, USA) for all five karate kicks. The results were that the subjects' kick data for each parameter in kick type were mainly normally distributed. All kicks were treated as normally distributed given the relatively large subject numbers for this type of study and that ANOVA is robust against the assumption of normality.

Chapter 4

4. Results

4.1 Chapter Outline

The 28 healthy karate players' results are presented in this chapter. Maximum angles and moments for hips and knees joints of both legs about 3 axes for the 5 main karate kicks in 3 modes of each kick. The main 5 karate kicks are a front kick, roundhouse kick, side kick, hook kick and back kick. Lower limbs joints are (left hip joint, left knee joint, right hip joint and right knee joint). The three modes of each kick are training mode (T), competition mode (C) and competition with step out mode (s). All kicks were performed on sides, left and right. Group mean curves are then presented for angles and moments, all four joints and kick types and modes, and finally significant differences are presented and highlighted.

Overall despite the wide variability in angles and moments, see group result figures, between subjects within a kick type and mode there were several results that showed significant differences, on one or multiple axes at one or multiple joints. Further qualitative differences are also described for the pattern of the kick and where it seems there are differences in the curves but not at maximum values and so not statistically tested.

4.2 Karate: Front kick results

4.2.1 Front kick (Right) angles and moments

Table 9 shows right front kick angles and moments of both support leg, left, and kicking leg, right, of both the knee and hip joints for the three kicking modes.

Table 9 Front kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	-9	16	20	82	-17	-10	147	4	12	125	4	-22
Max SD	9	2	3	17	9	10	15	4	8	15	6	11

Competition angles/Degrees

Max mean	-7	14	18	81	-16	-13	144	5	9	132	5	-25
Max SD	10	9	11	15	11	9	12	4	8	18	7	11

Competition step angles/Degrees

Max Mean	-13	26	19	82	-34	-17	145	8	15	152	3	-19
Max SD	9	8	8	6	8	6	8	5	9	14	7	9

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	1.0	1.6	0.5	0.5	0.2	0.1	1.3	0.8	0.3	0.2	0.1	0.4
Max SD	1.0	1.7	1.0	0.5	0.4	0.3	0.7	0.6	0.3	0.6	0.3	0.4

Competition moments/N.m/kg (Normalised)

Max mean	1.7	1.8	0.5	0.8	0.2	0.2	1.8	0.8	0.2	0.3	0.3	0.6
Max SD	1.0	1.5	0.8	0.6	0.6	0.7	0.8	0.5	0.3	0.2	0.2	0.3

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.4	1.8	0.7	1.2	0.9	0.3	1.0	0.4	0.3	1.0	0.1	0.2
Max SD	1.0	1.2	0.9	0.8	0.6	0.1	0.8	0.5	0.3	0.5	0.2	0.1

4.2.2 Front kick (Left) angles and moments

Table 10 shows left front kick angles and moments of supports legs, right, and kicking leg, left, of both the knee and hip joints for the three kicking modes.

Table 10 Front kick (both sides) knee angles and moments for support and kicking legs

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Training angles/Degrees												
Max mean	-10	-15	-20	90	20	18	140	6	18	152	-5	20
Max SD	8	6	9	8	14	10	7	3	10	17	6	8
Competition angles/Degrees												
Max mean	-5	-10	-20	87	17	17	138	6	17	120	-4	18
Max SD	8	5	10	11	10	11	10	3	8	20	8	8
Competition step angles/Degrees												
Max Mean	-10	-20	-13	75	34	20	143	7	19	140	-2	13
Max SD	9	6	8	9	7	8	8	6	9	15	8	9

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Training moments/N.m/kg (Normalised)												
Max mean	1.0	1.0	0.2	0.8	0.2	0.1	1.3	0.5	0.3	0.8	0.1	0.1
Max SD	1.1	1.0	1.0	0.7	0.5	0.1	0.6	0.6	0.1	0.4	0.2	0.1
Competition moments/N.m/kg (Normalised)												
Max mean	1.0	1.0	0.2	0.5	0.4	0.1	1.2	0.5	0.2	0.5	0.1	0.1
Max SD	1.2	1.0	0.9	1.0	0.3	0.1	0.8	0.5	0.1	0.7	0.1	0.1
Competition Step moments/N.m/kg (Normalised)												
Max Mean	1.0	1.0	0.4	0.7	0.7	0.1	0.8	0.5	0.1	0.7	0.1	0.2
Max SD	1.0	1.0	0.9	1.0	1.0	0.2	0.7	0.5	0.2	1.0	0.1	0.1

4.2.3 Front kick significant differences

Front kick modes have 5 significant differences in multiple joints and axes. The right side has 2 significant differences: Left support hip angle on Y axes (adduction-abduction): T mode (16 degrees) with S mode (26 degrees) and C mode (14 degrees) with S mode (26 degrees), both with large Cohen's D effect size. Right kicking hip angle, Y-axis: T mode (17 degrees) with S mode (34 degrees), and C mode (16 degrees) with S mode (34 degrees) also both with large Cohen's D effect size. The left side had 3 significant differences: Left kicking hip angle, Y-axis: T mode (20 degrees) with S mode 34 degrees) and C mode (17 degrees) with S mode (34 degrees), both with large Cohen's D effect and size. Left kicking hip moments, Y-axis: T mode (0.2 N.m/kg) with S mode (0.7 N.m/kg) with large Cohen`s D effect size. C mode (0.4 N.m/kg) with S mode (0.7 N.m/kg) with medium Cohen`s D effect size. Left kicking knee angle, X-axis: T mode (152 degrees) with C mode (120 degrees) and T mode (152 degrees) with S mode (140 degrees) and C mode (120 degrees) with S mode (140 degrees), the Cohen`s D and effect size were large and medium. Table 11

Table 11 Significant differences on the right and left of Front kick

Front kick – Kicking leg is Right

	Joint	Axes	Modes	Cohen`s D
1	Left hip angle	Y	T & S	1.10
			C & S	1.40
2	Right hip angle	Y	T & S	1.78
			C & S	1.71

Front kick – Kicking leg is Left

	Joint	Axes	Modes	Cohen`s D
1	Left hip angle	Y	T & S	1.26
			C & S	1.96
2	Left hip moment	Y	T & S	0.63
			C & S	0.40
3	Left knee angle	X	T & C	0.93
			T & S	0.38
			C & S	0.53

4.2.4 Front kick angles (Right and left)

Right front kick had 2 significant differences both on Y axis between T & S and C & S modes Table 11. At the same time left front kick has 3 significant differences spread between kicking leg and support leg on different joint angles and moments Table 11. It is worth mentioning that there are other differences but they are not significant: Right front kick, right kicking hip, X-axis angles, S mode is different from T and C modes in the second half of the kick and by comparing it with left front kick right hip as support hip it will be similar. Z-axis angle of the supporting hip on the right front kick S mode was a different shape compared with T and C modes even though they are very similar at maximum angle. It is clear to see that the S mode kicking leg on both sides takes a path not like other modes, especially in X and Y axes, in both legs in both positive and negative angles. As expected support leg, hip angles on both sides have very small values compared with kicking leg hip angles but it is interesting to note that sometimes the angles can indicate that the pelvis or torso is tilted back, that during the kick some lean back more. Support legs knee angles have small change through the kicking motion and all subjects kept a flexed support knee during the kick which is considered good form. Having a straight supporting leg at the knee would lower the range of internal-external rotation the knee can safely undergo Figure 28, Figure 29, Figure 30 and Figure 31.

4.2.5 Front kick moment normalised (Right and left)

By looking on Left knee moment on X-axis on right front kick C mode has a higher value of 1.7 N.m/kg compared with T mode at 1 N.m/kg and S mode 1.4 N.m/kg on the right front kick Y axis moments all modes have high moments and large standard deviation: T mode 1.6/1.7 N.m/kg, C mode 1.8/1.5 N.m/kg and S mode 1.8/1.2 N.m/kg. S mode moments on right and left supporting hip have greater value then T and C modes. The variations in normalised moments across subjects for the support leg are bigger than in the kicking leg. The relative size of the standard deviation for the support leg compared to kicking leg when the range of motion is considered (the range of the kicking leg was much larger but the width of the Standard deviation is not so different is notable. This could indicate that as the kicking technique is quite well defined all subjects performed it similarly but that the support leg was less similar across subjects with some having much higher moments and angles than the mean. Given the higher peak moments on the supporting leg than the kicking leg this could be something to consider with respect to some people being more at risk from performing the front kick Figure 28, Figure 29, Figure 30 and Figure 31.

A typical front kick performance at full kick extension is presented in Figure 27 for visualisation purposes.

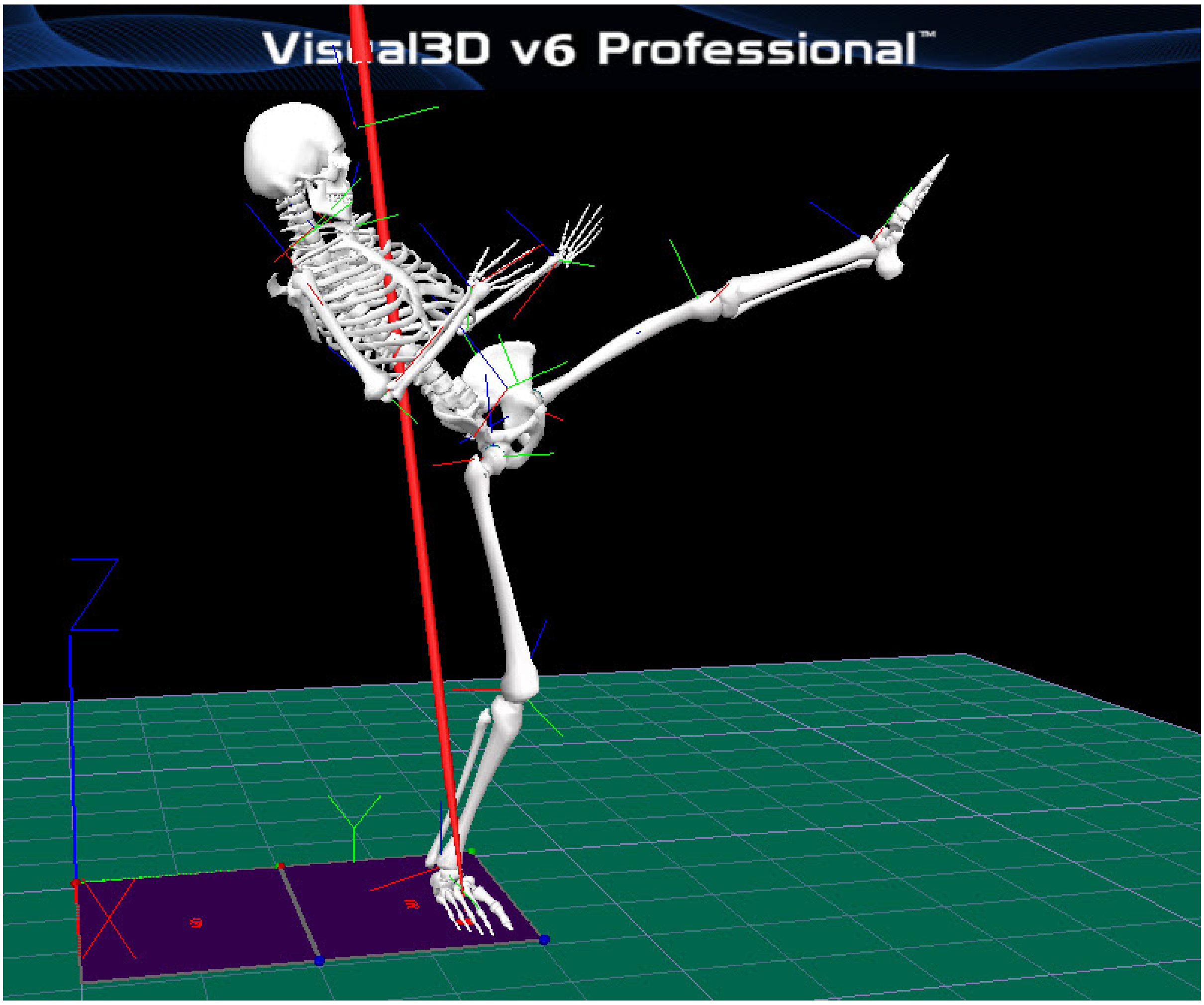

Figure 27 Front kick skeleton with coordinate system X, Y and Z

Front kick is considered as one of safer kick because it is linear kick, but this study showed that it has the highest joint moment at 1.8 Nm/kg on the support hip and support knee. The significant differences between kick modes were greatest for abduction – adduction on the support leg more that kicking leg for both angle and moment. This information found from 3D motion analysed should be considered by coaches and players when they are training in different modes.

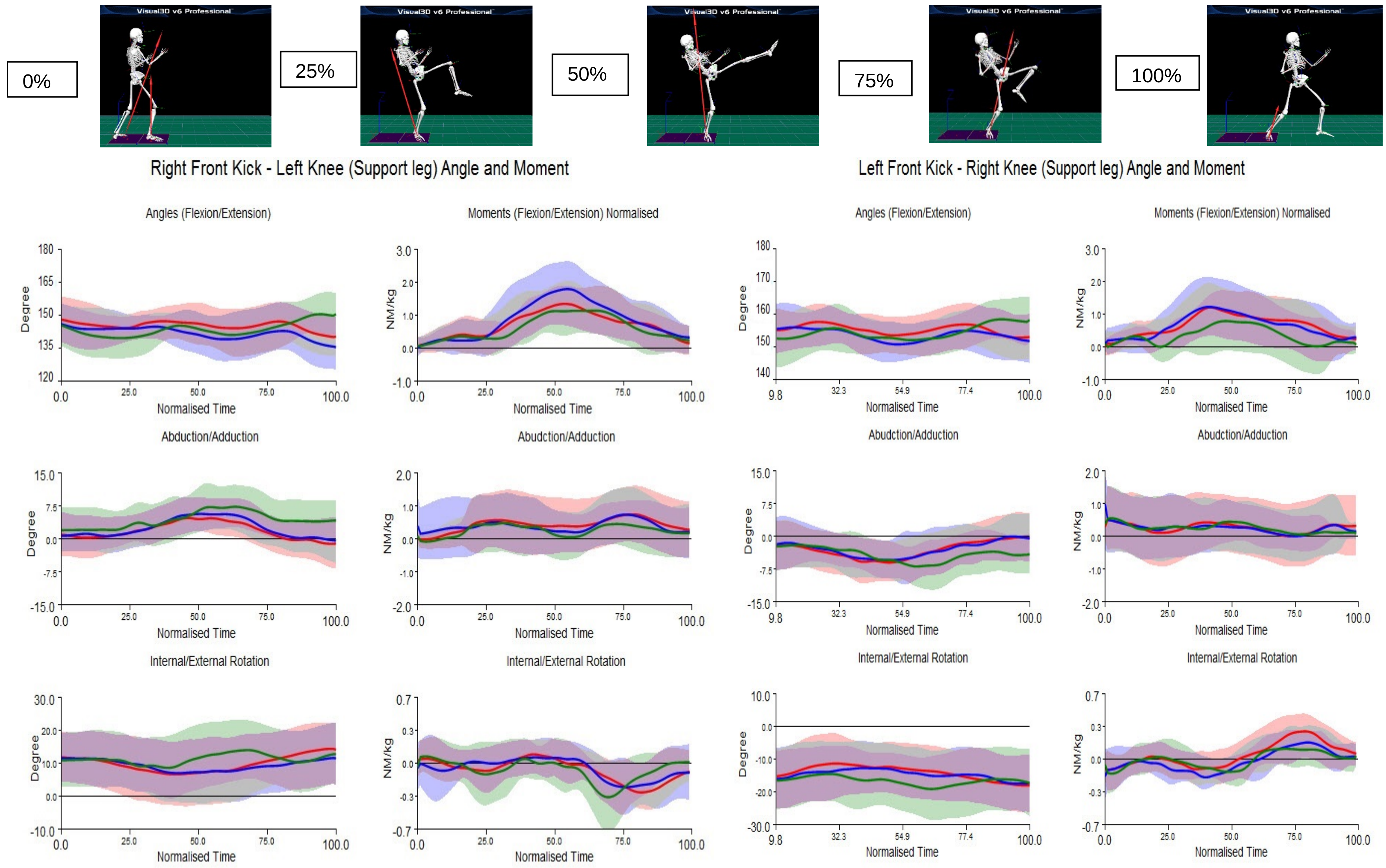

Figure 28 Front kick (both sides) knee angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

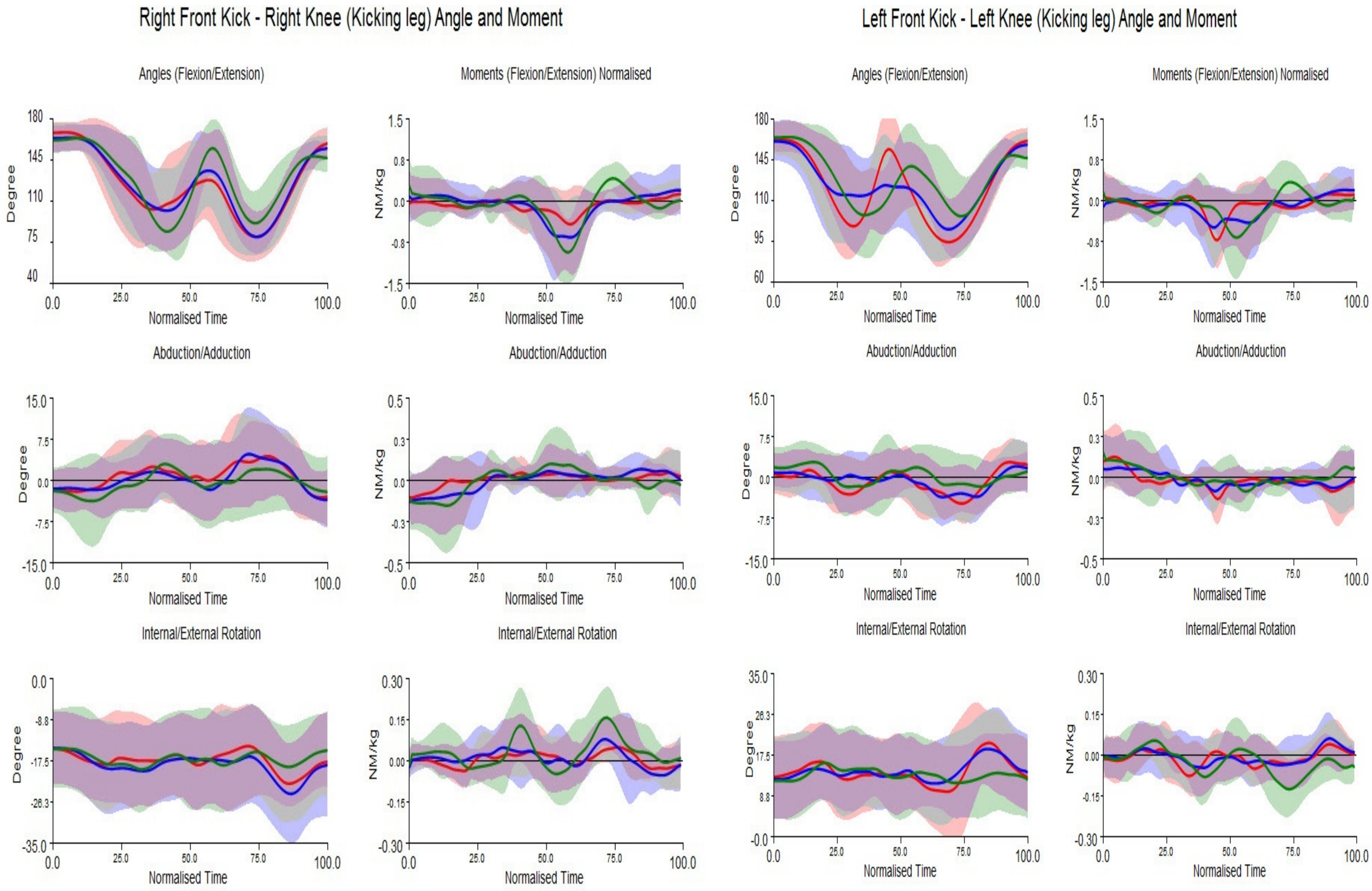

Figure 29 Front kick (both sides) knee angles and moment for kicking leg
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

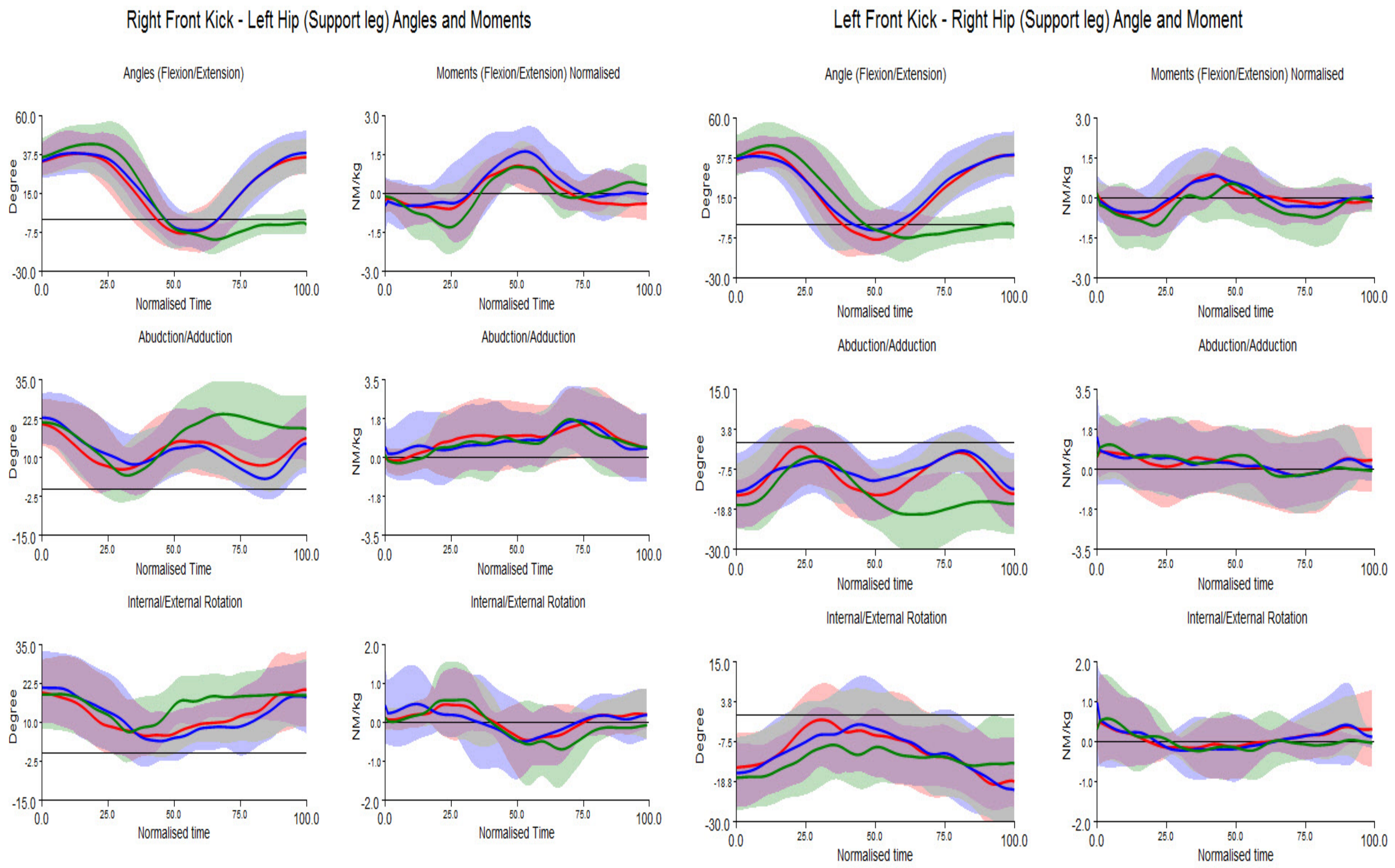

Figure 30 Front kick (both sides) hip angles and moment for support leg
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

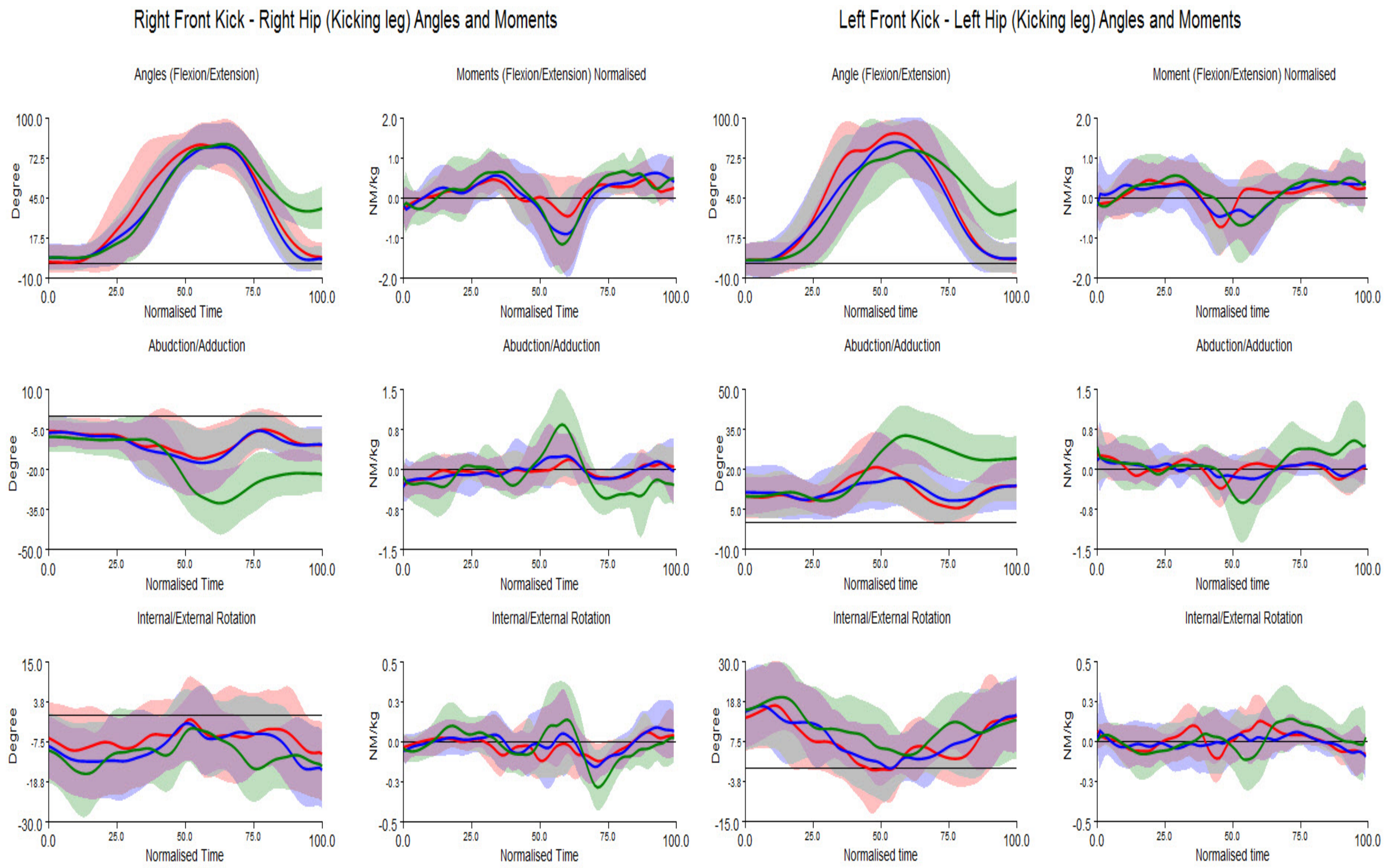

Figure 31 Front kick (both sides) knee angles and moment for kicking leg
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

4.3 Karate: Roundhouse kick results

4.3.1 Roundhouse kick (Right) angles and moments

Table 12, right roundhouse kick angles and moments of the support leg, left, and kicking leg, right, of both the knee and hip joints for the three kicking modes.

Table 12 Roundhouse kick (both sides) knee angles and moments for support and kicking legs

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Training angles/Degrees												
Max mean	48	42	23	62	-40	-19	155	6	14	125	5	-20
Max SD	22	12	10	15	9	11	15	5	8	22	6	10
Competition angles/Degrees												
Max mean	45	41	24	68	-43	-18	150	7	15	125	5	-22
Max SD	20	11	9	17	10	9	20	7	8	20	5	11
Competition step angles/Degrees												
Max Mean	58	50	24	70	-47	-24	155	9	19	135	4	-21
Max SD	32	12	11	14	10	10	13	6	9	21	5	9

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Training moments/N.m/kg (Normalised)												
Max mean	1.0	1.5	0.8	0.3	0.2	0.2	1.0	0.8	0.4	0.4	0.1	0.1
Max SD	0.6	1.2	1.0	0.4	0.8	0.3	1.0	0.6	0.3	0.4	0.1	0.2
Competition moments/N.m/kg (Normalised)												
Max mean	1.2	1.5	0.8	0.4	0.4	0.2	1.0	0.8	0.3	0.5	0.2	0.1
Max SD	0.8	1.3	1.0	0.6	1.0	0.2	0.7	0.5	0.3	0.7	0.2	0.1
Competition Step moments/N.m/kg (Normalised)												
Max Mean	1.4	1.0	0.7	0.5	0.8	0.3	0.8	0.6	0.3	0.6	0.3	0.2
Max SD	0.7	1.3	1.0	0.5	1.0	0.3	1.0	0.5	0.3	0.8	0.3	0.2

4.3.2 Roundhouse kick (Left) angles and moments

Table 13, left roundhouse kick angles and moments of the support leg, right, and kicking leg, left, of both the knee and hip joints for the three kicking modes.

Table 13 Roundhouse kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	50	-46	-22	63	50	20	160	-4	-19	125	-6	18
Max SD	22	9	13	17	9	10	11	5	8	35	5	11

Competition angles/Degrees

Max mean	48	-44	-20	65	45	24	155	-5	-18	130	-5	18
Max SD	23	9	11	17	11	9	12	6	8	41	4	10

Competition step angles/Degrees

Max Mean	60	-47	-26	64	46	24	162	-4	-20	135	-4	16
Max SD	27	8	8	16	13	9	13	5	10	38	3	9

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	1.0	1.3	1.0	0.2	0.1	0.1	0.6	0.3	0.2	0.3	0.1	0.2
Max SD	1.0	0.4	1.0	0.4	0.4	0.3	0.7	0.4	0.3	0.6	0.2	0.1

Competition moments/N.m/kg (Normalised)

Max mean	1.5	1.5	1.0	0.5	0.2	0.2	1.0	0.2	0.4	0.4	0.2	0.1
Max SD	1.0	0.5	1.0	0.3	0.6	0.6	0.8	0.5	0.3	0.2	0.2	0.1

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.5	1.7	1.4	0.7	0.8	0.3	0.7	0.4	0.3	0.5	0.3	0.3
Max SD	1.0	0.5	1.0	0.4	0.6	0.3	0.8	0.4	0.3	0.5	0.3	0.1

4.3.3 Roundhouse kick significant differences

Roundhouse kicks have 1 significant difference on the right side on the left hip joint angle of support leg on X-axis among the three modes, T mode (48 degrees) with S mode (58 degrees) as Medium effect, C mode (45 degrees) with S mode (58 degrees) as big effect. At the same time left side has also 1 significant difference on the right hip joint angle, X-axis: T mode (50 degrees) with S mode (60 degrees) and C mode (48 degrees) with S mode (60 degrees). They considered the medium effect, Table 14.

Table 14 Significant differences on the right and left of Roundhouse kick

	Joint	Axes	Modes	Cohen`s D
Roundhouse kick – Kicking leg is Right				
1	Left hip angle	X	T & S	0.36
			C & S	1.20
Roundhouse kick – Kicking leg is Left				
1	Right hip angle	X	T & S	0.40
			C & S	0.47

4.3.4 Roundhouse kick angles (Right and left)

Roundhouse kick on both sides (right and left) support hip angle X, Y and Z axes for all modes have very similar angles. The x-axis (45-60 degrees), Y axes (41-50 degrees) and Z axis (20-26 degrees), even there are multiple differences (significant and non-significant) among the same side modes. Support knee angle, X-axis on the left side slightly bigger than the right side of all 3 modes. Other angles are similar on both sides Figure 33, Figure 34, Figure 35 and Figure 36.

4.3.5 Roundhouse kick moment (normalised) (Right and left)

Left knee moment on the kicking leg on the left side on Y-Axis The support hip moment on the left side S Mode Y axis has a greater value of mean (1.7 N.m.kg) than the hip joint angle on the right side (1 N.m/kg). Support hip moment on the left side for C and S modes slightly bigger mean and standard deviation values (C mode 1.5/1 N.m/kg and S mode 1.5/1 N.m/kg) than the right side same joint moments (C mode 1.2/0.8 N.m/kg and S mode 1.4 N.m/kg). The rest of the joints moments are similar Figure 33, Figure 34, Figure 35 and Figure 36.

Roundhouse kick performance using visual3D software to upper joints angles and moments, Figure 32.

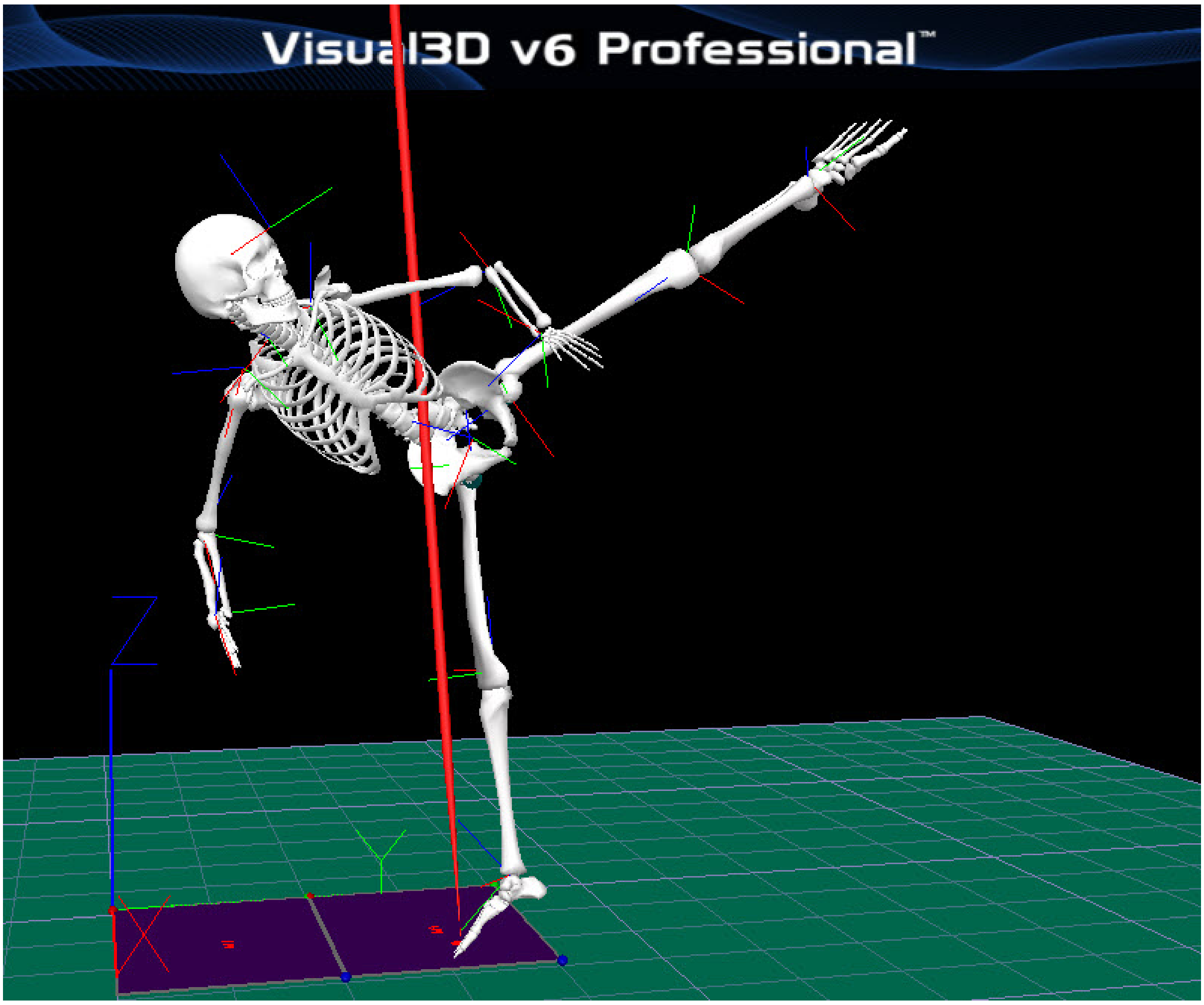

Figure 32 Roundhouse kick skeleton with coordinate system X, Y and Z

Roundhouse kick is the fastest kick and the most used in the competition, from data analysed in this study this kick has the second highest moment overall of 1.7 Nm/kg, on the support hip. There are just two significant differences among the modes for the support hip angle. It is important to take more care of the supporting leg within training and competition to get best result with safer technique.

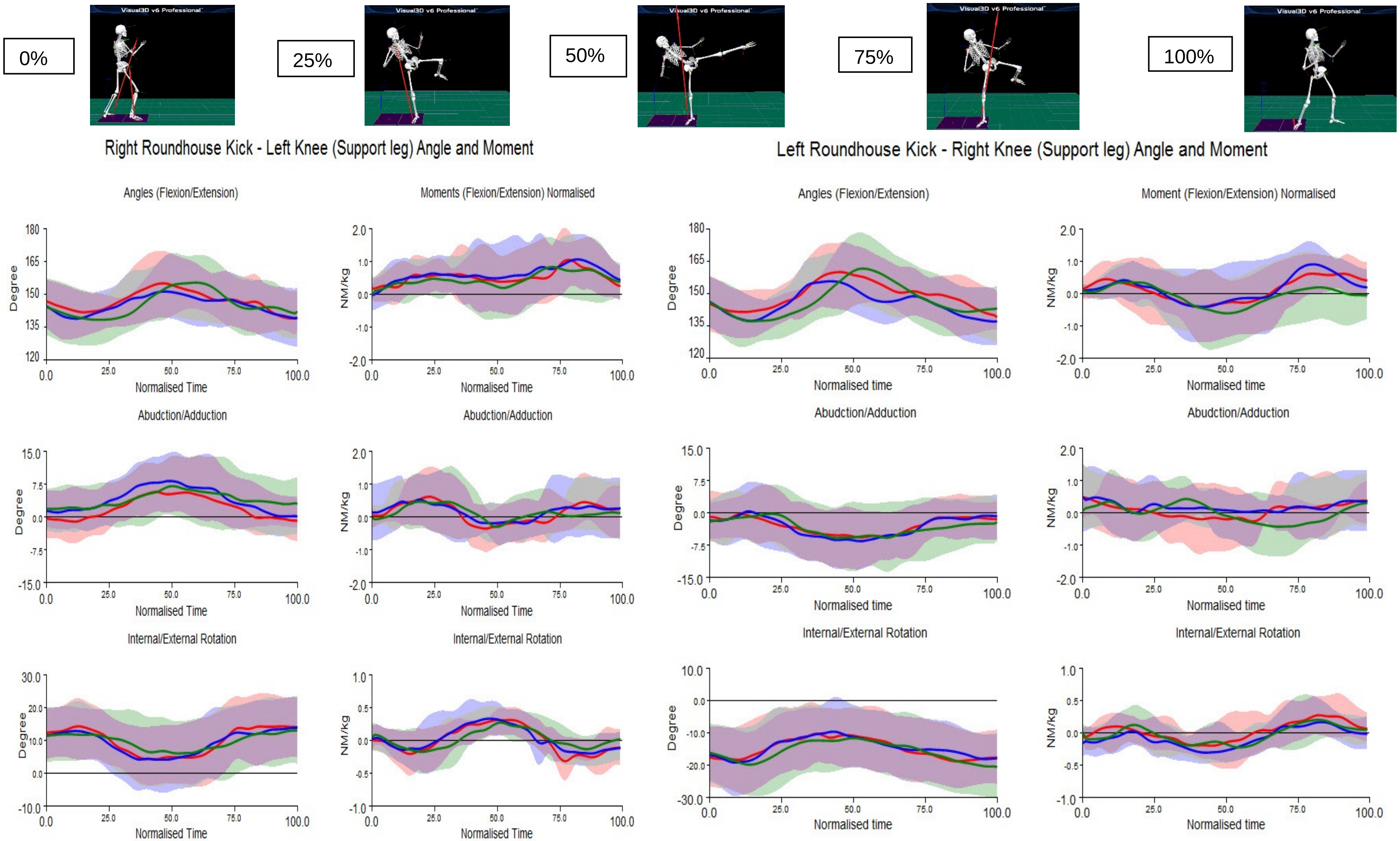

Figure 33 Roundhouse kick (both sides) knee angles and moment for Support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

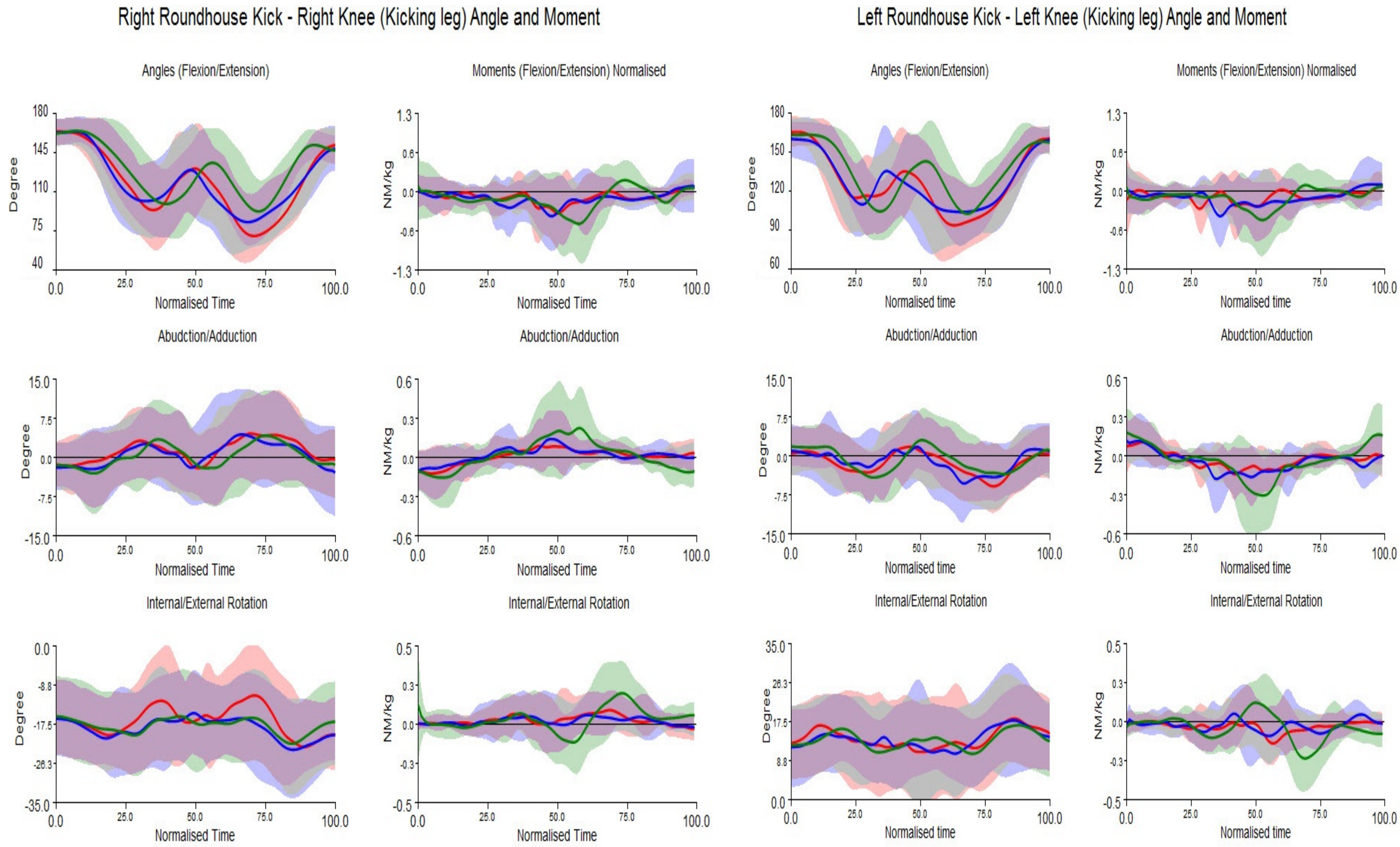

Figure 34 Roundhouse kick (both sides) knee angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

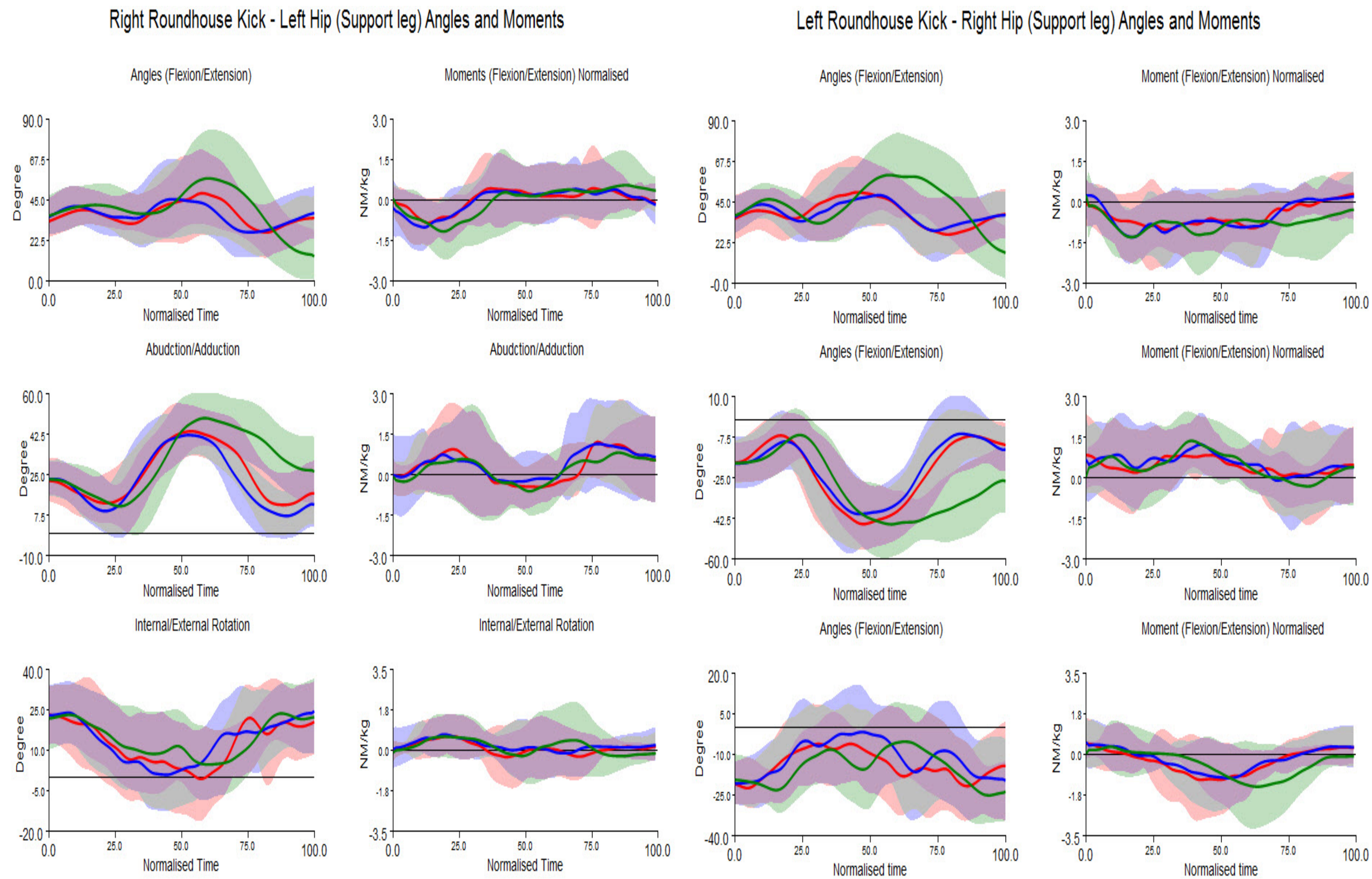

Figure 35 Roundhouse kick (both sides) hip angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

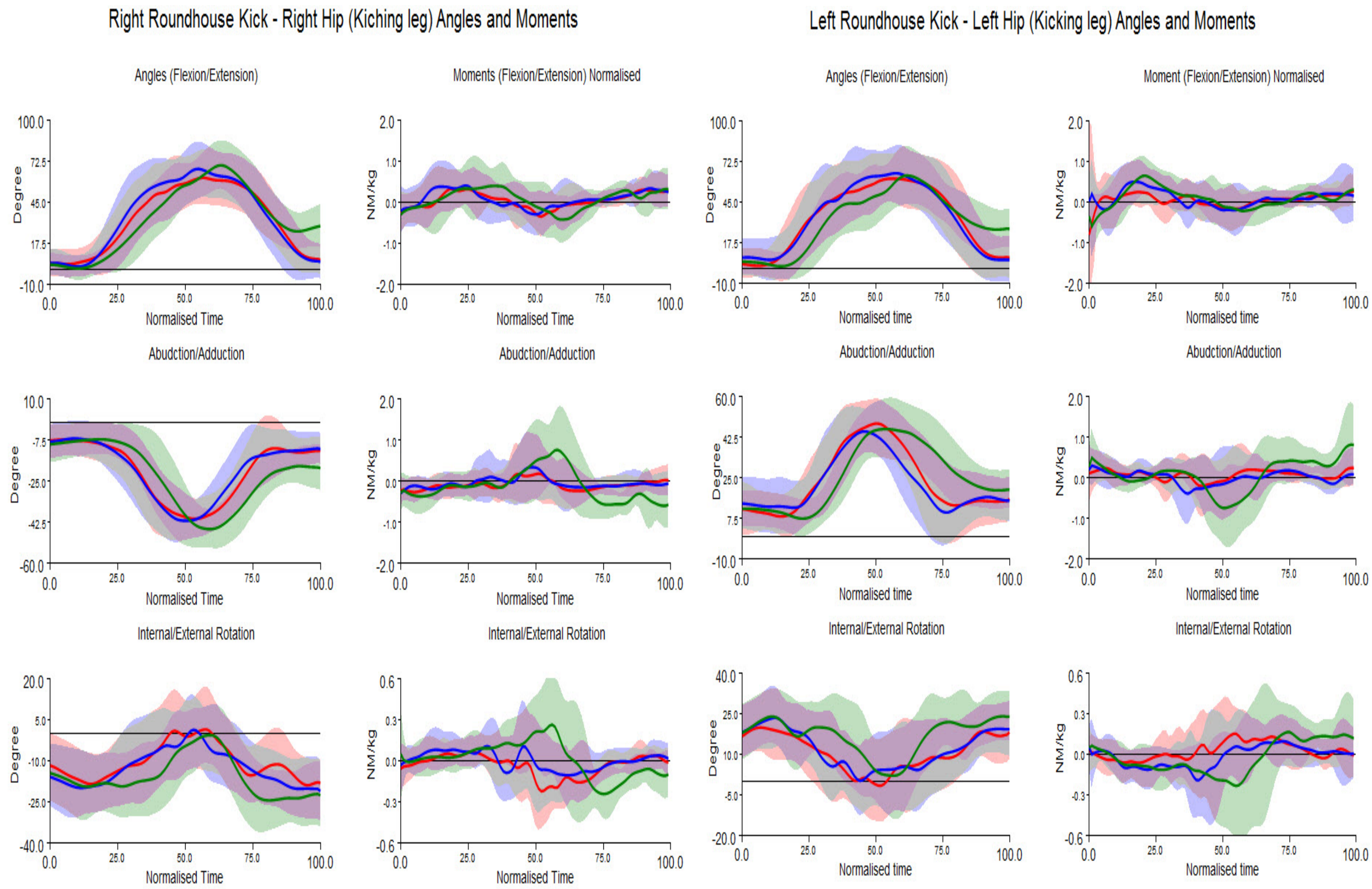

Figure 36 Roundhouse kick (both sides) hip angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

4.4 Karate: Side kick results

4.4.1 Side kick (Right) angles and moments

Table 15 right side kick angles and moments of the support leg (left) and kicking leg (right) of both the knee and hip joints for the three kicking modes.

Table 15 Side kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	67	48	24	66	38	21	160	5	14	158	4	-21
Max SD	13	9	13	14	6	10	10	6	8	15	4	11

Competition angles/Degrees

Max mean	67	47	23	71	41	20	155	6	13	145	3	-20
Max SD	12	9	11	13	7	9	9	8	8	17	5	11

Competition step angles/Degrees

Max Mean	72	50	25	51	41	20	160	7	12	144	5	-21
Max SD	11	8	8	12	6	9	12	6	9	13	7	9

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	0.9	1.2	0.5	0.3	0.2	0.2	1.1	0.7	0.3	0.2	0.1	0.1
Max SD	1.0	1.0	0.4	0.5	0.4	0.1	0.7	0.6	0.5	0.3	0.3	0.1

Competition moments/N.m/kg (Normalised)

Max mean	1.0	1.3	0.7	0.6	0.2	0.1	1.0	0.8	0.4	0.2	0.2	0.1
Max SD	1.0	1.2	0.4	0.6	0.6	0.1	0.8	0.5	0.4	0.2	0.3	0.1

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.5	1.4	1.0	0.8	0.5	0.2	0.9	0.8	0.2	0.3	0.3	0.2
Max SD	1.0	1.0	0.5	0.7	0.9	0.1	0.8	0.5	0.5	0.3	0.3	0.1

4.4.2 Side kick (Left) angles and moments

Table 16 left side kick angles and moments of the support leg (right) and kicking leg (left) of both the knee and hip joints for the three kicking modes.

Table 16 Side kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	55	45	25	72	40	18	165	-6	-18	140	-6	20
Max SD	17	8	11	17	9	13	12	7	8	19	5	9

Competition angles/Degrees

Max mean	62	40	21	64	44	18	155	-6	-18	130	-5	18
Max SD	10	7	10	11	11	9	10	8	8	15	6	8

Competition step angles/Degrees

Max Mean	66	47	25	60	43	21	165	-5	-19	135	-4	19
Max SD	15	10	9	10	5	9	12	5	9	18	7	8

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	1.2	0.9	1.0	0.3	0.3	0.2	0.6	0.4	0.2	0.2	0.1	0.1
Max SD	1.0	1.0	1.0	0.2	0.2	0.1	0.7	0.6	0.1	0.2	0.2	0.2

Competition moments/N.m/kg (Normalised)

Max mean	1.5	0.9	1.0	0.3	0.2	0.2	0.4	0.3	0.3	0.2	0.1	0.1
Max SD	1.0	1.0	0.9	0.2	0.1	0.1	0.8	0.8	0.1	0.2	0.1	0.2

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.5	1.0	1.3	0.5	0.5	0.3	0.9	0.7	0.3	0.3	0.2	0.3
Max SD	1.0	1.0	0.9	0.3	0.2	0.2	0.8	0.7	0.2	0.4	0.2	0.2

4.4.3 Side Kick significant differences

Side kick has 2 significant differences, on the right kick on right hip angle (kicking leg) on X axis among T mode (66 degrees) with S mode (51 degrees) and C mode (71 degrees) with S mode (51 degrees). On the left kick the significant differences on left knee moment Z axis among T mode (0.1/0.2 N.m/kg) with S mode (0.3/0.2 N.m/kg) and C mode (0.1/0.2 N.m/kg) with S mode (0.3/0.2 N.m/kg), all of them considered as big effect sizes Table 17.

Table 17 Shows significant differences on the right and left of Side kick

	Joint	Axes	Modes	Cohen`s D
Side kick – Kicking leg is Right				
1	Right hip angle	X	T & S	0.61
			C & S	0.97
Side kick – Kicking leg is Left				
1	Left knee moment	Z	T & S	0.99
			C & S	0.99

4.4.4 Side kick angles (Right and left)

Right side kick hip angle (support leg) of X-axis for T and C modes have the same max angle (67 degrees) and almost the same path of motion but S mode has a slightly bigger angle (72 degrees) with different motion path. Y-axis also very similar angle for T and C modes (47 and 48) degrees, S mode slightly bigger angle (50 degrees), Z axis all the modes were very similar, In the left side kick, support hip angles S mode was also higher on X and Y axes (66 and 47 degrees). It is clear to see that S mode in the supporting hip on both left and right-side kick on X and Y axes higher than T and C modes with the different path on the second half of motion.

Knee angles of support leg on both sides for T and S modes the same max angles and it is higher than C mode. Right side: T and S modes 160 and C mode 155 degrees, left side: T and S 165 degrees and C mode 155 degrees. The rest of knee angles for both sides were similar. Kicking knee angles for the right side were higher than same angles on the left side for all three modes. Right side: T mode 158 degrees, C mode 145 degrees and S mode 144 degrees, left side: T mode 140 degrees, C mode 130 degrees and S mode 135 degrees Figure 38, Figure 39, Figure 40 and Figure 41.

4.4.5 Side kick moment (normalised) (Right and left)

Side kick has one significant difference moment on left knee joint Z axis among T with S modes and C with S modes, see Figure 18. S mode has slightly higher moment's values of almost all hips and knees moments for both kicking and support legs on both sides. Right side kick support hip moment X-axis of: S mode was 1.5 N.m/kg comparing with T mode 0.9 N.m/kg and C mode 1 N.m/kg. Left side kick, support hip, Z axis moment, S mode 1.3 N.m/kg compared with T mode 1 N.m/kg and C mode 1 N.m/kg Figure 38, Figure 39, Figure 40 and Figure 41. Side kick performance using visual3D software, to upper joints angles and moments Figure 37.

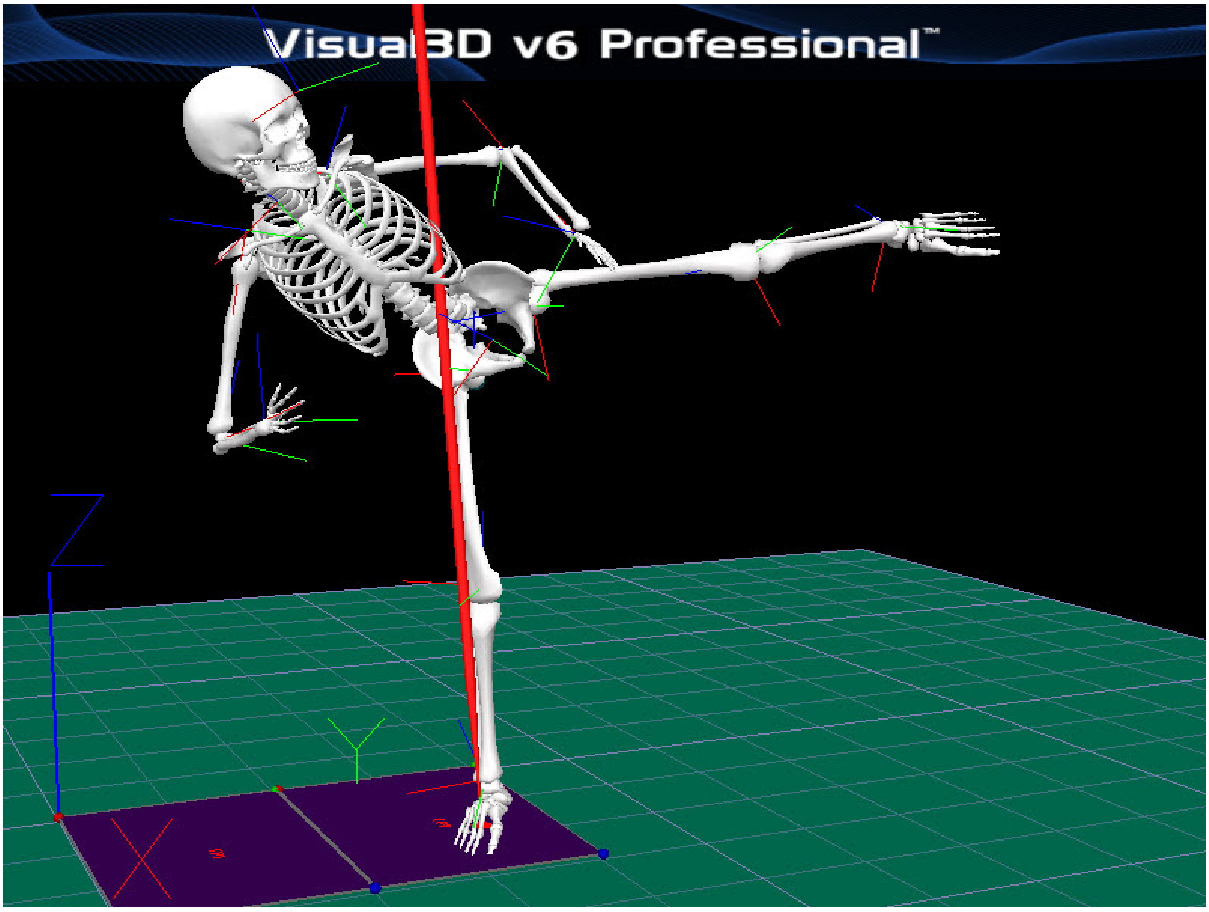

Figure 37 Side kick skeleton shape with coordinate system X, Y and Z

Side kick is strong and safe kick, but it less used to compare with the other four kicks, it has one high moment at 1.5 Nm/kg for the support hip moment of flexion – extension. Two significant differences on the support leg hip moment and knee angles were found between modes. The advice for players is to make the supporting leg knee angle about 160° to get more distance, speed, power and safety kick.

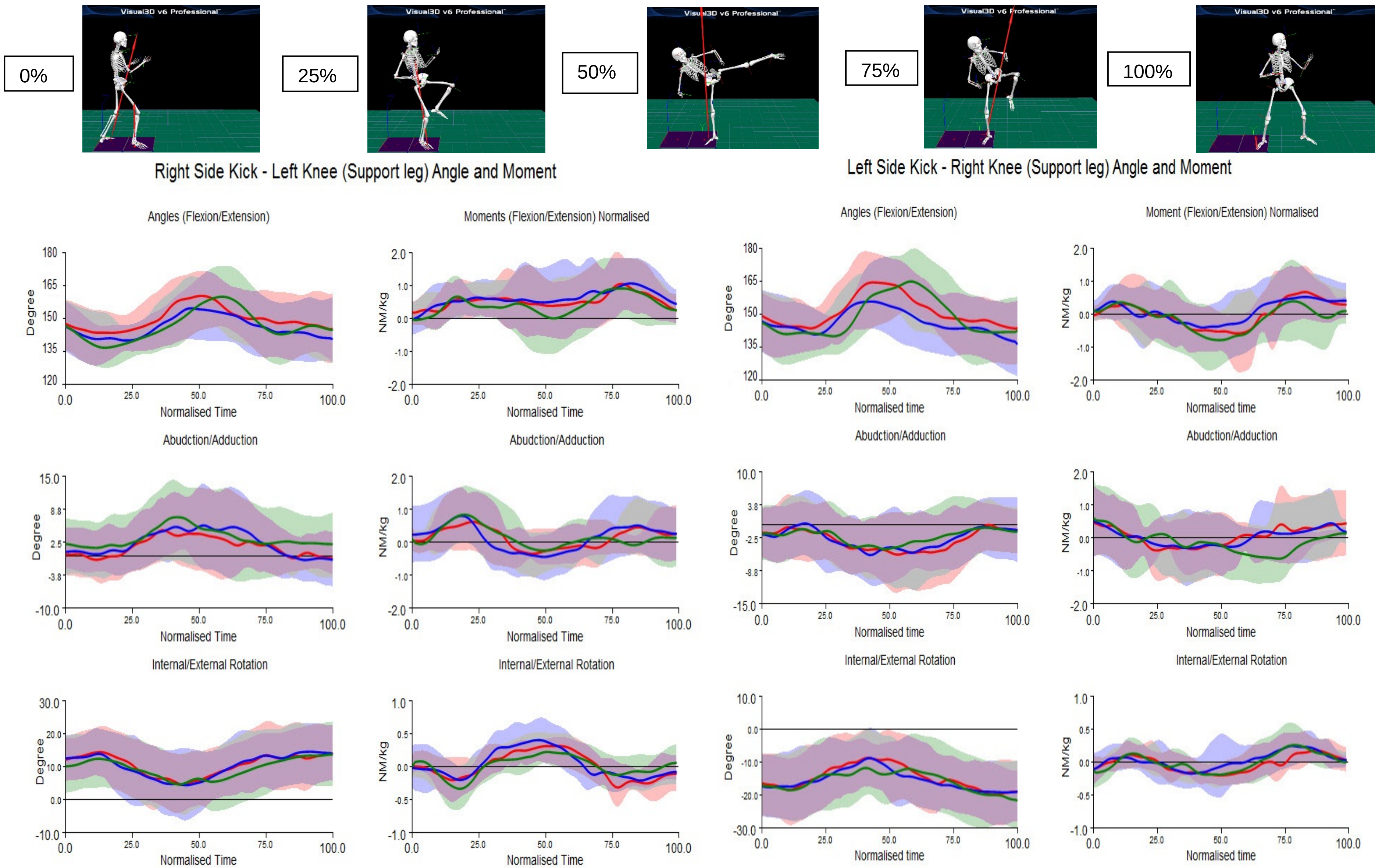

Figure 38 Side kick (both sides) knee angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

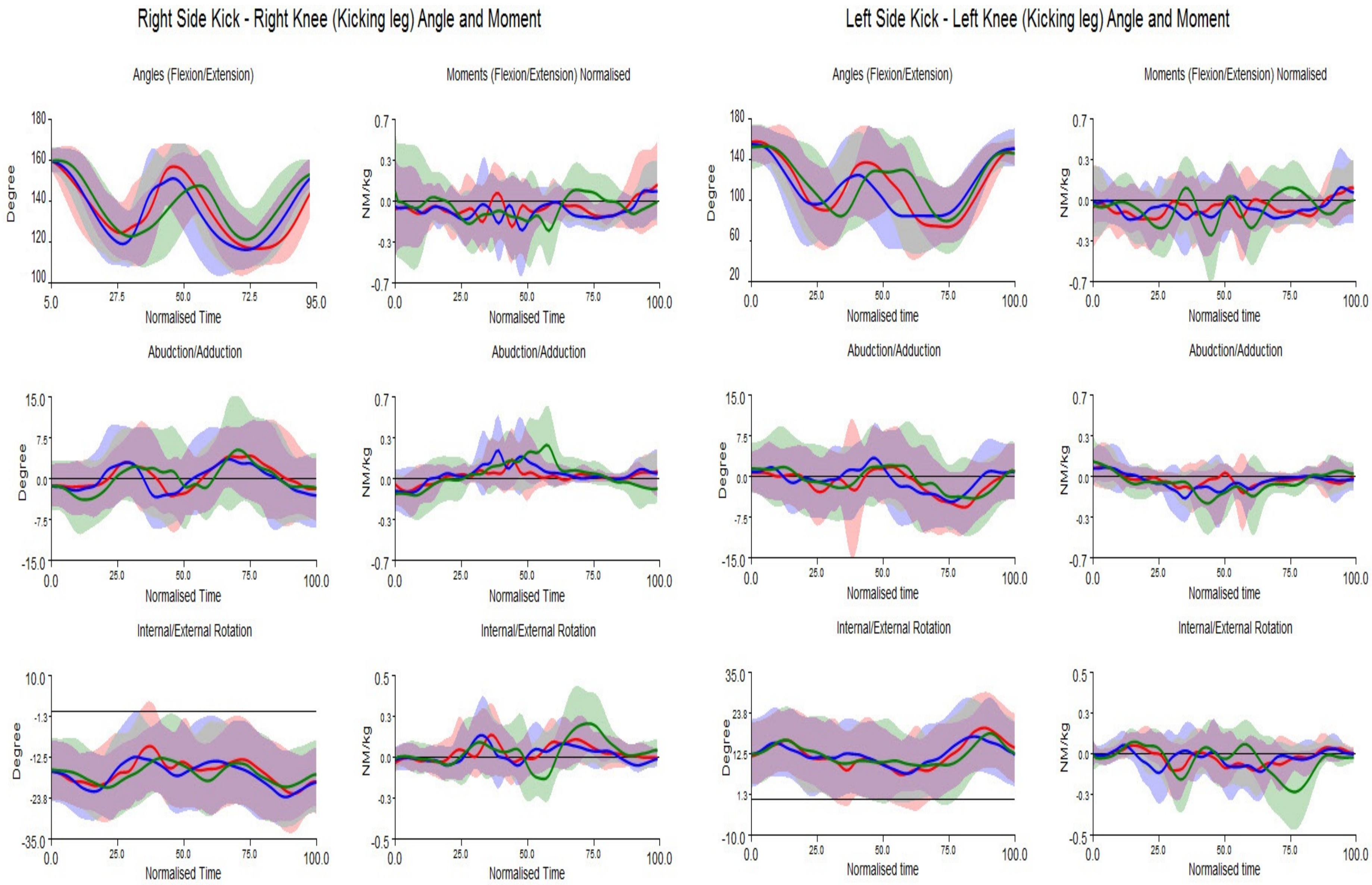

Figure 39 Side kick (both sides) knee angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

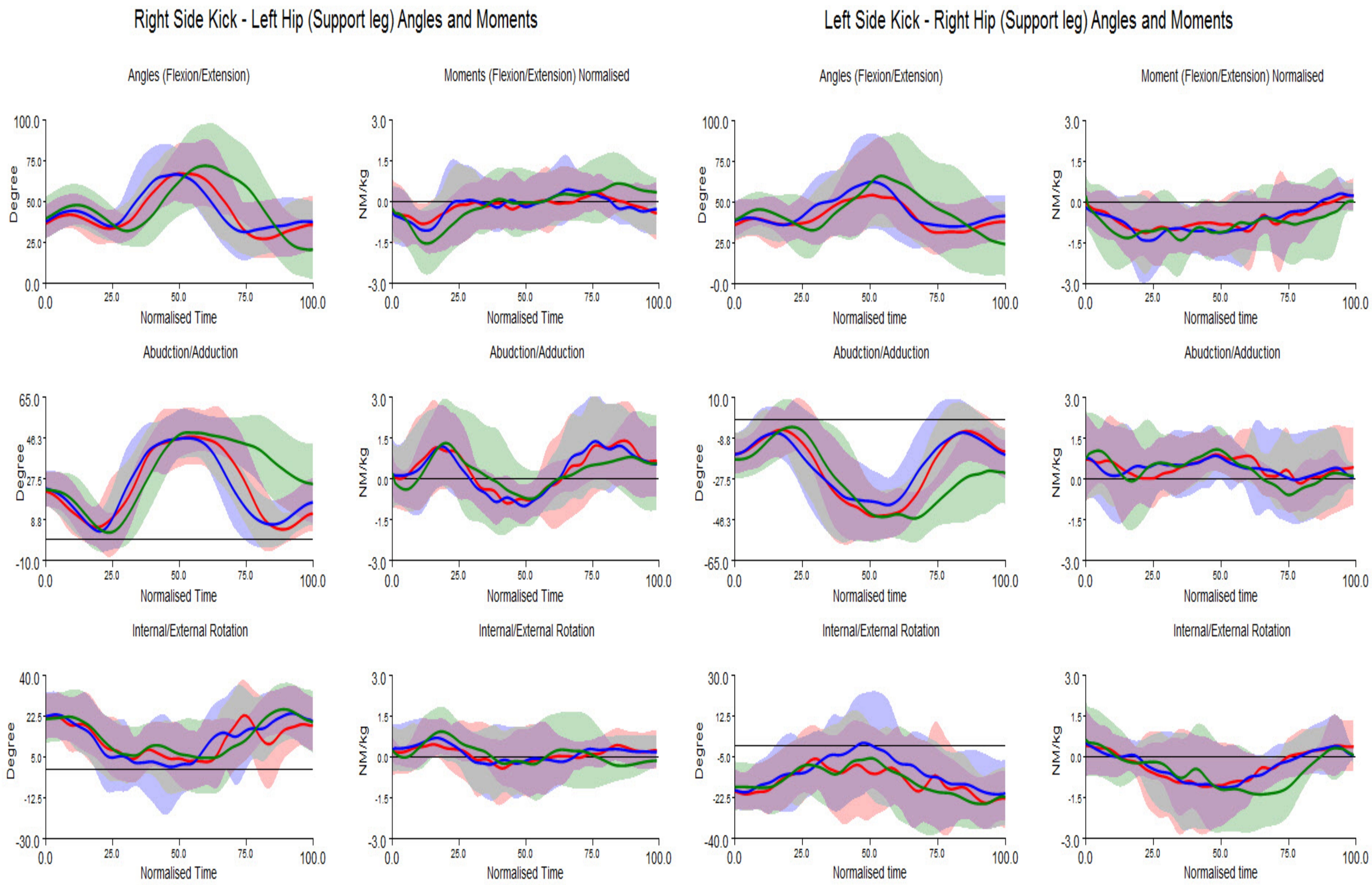

Figure 40 Side kick (both sides) hip angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

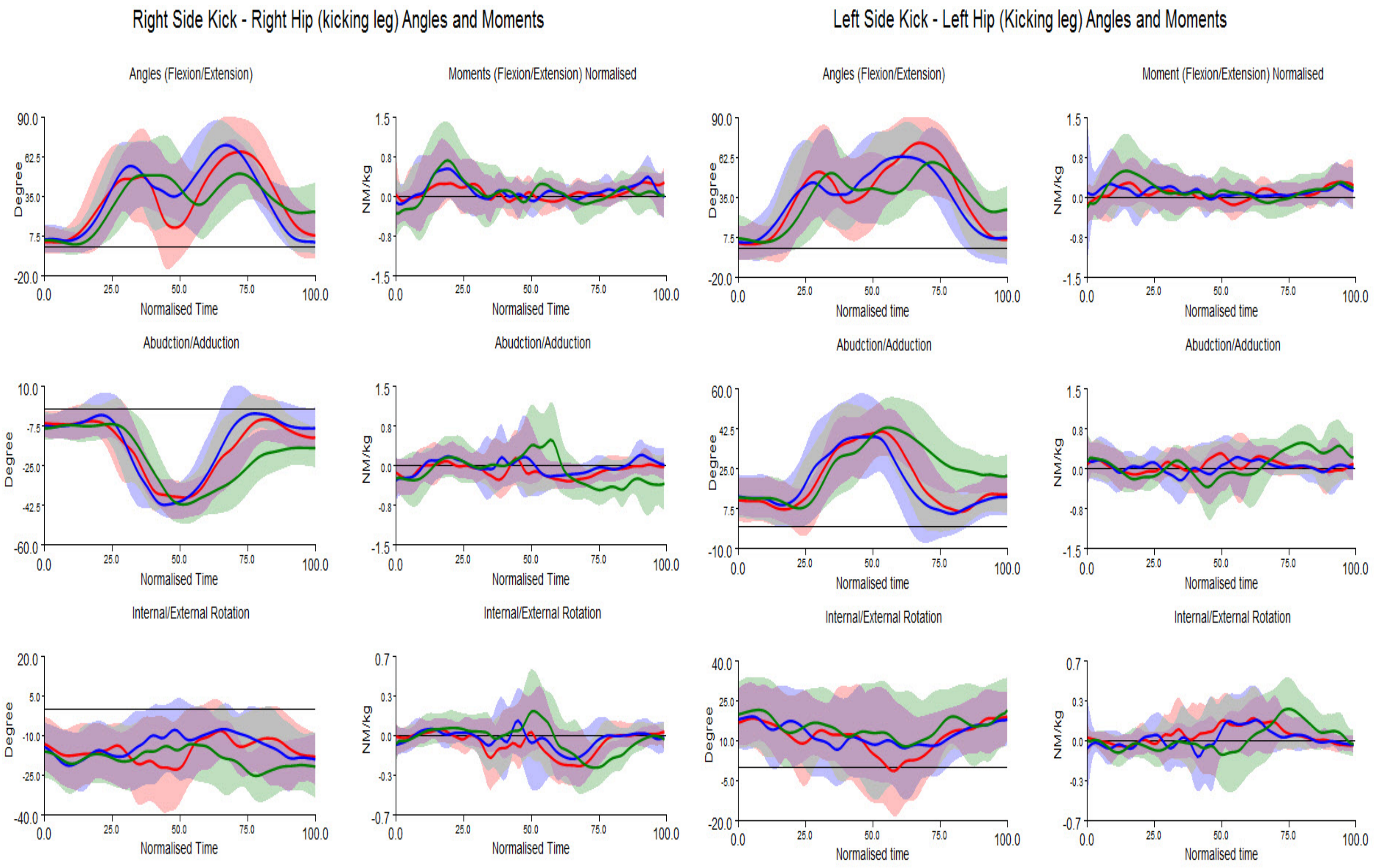

Figure 41 Side kick (both sides) hip angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

4.5 Karate: Hook kick results

4.5.1 Hook kick (Right) angles and moments

Table 18 right hook kick angles and moments of the support leg (left) and kicking leg (right) of both the knee and hip joints for the three kicking modes.

Table 18 Hook kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	70	50	21	63	45	21	165	3	-14	130	4	23
Max SD	13	5	8	13	10	6	14	7	8	35	11	11

Competition angles/Degrees

Max mean	77	48	20	66	45	25	160	4	-15	132	5	23
Max SD	10	5	6	18	11	7	13	8	8	41	11	11

Competition step angles/Degrees

Max Mean	81	53	25	51	44	24	162	10	-17	135	8	8
Max SD	17	7	8	22	9	8	16	5	9	37	7	9

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	1.0	1.2	0.3	0.4	02	0.1	1.3	1.0	0.3	0.2	0.1	0.1
Max SD	0.8	1.0	0.2	0.3	0.2	0.3	1.1	0.6	0.3	0.1	0.2	0.2

Competition moments/N.m/kg (Normalised)

Max mean	1.5	1.1	0.3	0.9	0.4	0.2	1.3	1.0	0.3	0.3	0.2	0.1
Max SD	1.0	1.0	0.3	0.5	0.5	0.5	1.0	0.5	0.3	0.3	0.2	0.2

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.4	1.0	0.3	0.6	0.5	0.3	0.7	0.5	0.4	0.4	0.3	0.2
Max SD	0.8	1.0	0.2	0.4	0.4	0.3	0.8	0.5	0.3	0.2	0.2	0.2

4.5.2 Hook kick (Left) angles and moment

Table 19 left Hook kick angles and moments of the support leg (right) and kicking leg (left) of both the knee and hip joints for the three kicking modes.

Table 19 hook kick (both sides) knee angles and moments for support and kicking legs

Training angles/Degrees

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	55	50	22	58	48	21	168	-7	-17	130	5	18
Max SD	18	9	11	20	11	10	11	6	9	33	7	6

Competition angles/Degrees

Max mean	60	51	21	58	48	25	164	-7	-18	142	4	20
Max SD	16	9	15	24	11	9	12	5	7	38	4	9

Competition step angles/Degrees

Max Mean	61	52	28	50	47	27	167	-5	-20	128	5	15
Max SD	9	8	13	25	12	9	11	4	8	25	6	7

Training moments/N.m/kg (Normalised)

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Max mean	1.0	1.1	0.8	0.5	0.3	0.3	0.6	0.4	0.2	0.2	0.1	0.1
Max SD	1.0	1.0	1.0	0.4	0.5	0.3	0.7	0.4	0.1	0.1	0.2	0.1

Competition moments/N.m/kg (Normalised)

Max mean	1.4	1.1	1.4	0.6	0.4	0.3	0.6	0.3	0.2	0.3	0.2	0.2
Max SD	1.0	1.0	1.0	0.3	0.5	0.7	0.7	0.5	0.2	0.3	0.2	0.1

Competition Step moments/N.m/kg (Normalised)

Max Mean	1.5	1.0	1.7	0.6	0.6	0.3	0.6	0.6	0.2	0.3	0.2	0.2
Max SD	1.0	1.0	1.8	0.4	0.4	0.1	0.7	0.7	0.2	0.2	0.3	0.1

4.5.3 Hook kick significant differences

Hook kick has 3 significant differences in 3 different joints and axes. Firstly, right hook kick has one on the support leg on the Left knee joint moment, on X-axis among T mode (1.3 N.m/kg) with S mode (0.7 N.m/kg) and C mode (1.3 N.m/kg) with S mode (0.7 N.m/kg). Kicking leg has one significant difference on right hip moment as kicking leg, on the X axis: T mode (0.4 N.m/kg) with S mode (0.9 N.m/kg) and C mode (0.6 N.m/kg) with S mode (0.9 N.m/kg), Left side kick, on the support hip moment, Z axis: T mode (0.8NM/kg) with C mode (1.4 N.m/kg) and T mode (0.8NM/kg) with S mode (1.7 N.m/kg). by looking to Cohen`s D there are all of them have a big effect on the mode except last one Table 20.

Table 20 Significant differences on the right and left of Hook kick

	Hook kick – Kicking leg is Right			
	Joint	**Axes**	**Modes**	**Cohen`s D**
1	Left knee moment	X	T & S	0.62
			C & S	0.66
2	Right hip moment	X	T & S	0.56
			C & S	0.66
	Hook kick – Kicking leg is Right			
1	Right hip moment	Z	T & C	0.61
			T & S	0.20

4.5.4 Hook kick angles (Right and left)

Hook kick kicking hip angles on the right side have slightly higher values on X-axis, T mode (63 degrees) and C mode (66 degrees) than left side both T and C Modes have (58 degrees) but S mode on both sides has very similar angles (50 and 51 degrees) with different path on the second half of motion. Y-axis has almost the same values the right side (45 degrees) and very similar on the left side (48 degrees) on all modes, also S mode has different path comparing with T and C modes. There are similarities of angles on Z axis for both sides for all modes between (20–25 degrees). Support hip angles on right hook kick X axis, there are slightly change in the modes angles by getting bigger, T mode (70 degrees), C mode (77 degrees) and S mode (81 degrees), Left side X-axis support hip angles have smaller degrees than right side in all three modes, T mode (55 degrees), C mode (60 degrees) and S mode 61 degrees). Y-axis has very similar angles value on all three modes (50-52 degrees) with it is very similar to the right side, again with a different path of motion for S mode. Z axis on both sides of hook kick has a range of motion angle about (21-29 degrees) for all modes.

Support knee angles on both sides left and right for all modes have greater angles than kicking legs knee angles. On the right-side hook kick, support knee angle, X-axis, T mode (165 degrees) C mode (160 degrees) and S mode (162 degrees). Left side hook kick on the same angle and axis has greater angles than the right side, T mode (168 degrees), C mode (164 degrees) and S mode (167 degrees) Figure 43, Figure 44, Figure 45 and Figure 46.

4.5.5 Hook kick moment (normalised) (Right and left)

Support leg on the hip moment of the right side showed significant differences among the three modes on the X-axis and right hip moment as kicking leg X axis among the three modes, also right hip moment as support leg on the left side Z axis showed significant difference among kicks modes Table 17. On the support leg hip joint moments on both sides of kick showed similarity on all three axes, X-axis: T mode (1 N.m/kg), C mode 1.5 N.m/kg and S mode between (1.4-1.5 N.m/kg). Y axis showed also similarity values on all three modes for left side comparing with right side of kick, T mode (1.1 N.m/kg), C mode (1.1 N.m/kg) and S mode (1 N.m/kg, But Z axis for the three modes of left side has higher values X Axis T mode (0.8 N.m/kg), C mode 1.4Nm/kg) S mode 1.7 N.m/kg) comparing with right side T, C and S modes have the same values (0.3 N.m/kg). Kicking leg for both sides have very similar moments values on X axis for T mode about (0.5 N.m/kg) and C mode about (0.8 N.m/kg) but much higher value for left side S mode (1.2 N.m/kg) with just (0.5 N.m/kg) for right side.

Support knee of right side showed greater values on X axis for T mode (1.3 N.m/kg) and C mode (1.3 N.m/kg) comparing with left side T mode (0.6 N.m/kg) and C mode 0.6 N.m/kg) but S modes on both side showed similarity values (0.7 and 0.6 N.m/kg). Again, left side on Y axis showed higher values on T and C modes than the right side, left side T and C modes (1 N.m/kg) and right-side T and S modes (0.3 and 0.4 N.m/kg) Also Z mode on both sides showed similarity on S mode. Z axis of both side for all modes showed similarity on values. Kicking knee for both sides on all modes also have very similar values on all axes Figure 43, Figure 44, Figure 45 and Figure 46.

Hook kick performance using visual3D software to upper joints angles and moments Figure 42.

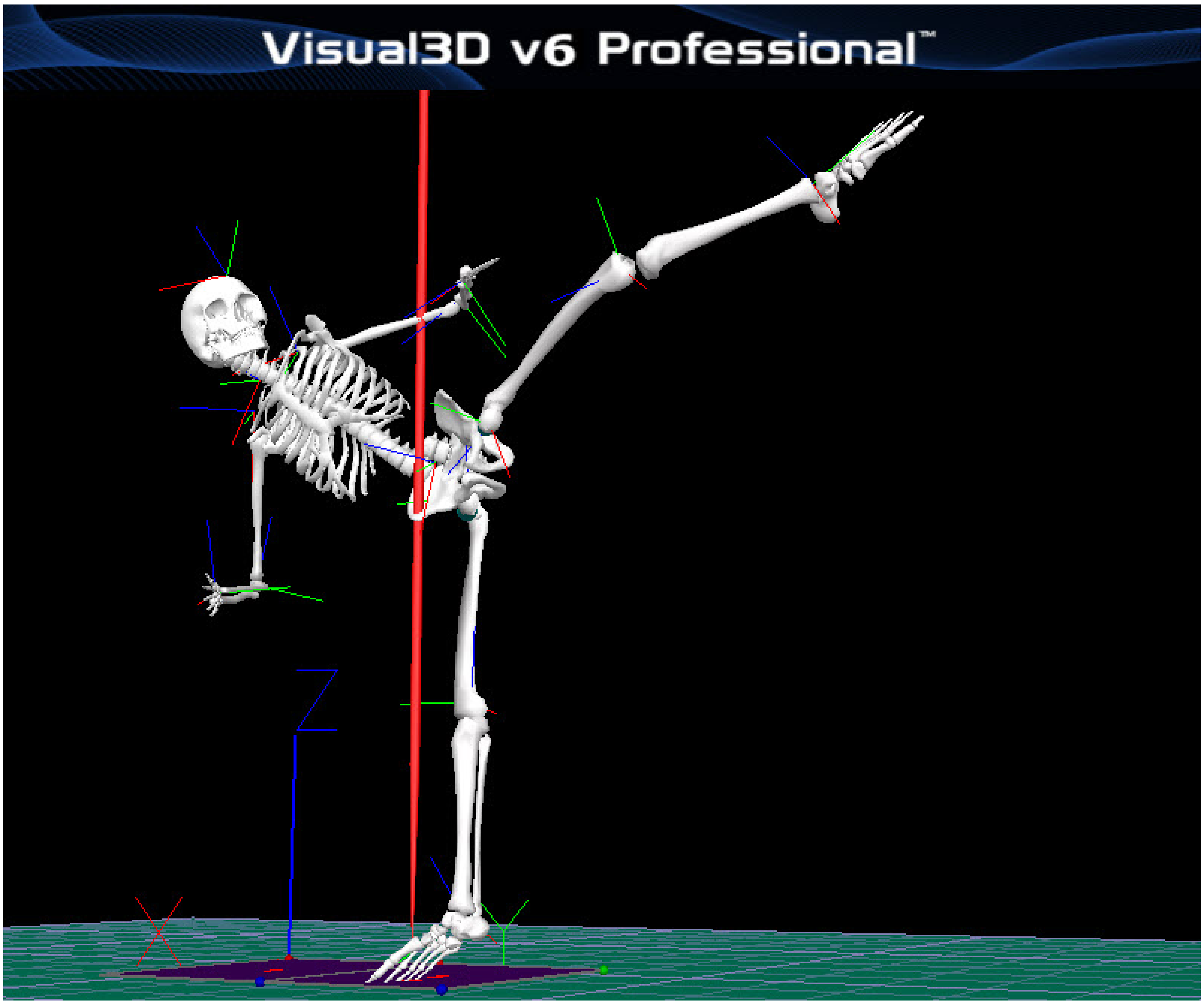

Figure 42 Hook kick skeleton with coordinate system X, Y and Z

The multi direction of hook kick line from start till it reaches the target makes it difficult to perform and not all players can do it perfectly and get 3 points. From this data, support hip moment of internal – external rotation was 1.7 Nm/kg and that is considered high. It may be that less flexible karateka are performing this kick with a load of the range being made up on the supporting hip as it is not as dynamics as forceful a kick as others but has high joint loading on the supporting hip.

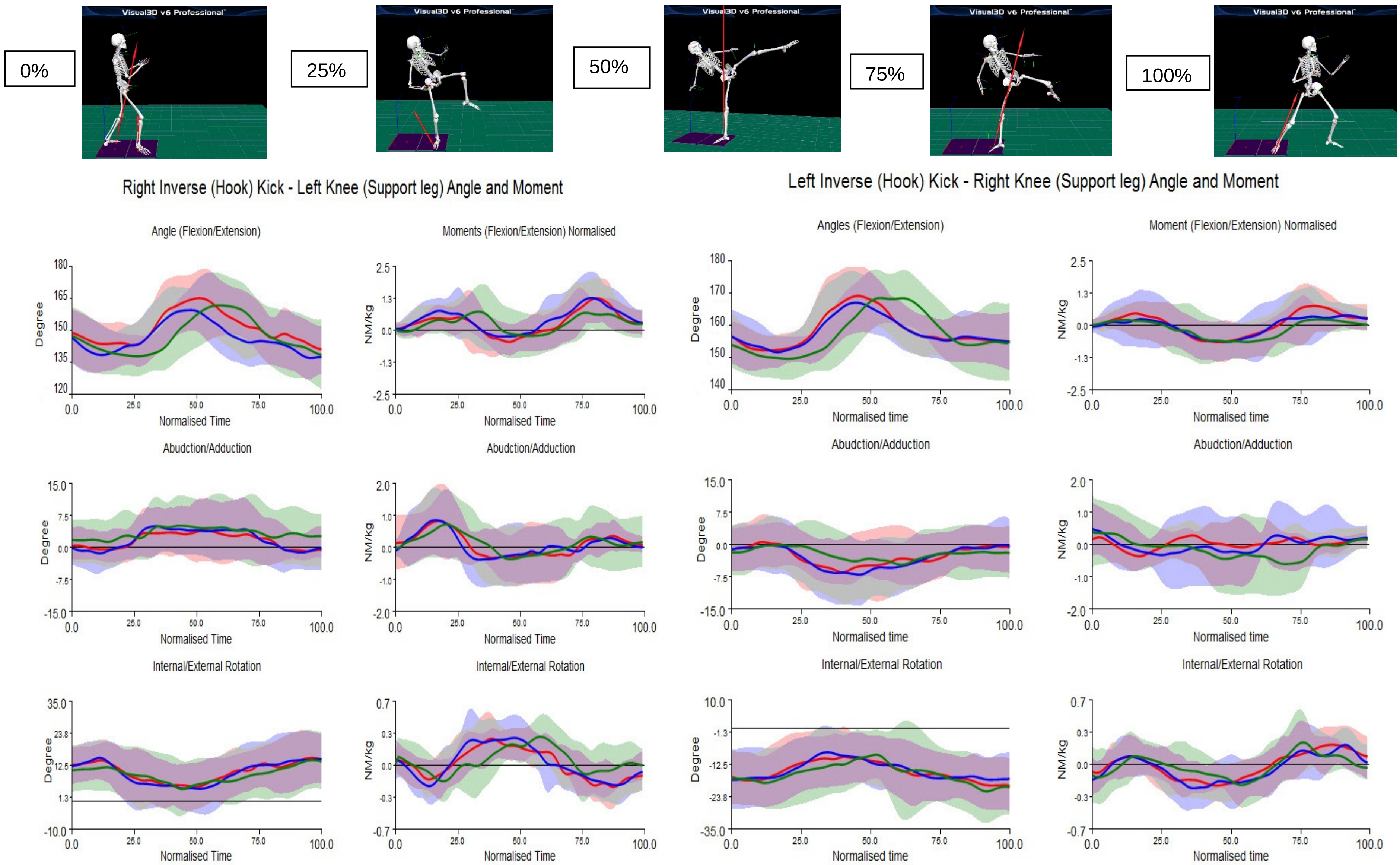

Figure 43 Hook kick (both sides) knee angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

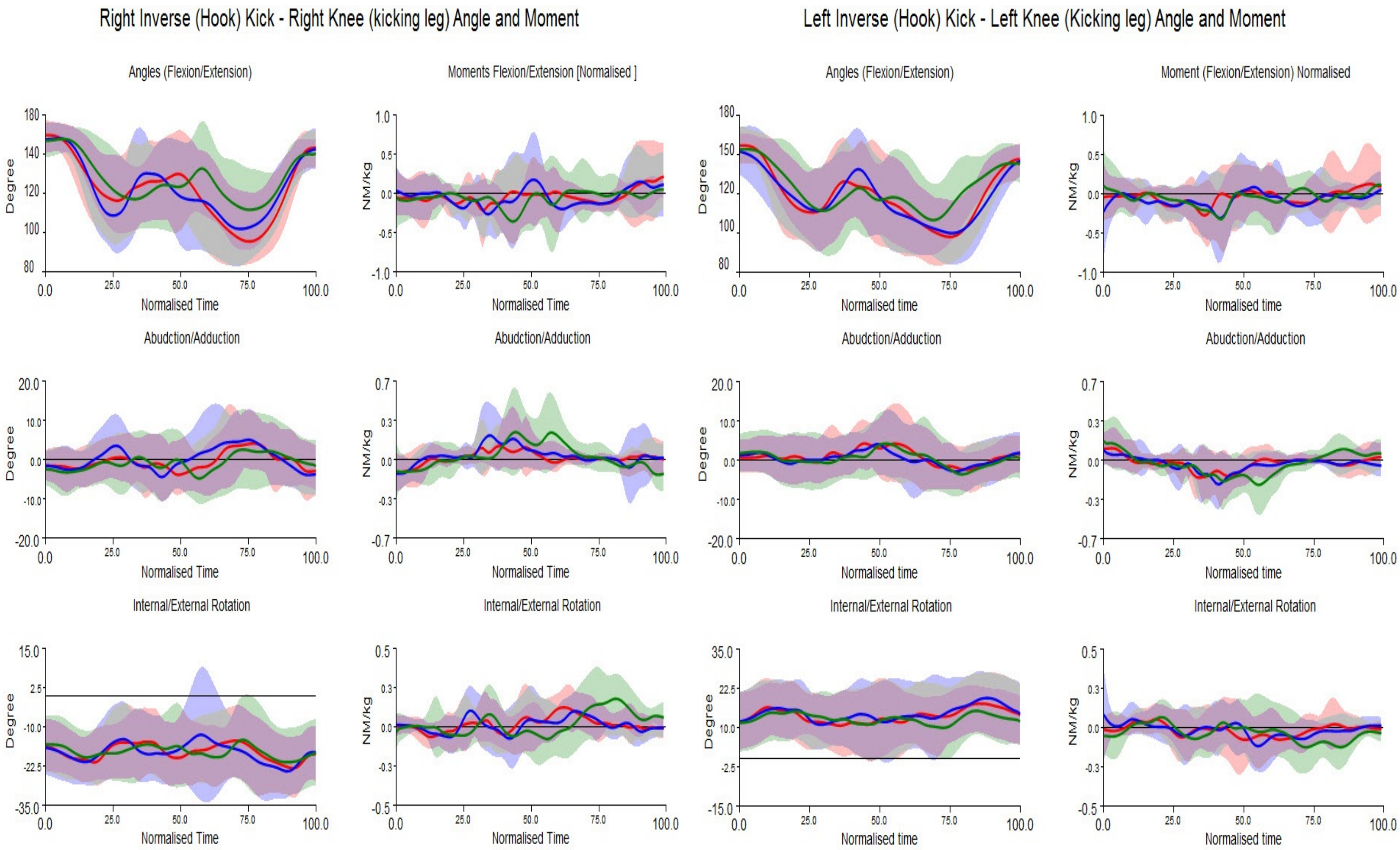

Figure 44 Hook kick (both sides) knee angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

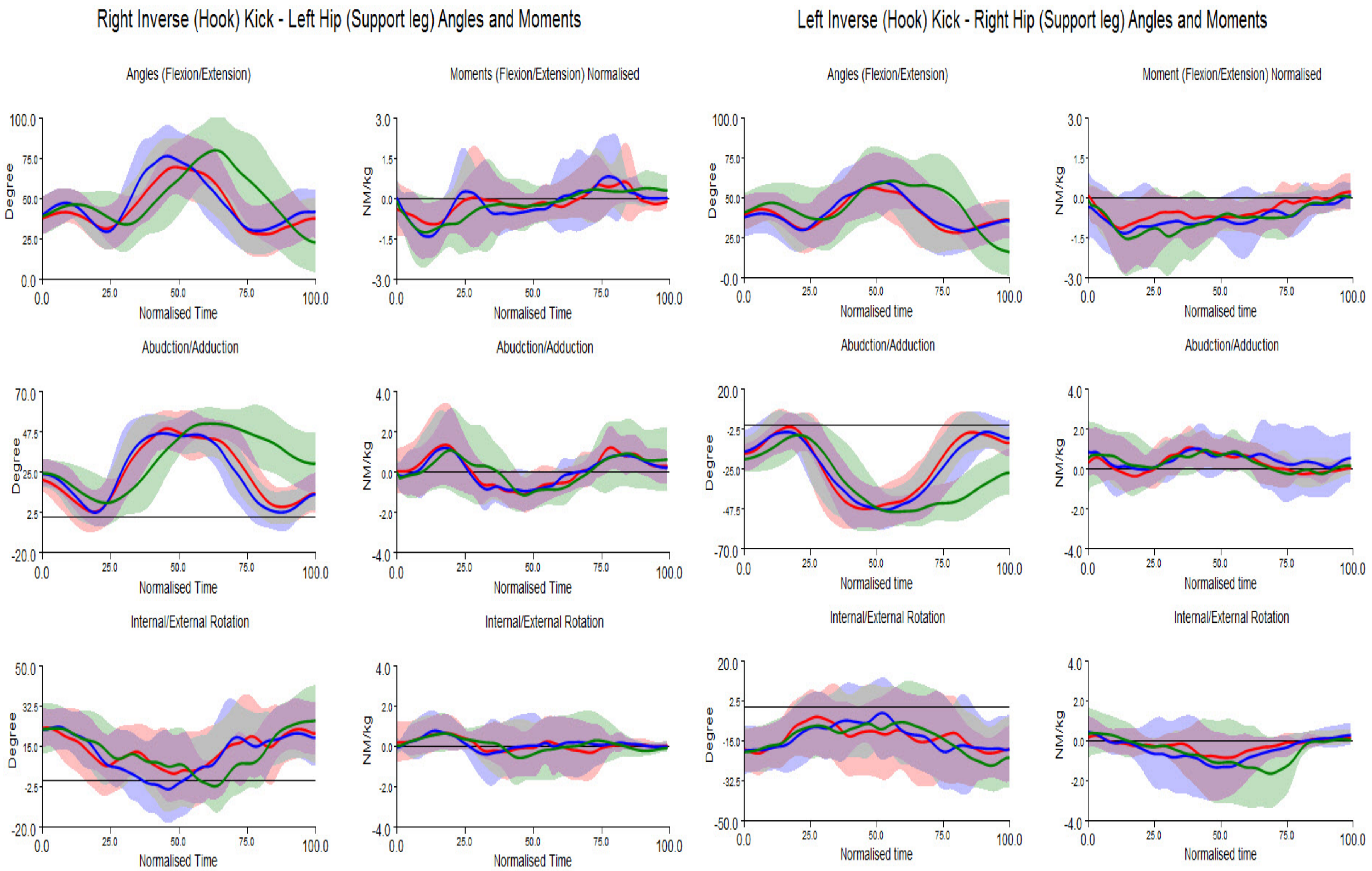

Figure 45 Hook kick (both sides) hip angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

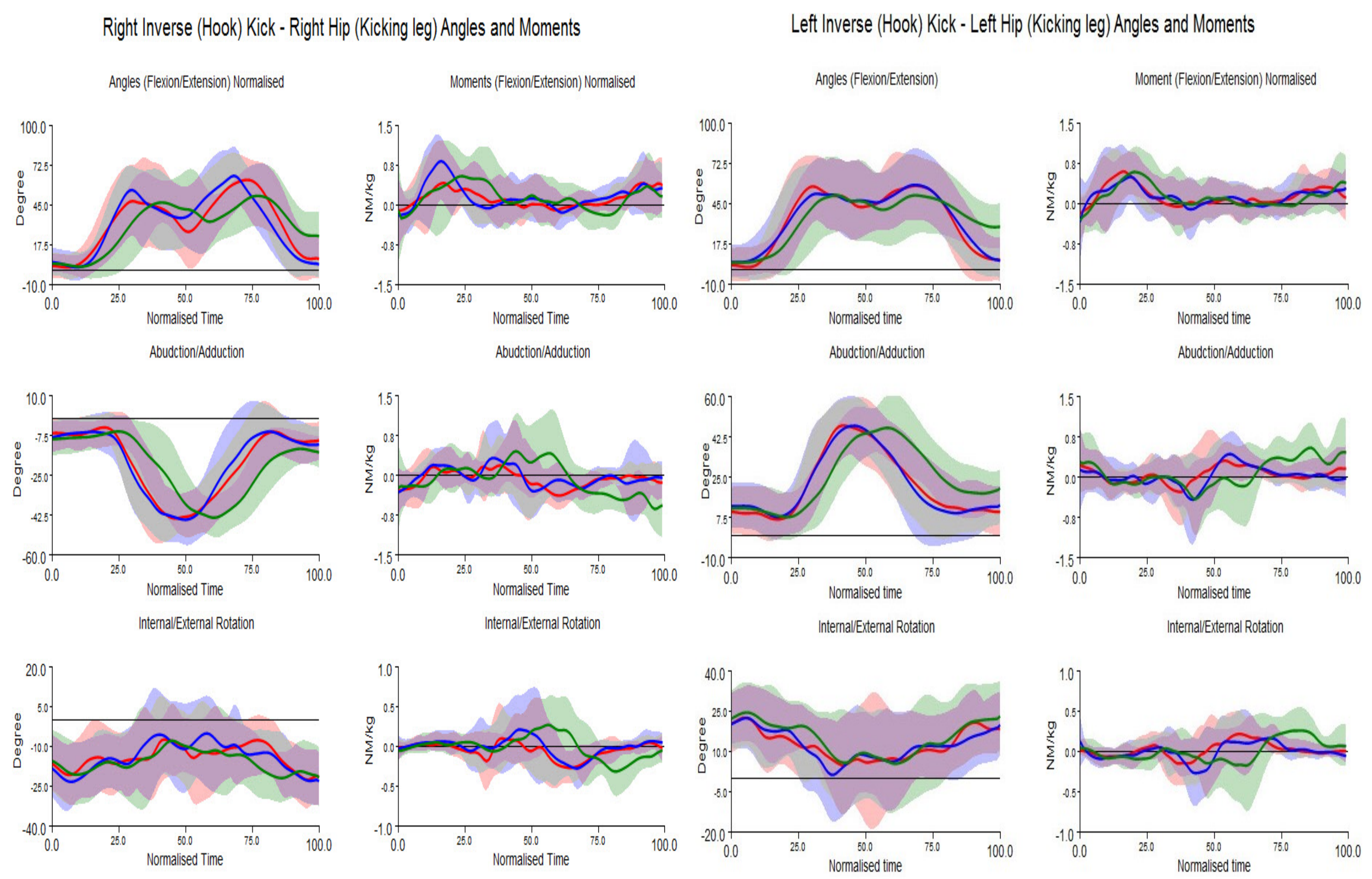

Figure 46 Hook kick (both sides) hip angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

4.6 Karate: Back kick results

4.6.1 Back kick (Right) angles and moments

Table 21, right Back kick angles and moments of both the support leg, left and kicking leg, right of both the knee and hip joints for the three kicking modes.

Table 21 Back kick (both sides) knee angles and moments for support and kicking legs

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Training angles/Degrees												
Max mean	73	33	17	65	26	19	160	4	14	133	-5	-20
Max SD	16	10	12	18	8	11	10	3	10	38	3	11
Competition angles/Degrees												
Max mean	78	34	16	60	25	15	152	5	16	138	-4	-19
Max SD	13	9	13	17	7	10	12	4	9	40	4	10
Competition step angles/Degrees												
Max Mean	81	44	26	58	33	24	153	8	16	132	-3	-13
Max SD	15	11	9	14	4	10	11	5	8	36	3	12

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
Training moments/N.m/kg (Normalised)												
Max mean	1.0	0.8	0.6	0.3	0.3	0.2	1.3	1.0	0.3	0.8	0.2	0.1
Max SD	1.0	1.0	0.8	0.4	0.3	0.2	0.7	0.6	0.3	0.4	0.1	0.1
Competition moments/N.m/kg (Normalised)												
Max mean	1.5	0.9	0.5	0.5	0.4	0.3	1.2	1.0	0.3	0.5	0.1	0.1
Max SD	1.0	1.0	0.7	0.5	0.2	0.4	0.8	0.5	0.3	0.3	0.1	0.1
Competition Step moments/N.m/kg (Normalised)												
Max Mean	1.0	1.0	0.7	0.4	0.4	0.2	1.0	0.5	0.4	0.7	0.1	0.1
Max SD	1.0	1.0	0.9	0.3	0.5	0.2	0.8	0.5	0.3	0.5	0.1	0.1

4.6.2 Back kick (Left) angles and moments

Table 22, left Back kick angles and moments of the support leg (right) and kicking leg (left) of both the knee and hip joints for the three kicking modes.

Table 22 Back kick (both sides) knee angles and moments for support and kicking legs

	Support hip			Kicking hip			Support knee			Kicking knee		
	X	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**	**X**	**Y**	**Z**
Training angles/Degrees												
Max mean	68	26	18	59	28	20	157	-5	-19	125	6	15
Max SD	15	13	12	20	21	19	12	6	9	40	9	10
Competition angles/Degrees												
Max mean	67	25	17	50	26	21	154	-5	-21	120	6	15
Max SD	17	14	13	19	20	20	10	5	7	37	9	9
Competition step angles/Degrees												
Max Mean	76	39	30	60	34	17	153	-5	-21	125	5	12
Max SD	21	21	19	21	12	21	11	5	10	42	8	10
Training moments/N.m/kg (Normalised)												
Max mean	1.0	0.9	1.0	0.2	0.2	0.2	1.0	0.5	0.4	0.2	0.1	0.1
Max SD	0.4	0.5	1.0	0.5	0.1	0.1	0.6	0.7	0.3	0.5	0.2	0.1
Competition moments/N.m/kg (Normalised)												
Max mean	1.4	0.6	1.4	0.4	0.3	0.2	0.9	0.5	0.4	0.3	0.1	0.1
Max SD	0.3	0.7	1.6	0.3	0.2	0.1	0.9	0.6	0.2	0.3	0.2	0.1
Competition Step moments/N.m/kg (Normalised)												
Max Mean	1.4	0.9	1.4	0.5	0.3	0.3	1.3	0.7	0.5	0.3	0.1	0.2
Max SD	0.5	0.7	1.5	0.5	0.2	0.2	1.0	0.6	0.4	0.6	0.2	0.2

4.6.3 Back kick significant differences

Back kick has 4 significant differences on multiple joint angles and multiple axes among the three modes. 3 on right back kick and 1 on left kick. On the right side: Left hip angle as support leg on X axis: T mode (73 degrees) with S mode (81 degrees) and C mode (78 degrees) with S mode (81 degrees). Y-axis: T mode (33 degrees) with S mode (44 degrees) and C mode (34 degrees) with S mode (44 degrees). Z axis: T mode (17 degrees) with S mode (26 degrees) and C mode (16 degrees) with S mode (26 degrees). Left knee angle as support leg, X-axis: T mode (160 degrees) with C mode (152 degrees) and T mode (160 degrees) with S mode (153 degrees). Y-axis: T mode (4 degrees) with S mode (8 degrees) and C mode (5 degrees) with S mode (8 degrees). Z axis: T mode (14 degrees) with C mode (16 degrees) and T mode (14 degrees) with S mode (16 degrees). Right hip angle, kicking leg, Y-axis: T mode (26 degrees) with S mode (33 degrees) and C mode (25 degrees) with S mode (33 degrees). Left side on the left hip angle as kicking leg, Y-axis: T mode (28 degrees) with S mode (33 degrees) and C mode (26 degrees) with S mode (34 degrees) Table 23.

Table 23 Significant differences on the right and left of Back kick

Back kick – Kicking leg is Right

	Joint	Axes	Modes	Cohen`s D
1	Left hip angle	X	T & S	0.51
			C & S	0.21
		Y	T & S	1.04
			C & S	0.99
		Z	T & S	0.84
			C & S	0.89
2	Left knee angle	X	T & S	0.66
			C & S	0.08
		Y	T & S	0.97
			C & S	0.66
		Z	T & C	0.21
			T & S	0.22
3	Right hip angle	Y	T & S	1.10
			C & S	1.40
		Z	T & S	0.47
			C & S	0.90

Back kick – Kicking leg is left

	Joint	Axes	Modes	Cohen`s D
1	Left hip angle	Y	T & S	0.35
			C & S	0.48

4.6.4 Back kick angles (Right and left)

Right and left back kick have many significant differences on multiple joint and axes for the three modes but there are some other non-differences with the left side. Right side left hip angle, left knee angle, right hip angle and left side kicking leg hip angle were presented as significant differences. Support hip, X and Y axes on the right side has greater angle values on all three modes but Z axis has similar angles values for T, C and S mode. Kicking hip angles X axis for the right side on T mode (65 degrees) and C mode

(60 degrees) has slightly higher value than the left side T mode (59 degrees) and C mode (50 degrees) and very similar degrees on S mode about (58-60) degrees. Also on Y-axis all modes T, C and S have similar small angles between (25-34) degrees. Z axis on the right side for T mode has similar value with left side but a lower value for C mode compared with the left side and slightly higher value on S mode.

Support knee X axis for both sides for all three modes have very similar angles between (152-160) degrees. Y-axis also has similar and small angles for both sides on all modes about (4-8) degrees. Z axis on the right side for all modes has slightly lower angles than the left side. Kicking knee of the right-side X-axis for all modes T, C and S) has higher values comparing with the left side, right side T mode (133 degrees) C mode (138 degrees) and S mode (132 degrees. Left side: T mode (125 degrees) C mode (120 degrees) and S mode (125 degrees). Y-axis for both side right and left on all modes have very similar small angles about (3-6) degrees. Z axis on the right side has slightly higher angles on the all modes Figure 48, Figure 49, Figure 50 and Figure 51.

4.6.5 Back kick moment (normalised) (Right and left)

Support hip moment X axis for both sides on T and C modes have very similar moments values, T mode (1 N.m/kg) and C mode (1.4-1.5 N.m/kg) but S mode on the left side has higher value (1.4 N.m/kg) than right side (1 N.m/kg). Y-axis on both sides on all modes has similar values about (0.6-1 N.m/kg). Z axis on the left side for T mode has slightly higher value (1 N.m/kg) than the left side T mode has (0.6 N.m/kg), but left side on C and S mode have greater values (1.4 N.m/kg) than the right-side T mode 0.5 N.m/kg) C mode (0.7 N.m/kg). Kicking hip X, Y and Z axes for both sides have similar values for all mode T, C and S about (0.2-0.5 N.m/kg).

Support knee right side X Axis T and C mode have slightly higher values (T mode 1.3 N.m/kg) C mode (1.2 N.m/kg) comparing with left side T mode (1 N.m/kg) C mode (0.9 N.m/kg) but S mode on the left side has higher value (1.3 N.m/kg) than the right side (1 N.m/kg). Y axis on the right side has higher values for T and C modes (1 N.m/kg) comparing with left side T and C modes (0.5 N.m/kg) but similar values on the S mode about (0.5-0.7 N.m/kg). Z axis also has very similar values for both legs on all modes about (0.3-0.5 N.m/kg). Kicking knee on the left side X axis has slightly higher values for all modes, T mode (0.8 N.m/kg), C mode (0.5 N.m/kg) and S mode (0.7 N.m/kg) comparing with left side T mode (0.2 N.m/kg), C mode 0.3 N.m/kg) and S mode (0.3

N.m/kg). Y and Z moments for both side on all modes have very similar values about (0.1-0.2 N.m/kg) Figure 48, Figure 49, Figure 50 and Figure 51.

Back kick performance using visual3D software to upper joints angles and moments Figure 47.

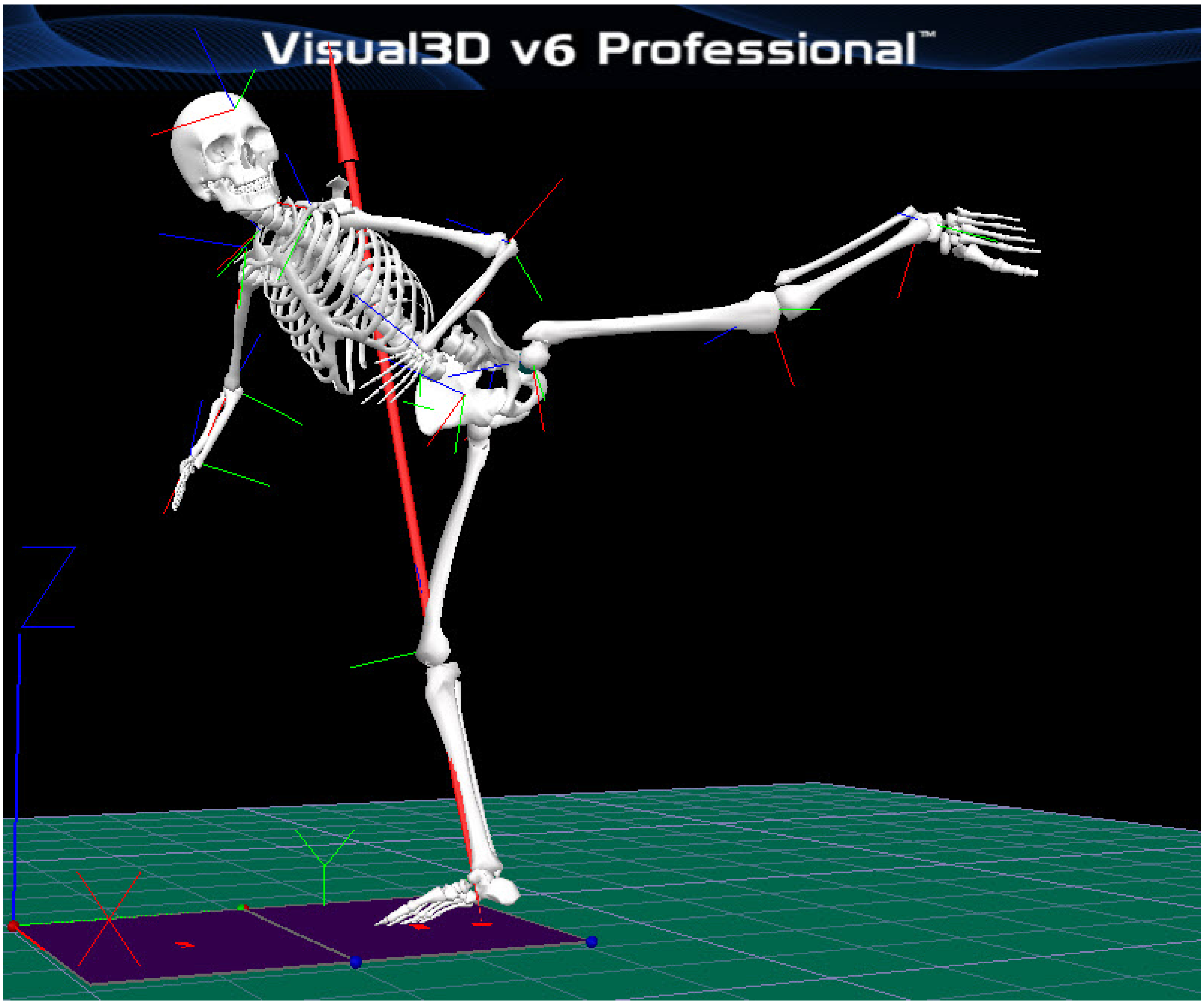

Figure 47 Back kick skeleton shape with coordinate system X, Y and Z

Back kick has the highest significant differences among kicks modes, most of them on support leg hip and knee angles, the moment on support hip was 1.5 Nm/kg which is a high value. The change of kick direction line (180°) makes it the most difficult of karate kicks to apply properly and the risk of use it is high by opening the player's back even if for a very short time, the body rotation and the linear kick at the same time in less than a second some time very risky and with the differences between modes it would seem the basic practice and application are very different. Whether this means the basic practice should be looked at to make it more applied to competition or more skill is needed before trying to apply needs further analysis

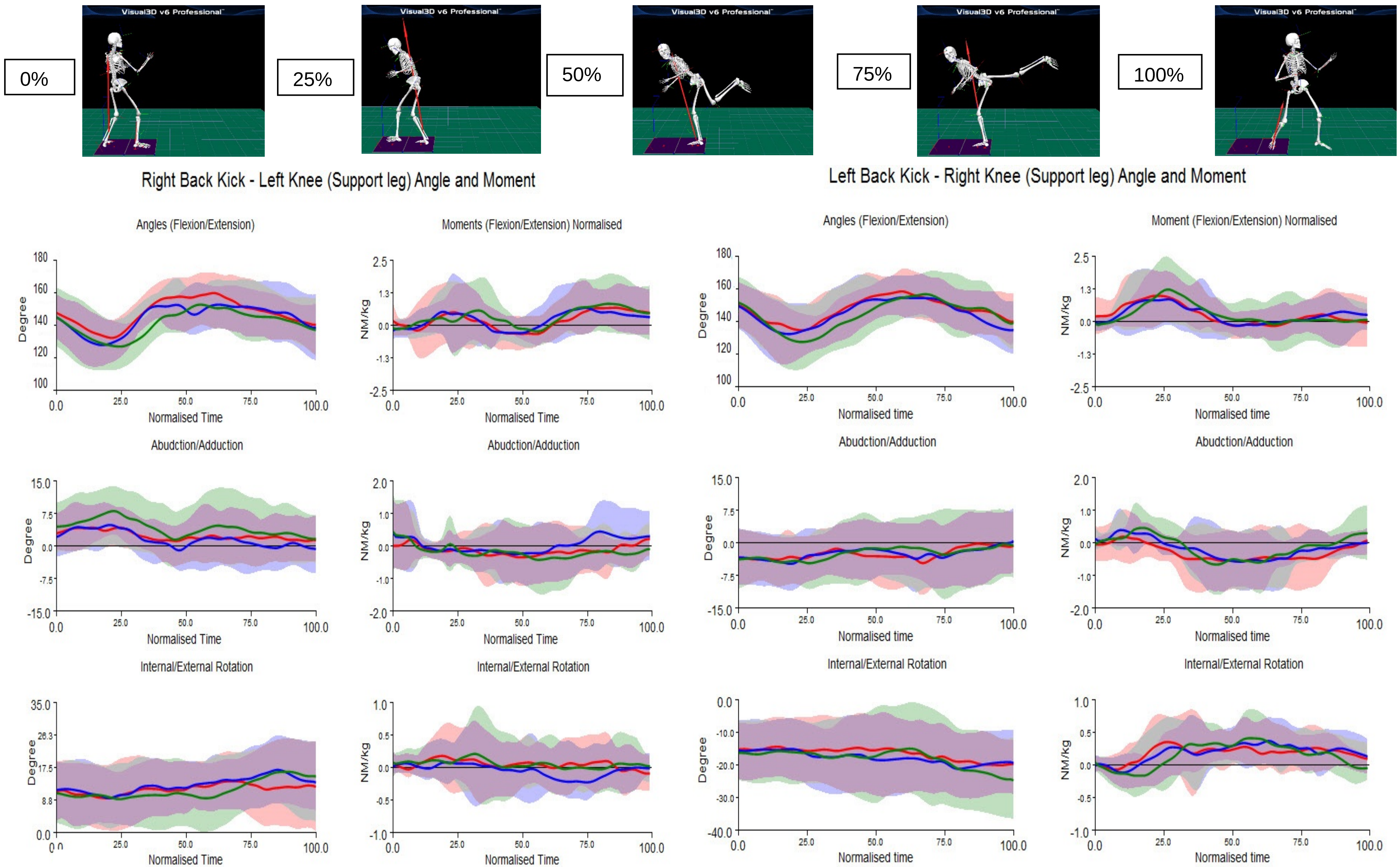

Figure 48 Back kick (both sides) knee angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

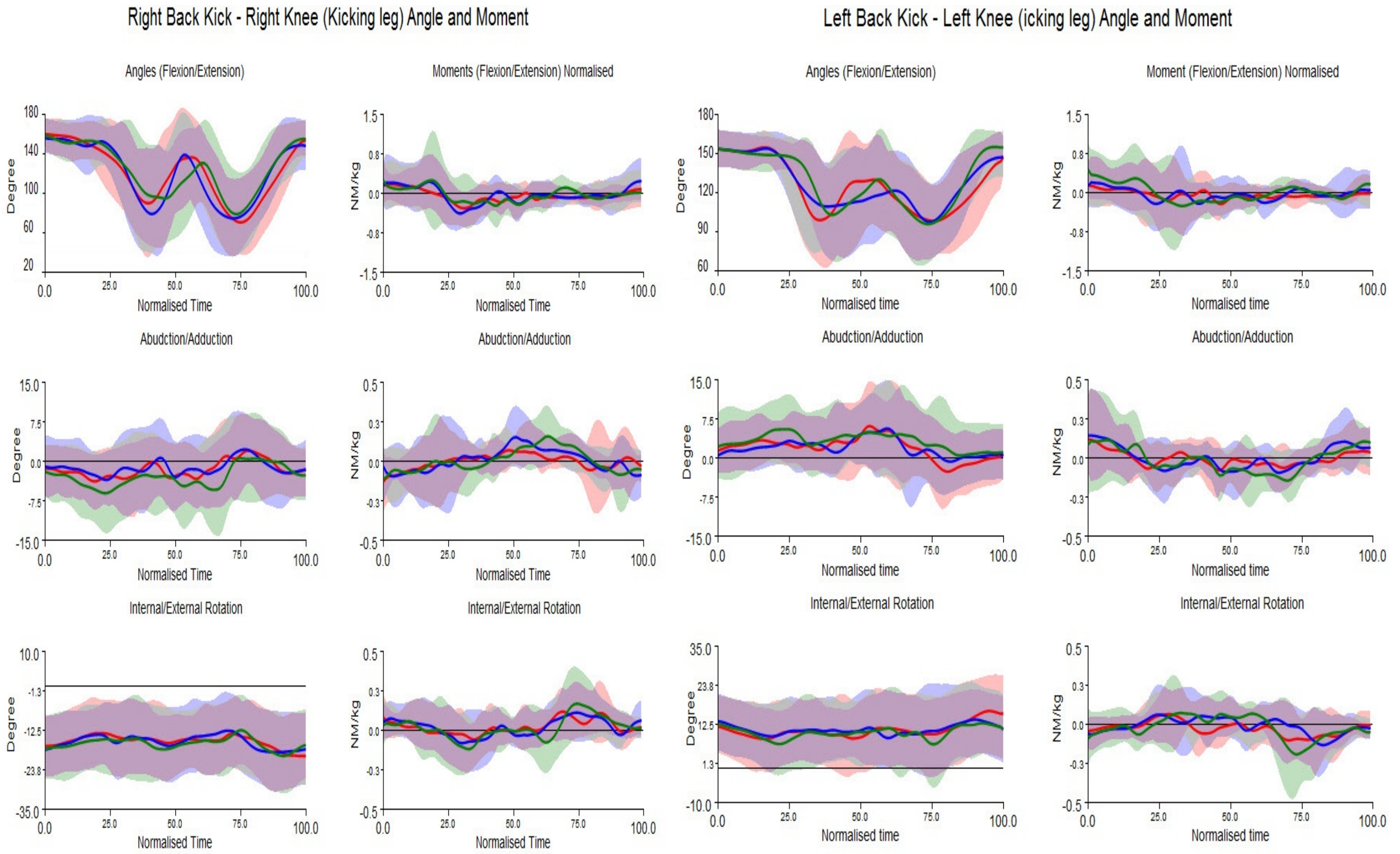

Figure 49 Back kick (both sides) knee angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

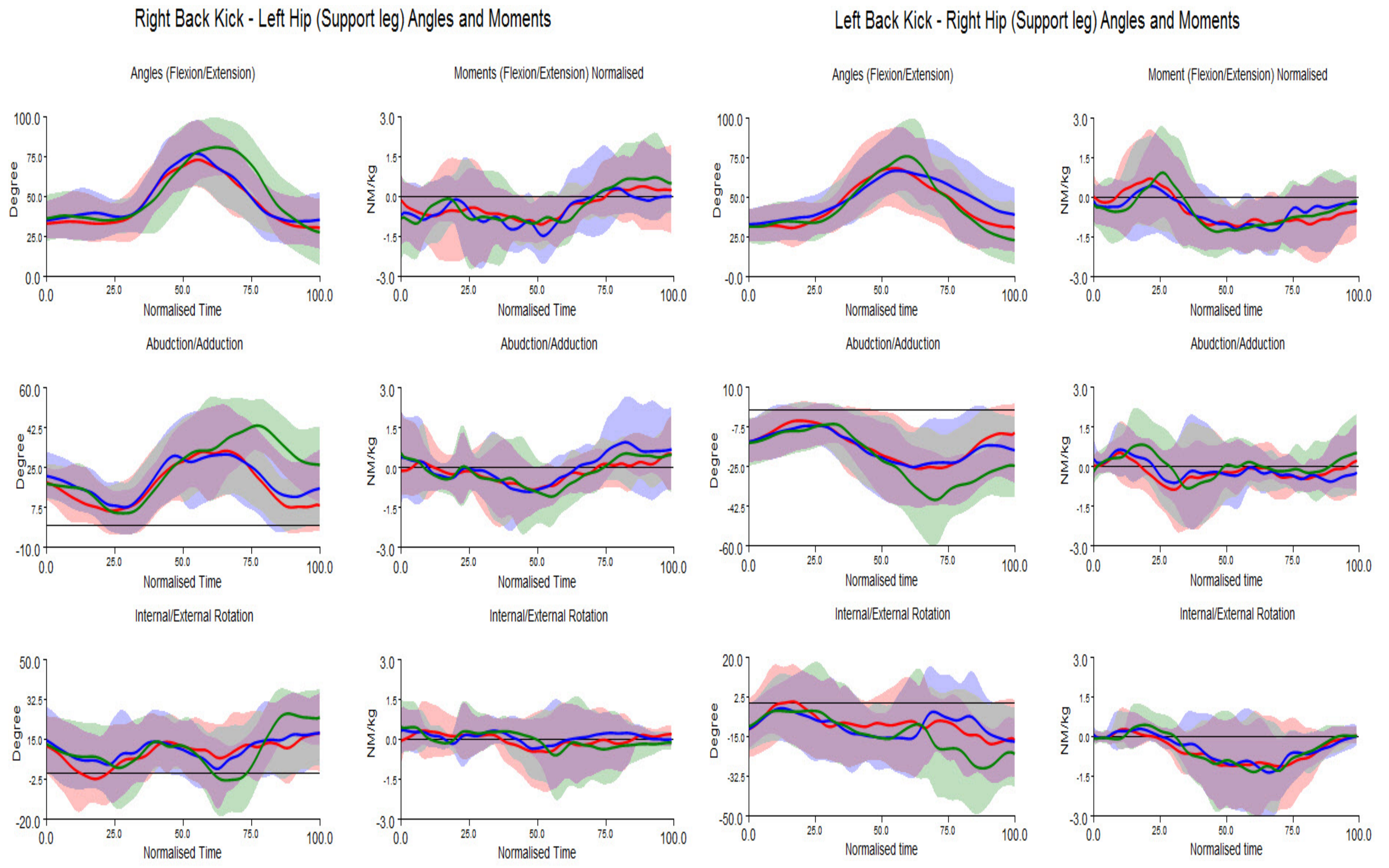

Figure 50 Back kick (both sides) hip angles and moment for support legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

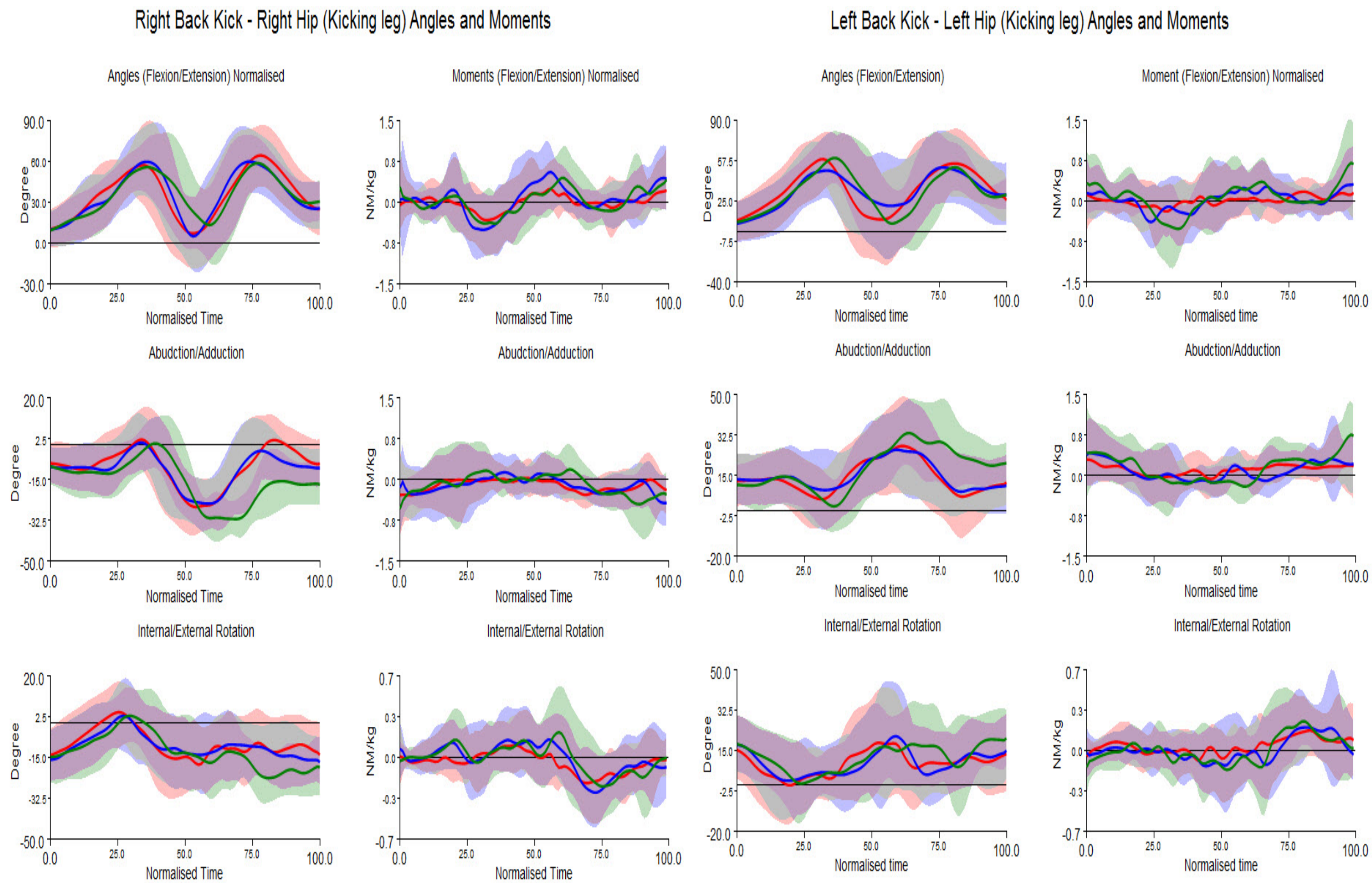

Figure 51 Back kick (both sides) hip angles and moment for kicking legs
Note: Red line = Training mode. Blue line = Competition mode. Green line = Step mode.

Chapter 5

A case study of a Taekwondo player with a lower back injury which had undergone rehabilitation for six months

5.1 Taekwondo player lower back (Trunk) injured

A high-level Taekwondo player had a lower back injury that was persistent and had been undergoing continued treatment and rehabilitation exercises for about 6 months. The subject came with his coach and his physiotherapist to analyse his kicking and his lower back motion during them. Kicks and kicking combinations were selected by the Taekwondo support team. 3D motion capture using a 9 camera VICON system and 2 force plates was performed as described in previous chapters, however, a whole-body marker set was used. In addition, the V3D model included a lower back joint, connecting the pelvis and torso were not used in the previous Karate player testing. This segment was the same as for karate apart with full body markers and extra torso segments which is not tracked on heathy karate players. The subject warmed up as per the coaches and physio's instructions and the full body marker of 53 markers. Ranges of motion were tested first then various kicks. There were 10 range of motion tasks, forward, backward and side bends, leaning back and to the left or right combined, leaning back and to the side combined with the addition of a knee lift (contralateral and ipsilateral knee) Figure 52, Figure 53, Figure 54, Figure 55, Figure 56, Figure 57 and Figure 58. Data collection methods, processing in Nexus, and analysis in V3D was performed as previously, apart from five joints were examined. (Trunk, kicking hip, support hip, kicking knee and support knee). As in the previous chapters X = (Flexion-Extension), Y = (Abduction-Adduction) and Z = (Internal-External rotation). Descriptions of the angle ranges and peak joint moments are presented, and comparisons made between the left side and right-side kicks. The subject information is shown in Table 24.

Table 24 Taekwondo case 1 information

Injured Subjects	Sex	Age	Height	Weight
TKD1	*Male*	26	182	78

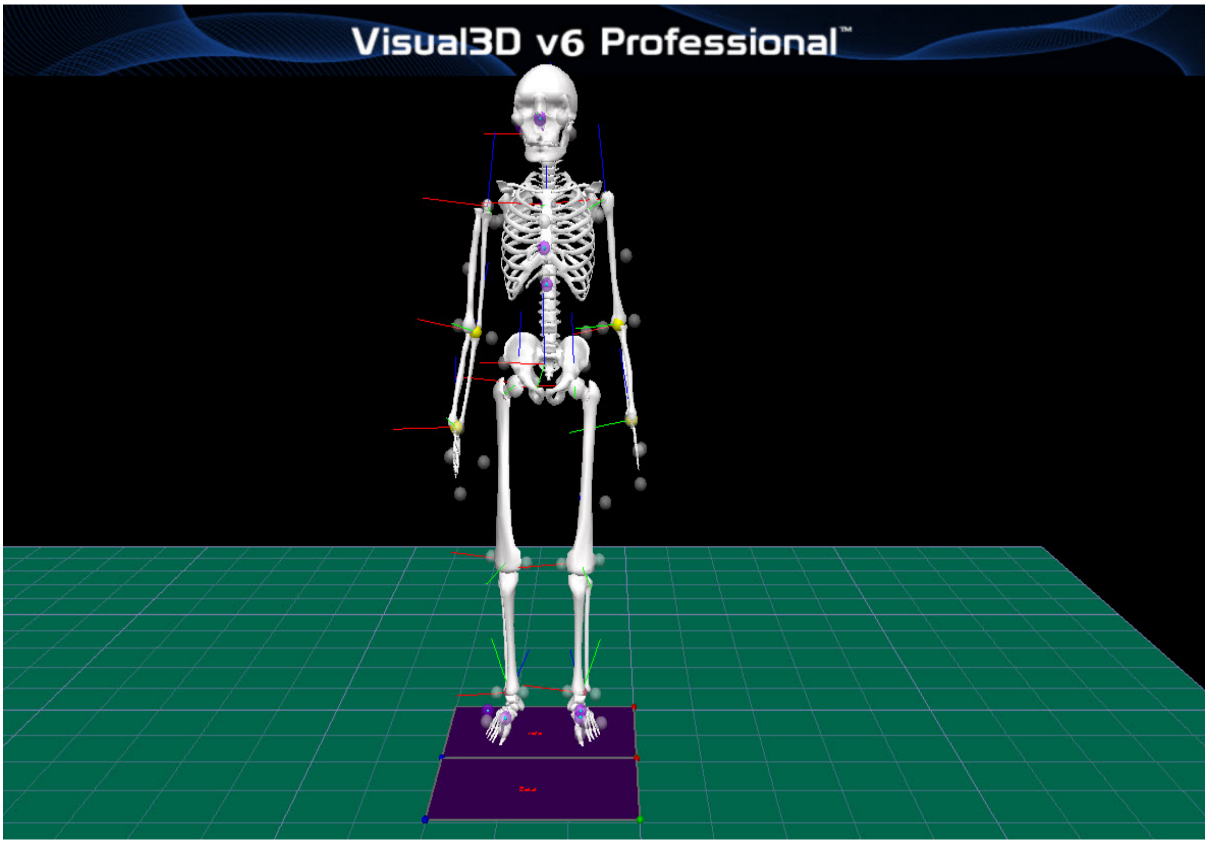

Figure 52 Static skeleton on the force plates

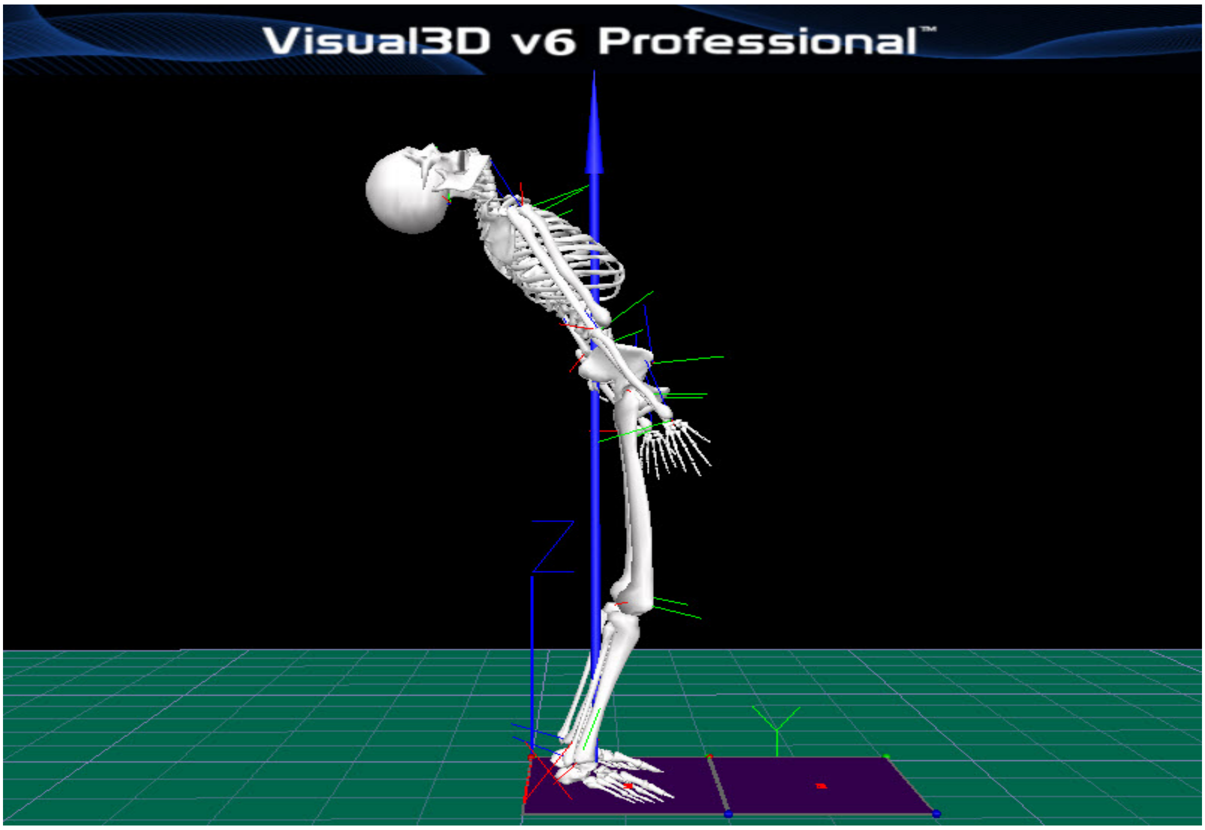

Figure 53 Leaning backwards

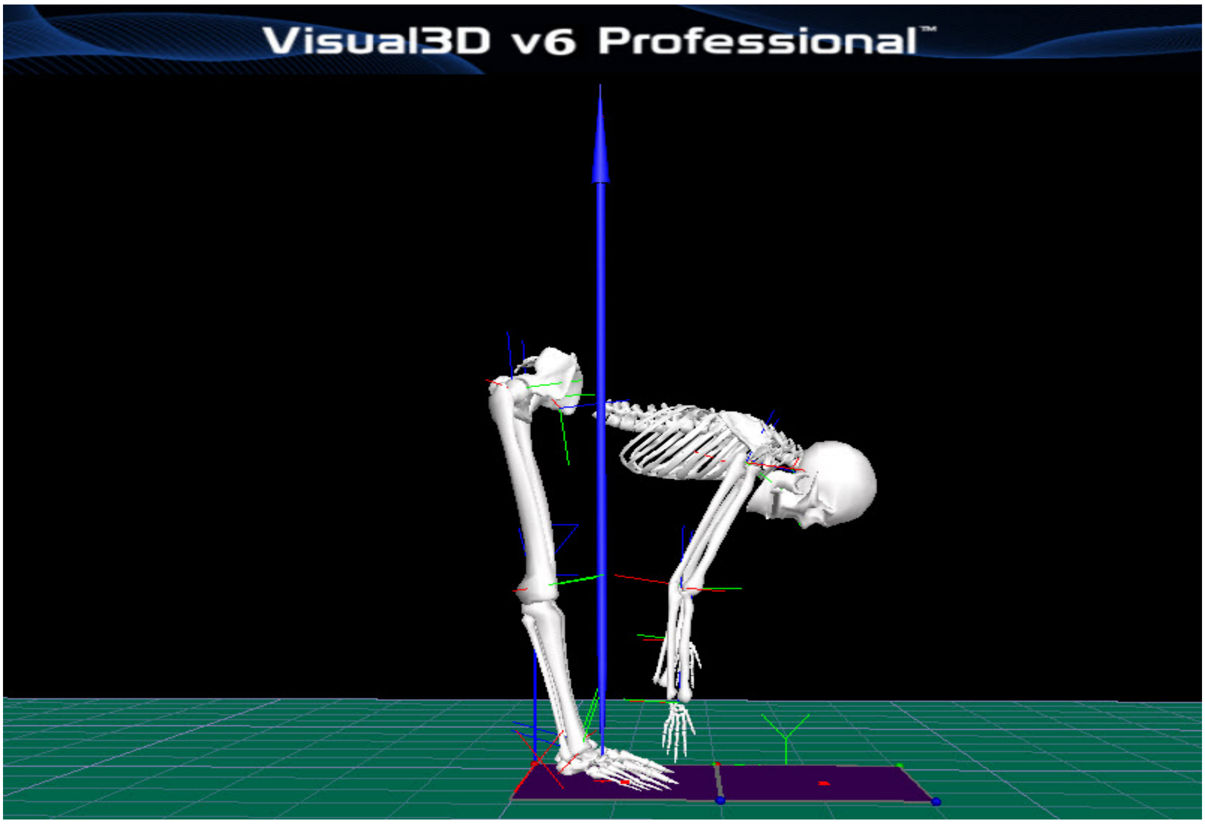

Figure 54 Leaning forward

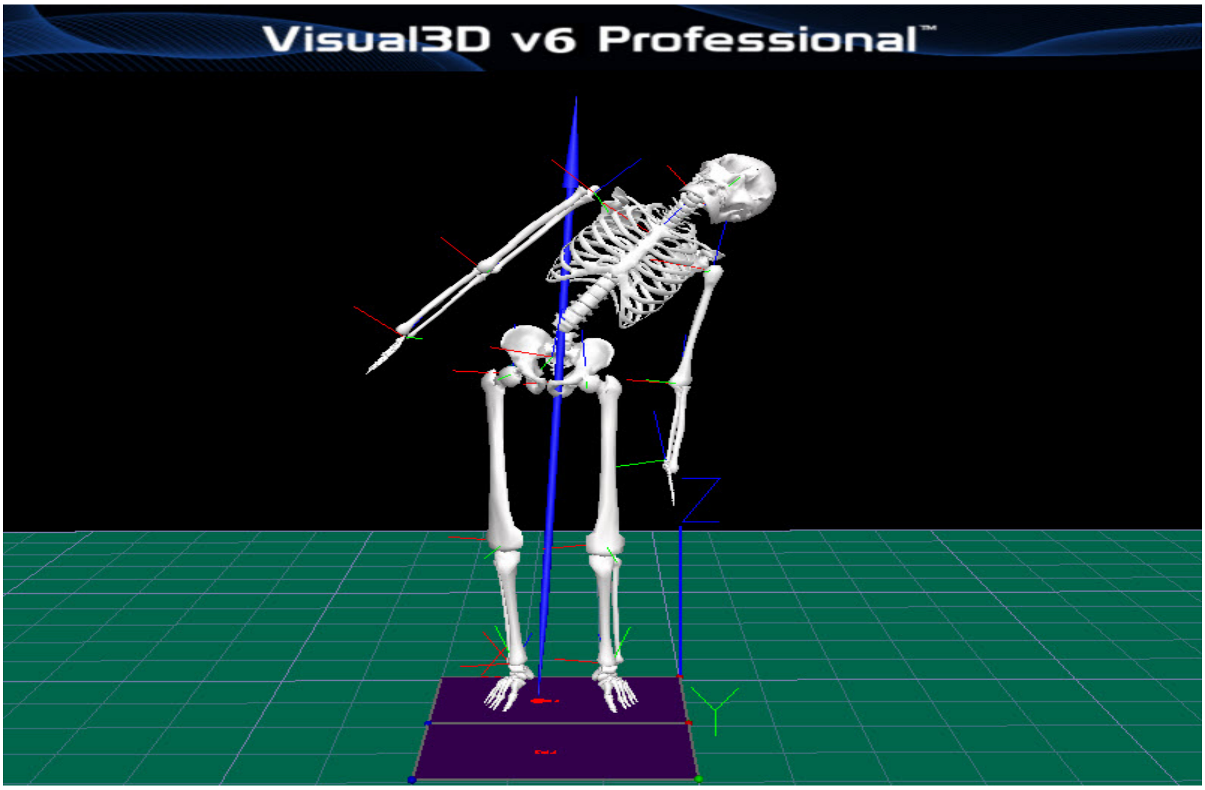

Figure 55 Leaning left side

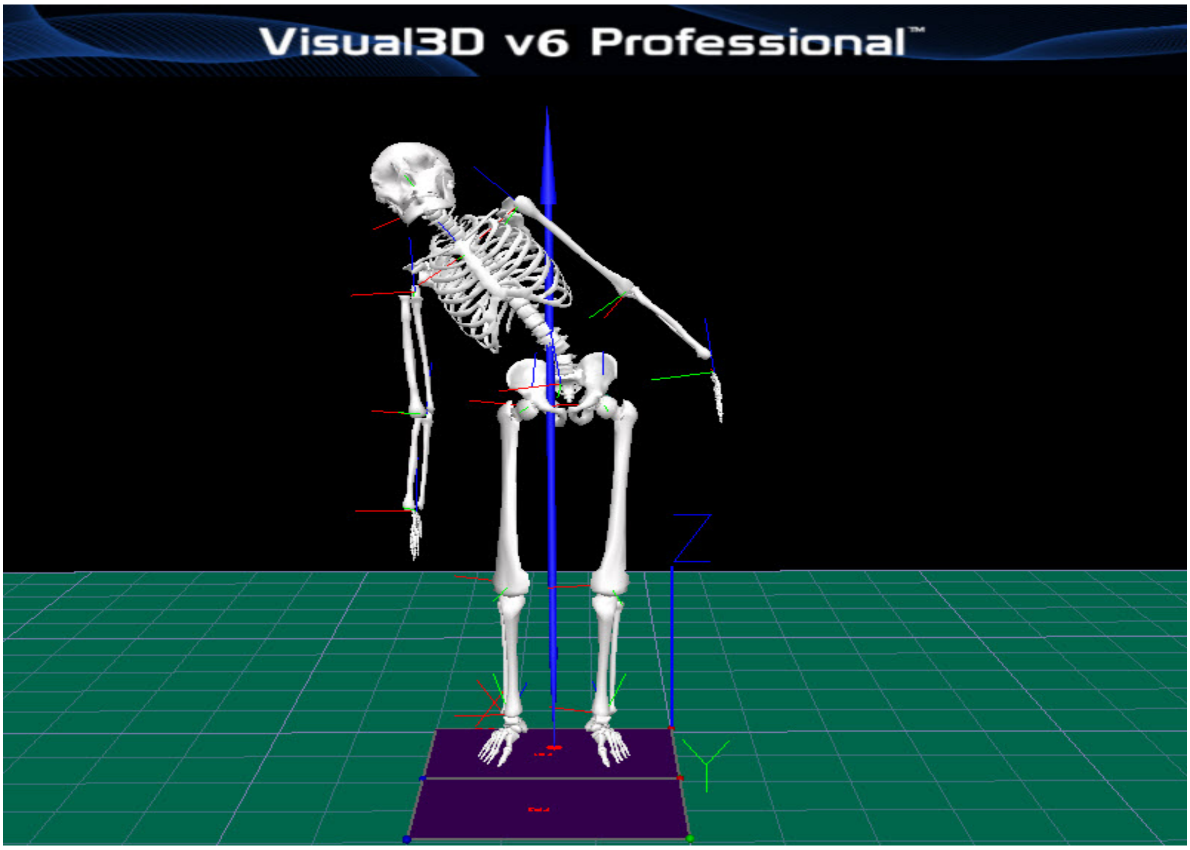

Figure 56 Leaning right side

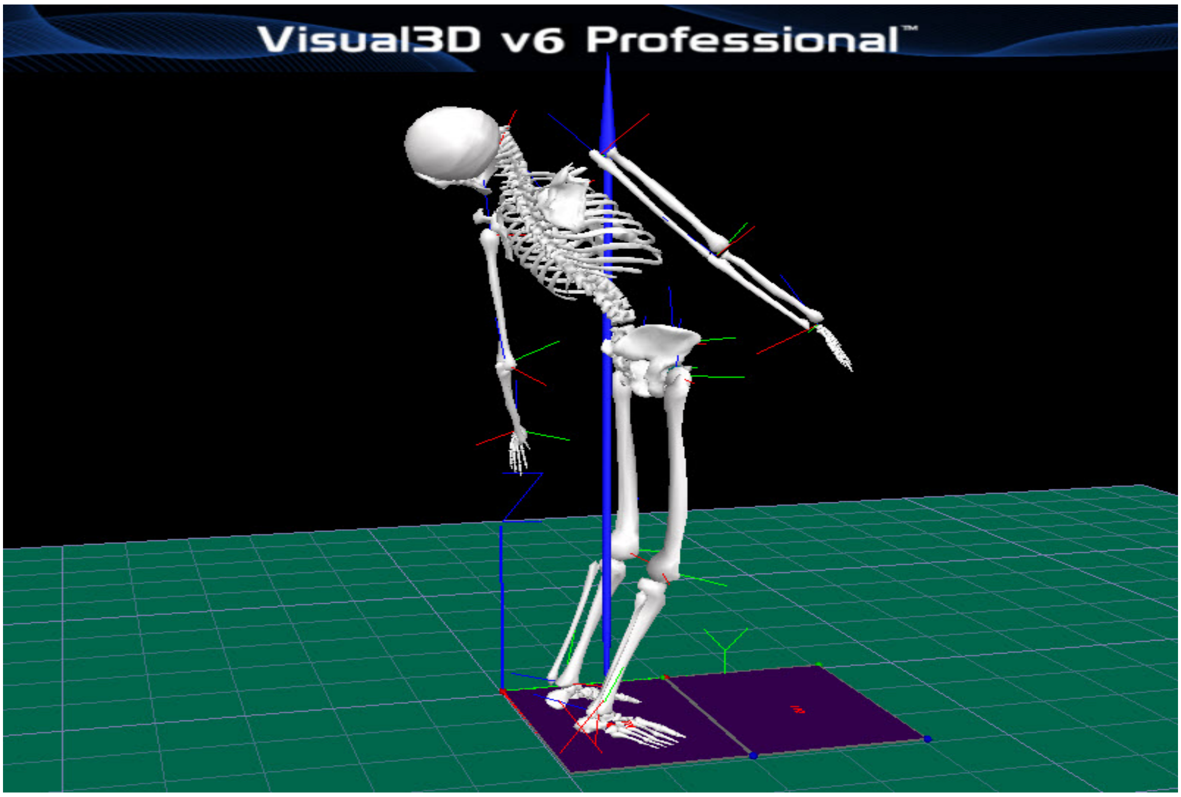

Figure 57 Leaning back and left side

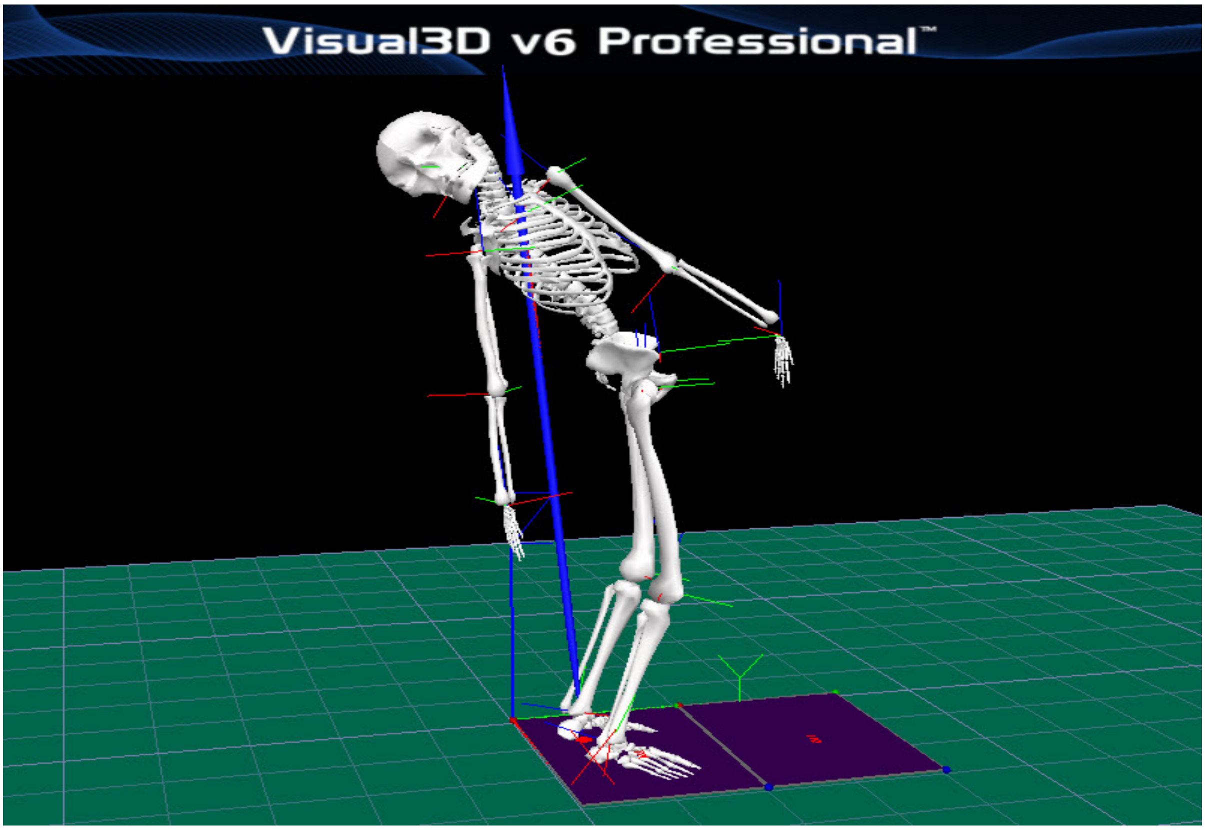

Figure 58 Leaning back and right side

5.2 Trunk angles during range of motion tests

Table 25 shows trunk angle ranges for a series of range of motion tests based around leaning and stretching in the various directions as measured at the trunk joint, which connected the pelvis and torso motion trunk joint max angles. The leaning backward angle Figure 59 is in the range of trunk motion angles expected for this level of player but the leaning forward angle Figure 59 was slightly lower than expected a high-level young adult martial arts player, (Kumar, Narayan, & Zedka, 1998). Possibly directly because of the injury the subject had in his lower. Leaning to left side Figure 59 was 28° (abduction-Adduction) and leaning to right side Figure 59 was larger, 31° and when bending to the left there was also more back extension. It is generally easier to bend side with some forward flexion so the larger right-side value for side flexion could be due to not being so straight, upright, during this task.

Leaning to back right and leaning to back left Figure 60 was very similar on flexion-extension but there was a difference in abduction-adduction, back right 11° and back left were much larger at 18° Table 25. The rotation to back and right was more abrupt and the reduced side flexion is notable. Indicating limited ability for combined side flexion and rotation. Leaning to right back with right or left knee up Figure 61 flexion – extension for both sides was very similar Also Internal – external rotation they were the same angle. Abduction – adduction was different with the right knee up at 15° compared with left knee up at just 8° Table 25.

Leaning left back with right or left knee up Figure 61 in flexion-extension was very similar and internal-external rotation was also quite similar for both sides 22° and 26°. Abduction – Adduction was very different with right knee up, 11°, compared to left knee up, almost three times larger at 30° Table 25. The subject can do leaning with knee lift in the same direction as leaning with angles 2 to 3 times larger than when lifting the reverse knee. If this restriction is present during kicking the player will not be able to do some kicks probably which require these combined motions. One thing to note is that with the left leg lifted and twisting to the right the peak rotation and the peak flexion do not coincide, which they do in the 3 other variations, instead side flexion is near zero. There is a lot of asymmetry in the left to right side during this combined motion than the more isolated task Figure 61 and that combined side flexion and rotation to the right is even more limited than the previous test would indicate.

Table 25 Range of motion tests – Trunk joint max angles (degrees)

No.	Motions	Trunk angles (degrees)		
		X	**Y**	**Z**
1	Leaning Backward	30	-	-
2	Leaning Forward	29	-	-
3	Leaning to Left	-	28	-
4	Leaning to Right	-	31	-
5	Leaning to Back right	28	11	21
6	Leaning to Back left	29	18	19
7	Leaning to Right back – Right knee up	16	15	29
8	Leaning to Right back – left knee up	18	8	29
9	Leaning to Left back – Right knee up	19	11	22
10	Leaning to Left back – left knee up	18	30	26

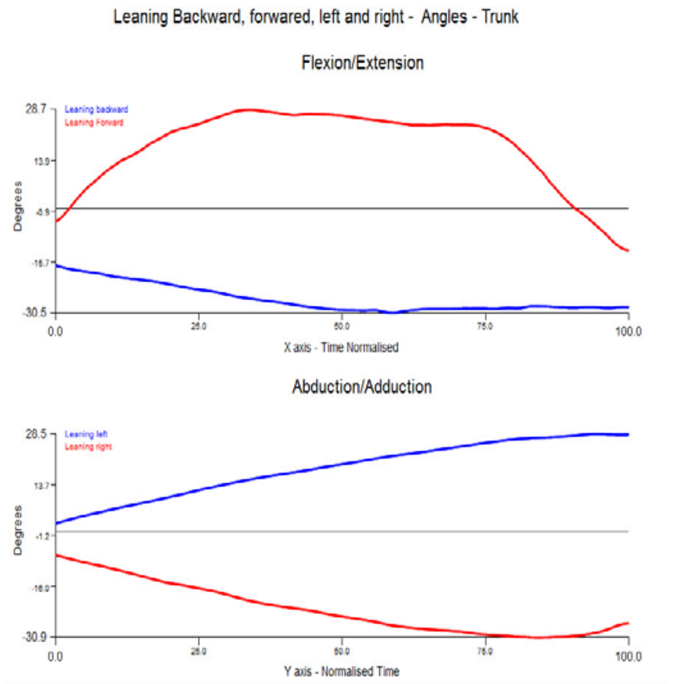

Figure 59 Leaning backwards, forward, left and right angles

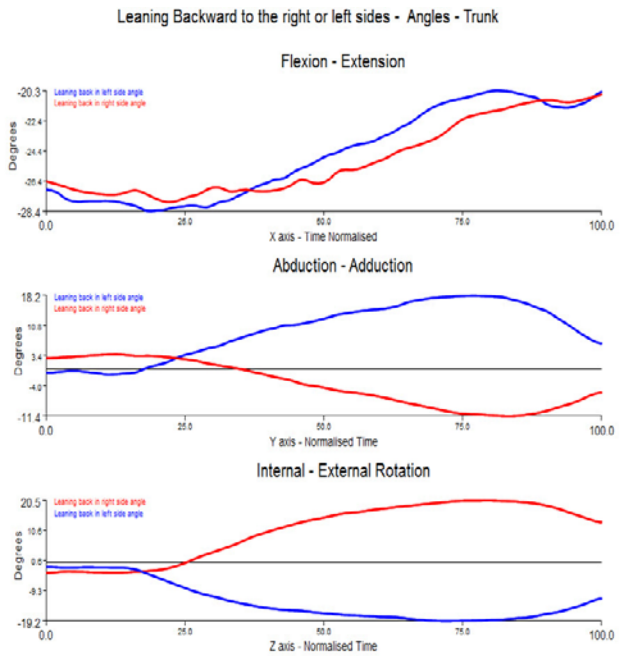

Figure 60 Leaning backwards in angle to left right or left sides’ trunk angles

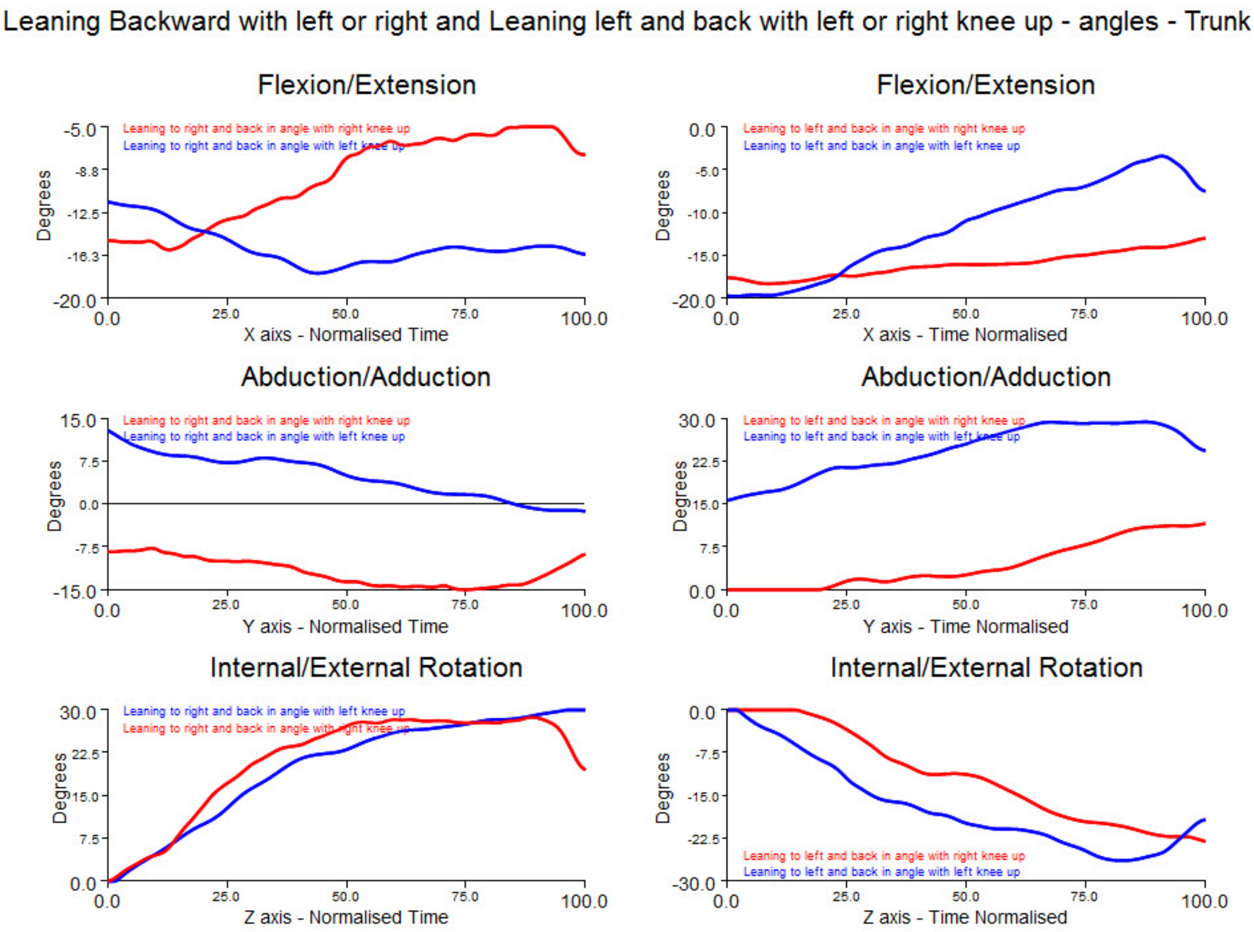

Figure 61 Leaning to right back and left back with right or left knee up

5.3 Summary of trunk, hip and knee angles and moments for six kicks

The subject did six different kicks (three each side), right back kick, left back kick, right roundhouse kick, left roundhouse kick, right swap roundhouse kick and left swap roundhouse kick. Angles, Figure 62 back kick skeleton, and moments, Table 27 of three kicks both sides joints; trunk, kicking hip, support hip, kicking knee and support knee are presented and described.

5.4 Back kick joint angles and moments (Normalised)

Taekwondo back kick is strong kick used in competition to reach the target with power and the aim is to have a large effect through a forceful impact that can not only score but wind or slow the opponent down briefly Figure 62.

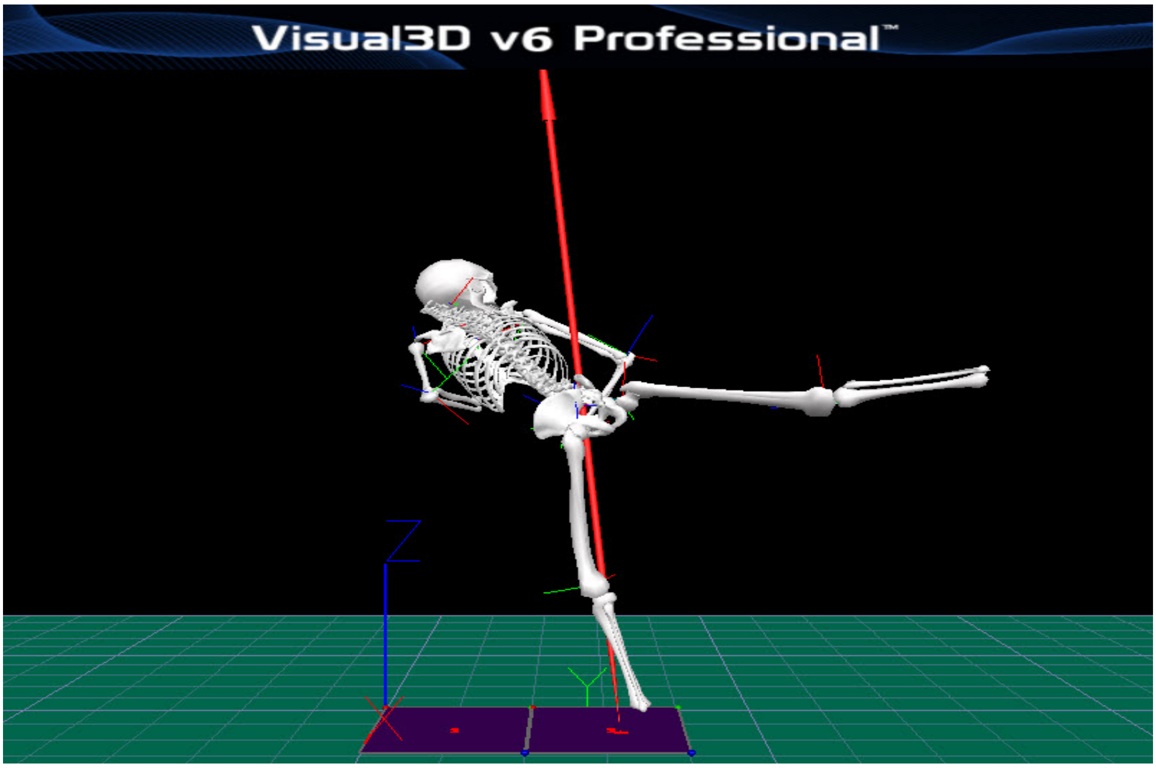

Figure 62 Back kick skeleton

Table 26 Back kick – right and left maximum joint angles

No.	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	**Right Back**	20	25	29	55	34	36	70	31	23	160	15	18	65	4	14
	Left Back	9	25	30	88	32	26	76	20	28	167	11	21	65	6	17

Table 27 Back kick – right and left maximum joint moments, normalised (N.m/kg)

No.	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	**Right Back**	1.2	1.2	1.4	1.7	1.4	0.4	0.8	0.3	0.5	0.5	0.2	0.3	0.1	0.1	0.1
	Left Back	2.2	1.7	1.7	1.9	1.0	1.4	0.8	0.4	1.2	0.5	0.3	0.2	0.2	0.2	0.1

5.4.1 Trunk angles

Right back kick flexion-extension angle was 20° which was more than double that of the left back kick, 9°. Abduction – adduction angles were the(Frank et al., 2013b) same for both sides at 25°. Also, internal-external rotation angles were very similar on both sides 29° and 30° Figure 63.

5.4.2 Trunk peak moments

Peak moments for left side flexion - extension had a very high value at, 2.2 N.m/kg, (Ficanha, Rastgaar, & Kaufman, 2015) which was almost double of right side which is also considered as the high value at 1.2 N.m/kg. Abduction – adduction moment for both sides also had large values but the left side was, 1.7 N.m/kg, much higher at than right side, 1.2 N.m/kg. Also, the internal-external rotation for the right and left sides were had large values, left side was 1.7 N.m/kg, slightly higher than the right side, 1.4 N.m/kg Figure 63.

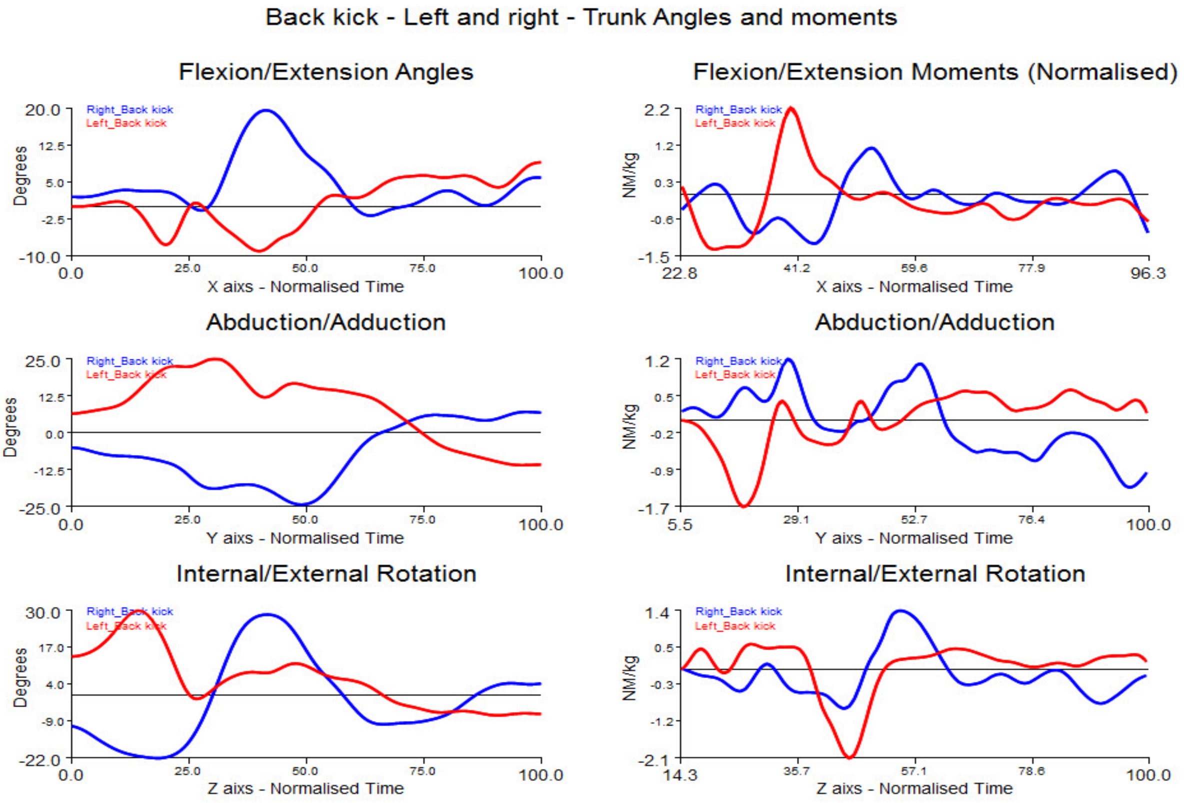

Figure 63 Back kick of left and right sides trunk angle and moments

5.4.3 Kicking hip angles

Left-back kick, flexion-extension angle was large, 88°, compared to right back kick at 55°. Abduction – adduction angle for both sides were very similar, right 34° and left 32°.

Internal-external rotation angle on the right side was larger, 36°, than the left side, 26°, Figure 64.

5.4.4 Kicking hip peak moments

Left side flexion-extension was 1.9 N.m/kg which was slightly larger than the right side, 1.7 N.m/kg. Abduction – adduction of the left side was 1.0 N.m/kg, which was a lower value than right side peak moment, 1.4 N.m/kg. Left side internal-external rotation moment was 1.4 N.m/kg, which was much larger than right side at just 0.4 N.m/kg, Figure 64.

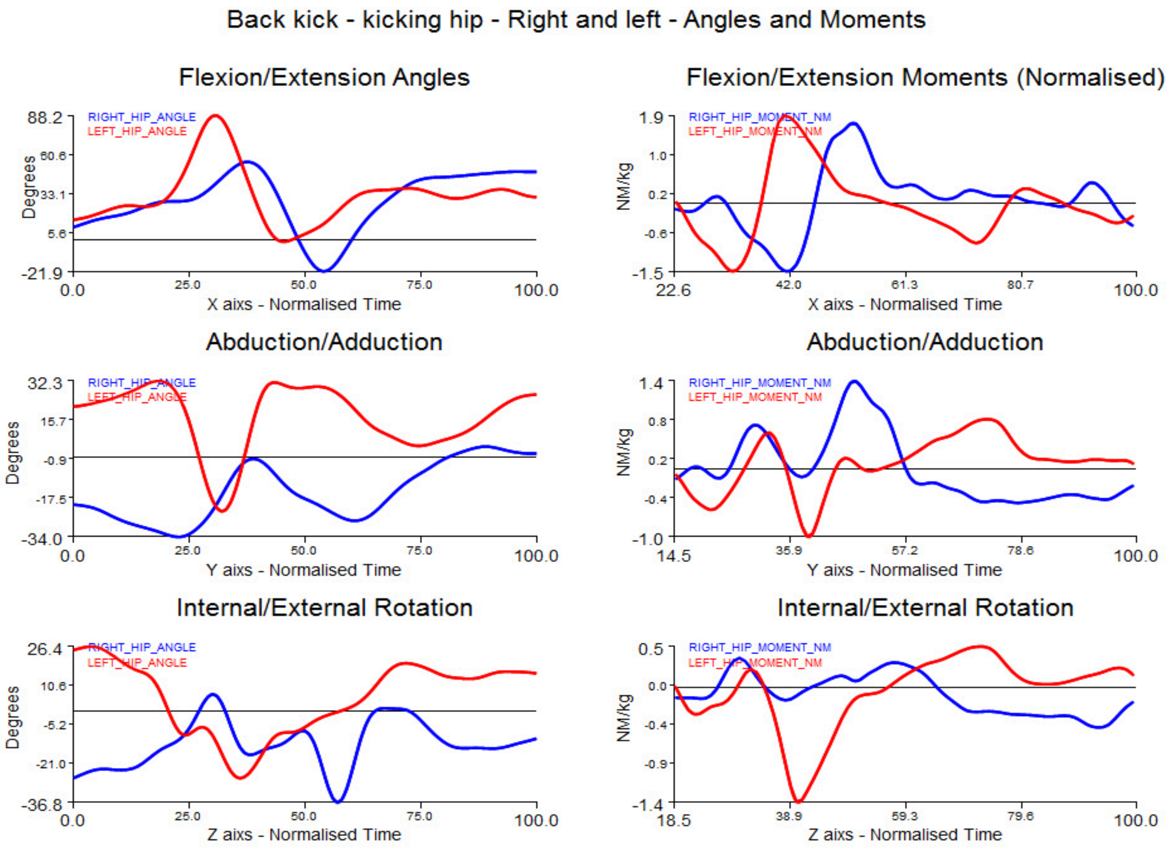

Figure 64 Back kick - kicking hip of right and left sides' angles and moments

5.4.5 Support hip angles

Right back kick was slightly smaller at 70° than left back kick at 76°. Abduction – adduction angles for the left back was 20° lower than right back at 31°, which means that the player's right back kick is going to the right side with a large angle, and this makes the kick take a longer route to the target so being a worse kick. Internal-external rotation angle was slightly different with the left back, 28°, slightly larger than right back, 23° Figure 65.

5.4.6 Support hip peak moments

For both sides flexion-extension was the same, 0.8 N.m/kg. Also, abduction-adduction moments of both sides were very similar at, 0.4 N.m/kg left side and 0.3 N.m/kg right side. However, left side moment for internal-external rotation was much higher, 1.2 N.m/kg than right side at just 0.5 N.m/kg Figure 65.

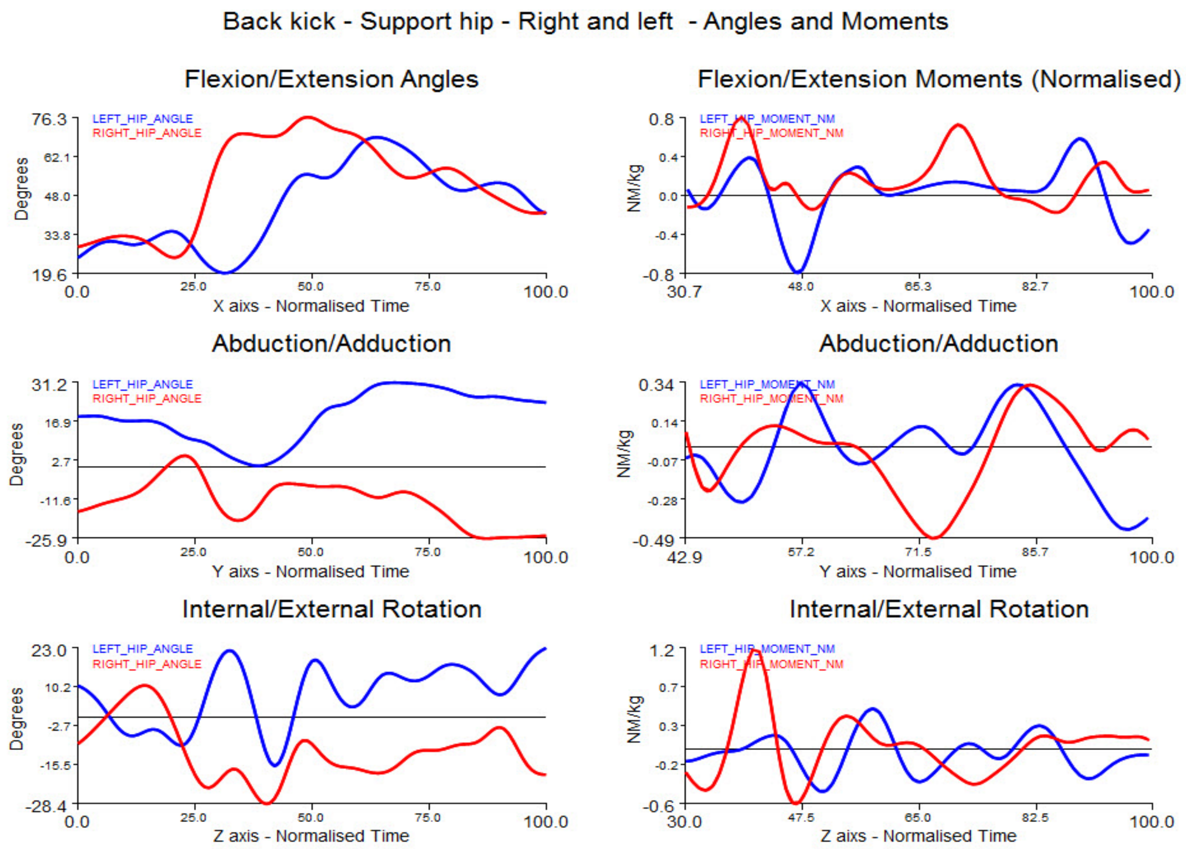

Figure 65 Back kick - support hip of right and left sides' angles and moments

5.4.7 Kicking knee angles

Left-back kick flexion-extension angle was 167°, larger than right back kick at 160°, with a larger angle being better as it gives more distance on the kick. Abduction – adduction angles for left back kick was 11° lower than right back kick at 15°, with less of an angle being better to reduce time. Internal-external rotation angle for both sides was the same 65°. Abduction – adduction angles for both sides were very small and similar right 4° and left 6° Figure 66.

5.4.8 Kicking knee peak moments

Peak moment of the kicking knee for both right and left sides was very similar in all directions, flexion – extension: right and left sides,0.5 N.m/kg, abduction adduction: right side 0.2 N.m/kg, left side 0.3 N.m/kg, internal – external rotation: right 0.3 N.m/kg, left 0.2 N.m/kg, Figure 66.

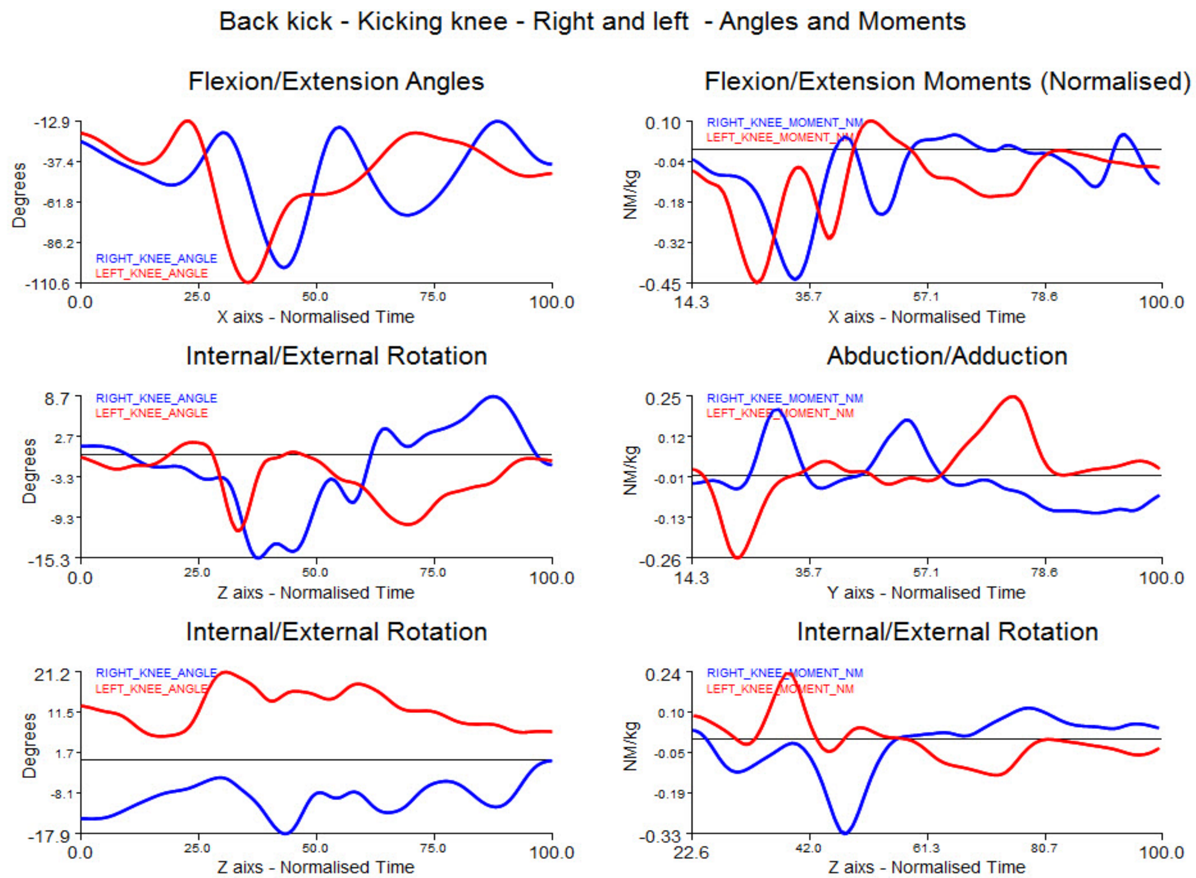

Figure 66 Back kick - kicking knee of right and left sides` angles and moments

5.4.9 Support knee angles

Flexion-extension angles between right and left sides were very similar at 176° for the right side and 178° for the left side. There were very small angles for abduction-adduction angles on either side at just 7° right side and 4° left at side. There were similar angles on internal-external rotation for right and left sides at 15° right side and 17° left side Figure 67.

5.4.10 Support knee peak moments

Peak moment for the right side in all directions (flexion-extension, abduction-adduction and internal-external rotation) were very small values at just, 0.1 N.m/kg, left side moment and right side just, 0.2 N.m/kg and the same small value on internal-external rotation at just, 0.1 N.m/kg Figure 67.

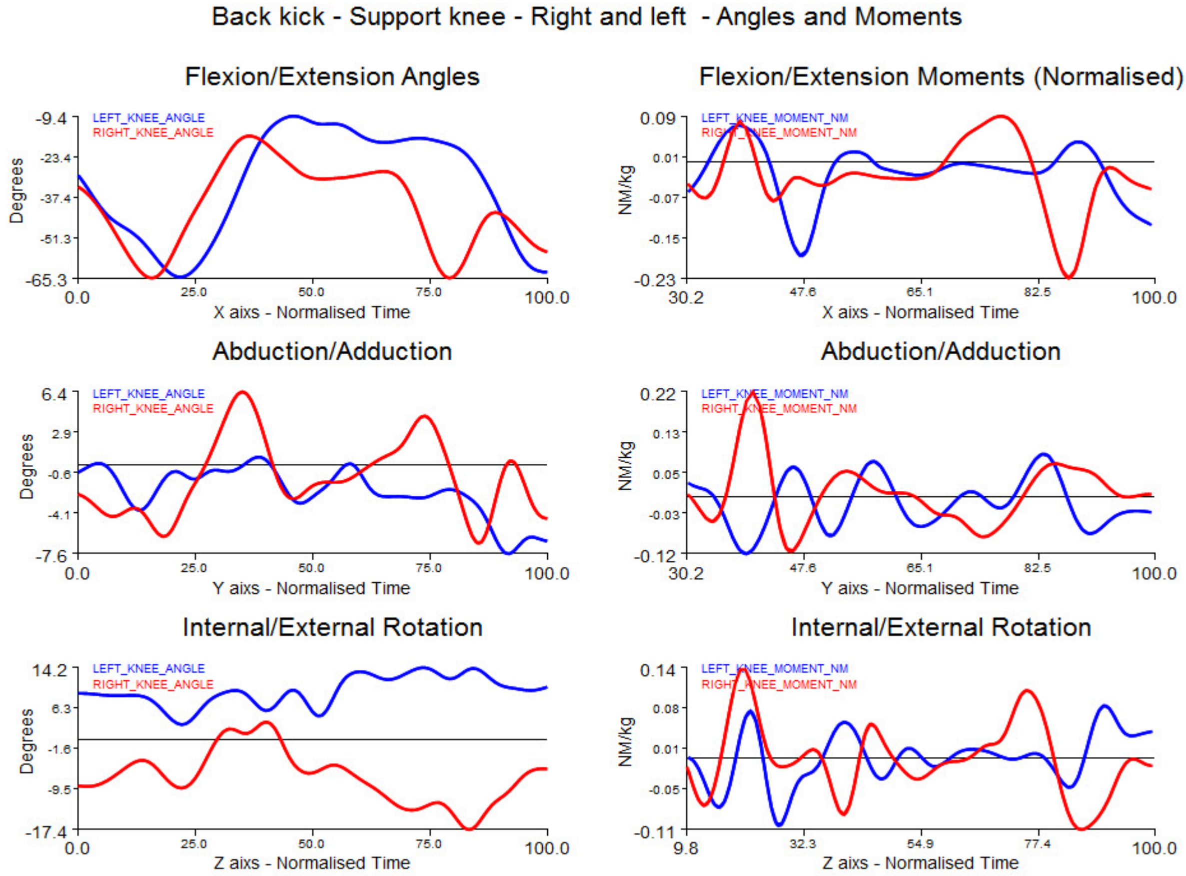

Figure 67 Back kick - support knee of right and left sides` angles and moments

By looking at back kick angles for all joints it can be find out which kick is better. Trunk angles, left back kick has a lower angle in flexion-extension and the same or very similar in the other axes that make it a better technique. Kicking hip and kicking knee angles, left side flexion-extension angle was larger than on the right side, which gives more distance. The support hip and support knee for left side abduction-adduction angles were lower, which is considered better to reduce time to the target. Smaller or similar internal-external rotation angles for both kicking hip and support hip also give some advantage to the left side. The larger kicking knee flexion-extension angle for left side give more advantage by gives more distance to reach the target. Finally, kicking knee and support knee with smaller or similar angles with more range in internal – external rotation angles give more advantage for left back kicks technique, that means the player turn in very vast motion with a small load on knee joint which it saves time and distance to reach his target.

In addition, the player focused on his lower back joint and his kicking leg to swing his leg to generate power and speed to reach the target with a very fast kick in a short time to make distance he used his joint flexibility, the other option is players using a shift to extend the kick which should be less stressful on the lower back but may take longer and bring the attacker closer for a counter attack.

Overall for the back-kick joints moments for the trunk were similar values to the kicking hip but high values compared to the supporting hip, kicking knee and support knee joints. Kicking hip was higher than the supporting hip which has not always been the case for most kicks tested in karate players. Kicking knee and support knee have small values comparing with other joints. That led to the strategy of the Taekwondo player in this case, generating the power, speed and range for the kick from the trunk and kicking hip with less power in support hip and kicking knee. The values during this kick are high and this kick performed the way it is could be a contributing factor to his lower back injury as putting more loading on lower back joint in very short time in so fast kick will increase the risk of injury Table 27 and Table 27.

5.5 Roundhouse kick, joint angles and peak moments (Normalised)

The roundhouse kick is a fast kick used a lot in competition due to it is easy to apply and players can develop a fast kick within a short training time Figure 68 compared with other kicks, such as back kick previously described. Angles Table 28 and moments Table 29 of the trunk, kicking hip, support hip, kicking knee and support knee joints have been measured and calculated.

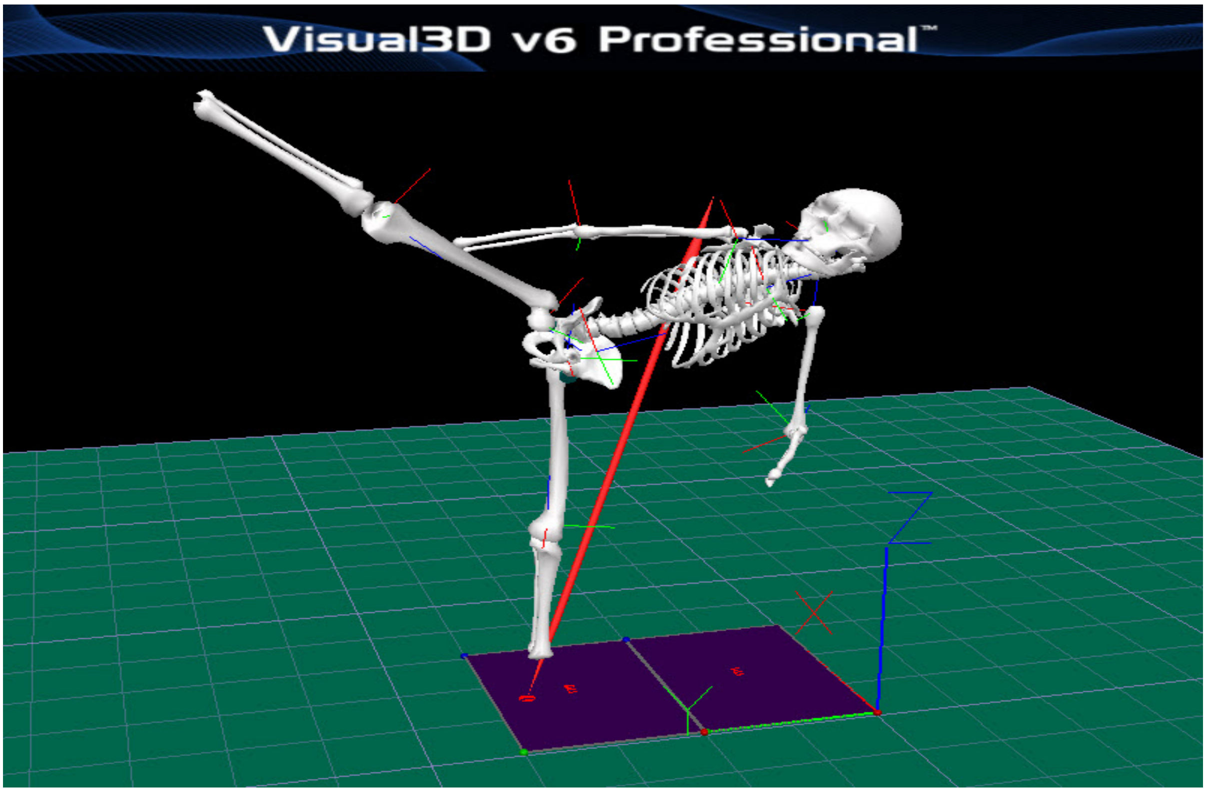

Figure 68 Roundhouse kick skeleton

Table 28 Roundhouse kick – right and left maximum joint angles

	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
2	**Right Roundhouse**	7	20	20	66	56	23	39	71	49	179	8	19	176	7	15
	Left Roundhouse	20	15	17	55	81	25	57	48	72	177	10	20	178	4	17

Table 29 Roundhouse kick – right and left maximum joint moments, normalised (N.m/kg)

No.	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
2	**Right Roundhouse**	0.9	1.5	0.7	0.5	1.2	0.9	0.2	0.6	0.4	0.6	0.3	0.1	0.1	0.1	0.1
	Left Roundhouse	1.6	1.9	1.0	1.5	1.0	0.5	0.7	0.8	0.2	0.2	0.3	0.1	0.1	0.1	0.1

5.5.1 Trunk angles

Right roundhouse kick flexion-extension was very small at just 7° but the left side was larger at 20°. Right side abduction – extension has a slightly larger angle at 20° than the left side angle, 15°. Internal-external rotation angle quite similar, 20° right and 17° left Figure 69.

5.5.2 Trunk peak moments

Left roundhouse kick trunk flexion-extension peak moment value was 1.9 N.m/kg and was double of the right roundhouse kick, 0.9 N.m/kg. Also left side abduction-adduction moment value was 1.9 N.m/kg which was higher than the right-side moment value of 1.5 N.m/kg. Internal-external moment of left side was 1.0 N.m/kg slightly larger than right side moment of 0.7 N.m/kg. All three axes (X, Y and Z) moment values of left roundhouse kick were higher than that of the right roundhouse kick moments values. High moments may not be indicative of injury risk but the large difference between the left and right sides indicates either one side is severely hampered by the existing injury or that one side is being loaded much more and is at greater risk of injury (or limiting recovery) Figure 69.

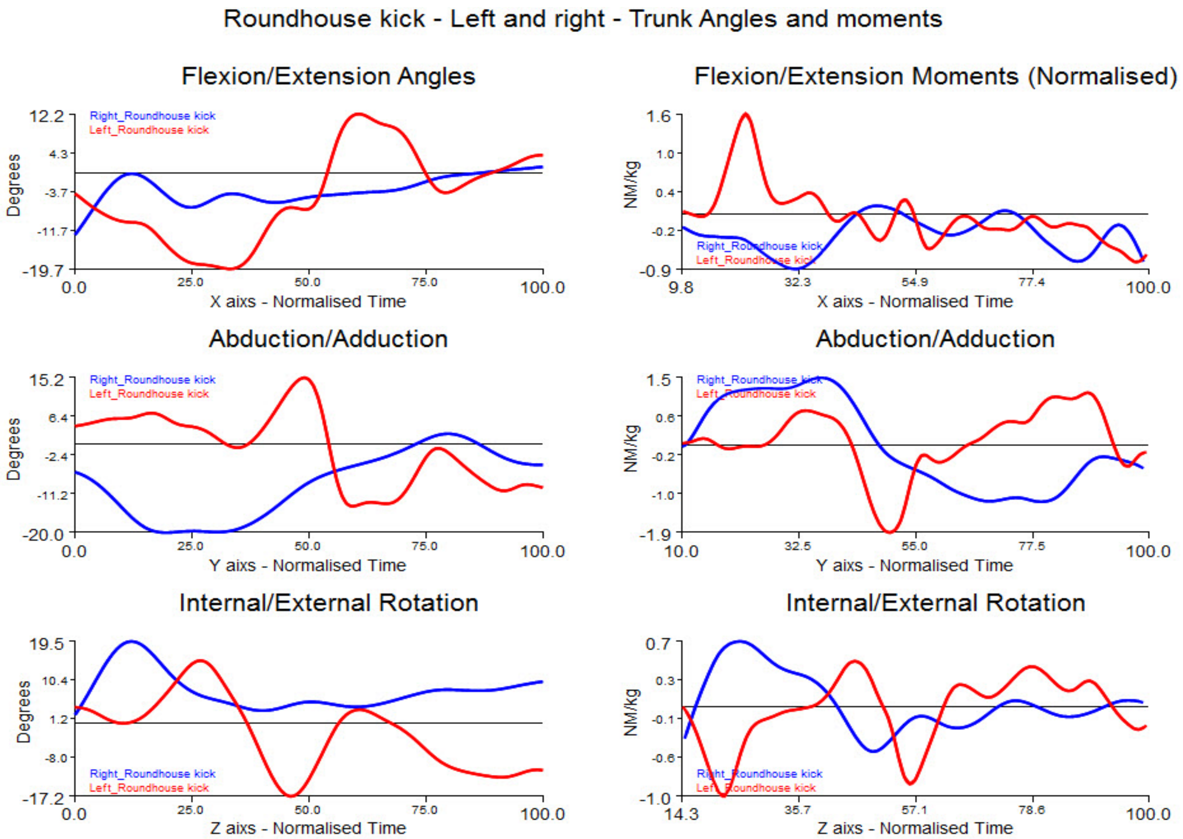

Figure 69 Roundhouse kick - left and right sides` trunk angles and moments

5.5.3 Kicking hip angles

Right side flexion-extension angle was larger at 66° than the left side, 55°. Right side abduction-adduction was much lower, 56° than the left side, 81°. Internal-external rotation angles for both sides were very similar values at 23° right and 25° left Figure 70.

5.5.4 Kicking hip peak moments

Left side moment value was 1.5 N.m/kg which is three times larger than the right-side moment value of only 0.5 N.m/kg. Abduction – adduction moment value of the left side was 1.0 N.m/kg, slightly lower than the moment value on the right side at 1.2 N.m/kg. Also, internal-external rotation moment for the left side was 0.5 N.m/kg, slightly lower than right side moment at 0.9 N.m/kg. The large moment values of the left roundhouse kick on flexion-extension could put the player at greater risk of injury compared with the right roundhouse kick moments Figure 70.

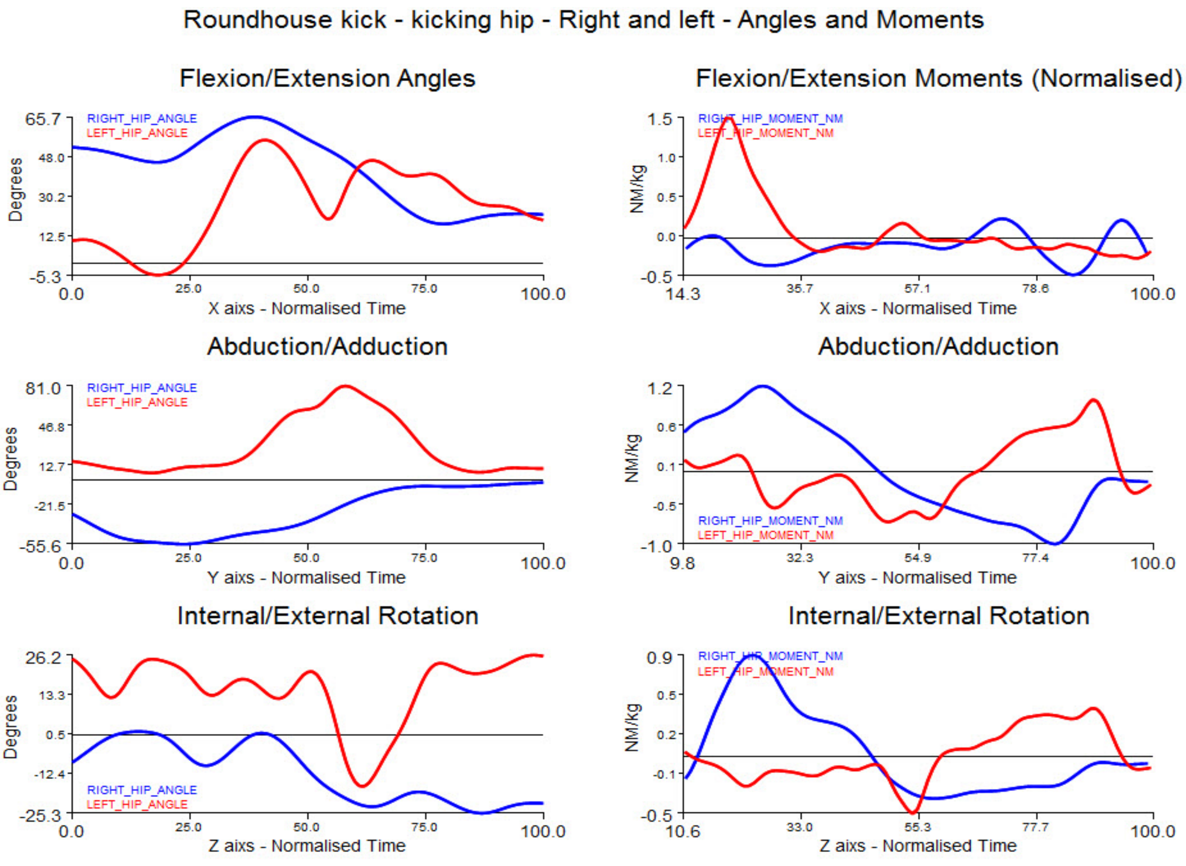

Figure 70 Roundhouse kick - kicking hip of right and left sides` angles and moments

5.5.5 Support hip angles

Flexion-extension angle for the right roundhouse kick was 39°, much smaller than left roundhouse angle at 57°. Right roundhouse abduction-adduction angle was 71° and was much larger than the left roundhouse angle at just 48°. Internal-external rotation left side angle was 72°, again much higher than the right side, 49° Figure 71.

5.5.6 Support hip peak moments

Left side flexion – extension moment value was 0.7 N.m/kg and was much higher than right side moment value of just 0.2 N.m/kg. Left side abduction-adduction moment value was 0.8 N.m/kg, slightly higher than right side moment value of 0.6 N.m/kg. For internal-external rotation moment the left side was only 0.2 N.m/kg and lower than right side at 0.4 N.m/kg Figure 71.

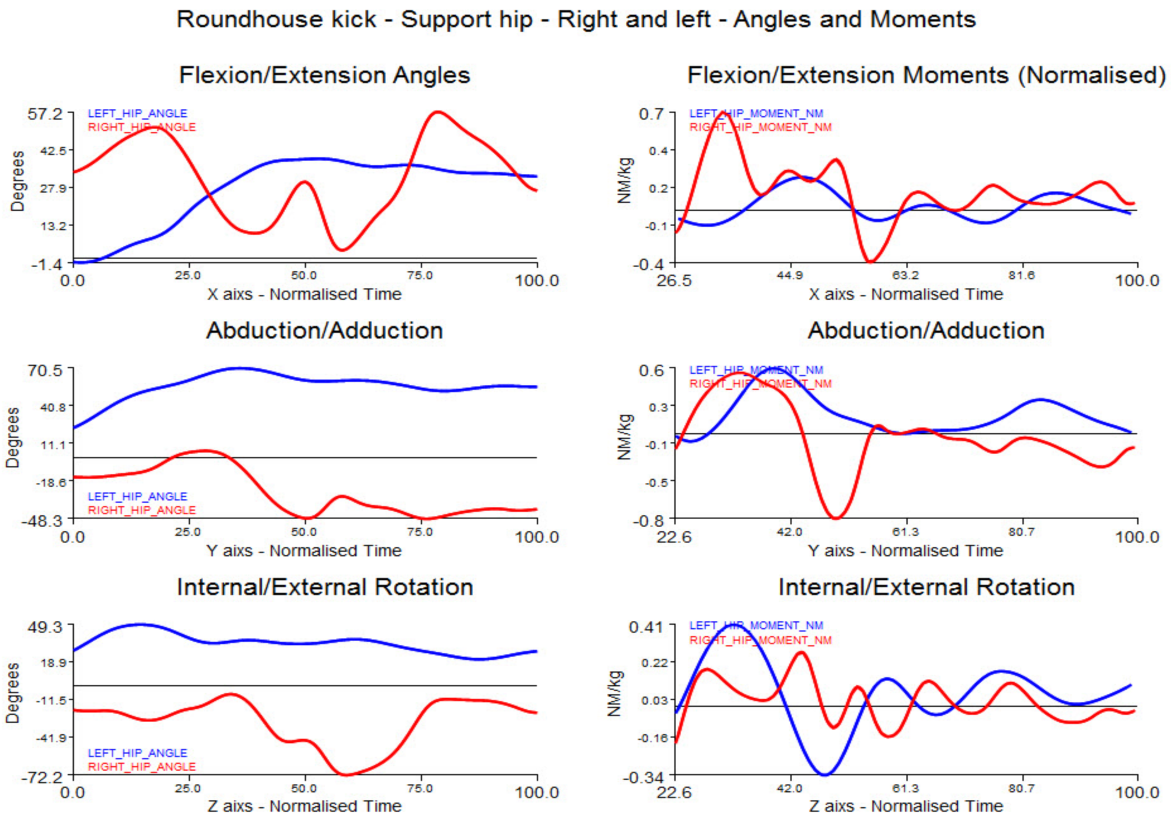

Figure 71 Roundhouse kick - support hip of right and left sides` angles and moments

5.5.7 Kicking knee angles

For both sides flexion-extension angles were very similar at 179° right side and 177° left side. Also, abduction-adduction angles for both right and left sides were very similar and small at just 8° right and 10° left. Internal-external rotation angles were almost the same at 19° right and 20° left Figure 72.

5.5.8 Kicking knee peak moments

Right side knee moment value for flexion-extension was 0.6 N.m/kg, higher than the left side moment of just 0.2 N.m/kg. Abduction – adduction and internal-external rotation moments values for both sides was the same at 0.3 N.m/kg and 0.1 N.m/kg respectively Figure 72.

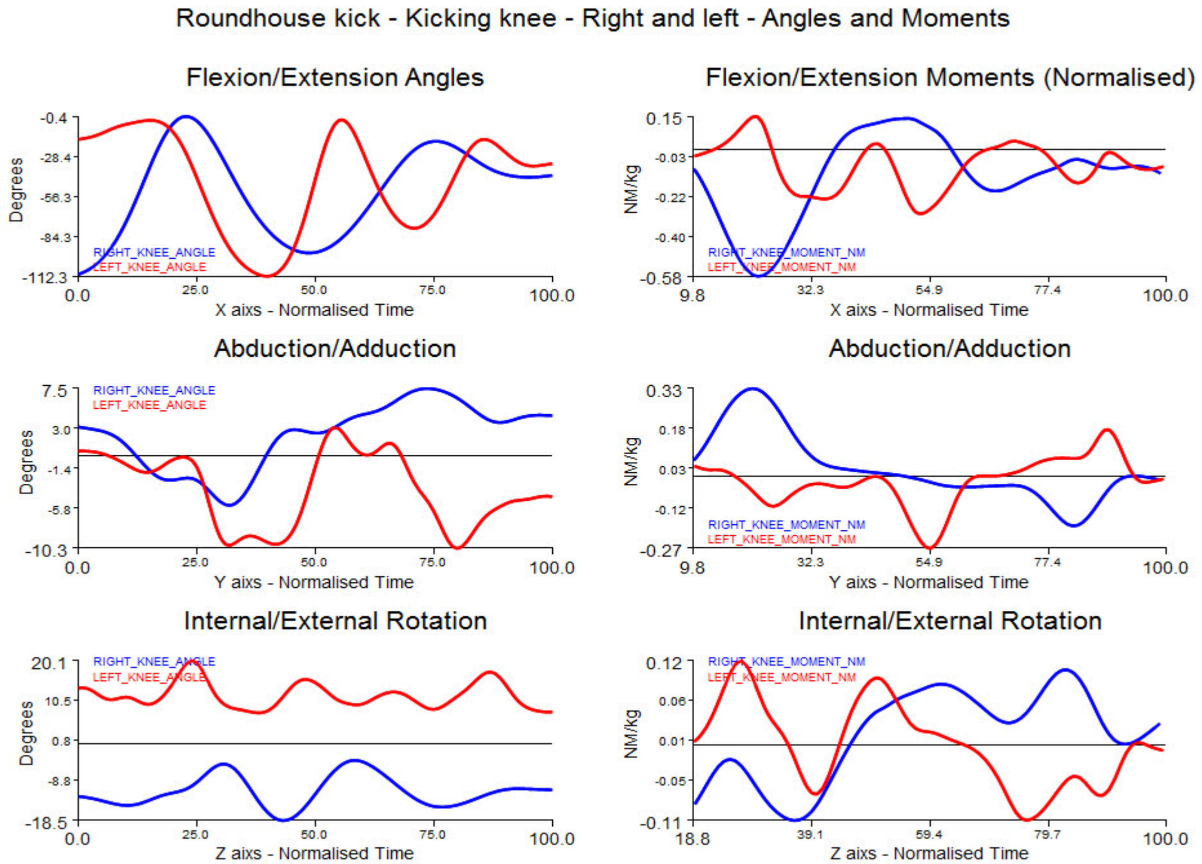

Figure 72 Roundhouse kick - kicking knee of right and left sides` angles and moments

5.5.9 Support knee angles

Flexion-extension of support knee was very similar at 176° and 178°. Very small angles of abduction-adduction for both sides 7° and 4° which is a very good sign of the good technique the player performed. Internal-external rotation record very similar angles on right and left legs at 15° and 17° Figure 73.

5.5.10 Support knee peak moments

Both sides left and right on flexion-extension, abduction-adduction and internal-external rotation moments values were very small at just (0.1 N.m/kg) Figure 73.

Overall, right roundhouse kick trunk joint on flexion-extension axis has small angle at just 7° comparing with left roundhouse kick trunk joint same axis at almost 3 times at 20° that lead to think that left kick better than right kick in accordance with the range of motion in trunk joint to give the player more freedom to twist which it means more power and more speed.

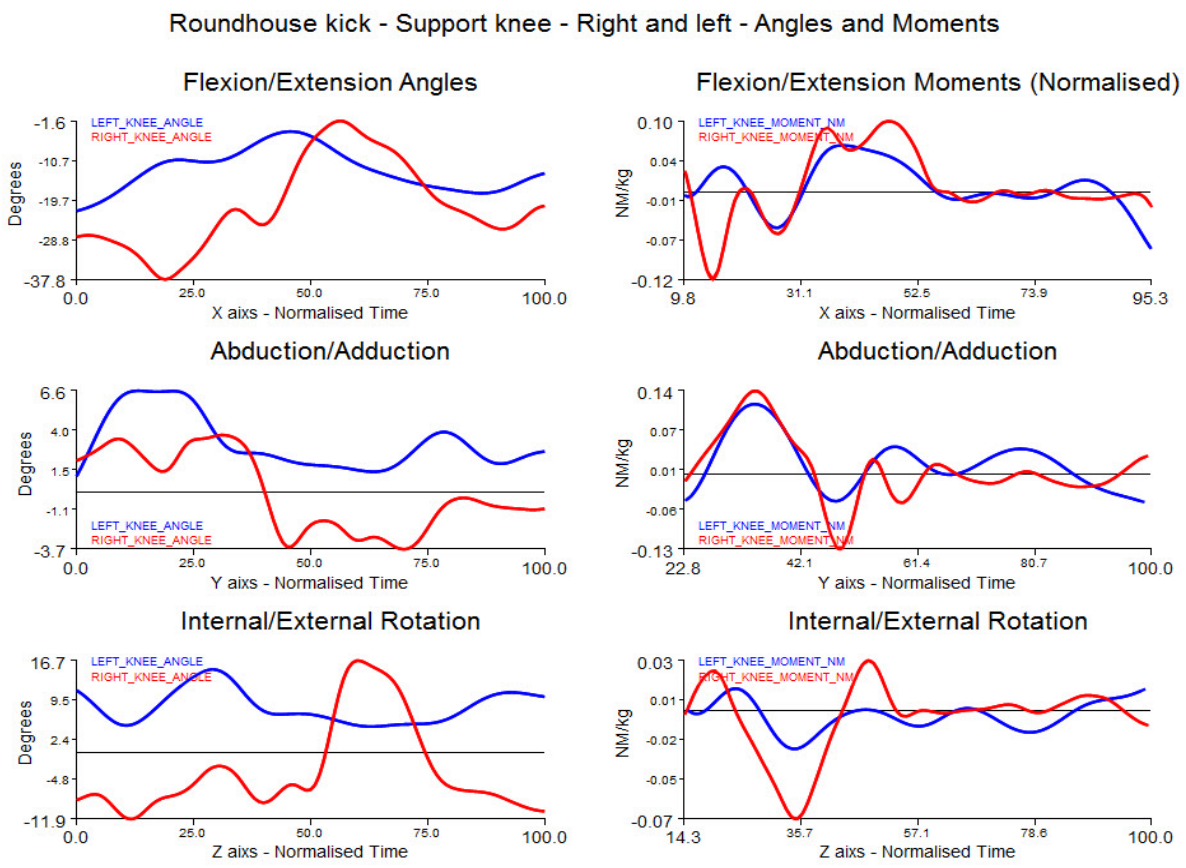

Figure 73 Roundhouse kick - support knee of right and left sides` angles and moments

5.6 Swap Roundhouse kick joint angles

Swap or switch roundhouse kick is one of the most used kicks by Taekwondo players due to it being very fast and the switch not only gives it more speed it changes the direction of attack between kicks. Sometimes players do more than one in the competition at the same time on both legs, in that case just the front of the foot touches the ground, Figure 74. Angles and moments of five joints; trunk, kicking hip, support hip, kicking knee and support knee have been measured, Table 30 and Table 31.

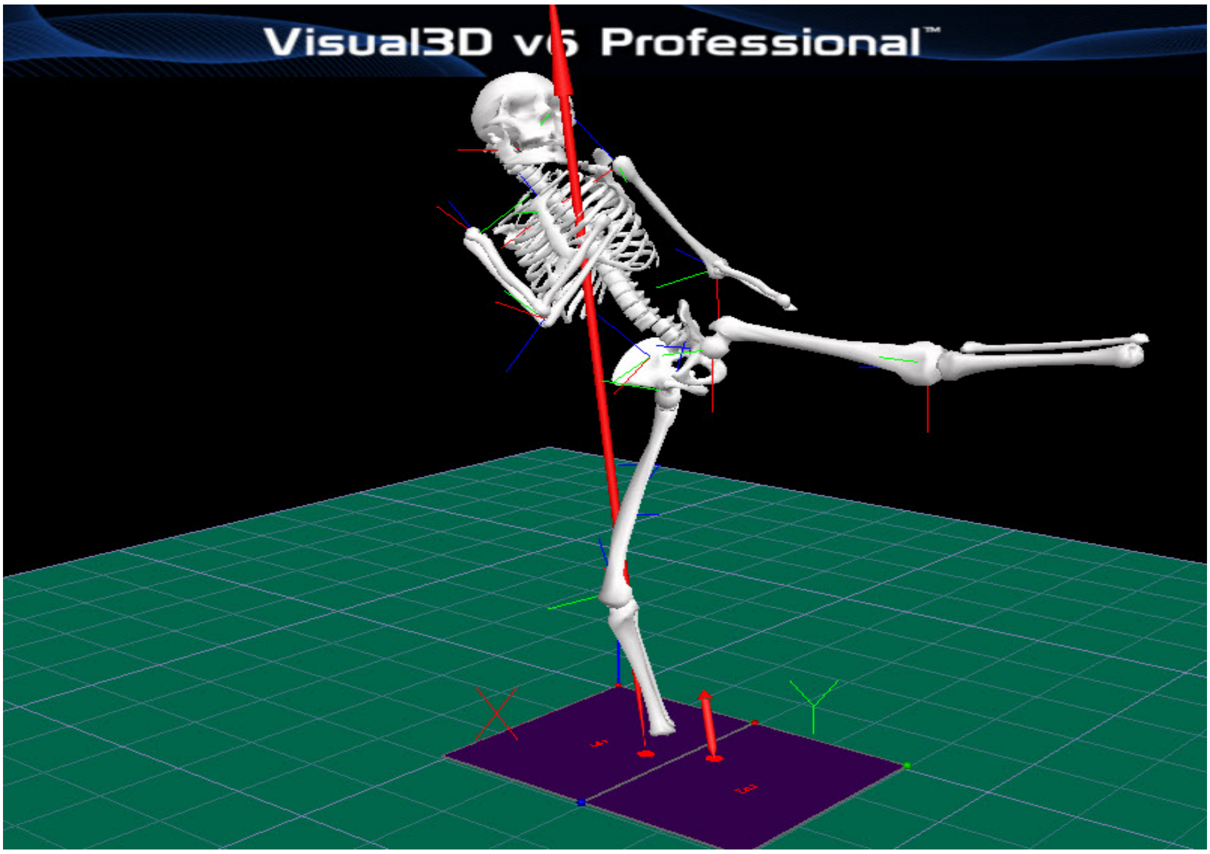

Figure 74 Swap roundhouse kick skeleton

Table 30 swap roundhouse kick – right and left maximum joint angles

	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
3	**Right Swap Roundhouse**	26	32	24	53	57	26	50	56	54	174	13	19	162	5	17
	Left Swap Roundhouse	15	13	18	46	48	31	59	51	26	176	13	17	157	9	15

Table 31 Swap roundhouse kick – right and left maximum joint moments, normalised (N.m/kg)

No.	Kicks names	Trunk			Kicking hip			Support hip			Kicking knee			Support knee		
		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
3	**Right Swap Roundhouse**	2.4	1.8	1.3	1.7	1.6	0.6	0.9	1.0	0.8	0.6	0.5	0.2	0.2	0.2	0.2
	Left Swap	0.9	1.4	1.2	1.2	1.7	0.4	0.6	1.1	0.9	0.5	0.4	0.2	0.2	0.2	0.1

5.6.1 Trunk angles

Right swap roundhouse kick angle, flexion-extension was 26°, much larger than the left swap roundhouse kick angle of just 15°. Abduction – extension angle for the right side was 32°, also much larger than left side angle of just 13°. Right side internal-external rotation angle was 24°, higher than left side angle of 18° Figure 75.

5.6.2 Trunk peak moments

The right swap roundhouse kick trunk flexion-extension moment value was 2.4 N.m/kg and was much larger than left swap roundhouse kick moment value of 0.9 N.m/kg. Also, the moment value of abduction-adduction for right swap roundhouse kick was 1.8 N.m/kg which is slightly larger than left swap roundhouse kick moment value, 1.4 N.m/kg. Internal-external rotation moment of right swap roundhouse kick was 1.3 N.m/kg, very similar to left side moment value at 1.2 N.m/kg Figure 75.

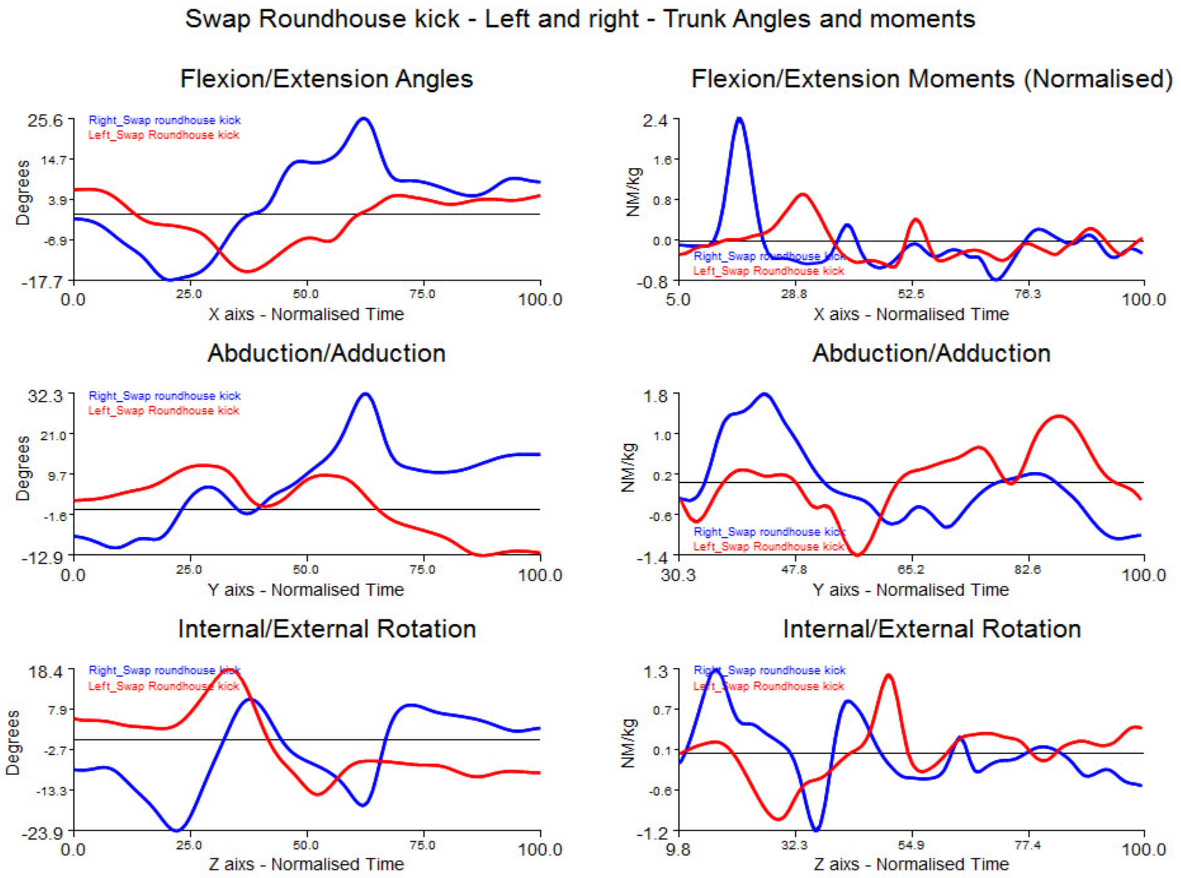

Figure 75 Swap roundhouse kick - left and right sides` of trunk angles and moments

5.6.3 Kicking hip angles

Flexion-extension angle for right side was 53°, slightly higher than left side angle of 48°. Also, right side abduction-adduction angle was 57°, higher than the left side, 48°. Internal-external rotation angle for right side was 26°, lower than the left side of 31° Figure 76.

5.6.4 Kicking hip peak moments

A flexion-extension moment on the right side was 1.7 N.m/kg, a bit higher than the left side moment value of 1.2 N.m/kg. Abduction – adduction moment value of the right side was 1.6 N.m/kg and like the left side moment value of 1.7 N.m/kg. Internal-external rotation moment value of the right side was 0.6 N.m/kg, slightly larger than left side moment value, 0.4 N.m/kg Figure 76.

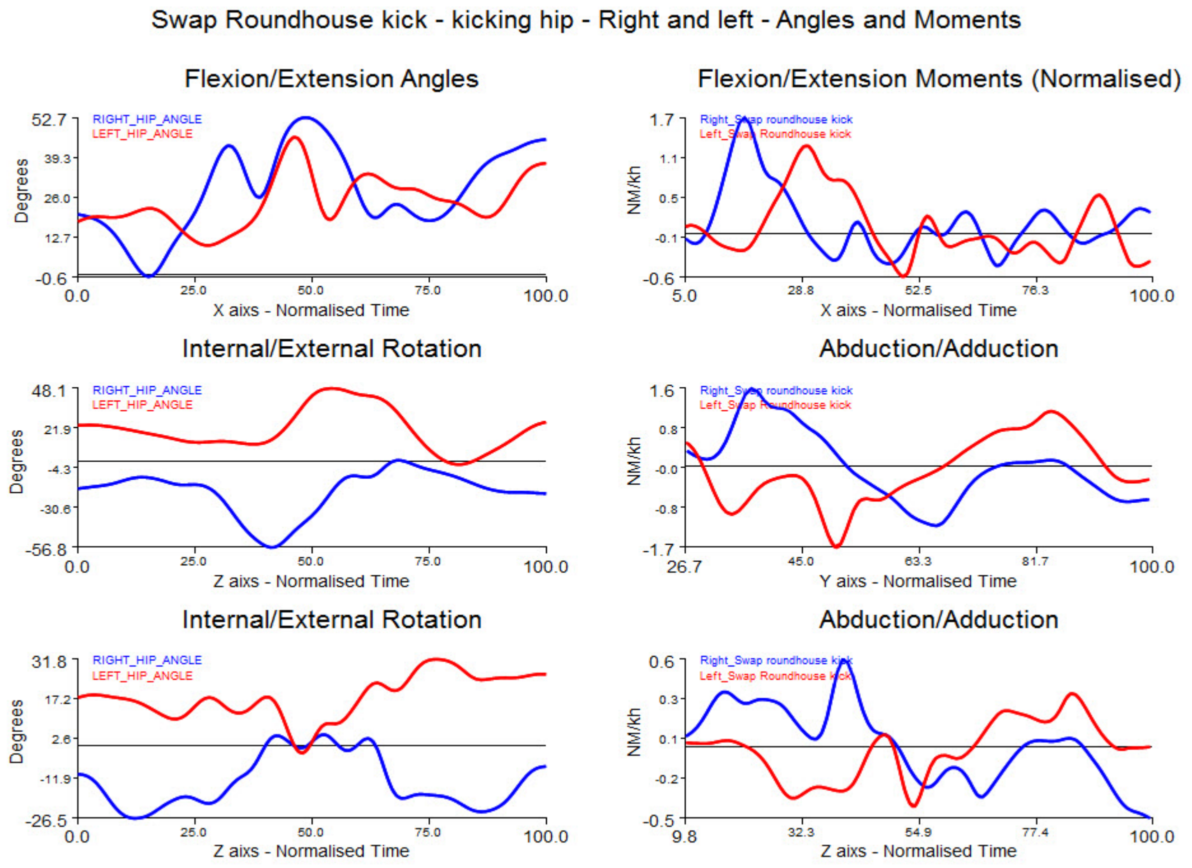

Figure 76 Swap roundhouse kick - kicking hip of right and left sides` angles and moments

5.6.5 Support hip angles

Flexion-extension right side angle was 50° smaller than a left side angle of 59°. Abduction – adduction angle of the right side was 56° slightly larger than a left side angle of 51°. Also, the internal-external rotation angle of the right side was 54° more than double of left side angle at just 26° Figure 77.

5.6.6 Support hip peak moments

Right flexion – extension moment value was 0.9 N.m/kg, slightly higher than left side moment value at ,0.6 N.m/kg. Both sides right and left were having very similar moments values of abduction-adduction at 1.0 N.m/kg for the right side and 1.1 N.m/kg for the left side. Internal-external moments values of both sides were very similar at 0.8 N.m/kg right and 0.9 N.m/kg left Figure 77.

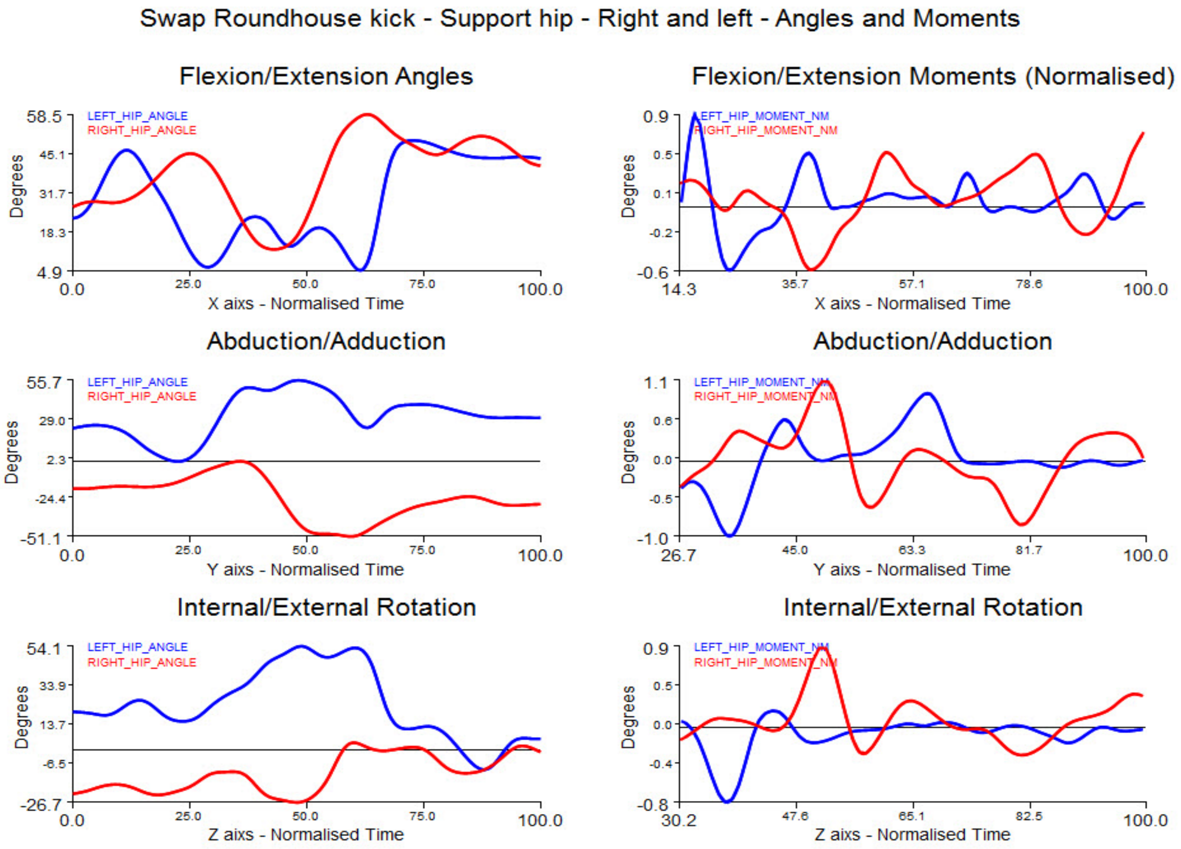

Figure 77 Swap roundhouse kick -support hip of right and left sides` angles and moments

5.6.7 Kicking knee angles

Flexion-extension angles for both sides, right and left, were almost the same at 174° for the right side and 176° for the left side. Abduction – adduction angle for both sides were the same at 13°. Internal-external rotation angles for both sides were also very similar, 19° right side and 17° left side Figure 78.

5.6.8 Kicking knee peak moments

Flexion-extension moments values were similar for both side, 0.6 N.m/kg for the right side and 0.5 N.m/kg for the left side. Abduction – adduction moment values for right and left sides were also similar at 0.5 N.m/kg and 0.4 N.m/kg respectively. Internal-external rotation moments values for both sides were the same, 0.2 N.m/kg Figure 78.

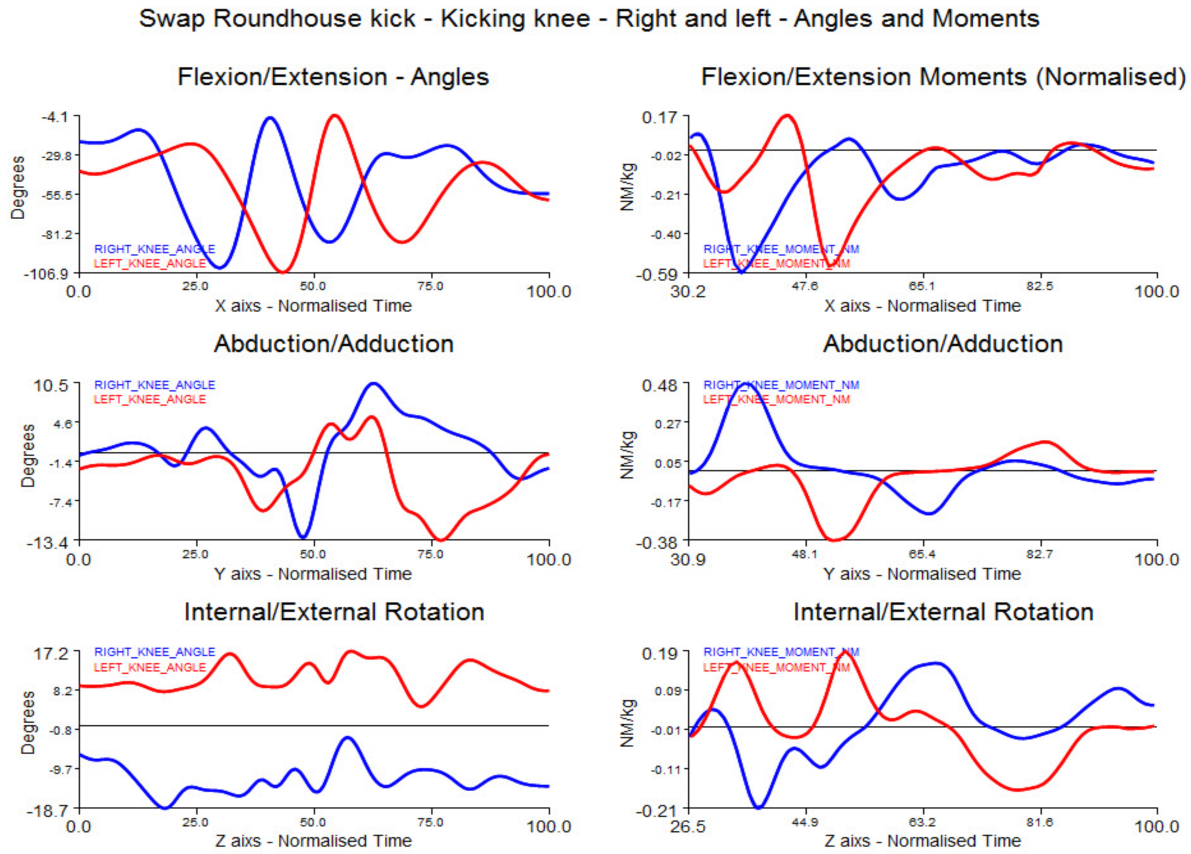

Figure 78 Swap roundhouse kick - kicking knee of right and left sides` angles and moments

5.6.9 Support knee angles

Right side flexion-extension angle was 174°, slightly larger than the left side angle of 176°. There was only small abduction-adduction angles for sides, 5° right and 9° left. There were also similar internal-external rotation angles for sides, 17° right side and 15° for left side Figure 79.

5.6.10 Support knee peak moments

Values for both sides and for all axes were the same or almost the same at, 0.2 N.m/kg, Figure 79.

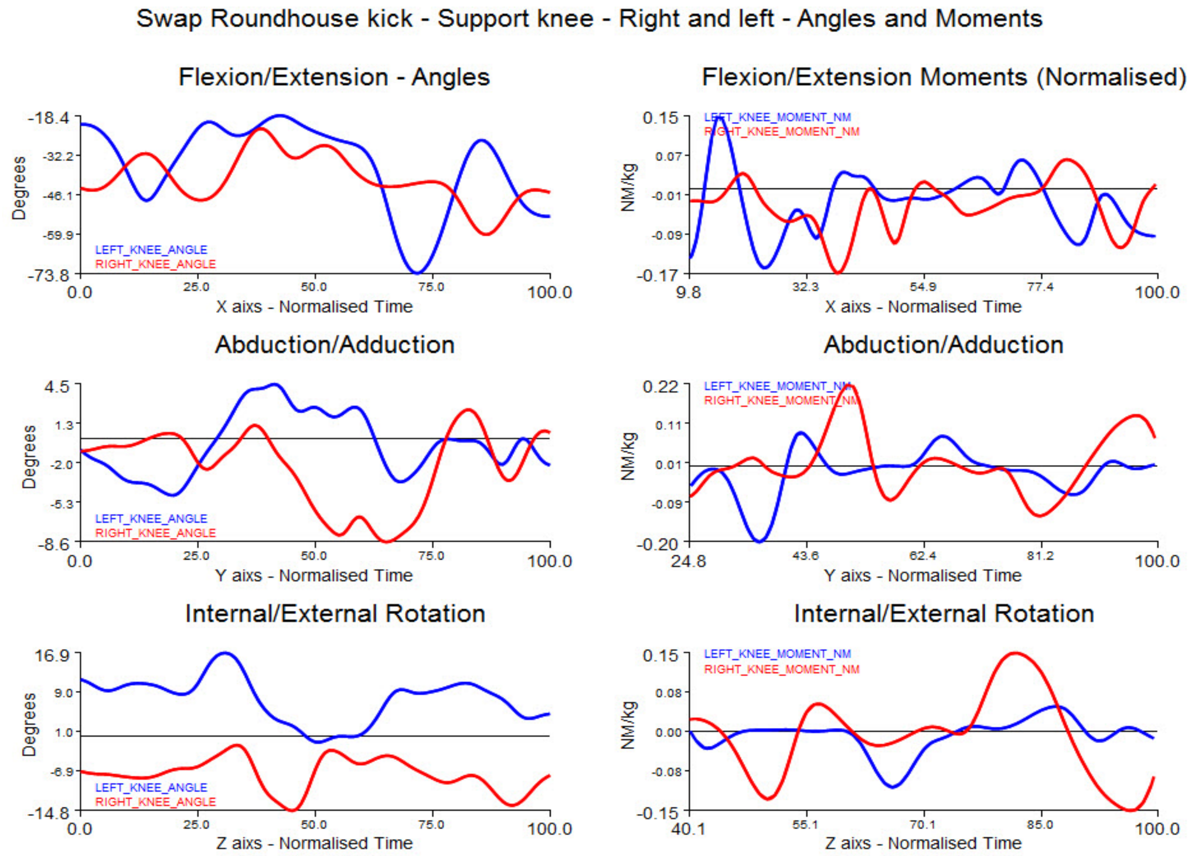

Figure 79 Swap roundhouse kick - support knee of right and left sides` angles and moments

5.7 Discussion and Conclusion

There is a large asymmetry in range of motion at the lower back between the left and right sides in terms of combined side flexion and rotation. Individual direction ranges are not too dissimilar, but the rotation and side flexion combined as seen during kicking is quite large. The ranges of motion are not large compared to other martial artists. The back kick and the swap roundhouse kicks had the greatest range of motion and moments, summarised here.

Trunk flexion-extension angle of the right side of swap roundhouse kick was largest at 26°. Also, right swap roundhouse kick had the largest abduction – extension angle at 32°. Left-back kick has the largest internal-external rotation at 30°. Kicking hip highest flexion-extension angle was 88° for a left back kick. The largest value of abduction-adduction angle was 81° for a left roundhouse kick. The highest value of internal-external rotation was 36° for a right back kick. Support hip largest angles; flexion – extension largest angle was 76° for a left back kick. Right roundhouse kick has the highest angle value of 71°. Largest internal-external rotation angle was 72° for a left roundhouse kick. Kicking knee largest angles; Flexion-extension largest angle was 179° for a right roundhouse kick. Right back kick has the largest abduction-adduction angle at

15°. Left-back kick has the largest internal-external rotation angle of 21°. Support knee largest angles; Left roundhouse kick has the highest value of flexion-extension angle at 178°.
Overall overview of all trunk moment values the right swap roundhouse kick has the greatest value at 2.4 N.m/kg, which is considered a large moment value and the player, and the coach should know this is a sign of risk. Kicking hip on flexion-extension also had a large moment at 1.7 N.m/kg for the right swap roundhouse kick and at the same time kicking hip abduction-adduction had high moments' values about 1.7 N.m/kg. Support hip, kicking knee and support knee joints moments have slightly high values at 1.1 N.m/kg.

For the most parts the kicks stay within the ranges of motion seen in the static tasks, however, note that for right side flexion this range is reduced depending on the amount of rotation, especially with a left leg lift. During the kick execution from start till contact the transitions are smooth. However, on several kicks, with it seemingly most pronounced with a combination of the torso being nearer horizontal and with forward motion during the kick (including the swap kick which has relative forward motion) the recovery has the fastest and widest range of angle changes beside flexion combined with rotation, and in some cases also combined with the large forces as the kicking leg hits the ground on landing. This rate of change in angles is much higher than you would want to see. During the kick with the torso behind which is then rotated and twisted forwarded as the leg comes down causing a rapid and violent rotation.

The back kick and the swap roundhouse indicate that there is great asymmetry in the performance and high peak joint loads to the lower back which is also asymmetrical. Although it cannot be determined if this is due to the injury or part of the cause now the poor side needs to be improved. Kicking performance of the kicking leg and making the target was not much different side to side but the support and backloading were the worst combinations of joint range with high moments were in kicks with a lot of forwarding momentum as well as rotation and the recovery after delivering the kicks. Core muscle strength and flexibility as well as the establishment of the trunk motion during kicks on the poor side to be more like the good side needs to be achieved. Keeping the trunk and core stabilised and balanced should also reduce the poor recovery posture after the kicks.

The player and the coach should work on the kicking techniques to develop it back to the normal technique, the standard way of performing it during training, not just look for good scoring results because it might be worse if the player continues developing and performing this way of kicking with its great asymmetry.

Chapter 6

A case study of a Taekwondo player with a left knee injury which had undergone rehabilitation for six months

6.1 Summary of this case of study

The player had an injury to his left knee (hypermobility, with large hyperextension), and had been undergoing treatment and rehabilitation within a restricted training regime for about six months under the supervision of the Taekwondo team physiotherapist. The testing was to determine the effect of taping, as applied by the physiotherapist, on the range of hyperextension during dynamic kicking and how the joint instability affects his performance in several Taekwondo kicks.

The qualitative assessment indicated there was large hypermobility on the left knee motion with relatively small hypermobility on the right knee motion. Large ranges of motion were obtained from both hips of 100° or more. Both knee angles were more than 180° for an extension, which it considers as hyperextension, but the left was noticeably larger than the right and the right was negligible for passive tasks. Hyperextension was visible in standing, stretching and range of motion tests and can occur during many kicks, especially high kicks when the player tries to kick the opponents head.

The subject came with his coach and his physiotherapist to analyse his kicking and his lower back motion during them. Kicks and kicking combinations were selected by the Taekwondo support team. 3D motion capture using a 9 camera VICON system and 2 force plates was performed as described in previous chapters, however, a whole-body marker set was used (53 markers) Figure 80.

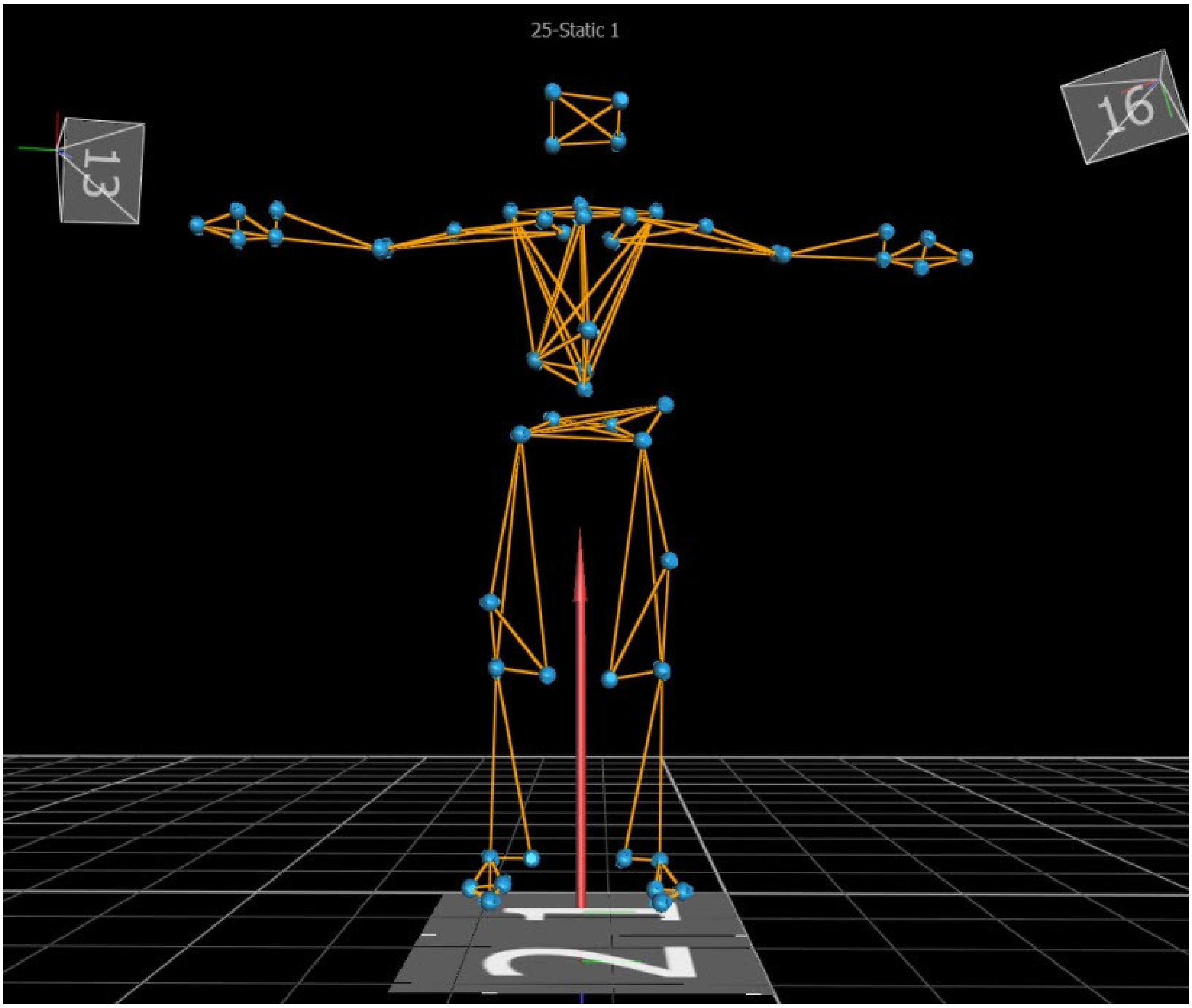

Figure 80 Full body markers

The subject warmed up as per the coaches and physiotherapist's instructions and the full body marker set was applied. Ranges of motion were tested first then various kicks and then kicks with strapping. Although a large number of a range of motion tasks were performed the results focus on backward Figure 82 and forward Figure 83 hip flexion with straight legs as this gave the best indicators of knee hypermobility for the player. Data collection methods, processing in Nexus, and analysis in V3D were performed as previously described in a case study in Chapter 5 apart from only four joints were examined (kicking hip, support hip, kicking knee and support knee). As in the previous chapters X = (Flexion-Extension), Y = (Abduction-Adduction) and Z = (Internal-External rotation). Descriptions of the angle ranges and peak joint moments are presented, and comparisons made between the left side and right-side kicks.

The static pose in Figure 81 with the player asked to stand with straight legs was used to define joint angles. Note the player had very long legs for his total height which is a physical advantage in kicking dominated sport with weight categories. The subject information is shown in Table 32.

Table 32 Taekwondo case two information

Injured Subjects	Sex	Age	Height	Weight
TKD2	*Male*	28	186	86

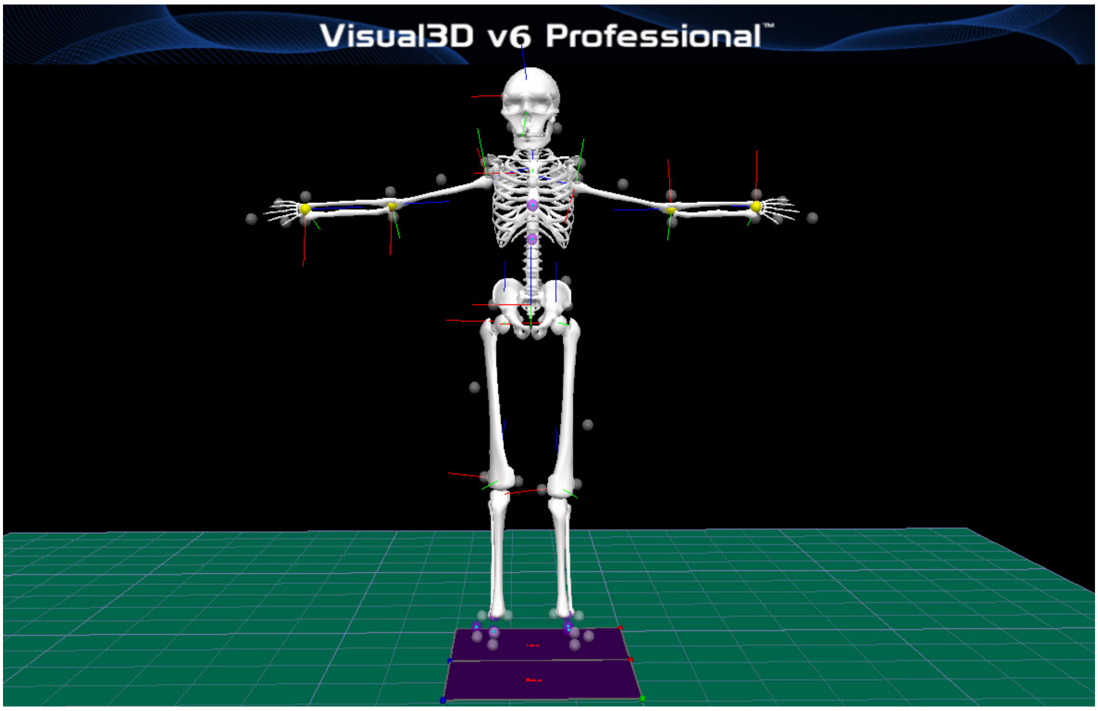

Figure 81 Static skeleton pose

6.2 Bending backwards and forward

From static position the player started bending backwards to reach the maximum of combined hip and back extension bending, hands were back and down but without touching body Figure 82. Maximum hip joints angles during bending backwards are presented in Table 33 and key differences are summarised here: the maximum angle of the left hip was 20°, larger than right hip angle by about 5°. The left knee angle was 23°, smaller than right knee angle of 27° Table 33 and Figure 82. Bending forward with hip flexion hip and knees ‘held straight’ the peak angles are in Table 33. The left hip was 101°, slightly smaller than right hip at 105°. The left knee angle was more than the straight angle at 183° (hyperextension) whereas the right knee angle was maintained at

180° Table 33 and Figure 83. Figure 84 also clearly indicated that as well as there being differences in the peak values that the overall changes in angle for knee flexion-extension when bending forward followed a different pattern between the left and right sides after 25% of the bending action. Until both knee flexion angles reached 180° they followed the same angle change and change rate, but when reaching 180° and the hip flexion continuing the left knee went into hyperextension and the right did not, but went into flexion.

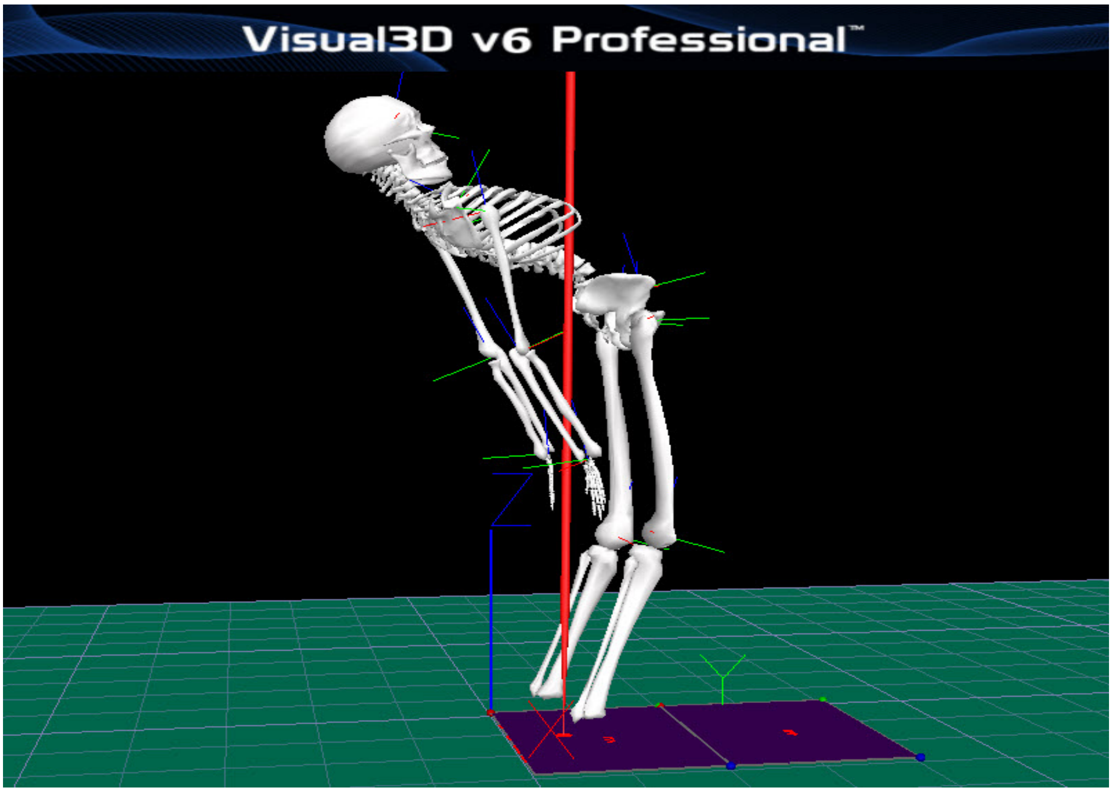

Figure 82 Bending backwards

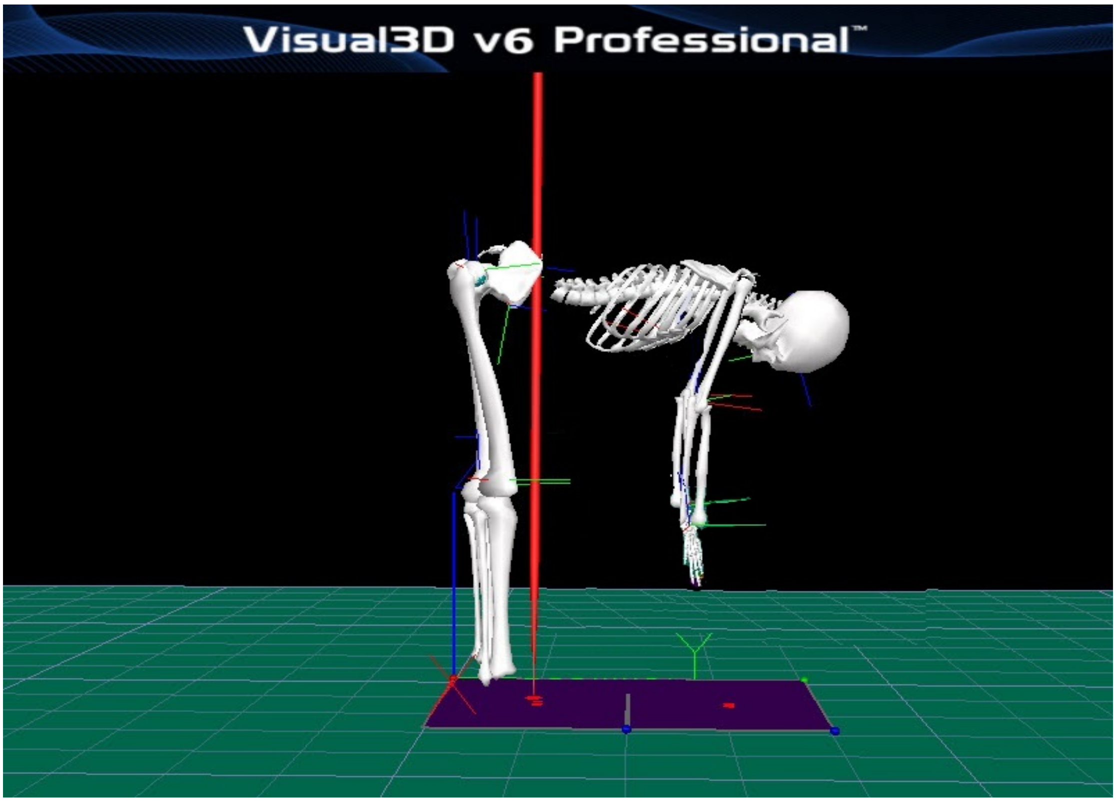

Figure 83 Bending forwards

Table 33 Bending backwards and forward flexion/extension of hips and knees maximum angles (degrees)

	Motions	Maximum Joint Angles (degrees)											
		Left Hip			Right Hip			Left Knee			Right Knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
1	Bending Backward	20	-	-	15	-	-	23	-	-	27	-	-
	Bending Forward	101	-	-	105	-	-	183	-	-	180	-	-

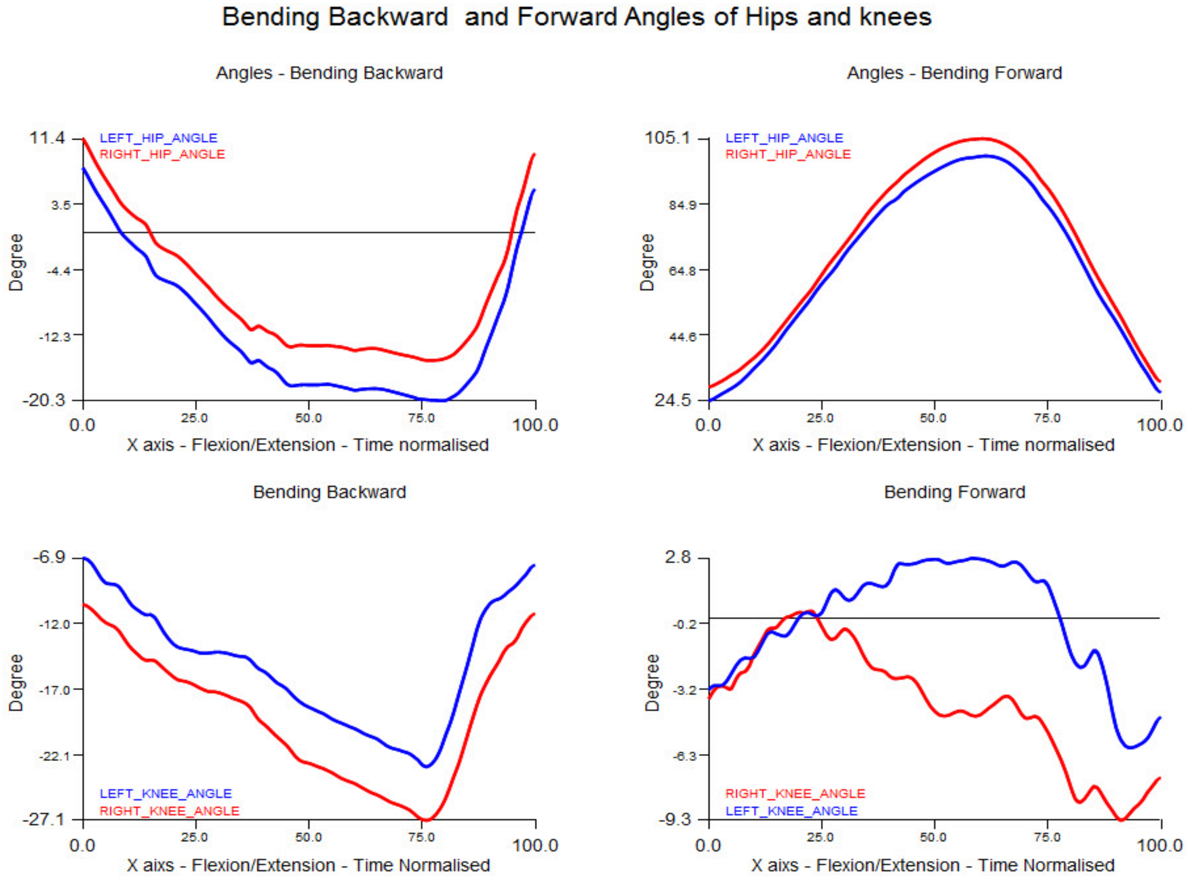

Figure 84 Bending backwards and forward hip and knee angles

6.3 Left front upon head (Axe) kick

Axe kick is one of the most popular recorded kicks used to kick to the head, shoulder and chest. The favourite and most used kick of this player is the axe kick, information provided by the coaching team that this related to the flexibility, agility, strength and physical fitness in addition to the length of his legs. These are all qualities that allow him to perform this kick quickly with power and consistency. The subject repeatedly used axe kick many times in competition, which it was surmised by the coaching and physiotherapist led to knee injuries and resulting hypermobility Figure 85.

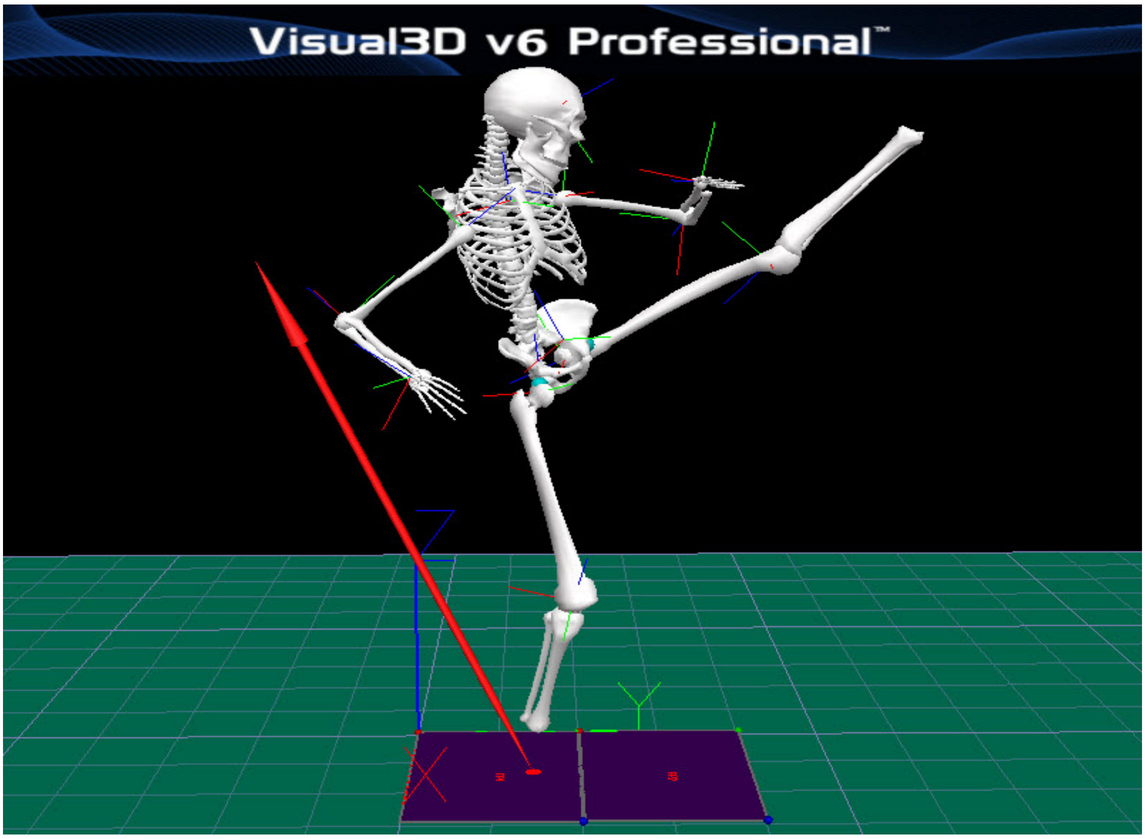

Figure 85 Upon head high (Axe) kick skeleton

6.3.1 Left front Axe kick angles with strapping off and strapping on

Table 34 Left Axe kick joint angles of hip and knee (strapping off and strapping on)

	Kick name	Maximum Joint angles (degrees)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
2	Left Front upon Head Strapping off	107	54	27	44	50	24	186	7	17	156	9	37
	Left Front upon Head Strapping on	93	49	33	45	50	29	195	10	15	156	10	35

Kicking hip angles: Left hip maximum angles of flexion-extension with strapping off were 107° and the hip angle with the strapping on was less, 93°. Abduction – adduction angle of Axe kick with strapping off was 54° and slightly larger than with strapping on, 49°. Internal-external rotation angle with strapping off was 27° lower than with strapping on an angle, 33° Figure 86.

Support hip angles: Flexion-extension angles for both strapping off and strapping on were very similar, 44° and 45°. Abduction – adduction angles were the same at 50°. Internal-external rotation angle with strapping off was 24°, slightly lower than with strapping on, 29° Figure 87.

Kicking knee angles: Flexion – Extension angle with strapping off was 186° lower than with the strapping on at 195°. Both angles were over the straight leg angle of 180° and considered as hypermobility during the axe kick. The player made more extension about 9° with the strapping on. Abduction – adduction angles for strapping off was just 7° but the angle got slightly larger with the strapping on at 10°. Internal-external rotation angles were very similar at 17° and 15° Figure 88.

Support knee angles: Flexion-extension angles of strapping off and strapping on were the same at 156°. Also, abduction-adduction angles were very similar at just 9° and 10°. Internal-external rotation angles were also similar at 37° and 35° Figure 89.

In this state of injury when performing the kick there is an inverse relationship between the kicking hip and knee angles when wearing and not wearing the strapping. With no strapping the subject substituted the knee angle limitation by increasing the hip angle to reach the required target height and with the strapping on the reverse is true, Table 34.

6.3.2 Left front Axe kick peak moments with strapping off and strapping on

Table 35 Left Axe kick joint moments of hip and knee (strapping off and strapping on)

	Kick name	Maximum Joint Moments, Normalised (N.m/kg)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
3	Left Front upon Head Strap off	2.1	1.8	1.1	0.7	0.7	0.4	0.1	0.2	0.2	0.1	0.1	0.1
	Left Front upon Head Strap on	1.7	1.3	1.1	0.7	0.6	0.5	0.1	0.1	0.2	0.2	0.1	0.1

Kicking hip moments: Flexion-extension moments for the Axe kick with strapping off was 2.1 N.m/kg, this was larger than the moment with the strapping on, 1.7 N.m/kg. Abduction – adduction peak moment, strapping off, was 1.8 N.m/kg which was also higher than the peak moment value with strapping on, 1.3Nm/kg. Internal-external rotation moments for both kicks were the same at 1.1 N.m/kg Figure 86.

Support hip moments: Flexion-extension moments of both kicks with and without strapping on the left knee were the same at just 0.7 N.m/kg. Abduction – adduction moments were also very similar for both conditions at just 0.7 N.m/kg and 0.6 N.m/kg. Internal-external rotation were also similar at 0.5 N.m/kg and 0.4 N.m/kg Figure 87.

Kicking knee peak moments: flexion-extension, abduction-adduction and internal-external rotation for both kicks without and with strapping were all small at just 0.2 N.m/kg Figure 88.

Support knee moments: Peak moments in this joint were very similar, or slightly lower, to the kicking knee moments, at just under 0.2 N.m/kg Figure 89.

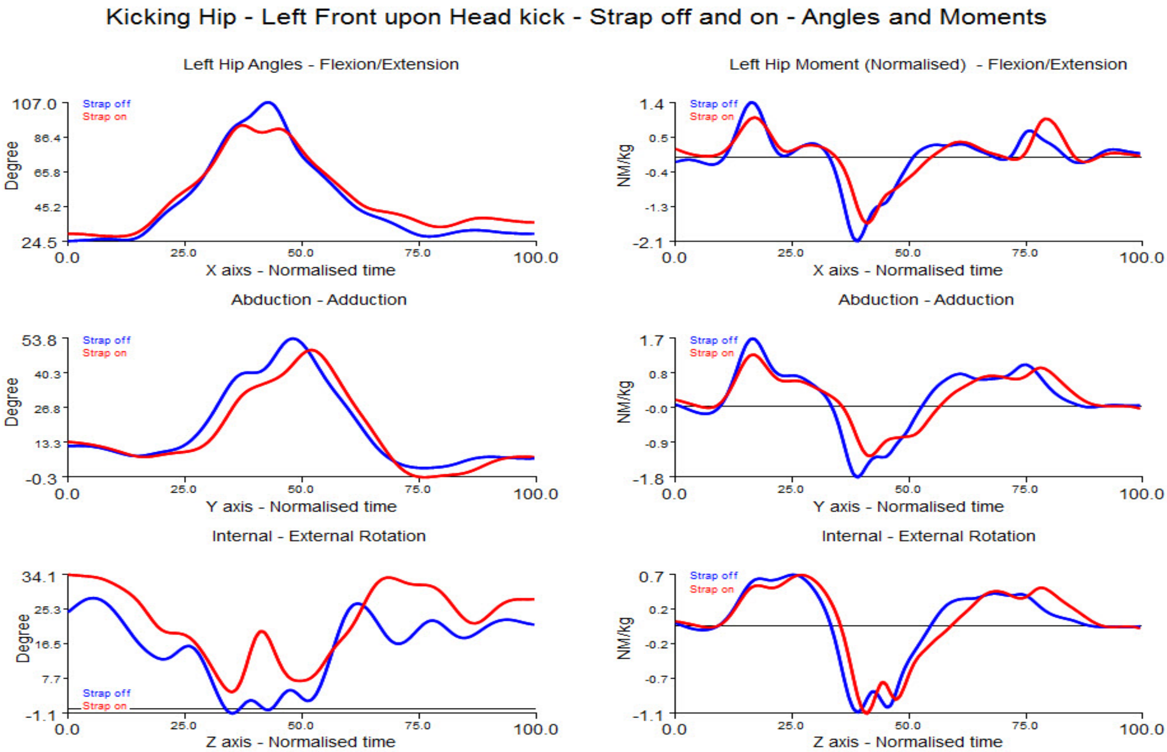

Figure 86 Kicking hip angles and moments

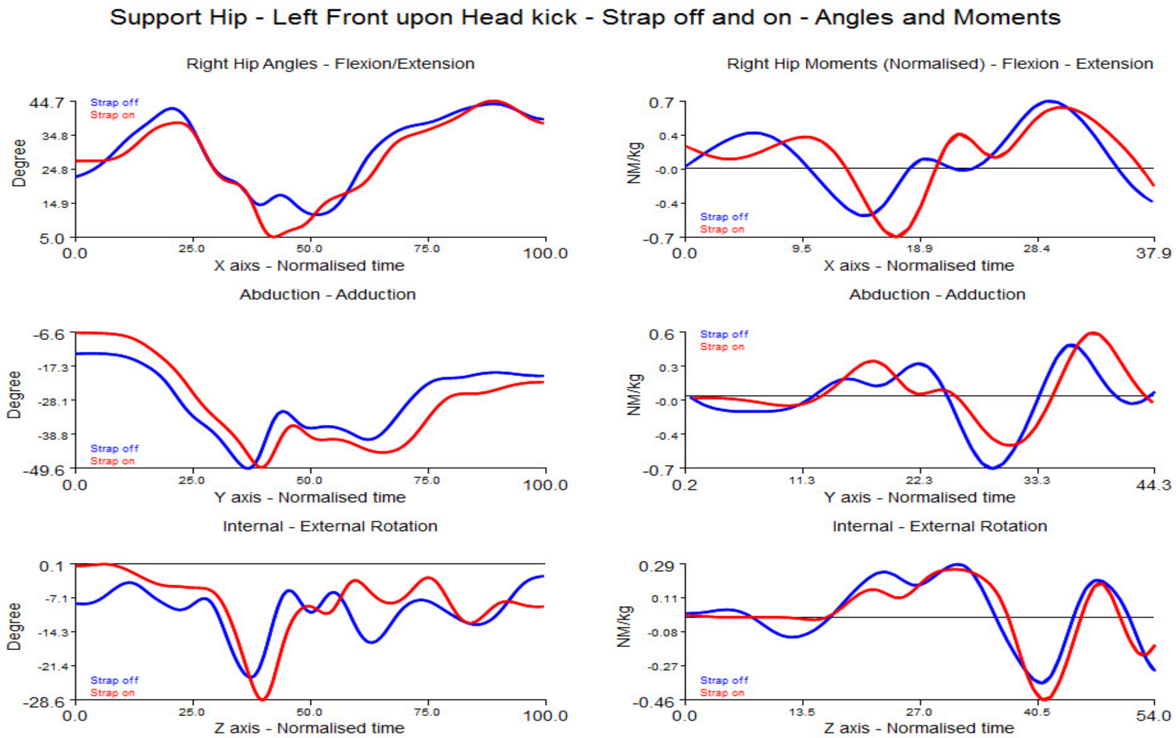

Figure 87 Support hip angles and moments

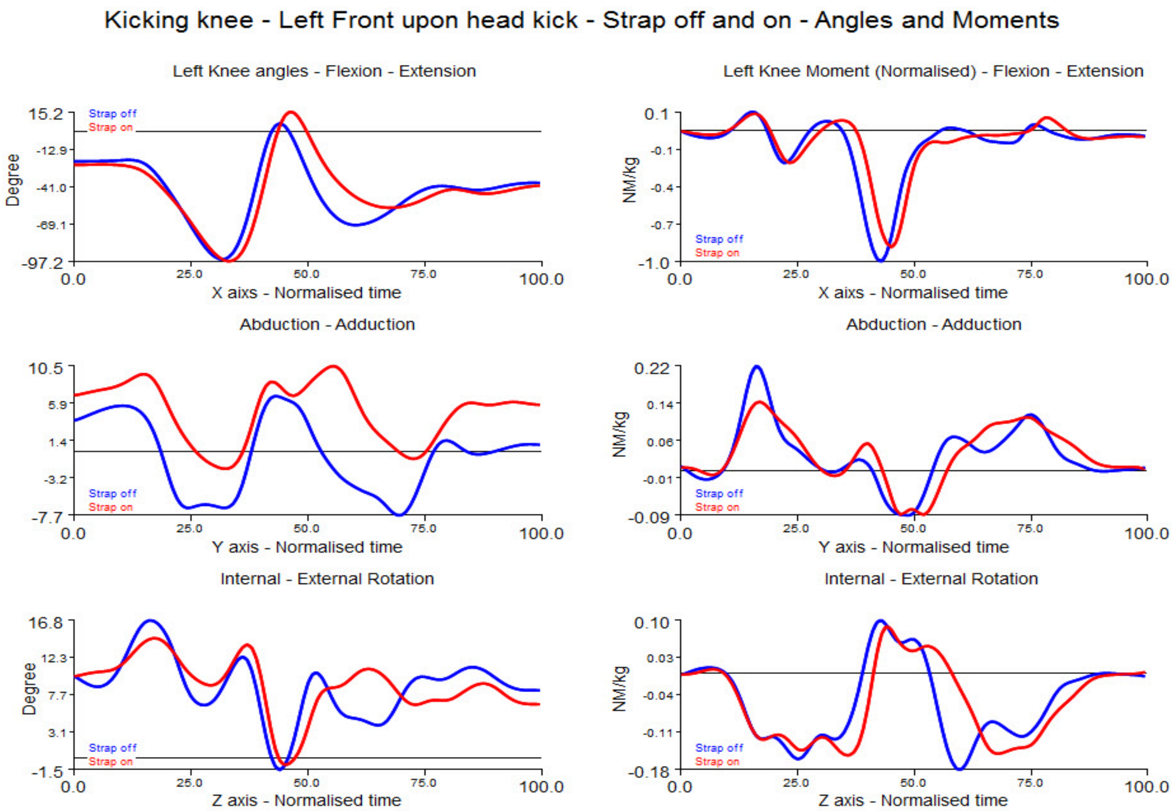

Figure 88 Kicking knee angles and moments

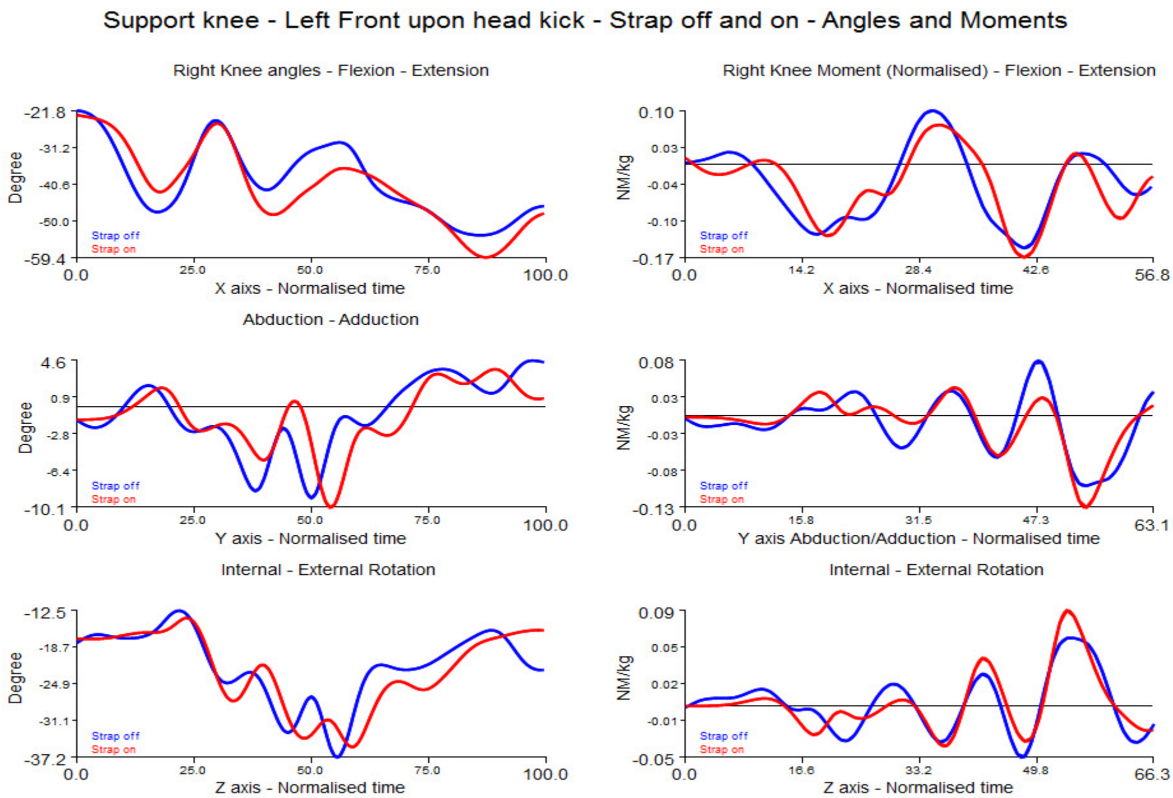

Figure 89 Support knee angles and moments

Overall view of Axe kick moments is that the largest peak moment generated was 2.1 N.m/kg for kicking hip flexion-extension in the strapping off condition. The player put a lot of effort into raising an extended leg, thus with a large moment of inertia, high and fast to get speed and power into the end of the kick. In this case the moments are higher compared to the support leg which it was less than 1 N.m/kg. This is different from the karate kicks seen in the earlier chapters where his leg is commonly raised in a bent position and the player when performing the axe kick is also pushing and sliding forward so the support leg is not locked into the floor at this point. As the kick goes up then comes down for the contact the total time for the kick is a little longer than other kicks and means peak support moments can be lower in order to provide sufficient impulse to move the player’s body for the kick. The longer time from start to finish makes it a hard kick to score with and relies on it not being detected early by the opponent. The overall pattern of angle changes and joint moments were similar for the strapping on and off and peak values were generally similar but there was often a clear offset in timing of some of the peaks and troughs. So, in this kick the strapping looks to have affected the magnitude of the values a little and the timing. At the knee the player has a slightly larger range of motion for flexion-extension with the strapping but lower moment and less abrupt changes in angle. The strapping has also offset the abduction-adduction noticeably even though the range of motion is similar. The strapping seems to have allowed the player to have the confidence to perform the kick with more range at the knee but with a better alignment and less peak load Table 35.

6.4 Left front roundhouse kick

In Taekwondo many kicks are fast, but the roundhouse kick is the fastest kick. It is the most used in the competition because of it fast, easy, safer than other kicks and easy to change from side to side by using both legs in an alternating fashion Figure 90.

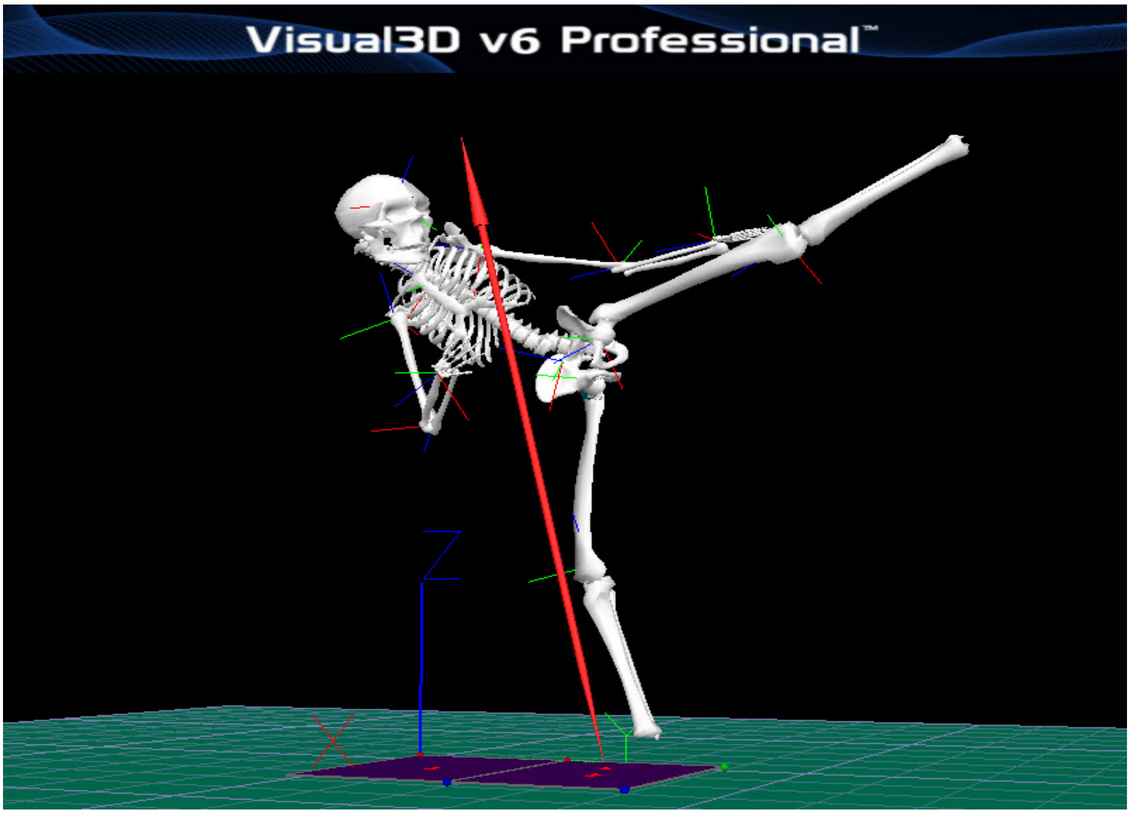

Figure 90 Left roundhouse kick skeleton

6.4.1 Left front roundhouse kick angles with strapping off and strapping on

Table 36 Left roundhouse kick joints angles of hip and knee (left knee strapping off and strapping on)

	Kick name	Maximum Joint Angles (degrees)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
4	Left Front Roundhouse Strap off	110	41	39	77	48	29	140	14	11	166	4	24
	Left Front Roundhouse Strap on	113	41	39	50	49	24	173	15	12	156	12	18

Kicking hip angles: Left front roundhouse kick maximum angles strapping off flexion – extension hip angle was 110° which is large but slightly lower than the hip angle when the strapping on, at 113°, both hip angles have large ranges of motion. Abduction – adduction angle strapping off and strapping on were the same at 41°. Internal-external rotation for both kicks strapping off and strapping on were the same at 39° Figure 91.

Support hip angles: Right hip flexion-extension support hip angles were smaller than for the kicking leg, 77° strapping off and even lower at 50° strapping on. Abduction – adduction angles for both kicks were almost the same at 48° and 49°. Internal-external rotation angles were 29° for strapping off and slightly lower at 24° for strapping on, Figure 92.

Kicking knee angles: Left knee flexion-extension maximum angle strapping off was 140° but much higher when the strapping on, 173°. Abduction – adduction maximum angle with strapping off was 14° very similar to the maximum angle with the strapping on, 15°. Internal-external rotation maximum angles were also very similar 11° and 12°, Figure 93.

Support knee angles: Right knee maximum angle of flexion-extension with strapping on was 166° and maximum angle with the strapping off was lower at 156°. Abduction – adduction maximum angle with strapping off was very small at just 4° and the maximum angle when strapping on was almost 3 times larger at 12°. Internal-external rotation maximum angle with strapping off was 24° and there was a smaller maximum angle with the strapping on at 18° Figure 94 and Table 36.

6.4.2 Left front roundhouse kick moments strap off and strap on

The roundhouse kick had higher loads in the kicking leg than the supporting leg and the kicking leg moments flexion – extension moment was largest for strapping off, but abduction-adduction was higher for strapping on Table 37.

Table 37 Left roundhouse kick moments at the hips and knees (left knee strapping off and strapping on)

	Kick name	Maximum Joint Moments, Normalised (N.m/kg)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
5	Left Front Roundhouse Strap off	1.4	1.1	0.7	0.7	0.8	0.8	0.7	0.5	0.6	0.4	0.2	0.2
	Left Front Roundhouse Strap on	0.9	1.3	0.7	0.9	0.8	0.8	0.8	0.3	0.4	0.6	0.5	0.8

Kicking hip moments: Left hip maximum moment for flexion-extension strapping off was 1.4 N.m/kg larger than the value of maximum moment when the strapping on at just 0.9 N.m/kg. Abduction – adduction peak moment for left hip, strapping off was 1.1 N.m/kg which was a smaller value of maximum moment than with the strapping on, 1.3 N.m/kg. Internal-external rotation peak moments strapping off and strapping on were the same at 0.7 N.m/kg, Figure 91.

Support hip moments: Right hip peak moments of flexion-extension for both modes, strapping off and strapping on, were very similar at 0.7 N.m/kg and 0.8 N.m/kg. Abduction – adduction peak moments for both strapping off and strapping on were the same, 0.8 N.m/kg. Internal-external rotation peak moments for both strapping off and strapping on were the same at 0.9 N.m/kg, Figure 92.

Kicking knee moments: Left knee peak moment of flexion-extension for strapping off was 0.7 N.m/kg and very similar to the value with strapping on at just 0.8 N.m/kg. Abduction – adduction moments for left knee strapping off was 0.5 N.m/kg and lower than that with the strapping on at just 0.3 N.m/kg. Internal-external rotation moment for strapping off was 0.6 N.m/kg and similar to strapping on of 0.4 N.m/kg Figure 93.

Support knee moments: Right knee peak moment flexion – extension strapping off was small at just 0.4 N.m/kg and slightly larger with strapping on at 0.6 N.m/kg. Abduction – adduction moment with strapping off was 0.2 N.m/kg and strap on was 0.5 N.m/kg. Internal-external rotation moment strapping off was 0.2 but was larger with the strapping on, 0.8 N.m/kg, Figure 94.

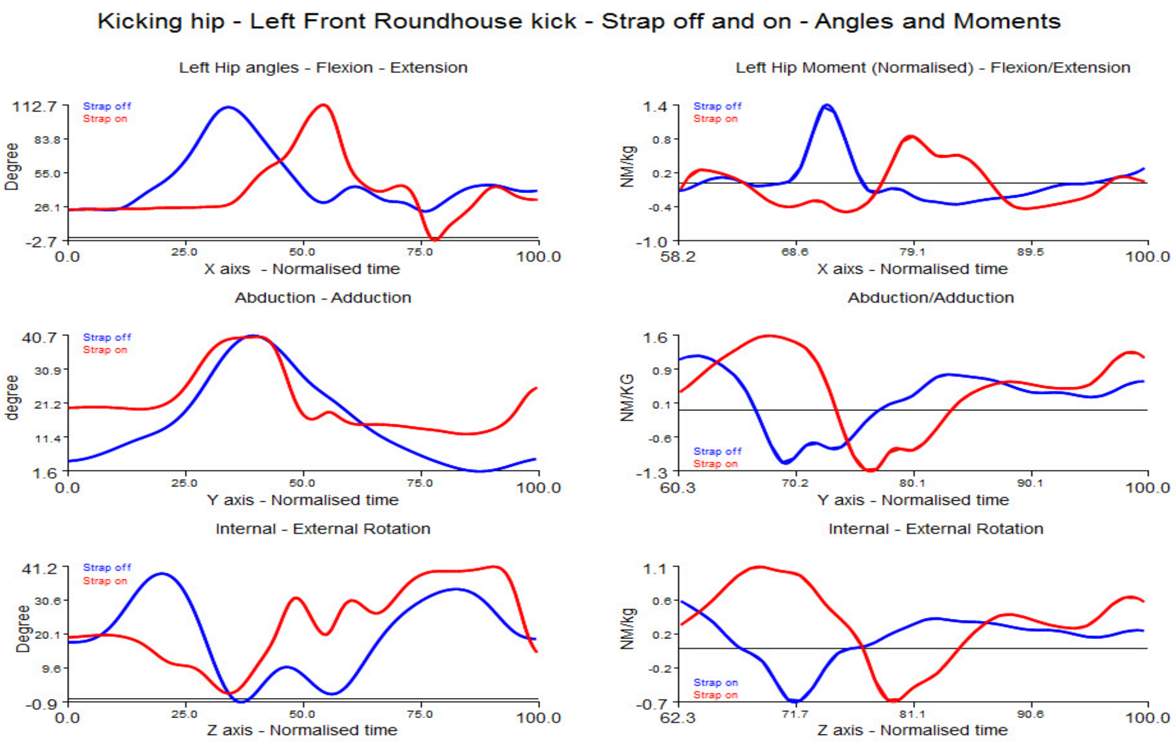

Figure 91 Kicking hip angles and moments

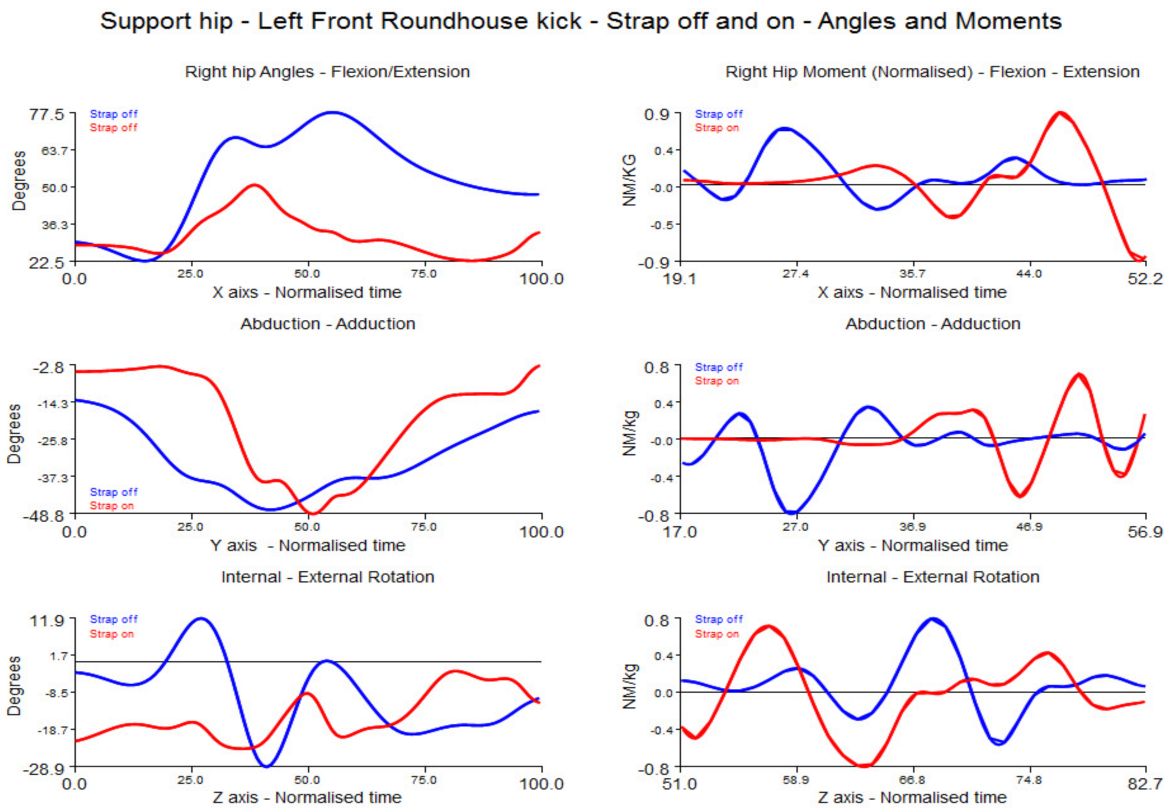

Figure 92 Support hip angles and moments

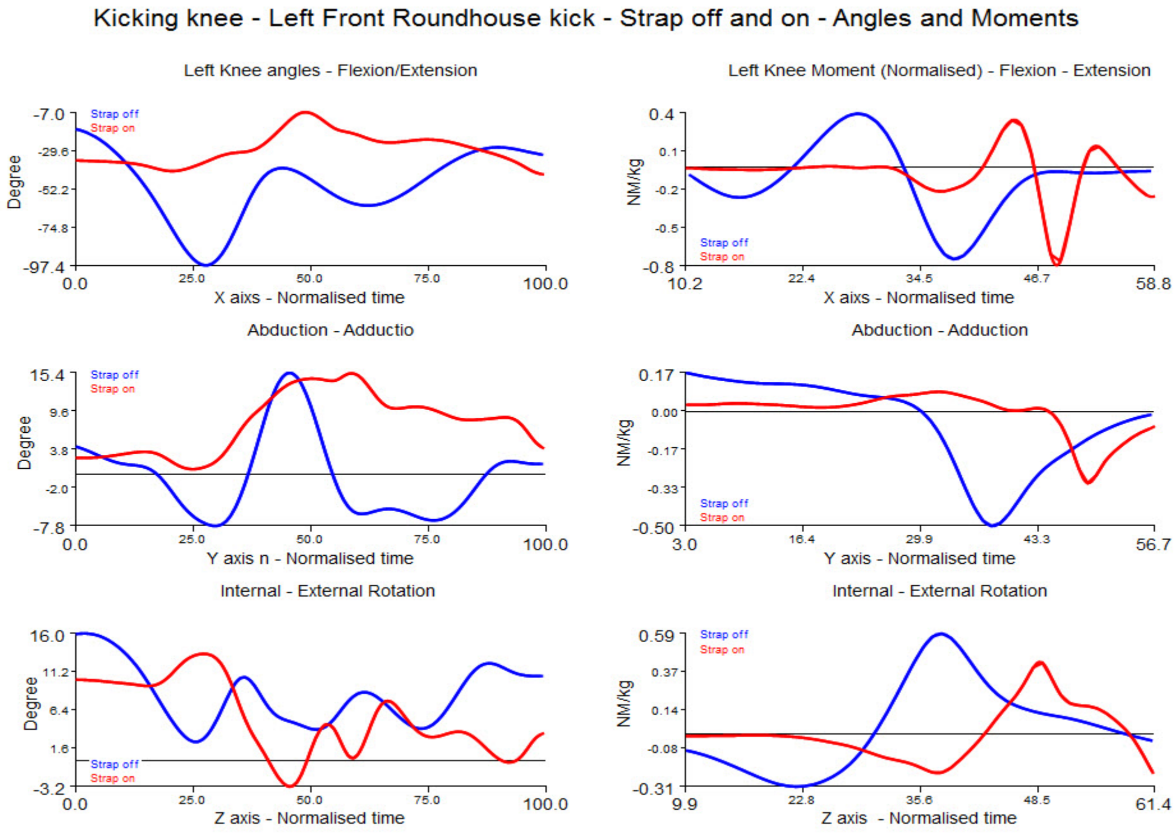

Figure 93 Kicking knee angles and moments

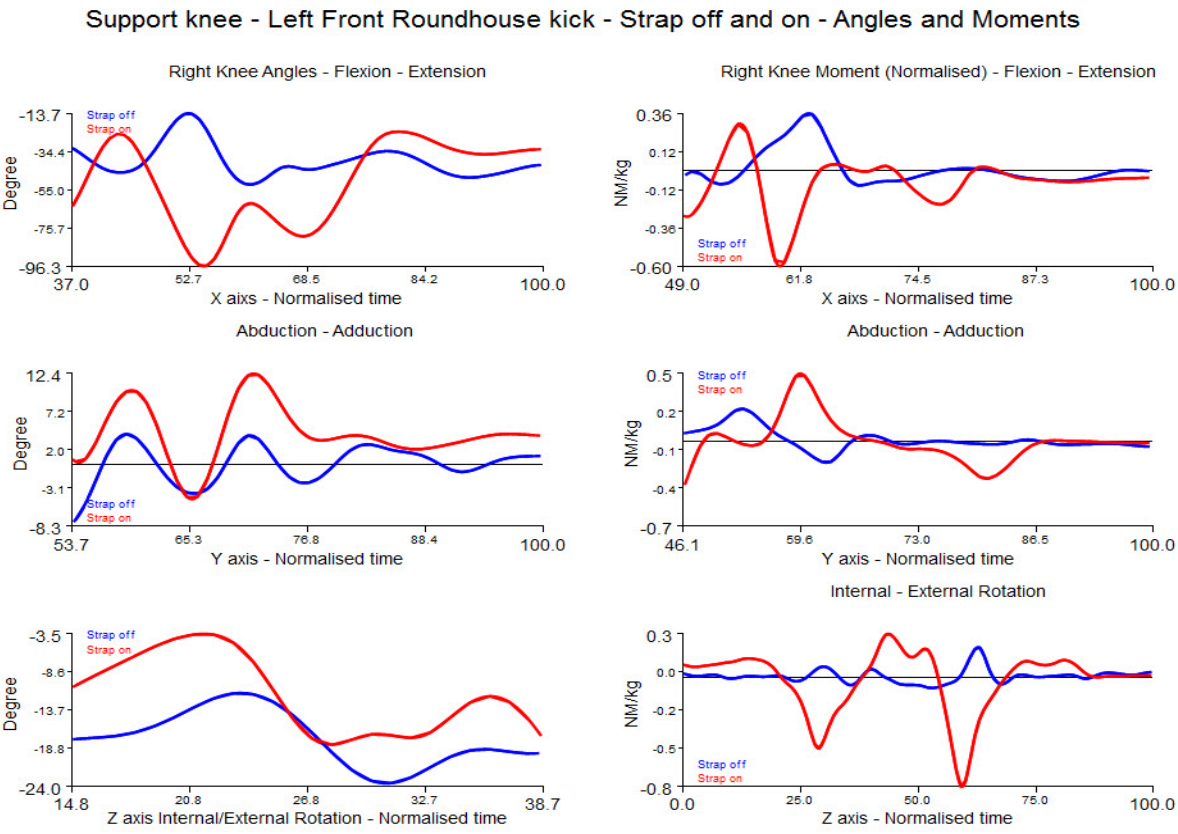

Figure 94 Support knee angles and moments

6.5 Right front roundhouse kick

In this part of the case of study, the aim of analysing the right roundhouse kick was to examine the effect of a left knee injury on the kick when it was the supporting leg and how strapping affected this, Figure 95.

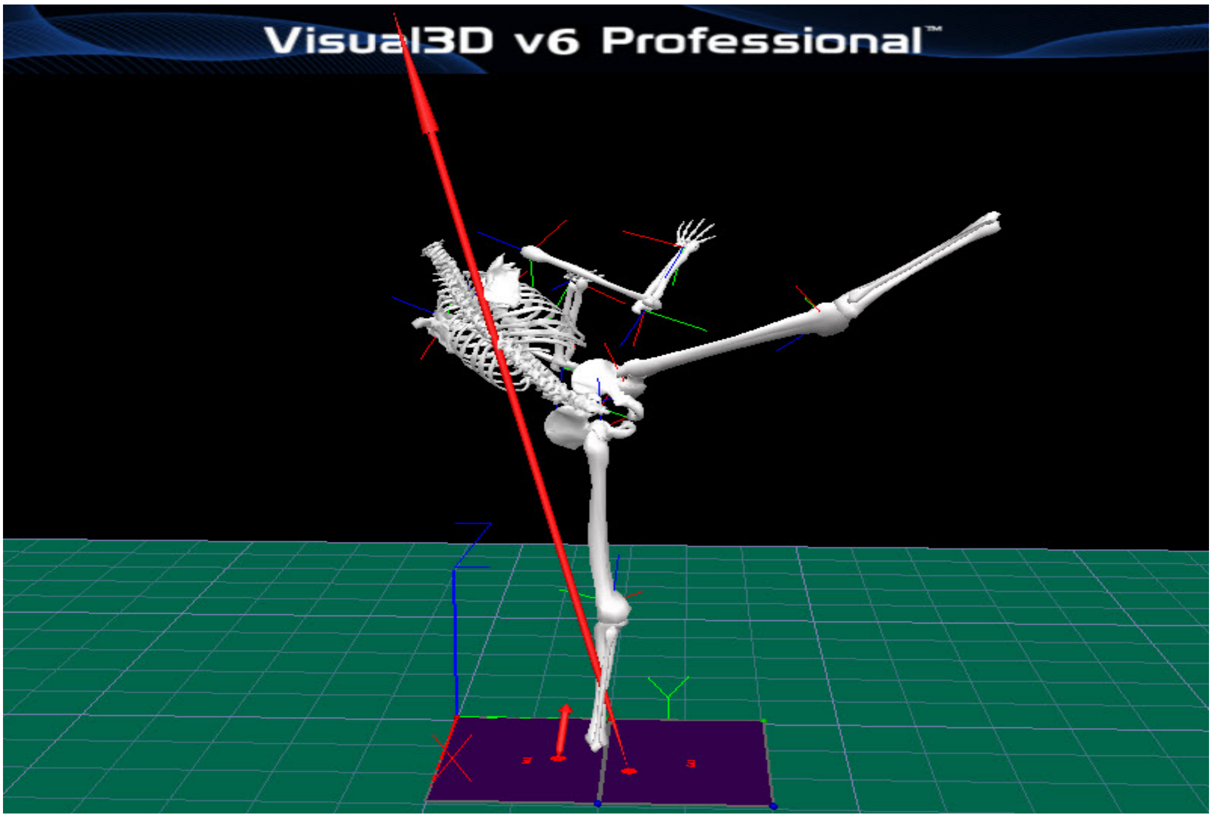

Figure 95 Right roundhouse kick skeleton

6.5.1 Right front roundhouse kick angles with strapping off and strapping on

Table 38 Right roundhouse kick joint angles of hip and knee (left knee strapping off and strapping on)

	Kicks names	Maximum Joint Angles (degrees)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
6	Right Front Roundhouse strap off	40	54	22	60	58	42	140	8	24	174	13	15
	Right Front Roundhouse strap on	50	42	20	63	47	24	125	32	27	169	9	13

Kicking hip angles: Right hip maximum angles, strapping off, flexion-extension; his angle was 40° lower than the maximum angles when the strapping on at 50°, both hips angles have a slightly small range of motion. Abduction – adduction angles strapping off were 54° higher than angle strapping on at 42°. Internal-external rotation angles for both kicks strapping off and strapping on almost the same about 20° Figure 96.

Support hip angles: Left hip flexion-extension support hip angles were similar, 60° strapping off and 63° strapping on. Abduction – adduction angles were 58° strapping off and lower at 50° strapping on. Internal-external rotation angles were 42° strapping off and lower at 20° strapping on Figure 97.

Kicking knee angles: Right knee flexion-extension maximum angle strapping off was 140° larger than angle strapping on at 125°. Abduction – adduction maximum angle strapping off was 8° and the larger angle at 30° for strapping on. Internal-external rotation maximum angle was 24° strapping off and slightly bigger at 27° strapping on Figure 98.

Support knee angles: Left knee maximum angles of flexion-extension for both kicks strapping off and strapping on almost the same about 170°. Abduction – adduction maximum angles were 13° strapping off and smaller at 9° strapping. Internal-external rotation angles were 15° strapping off and slightly similar at 13° for strapping on Figure 99.

Overall view of Right roundhouse kick maximum angles is on the left knee as support knee it is in the normal range of flexion-extension Table 38.

6.5.2 Right front roundhouse kick moments strapping off and strapping on

Right roundhouse kick performance measuring angles and moments of kicking hip and knee at the same time support hip and knee angles and moments Table 39.

Table 39 Right roundhouse kick joint moments of hip and knee (left knee strapping off and strapping on)

	Kicks names	Maximum Joint Moments, Normalised (N.m/kg)											
		Kicking hip			Support hip			Kicking knee			Support knee		
No.		X	Y	Z	X	Y	Z	X	Y	Z	X	Y	Z
7	Right Front Roundhouse strap off	1.0	2.4	0.5	0.2	0.3	0.2	0.7	0.5	0.3	0.9	0.3	0.2
	Right Front Roundhouse strap on	0.8	1.7	0.5	0.3	0.1	0.2	0.8	0.3	0.5	0.7	0.3	0.2

Kicking hip moments: Right hip peak moment for flexion – Extension strapping off was 1.0 N.m/kg larger than the value of maximum moment when strapping on at just 0.8 N.m/kg. Abduction – Adduction peak moment strapping off was at 2.4 N.m/kg significantly larger values than when strapping on at 1.7 N.m/kg, both of the values are considered as a large value and very risky loading on joints. Internal-external rotation peak moments were the same at just 0.5 N.m/kg for both kicks strapping off and strapping on Figure 96.

Support hip moments: Left hip peak moments of flexion-extension for both modes, stripping off and the strapping on, were very similar at 0.3 N.m/kg and 0.2 N.m/kg. Abduction – adduction moments strapping off was 0.3 N.m/kg and smaller for strapping on at 0.1 N.m/kg. Internal-external rotation moments strapping off and strapping on were the same at just 0.2 N.m/kg Figure 97.

Kicking knee moments: Right knee peak moments for flexion-extension strapping off was 0.7 N.m/kg and similar for strapping on at 0.8 N.m/kg. Abduction – adduction moments strapping off was 0.5 N.m/kg and smaller for strapping on at 0.3 N.m/kg. Internal-external rotation moments strapping off was 0.3 N/.m/kg and slightly larger for strapping on at 0.5 N.m/kg Figure 98.

Support knee moments: Left knee peak moment for flexion-extension strapping off was 0.9 N.m/kg and smaller at 0.7 N.m/kg when the strapping on. Abduction – adduction moments for both kicks modes, strapping off and strapping on, were the same at just 0.3 N.m/kg. Internal-external rotation peak moments for both modes, strapping off and strapping on, were the same at just 0.2 N.m/kg Figure 99.

Overall view of right roundhouse kick peak moments is the huge value of the Abduction adduction at 2.4 N.m/kg. That value considers as the risk value may lead to making chronic injuries and must be reduced. At the same time the strapping reduced the peak moment to be 1.7 N.m/kg but it is still large but better than without strapping Table 39.

6.6 The effected strap on the left knee

6.6.1 Front Axe kick

- Left front Axe kick angles:

  They were just two big changes on the kicking and supporting hips and knees angles, kicking hip, flexion-extension angle, 107° strapping off and lower for strapping on at just 93°, which it gives in very clear image how the strap on the left knee (had injured) reduce the hip angle by indirect way, by looking on the kicking knee flexion-extension angles and how it was changed, strap off was 186° and larger angle when the strap on at 195°, it is considered as hypermobility and risky knee angle of kick but the player uses it when he felt confident by putting the strap on the left knee and it was helped hip to use his capability of the preferring high kick the Axe kick Table 34.

- Left front Axe kick moments:

  There was only one big change on the joints moments, on the kicking hip moments, strapping off was 2.1 N.m/kg and reduced when the strapping on to be just 1.7 N,m/kg. That reduce happened related to the indirect effected of putting the strap on the left knee due to reducing the hip angle the joint load reduced also. It is big message can be sent to the coaches and players how the strap effect the hip and knee angles and moment to make the players feel confident and reduce the possibility of injuries may happen due to the unconfidently feeling.

6.6.2 Left roundhouse kick

- Left roundhouse kick angles:

There was two big change in the joints angles, Support hip, flexion-extension angles, strapping off was 77° and it reduced when the strapping on to be just 50°. Kicking knee flexion-extension angle, strapping off was just 140° and larger when the strapping on at 173°, these angles numbers a clear sign that the player got more freedom to play and kick without wearning about his knee due to the strap saving it.

- Left roundhouse kick moments:

  There was only one big change in the kicking hip, flexion-extension moments, strapping off was 1.4 N.m/kg and it was reduced to be 0.9 N.m/kg when the strapping on. Another small change was also on the kicking hip, abduction-adduction moments, strapping off was 1.1 Nm/kg and became slightly higher at 1.3 Nm/kg when the strapping on.

6.6.3 Right roundhouse kick

- Right roundhouse kick angles:

  There were big changes in kicking leg joints angles, the first change was on the kicking hip, flexion-extension angle, strapping off was, 40° and larger when strapping on at 50°. Abduction - adduction angle was 54° and smaller when strapping on at 42°. The second change was on the kicking knee, flexion-extension angles, strapping off was, 140° and smaller when strapping on at 125°. Abduction adduction angles, strapping off was 8° and much bigger when strapping on at 32°. So, the changes were in the kicking leg joints especially on the flexion-extension axis that due to the player became more confident to perform right roundhouse kick with a bigger angle on the kicking hip even his kicking knee angle has been reduced.

- Right roundhouse kick moments

  There was only one big change in the joints moments, on the kicking hip, abduction-adduction moment, strapping off was, 2.4 N.m/kg and lees when strapping on at 1.7 N.m/kg. That gives a clear idea about the affected of the strap how it protects the knee joint and makes the player confidential to play.

At the end of these results and discussion the message has to pass to the coaches and player is to take care about the joints angle through the kicks and putting the strap on all the time on training and competition to protect the joint.

6.7 Left and right roundhouse kick moments comparison

The overall view of the moments on the left and right roundhouse kick, is that there is a sign referring to the player behaviour and how he behaves with his left knee injury as kicking leg and when it is a support leg. The moment of the right roundhouse kick (left leg is the supporting leg) was much bigger on kick modes, strapping off 2.4 N.m/kg and strapping on 1.7 N.m/kg) than when the kicking leg is the left leg. Also, support hip moments for right roundhouse kick are bigger than the support hip moments for a left roundhouse kick. Which it means that the player put more loading on the support leg (right leg) when the kicking leg is left, due to right leg is healthy and strong enough to put more weight on it.

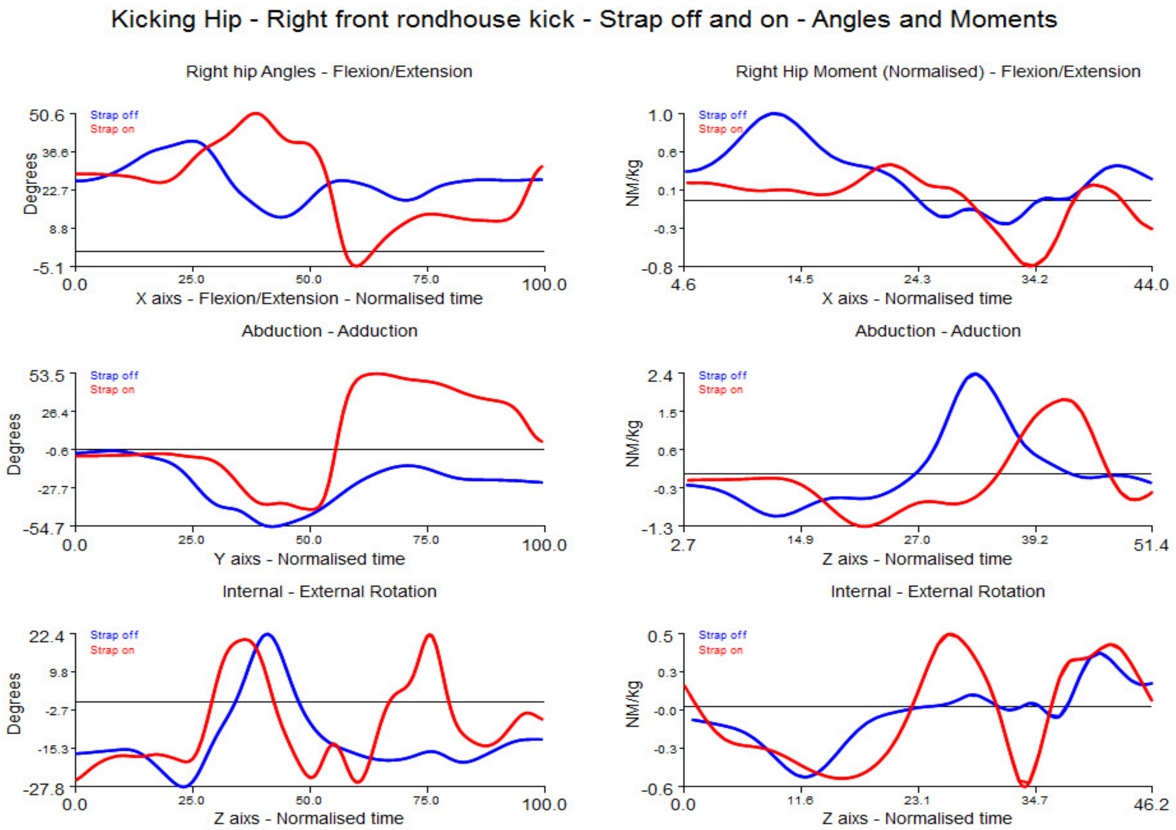

Figure 96 Kicking hip angles and moments

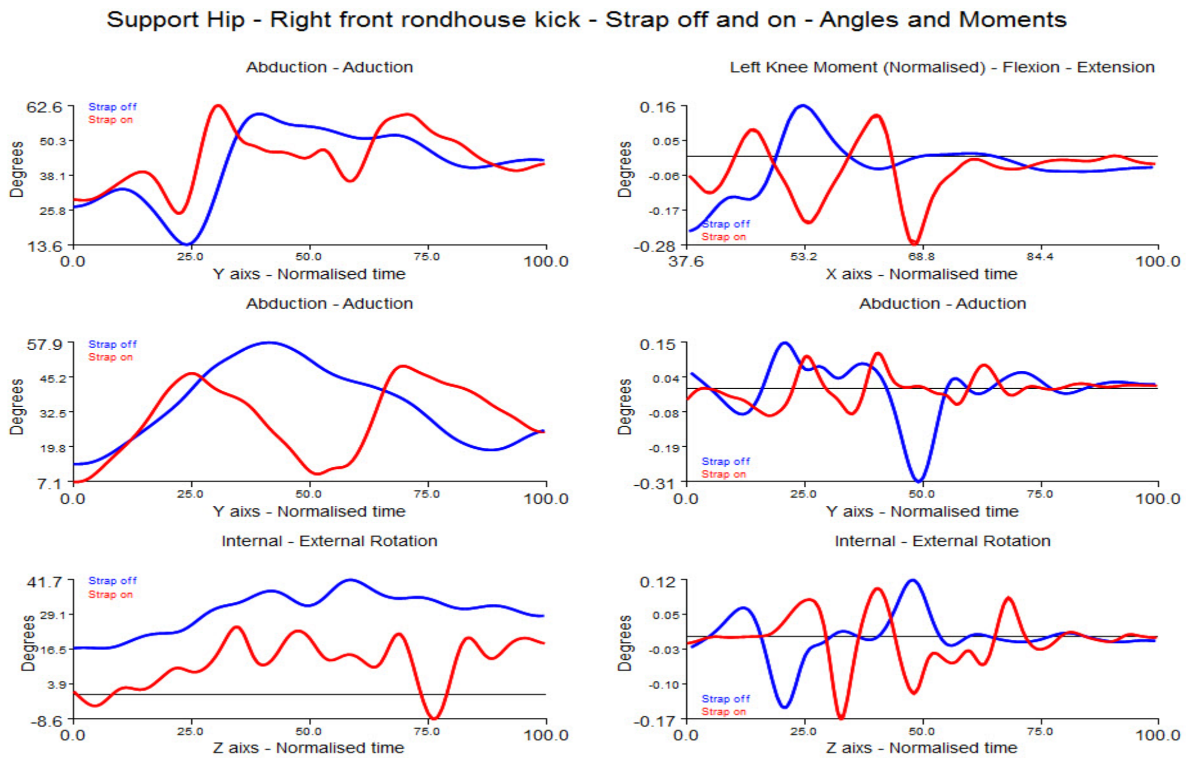

Figure 97 Support hip angles and moments

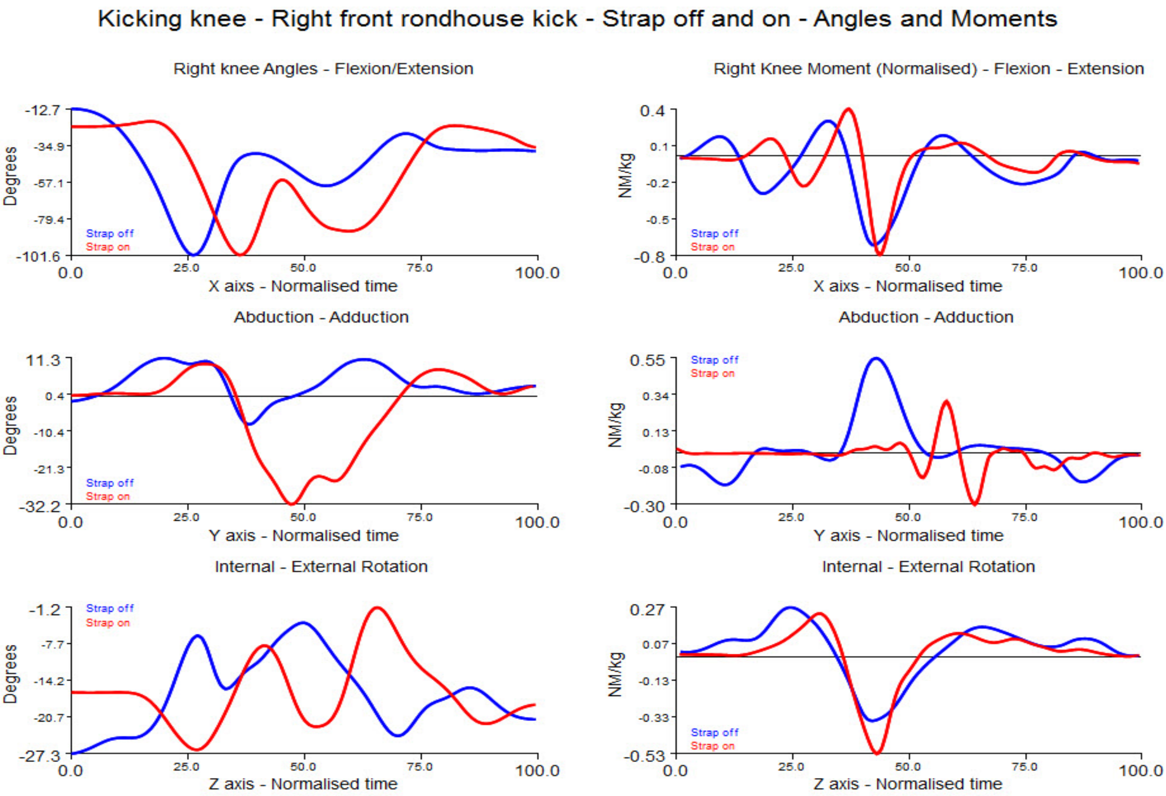

Figure 98 Kicking knee angles and moments

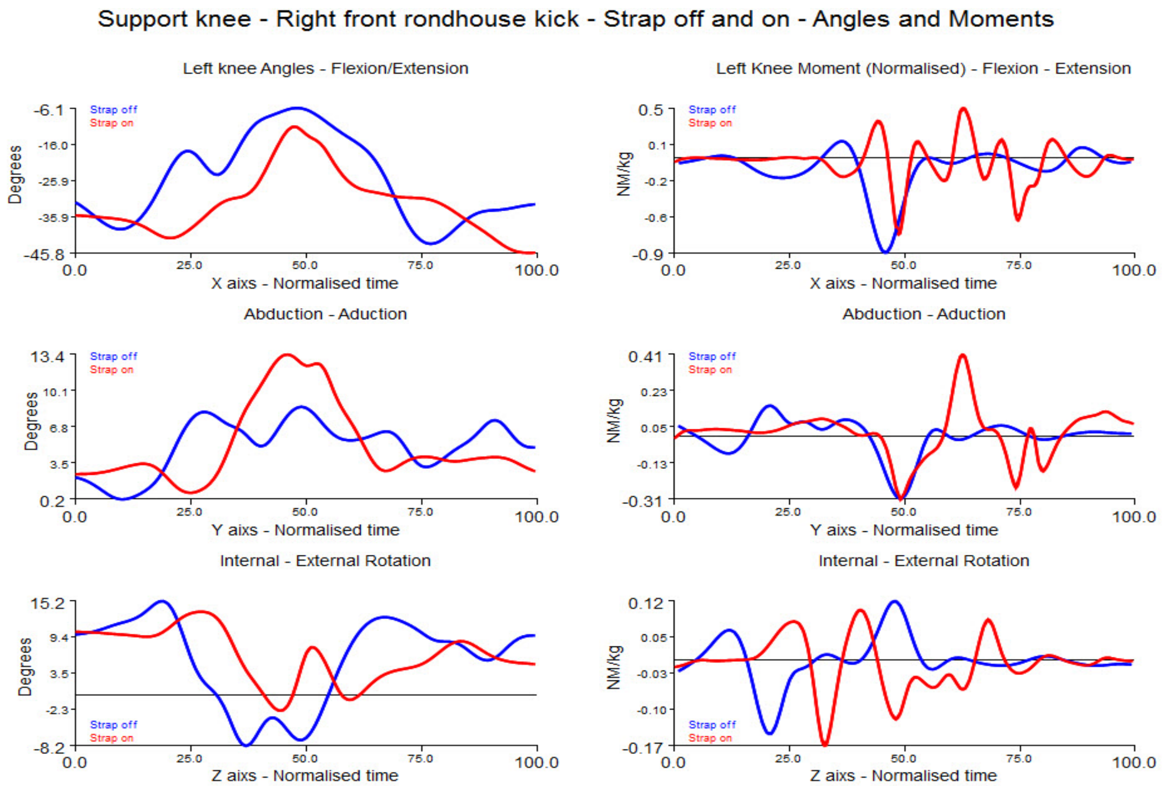

Figure 99 Support knee angles and moments

Chapter 7

7. Evaluation and Discussion

Over the years and with trying to gain entry to the Olympic Games Karate competition rules have changed in order to make things safer and more entertaining. This has reduced acute injuries and increased the variety of techniques used in competition, but it may also mean that the competition versions may be more stressful on the body and there is a history of chronic injuries in Western Karateka. To look at the stress put on the hip and knee joints during kicking in a traditional and competition manner this study was undertaken. Thirty kicks were performed by each of the 28 healthy Karate players, 15 kicks on each side. these covered the main Karate kicks performed in 3 modes, as previously explained in chapter 3. VICON system and two force plates were used to capture 3D motion and force data and Visual3D software was used to perform 3D inverse dynamics and calculate 3D angles and joint moments. Both the hip and knee for both the kicking and supporting legs have been analysed. Results exported to Excel files were organised then imported into SPSS software to do comparisons between the 3 modes for each kick and for each joint and all three axes.

7.2 Statistical Analysis

One-way ANOVA of the 3 modes of the kick was carried out for each kick for the peak joint angles and peak joint moments for each joint angle using SPSS software. Comparisons between the joints, hip and knee, and between kicks, front, side, round, back and reverse round, were not carried out as joint actions and loads are known to be different between kicks. An uncorrected significance level of 0.05 was chosen.

7.3 Summary of findings of the study

7.3.1 Front kick

11 significant differences were found, 4 on the abduction-adduction axis of two joints of the right and left hip angles and 7 were founded among the 3 modes on the flexion-extension, of left knee angle and abduction-adduction of left hip angle and moments Table 11.

The small angle extension of the support hip for all three modes gives the impression that the players did not try hard to get full extension, even in the step mode although the angle was bigger it was not very large. This led to a shorter distance of the kick than could be achieved and it may be that having a target would help with this in the future. Coaches and players should consider that important to reach full extension to get extra distance to reach the target. Kicking hip adduction - abduction angle for the step mode (-34°) was almost double the training (-17°) and competition (-16°) modes. This angle in these modes could be increased to almost that of step mode to get more advantage in the competition, but it may inhibit recovery and require a step forward so the trade-off between these factors should be kept in mind by coaches and players. Support knee flexion – extension angles on all three modes around (145°) were good to give balance to player body to kick in a very good position and allow mobility to recover after the kick, but kicking knee flexion – extension maximum angle was (152°) which it means, the leg was not straight enough and did not give full distance (see Table 9 and Table 10). There was a wide range of extension values, so players were reaching near full extension and those who don't, and their coaches could benefit from knowing others can do this. Of course, they also need to be able to do this safely.

Support hip moment of adduction – abduction for competition and step modes had the highest values of all kicks at 1.8 N.m/kg, and the competition was close at 1.7 N.m/kg, with a large standard deviation and these values could be considered risky moment values based on values from the literature (Leppänen et al., 2017; Stearns, Keim, & Powers, 2013; Duncan et al., 2005; Kernozek et al., 2005). For instance, Duncan et al. (2005), looked at cutting tasks, which are considered a high risk moves for non-contact knee injuries, and stated flexion – extension moments for the non-operative group had high values in all three tests of knee moments with values of around 1.21-1.46 N.m/kg, hip moments of around 1.15-1.27 N.m/kg and abduction-adduction hip moments of 1.15 N.m/kg – 1.57 N.m/kg. Kernozek et al. (2005) considered moments of females and males of about 1.6 N.m/kg as a value that may increase the risk of injury and also reported that abduction – adduction hip moment of 0.47 N.m/kg – 0.54 N.m/kg would be those considered to be in the safe range. The advice for coaches and players is to reduce this moment value by making some changes to the front kick performance, such as reduce the adduction – abduction and internal – external rotation moment. Kernozek el al. (2005) reported that abduction – adduction knee moment of 1.6 N.m/kg as high value that needed to be reduced to avoid ACL injury and Duncan et al. (2005) reported that knee abduction – adduction moment of 0.58 N.m/kg – 0.92 N.m/kg were in the range for mometnsnot to be reisky for ACL injury. Kicking hip moments values were not that high, just on step mode (1.2 N.m/kg) which is not considers as risky value according to studies that have looked at other movements with previously injured and uninjured subjects (Cabral et al., 2011; Duncan et al, 2005). Support knee moment value of competition mode, flexion – extension axis also had the highest moment value (1.8 N.m/kg) like support hip, at the same time the kicking knee moments were less than 1 N.m/kg for all modes. From these data it can be said that the support leg has highest moments values and that leads to it having more possibility of getting injured. Frank et al., considered knee extension moment of 1.1 Nm/kg and hip adduction 0.33 N.m/kg may increase the possibility of getting injured. Yu and Garrett, 2007 in their study found that an uninjured group had very low extension knee moments less than the injured group which was 0.12 N.m/kg for injured group. In addition Myer, 2007 considered the high-risk moment above 0.63 N.m/kg (Frank et al., 2013a; Myer, 2007; Yu & Garrett, 2007)

7.3.2 Roundhouse kick

4 significant differences were found, 2 on flexion-extension of the left hip angle of supporting leg and 2 on the right hip angle also on the supporting leg Table 14.

For the roundhouse kick step mode, support hip, flexion - extension angle (58°-60°) was higher than training and competition modes by about 10° and for abduction – adduction angles the step mode was also slightly higher. Maximum angles of kicking hip flexion - extension were generally higher (70°) on all modes (see Table 12 and Table 13), but Taekwondo maximum kicking hip angle was much bigger (113°) and internal – external rotation was bigger (39°) (See Table 36). Maximum abduction – adduction angle was generally similar (50°) that is good enough to kick fast and with an accurate kick (See Table 12 and Table 13). However, by making comparison between Karate roundhouse kick angles and Taekwondo roundhouse kick in kicking hip and support hip angles the

Taekwondo kicks are better in terms of range and reach. This may be due to either the higher performance level of the Taekwondo players or due to Taekwondo being more kick dominated. Taekwondo maximum kicking hip flexion and maximum support hip angles were similar but by comparing adduction - abduction angles, Taekwondo was higher (81°) (see Table 28). It may be that some of the kicking methods of Taekwondo would improve Karate kicking performance, but this would have to be looked at within the limitations of the different rules. The different rules include that in Karate some level of form is required in the score and in Taekwondo hard contact to the protective equipment can be made so they may be able to reach further and use the impact to aid recovery whereas the Karate must control and recover the technique themselves.

Roundhouse knee angles; maximum support knee angles were (162°) bigger than maximum kicking knee angles (135°) in all modes (see Table 12 and Table 13) and larger than the support leg during the front kick. This being larger than in the front kick even though in both kicks legs are instructed to stay bent can be down to round kicks being aimed to the head here and do helping with height. But a fully straight leg would be more prone to injury if there was force back through the body from impact and causing loss of balance, so it should be too straight even when kicking high. For the kicking leg for correct safe technique Karate players in their training (snap or pull the foot back from the target just as contact would be made. This leads to more control of the kick and is safer for the opponent, but also allows the kicker to recover away from the opponent if there is no score otherwise they may open themselves up to punches as they come forward too far or hit them on the back if overstretching. Comparing to Taekwondo roundhouse kick angles, the maximum kicking knee angle of Taekwondo (179°) almost full extension is much bigger than Karate roundhouse kick. Also, the same thing with maximum support knee angles (178°) it is much bigger than Karate support hip angles (see Table 28). A before in the discussion above differences between the two-martial arts, very few punches score in Taekwondo and none to the head so closing after a kick is not such a risk, or the mean values for Karate knee angles and just that of one Taekwondo player.

Roundhouse kick had the second highest moment (1.7 Nm/kg) on the support hip abduction – adduction), and flexion – extension has slightly large value (1.5 Nm/kg) but a smaller value on maximum kicking hip moment (0.8 Nm/kg) (see Table 12 and Table 13). Comparing Karate hips moment with Taekwondo hips moments the results were the opposite, Taekwondo maximum support hip moment had smaller value (0.9 Nm/kg) on flexion - extension and maximum kicking hip moment has greater value (1.9 Nm/kg) on abduction – adduction (see Table 29 and Table 37). These results give clear image, how Karate players depend on support leg to do their kicks, but Taekwondo depend on the kicking leg. So, from that the Karate players should focus on support leg to get best techniques and Taekwondo should focus on the kicking leg to get best techniques. It may be some aspects could be transferred between sports but again it must be considered within the rules of the sport. Both may have to be careful with high moment value when they are doing the full power kick which means more pressure on their hip and knee as in the literature review (Cabral et al., 2011; Cleather, Goodwin, & Bull, 2013; Lim, Hinman, Wrigley, Sharma, & Bennell, 2008). One thing to consider is that the higher and possibly stronger round kicks from Taekwondo had lower support leg moments and this seems to be from the kick having more of a jump or aerial phase during the kick than the Karate round kicks, even when stepping. This would reduce the moments at the support leg as weight is not supported during the main extension of the kick, but it makes the start phase of the kick from stationary take longer, which can be masked in competition, but also makes recovery away from the opponent if the kick fails very difficult.

7.3.3 Side kick

4 significant differences were found, 2 on flexion-extension of the right hip angle of kicking leg and 2 on the internal-external rotation of left knee moment of supporting leg Table 17.

Side kick, support hip angles, the flexion – extension axis, step mode was slightly higher than other two modes, (72°) and adduction – abduction axis angles were about (40°-50°) on all modes. Also, internal external rotation angles were about (21°-25°). The kicking hip flexion-extension axis in training and competition modes were very similar about (72°) and bigger than step mode at (51°-60°) as the step mode focussed on making a longer distance rather than getting higher as training and competition modes were. Side kick highest moment on support hip, flexion – extension (1.5 N.m/kg) in competition and step modes was high. The second highest moment in side kick was on the support hip, adduction – abduction (1.4 N.m/kg) in step mode. Highest moment on the support hip, internal – external rotation was (1.3 N.m/kg) on the step mode. Highest moment on the kicking hip moment was (0.8 N.m/kg) on the step mode. Support knee highest moment was (1.1 N.m/kg) and adduction – abduction highest moment was just (0.8 N.m/kg) Internal – external rotation moment was very small on all axes all modes (0.4 N.m/kg) and under. Kicking knee highest moment for all modes all axes was (0.3 N.m/kg) and under. Side kick has a risk on competition and step modes on flexion – extension, that should be reduced by coaches and players to avoid potential injuries.

Kicking hip and kicking knee angles need to be greater to get more chance to kick higher and further, and players and coaches should focus on this in their training (see Table 15 and Table 16). In the training and competition modes they focussed on not just hitting towards the mid body but going to the head. The side kick is only really scored to the body in competition but is practiced by those with good flexibility to head height and above in basic training. It is also difficult to recover a well extended side kick backwards, so this could be one reason why basic training has people kicking higher; they can stretch the kick but recover without falling forward. Making sure there is a transition of technique where the side kick is used for distance as in the step mode here would be something to be aware of when learning to apply side kicks in competition

7.3.4 Hook kick

6 significant differences were found, 4 on the flexion-extension of left knee moment and right knee moment on kicking and support leg and 2 on the internal-external rotation of right hip moment of kicking leg Table 20.

Hook kick flexion – extension angles in the step mode has the largest angle (81°), with all modes having angles between 70°- 81° which were bigger than kicking hip angles of between 55°-61°. The kicking hip needs a bigger angle to get better kick in all modes, that what should coaches, and players focus on. Abduction – adduction (about 45°) and internal – external rotation (about 25°) on both support hip and kicking hip similar angles values on all modes. Support knee flexion – extension angles (160°-168°) were bigger than the kicking knee angles (128°-142°). Again, should the coaches and players training to use bigger angles on the kicking knee to reach the target and better way. Abduction – adduction angles were small and similar about (7°). Also, internal – external rotation angles were similar (14°-20°) on all modes. which it is good for the knee. (see Table 18 and Table 19). To improve the kick the hip and knee angles should be bigger as it would be helpful to get more distance to reach the target from a safer distance, and get the foot higher to reach the head of the other competitor. The kicking knee angle may need to stay relatively flexed compared to the round kick as it commonly goes around the guard or block by passing the knee over the hand guard the kick the head which is not usually done with the round kick. As the knee extension cannot be used for distance then it will be easier when the player has more flexibility and strength at the hips.

The highest hook kick moment was on the support hip during step mode, for internal – external axis (1.7 N.m/kg) and it is the highest internal external moment on all kicks modes. Second highest moment was on the flexion – extension (1.5 N.m/kg) also on step mode for the support hip. Abduction adduction moments on all modes was very similar about (1.1 N.m/kg).. The kicking hip had much less flexion – extension moments on all modes about (0.4 N.m/kg - 0.9 N.m/kg). Abduction – adduction moments and internal – external rotation moments on all modes about (0.1 N.m/kg – 0.6 N.m/kg) (see Table 21 and Table 22).

The highest value being on hip internal external rotation is a novel to this kick as a large moment about this axis doesn't occur in other kicks. The need for the hook action to be controlled from the pivoting on the support leg is made very clear from this result. That this large moment for internal external rotation is unique to this kick indicates it needs its own specific training to be good at this kick and it isn't just a variation of another kick. This is often taught as a combination of two other kicks, but the transition to get the hook action to come backwards across the body will need specific conditioning even if developed from other kicks as they don't have these high moments

7.3.5 Back kick

18 significant differences were found, the highest number of significant differences among the kicks modes. 6 on the X, Y and Z axes of the left hip angle of the support leg, also, 6 on the X, Y and Z axes of left knee angle as supporting leg and 4 on the Y and Z axes of right hip angle as kicking leg Table 23.

Back kick, support hip has the highest flexion – extension angle on step mode (81°) and at the same time support hip angles of 73°-81° were bigger than the kicking hip angles of 50°-65°, here where should coaches and players training more to get more stretch on kicking hip to develop kicking skills. Highest adduction abduction angle was on the support hip, step mode (44°) and it is bigger than highest kicking hip angles (34°). Internal - external rotation highest angle for support hip (34°) bigger than the highest kicking hip angle (24°) all modes. Highest support knee flexion – extension angle (160°) bigger than highest kicking knee angle (138°), here needs to make the kicking knee angle bigger develop back kick and the coach and players should be aware of it.

Abduction – abduction angles on both support knee and kicking knee for all modes were similar (5°-8°) which it good for knee safety condition. Internal – external rotation angles on both support knee and kicking knee for all modes were similar (12°-20°) (see Table 21 and Table 22)

Back kick highest moment was on the support hip, competition mode, flexion – extension axis (1.5 N.m/kg), highest moments of adduction - abduction was (1.0 N.m/kg) on step mode. Internal – external rotation has second highest moment (1.4 N.m/kg) on step mode of support hip. Kicking hip moments was small about (0.3 N.m/kg 0.5 N.m/kg) on all modes. From that information, the highest moment should be reduced by doing some change on the back-kick technique by coaches and players. Highest moment of support knee was (1.3 N.m/kg) on flexion extension, training and step modes. Adduction – abduction highest moments was (1.0 N.m/kg) on training and competition modes. Highest Internal - external rotation moment was (0.5 N.m/kg) on step mode. Highest kicking knee moment was (0.8 N.m/kg) on training mode (see Table 21 and Table 22) Back kick has the highest significant differences among kicks modes, most of them on the support leg hip and knee angles, the maximum moment on support hip was 1.5 N.m/kg which as previously discussed is a high value. The change of kick direction line (180°) makes it the most difficult of karate kicks to apply properly and the risk when using it is high by opening the player's back, even if for a very short time. The body rotation and the linear kick at the same time, in less than a second, can be very risky and with the differences between modes it would seem the basic practice and application are very different. Whether this means the basic practice should be looked at to make it more applied to competition or more skill is needed before trying to apply needs further analysis. Couches and players should focus on make the all training modes very similar as possible as the can to get better result on the competitions.

7.3.6 Highest joints loading of karate kicks

Karate kicks results in terms of research questions showed some risky joint loading in some axes, on the support leg. They are high compared to non-kicking studies where these values are considered high (Kristianslund, Faul, Bahr, Myklebust, & Krosshaug, 2014) (Stearns & Pollard, 2013).

Table 40.

Table 40 Highest joints loading for each karate kicks

No	Kicks names	Kick mode	Joint name	Axis	Loading value
1	Front kick	Competition Competition Step	Support hip – left Support knee - left Support hip - left	Y X X	1.8 N.m/kg
2	Roundhouse kick	Step	Support hip - right	Y	1.7 N.m/kg
3	Side kick	Step Competition Step	Support hip – left Support hip – right Support hip – right	X X X	1.5 N.m/kg
4	Hook kick	Step	Support hip - right	Z	1.7 N.m/kg
5	Back kick	Competition	Support hip - left	X	1.5 N.m/kg

The front kick had the highest joint loading of all the Karate kicks at 1.8 N.m/kg in two kicks modes, competition mode, right front kick, left support hip, abduction-adduction axis, left support knee, flexion-extension axis and step mode, left support hip, flexion-extension axis.

Roundhouse kick highest joint loading was 1.7 N.m/kg in one mode, step mode, right support hip, abduction-adduction axis.

Side kick highest joint loading was 1.5 N.m/kg in two modes for one axis, step mode, left support hip, flexion-extension axis, competition mode, right support hip, flexion-extension axis and step mode, right support hip, flexion-extension axis.

Hook kick highest joint loading was 1.7 N.m/kg in one mode, step mode, right support hip, internal-external rotation.

Back kick highest joint loading was 1.5 N.m/kg in one mode, competition mode, left support hip, flexion-extension axis.

7.3.7 Highest joints, axis and modes loading of each karate kicks

For more details about karate kicks joints loading for each joint see Table 41.

Table 41 Highest joints, axes and modes loading for each karate kicks

No	Kicks names	Joints names	Kick mode	Axis	Loading value N.m/kg	Y or X Axis Loading value N.m/kg
1	Front kick	Supporting hip - left Support knee – left	Competition Step	Y	1.8	X=1.7
		Kicking hip – right	Step	X	1.2	0.9
		Supporting knee – right	Competition	X	1.8	0.8
		Kicking knee – right	Step	X	1.0	0.1
2	Roundhouse kick	Supporting hip – right	Step	Y	1.7	X=1.5
		Kicking hip – right & left	Step	X & Y	0.8	0.8
		Supporting knee – left & right	Training and Competition	X & Y	1.0	1.0
		Kicking knee – right	Step	X	0.6	0.3
3	Side kick	Supporting hip – left	Competition and Step	X	1.5	1.4
		Kicking hip – right	Step	X	0.8	0.5
		Supporting knee – right	Training	X	1.1	0.7
		Kicking knee – right	Step	X	0.3	0.3
4	Hook kick	Supporting hip – right	Step	Z	1.7	X=1.5 Y=1.1
		Kicking hip – right	Competition	X	0.9	0.4
		Supporting knee – left	Training and Competition	X	1.3	1.0
		Kicking knee – right	Step	X	0.4	0.3
5	Back kick	Supporting hip – right	Competition	X	1.5	0.9
		Kicking hip – right & left	Competition and Step	X	0.5	0.4
		Supporting knee – right	Training and Step	X	1.3	1.0
		Kicking knee – right	Training	X	0.8	0.2

7.3.7.1 Highest joints loading for karate kicks

1. Supporting hip: Left support hip, the front kick has the highest support joints loading at 1.8 N.m/kg.
2. Kicking hip: Right kicking hip, the front kick has highest kicking hips joint loading at 1.2 N.m/kg.
3. Support knee: Left support knee, the front kick has highest supporting knees joint loading at 1.8 N.m/kg.
4. Kicking knee: Right support knee, the front kick has highest kicking knees joint loading at 1.2 N.m/kg.

7.4 Summary and Conclusion

7.4.1 Purpose of study

There are many people who suffer from various chronic complaints of the lower limbs in karate. Chronic injuries are due to repetitive training or from minor non-contact injuries repeated intermittently. One question is it the case that the more competition based training kicks are more of an injury risk in terms of loading and poor performance leading to higher more potentially injurious loads?

The aim of this PhD study was to establish joint loading at the hips and knees of kicking training practices in both a basic fashion and a competition type fashion. This was performed on a wide range of adult karateka from the age range where the majority of competitors come from. It was hypothesised that the competition mode of training will have higher loading to the joints and thus could be more injurious if the karateka is not suitably conditioned.

7.4.2 Answers to Research Questions

Q1. What are the differences among karate kick performance modes in terms of joint moments and peak angles of the hip and knee for both the kicking and support legs?

All the absolute highest joint loading was during the front kick even though it is considered a safer kick due to it being linear kick due to the loads being found on the support leg. Traditionally the support foot and leg during the front kick is not meant to move, where, as in the other kicks it should be actively moved to drive the kick or body action into the kick. If this turning motion is done correctly and not impeded, such as by a high friction mat or an uneven surface, then the load should be spread over a longer period than the front kick staying still and resisting a turning motion at ranges of flexibility. As the kicks were performed on force plates we do not know what the effect of high friction mats or an uneven surface might be on the performance of the kicks with foot motion.

Over and over results from these Karate kicks indicate that it is the supporting leg that is most at risk due to it being planted on the ground supporting weight and resisting or providing motion. Unlike what has commonly thought the faster and less technically correct competition step style kicks with the body moving more and less weight on the support leg during the kick may be less risky to the supporting leg. However, it means motion for the kick starts earlier in some cases and then to land after the kick the supporting leg has an extra load, but this means the peak loads are lower and do not seem to be at extreme joint ranges. At the same time kicking leg joints have lower moment values in all five main karate kicks for all modes. It should be noted that for the Taekwondo athletes who performed their kicks much more as either actual jumping kicks or with a small jump component mainly had their highest loads in the kicking leg joints.

Q2. How are hip and knee joint moments and peak angles affected by kicking with the right or left side?

The results appear in clear view that the right-side kicks have high moment value than the left side. Right knee joint has 9 of the highest moments, the right hip has 8 of the highest moments but by looking to the left side; left knee joint has just 3 of highest moments and left hip has just 4 of highest moments Table 41. It is right that most players are good or even excellent on right leg when they performed kicks but at the same time, that does not mean they are dominant right? As no one said that he or she dominant right or left, that partly due to traditional training forcing a right side dominant training structure. There are a similarity and some differences on the peck angles of kicks hips and knees joints of right and left sides. Kicking hip peak angle; the similarity was found on the roundhouse kick, side kick and hook kick and back kick except front kick which it has differences in two modes; training and competition modes. Kicking knee peak angles; also, similarities were found in; roundhouse kick, hook kick and back kick and the differences were found a front kick and side kick. These similarities related to the training on both side which it is part of the main target of all coaches and players due to use both legs on competition to win and any player good in one side right or left, that is means he has a weakness point can other competitor use it against him.

Q3. Can the methods and analyses developed be used to study two injured elite athletes?

The knowledge gained from the karateka analysis was helpful in interpreting the angle and moment data. The injured subjects after six months of rehabilitation became strong enough to compete but in each case, had a dealed with his injury in a different way. The lower back case, made some change to his kicks between right and left sides to reach his target. The left knee injured subject, got an advantage from the strapping on the left knee. The strapping made him more confident to kick and get to his target with some changes on the left and right hips and knees, larger angles and moments with the strap, so it was acting as a confidence enhancer allowing him to try harder with the strapping on. Long term this may lead to more damage to the knee so he needs to strengthen the knee, so he is confident to get to the same level of kicking without the strap and then it will be the knee musculature strength that supports the joint, not the strapping, and so should make it safer long term. The V3D models used had to be adapted from the Karate V3D model and due to other kicks also being used by the Taekwondo players the case studies needed some changes to analysis. However, the principles learnt even if the norms for the karate joint results could not be directly applied, were successful in allowing the Taekwondo analysis.

Q4. Is it useful to make a database of karateka's kicks for the main five kicks?

By searching the papers published over the years, the researcher did not find any database, or multiple kicks from different studies that could be made into one. So, it is very useful that the database of the main five karate kicks has been made with a wide range of subjects and resulting values. Although there was a range of angles and moments the overall patterns and magnitudes of the values were similar, so it can act as a starter for doing more studies on karate kicks performance. It was found that there were clear characteristic patterns of each kick and that it was possible to find key significant differences between ways of executing the same kick. It was also possible to find qualitative differences in the time history of the kicks in different modes. Although quite a range of joint angles and moments were found the group patterns were maintained for the healthy karateka and so injured players could be compared against these in the future to see if they deviate. Karateka thought to be at risk could be compared to see if they are at the extremes or outside the ranges found here. It could be very useful to use this database to make comparison between joints moments of Karate and other martial arts such as Taekwondo, Kickboxing, kung Fu and Capoeira. The single biggest take-home message to deliver to coaches and players is that the supporting leg joints have the highest loading, so extra attention should be paid to these in training and competition.

In this study there was a limitation of work depended on the time available and the range of players that have been tested, it would be better if the number of participants increased with more kicks. The competition modes were still limited as they started from a neutral set up position and it would be good if doing the same kicks from other start positions, such as cutting side, switch direction and kicking on the focus pad or fast kick pad, could be tried. Also, the competition style kicks were also not done in an actual competition so there may be further differences and exaggeration of the differences found here. The methods used here for the Karateka and on the Taekwondo players indicate that extra work with injured Karateka would be useful as it was possible to determine injury related aspects of the Taekwondo players even without a database of non-injured values. Combining measures of injured or injury players and comparing to the healthy rangers would help understanding injuries or how much they are affecting performance.

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Appendix

1- Phd Karate study outline

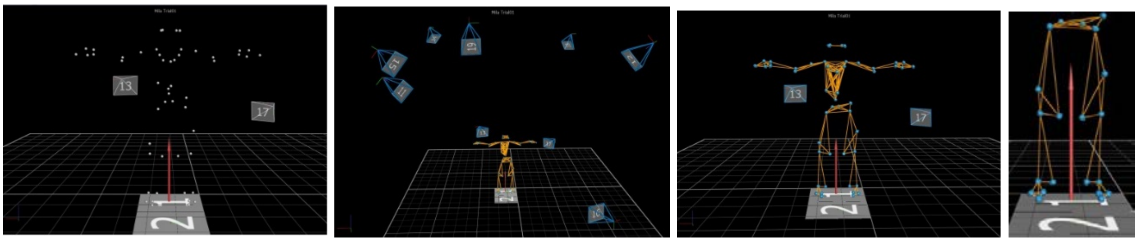
Dear Sir/Madam

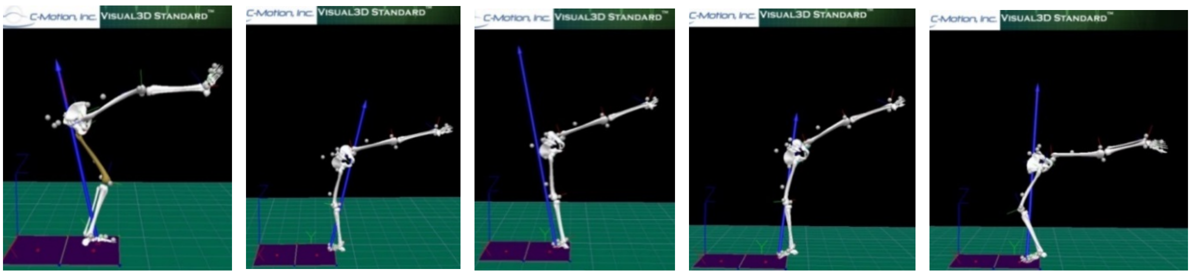
I am PhD student in Sport Science at Loughborough University. At the same time, I am teaching karate at the Loughborough University Shotokan club. I have black belt 4th DAN and was an Iraqi national team player 1998-2004 (60kg and 65kg) after that I became a coach from 2005-2011. In 2011 I came to London and 2012 in Manchester to studying English language courses, 2013 I started my PhD under Supervision of Dr. Matthew Pain Reader in Biomechanics and 5th DAN Karate.

I am looking for brown & black belt karate players (men and women) who have good karate kicking skills (Preferably those who participate, or have participated, in competitions) to collect movement data on their kicks. Under 18-year olds have to have one their parents' consent and the parent or coach come with them for them to take part.

The test is make the players perform the five main kicks in karate (Mae geri, Mawashi geri, Yoko geri kekomi, Ura mawashi geri and Ushiro geri) in four or five ways and capture them in the biomechanics lab. 3D biomechanics cameras will be used to analyse the kicks to measure hip and knee joint motion and calculate loads on the joints. The aim is to help understand long term injuries better.

Each person's test will take about 60 min.





Riyadh Al-Saeed - PhD student/Loughborough University r.alsaeed@lboro.ac.uk

<u>Subjects volunteering agreements to take part in this study</u>

Subject full name :

Age :

Sport : Karate

Sign :

Date :

2- SSEHS Risk Assessment 2014

Risk Assessment **SSEHS/RA-XXX**

Hip and knee joint loading of karate players during training and competition: biomechanics and rehabilitation. Mr Riyadh Alsaeed

Date	Assessed by (name and signature required)	Checked / Validated (delete as appropriate) by (name and signature required)	Location	Version no.	Review date
17 /7/ 2014	Riyadh Alsaeed Dr Matthew PAin		L.017 Biomechanics Laboratory (Wavy Top Building)	001	Day/ Month/ 2015

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Likelihood*	Severity**	Risk rating***	Result (T,A,N,U)	Additional controls required to adequately control the risk
Performing karate kicks and stances	Performing dynamic movements	Subjects, muscle strain or slip and fall causing bruising	Only skilled athletes will be used where this is part of their normal training and area will be free of trip or slip hazards.	3	2	6	A	
VICON Motion Analysis	Reaction to reflective markers	Subjects allergic reaction	Health screen questionnaire asks if any known allergies, reactions etc.	3	1	3	T	

Risk Assessment

SSEHS/RA-XXX

Hip and knee joint loading of karate players during training and competition: biomechanics and rehabilitation. Mr Riyadh Alsaeed

Activity	Hazard	Who might be harmed and how	Existing measures to control risk	Likelihood*	Severity**	Risk rating***	Result (T,A,N,U)	Additional controls required to adequately control the risk

Key: T= trivial risk; **A** = adequately controlled, no further action necessary; **N** = not adequately controlled, actions required; **U** = unable to decide (further information required)

***Likelihood**

5 Very likely – risk will occur repeatedly. To be routinely expected once every 20 – 100 operations, possibly weekly or more frequently if done regularly.

4 Likely – will occur several times a year so does not surprise when it happens.

3 Possible – may occur sometimes. Likely to occur once a year.

2 Unlikely – but may occur perhaps once in every 10 to 100 years.

1 Very unlikely to occur. Likelihood approaching zero.

*** **Risk rating = Likelihood x Severity**

****Severity**

5 Fatality – death of an employee or multiple fatalities.

4 Major injury – permanent disability, serious amputation e.g. Loss of hand.

3 Medium injury e.g. Bad scald, or burn, fracture, minor amputation, temporary injury, loss of consciousness. Reportable to the HSE as a three day lost time (employee unavailable for normal work for over 3 days) or serious injury.

2 Minor injury – More severe cut, sprain, strain, burn, etc. where return to work is not possible after treatment. It may be lost time less than 3 days.

1 No injury or very low injury – scratch, bruise, knock, minor cut, needle stick etc. where the injury allows return to work after first aid treatment – no lost time.

3- Ethical Clearance Checklist draft 28 March 2014 Riyadh & MTGP

Ethics Approvals (Human Participants) Sub-Committee

Loughborough University

Ethical Clearance Checklist

Has the Investigator read the 'Guidance for completion of Ethical Clearance Checklist' before starting this form?	Yes

Project Details

1. Project Title: Inverse dynamics analysis of karate kicks

Applicant(s) Details

2. Name of Applicant 1: Riyadh Alsaeed	10. Name of Applicant 2: Dr. Matthew Pain
3. Status: PGR student	11. Status: Staff
4. School/Department: Sport, Exercise and Health Science	12. School/Department: Sport, Exercise and Health Science
5. Programme (if applicable): Biomechanics	13. Programme (if applicable): Biomechanics
6. Email address: r.alsaeed@lboro.ac.uk	14. Email address: M.T.G.Pain@lboro.ac.uk
7a. Contact address: Sir John Beckwith Center for Sport Room JB019.	15a. Contact address: UU107.
7b. Telephone number: 07438495865	15b. Telephone number: 01509 226327.
8. Supervisor: No	16. Supervisor: Yes
9. Responsible Investigator: No	17. Responsible Investigator: Yes

Participants

Positions of Authority

18. Are researchers in a position of direct authority with regard to participants (e.g. academic staff using student participants, sports coaches using his/her athletes in training)?	Yes†

Vulnerable groups

19. Will participants be knowingly recruited from one or more of the following vulnerable groups?	
Children under 18 years of age	No
Persons incapable of making an informed decision for themselves	No
Pregnant women	No
Prisoners/Detained persons	No
Other vulnerable group Please specify: Click here to enter text	No
If you have selected No to all of Question 19, please go to Question 23.	
20. Will participants be chaperoned by more than one investigator at all times?	Choose an item
21. Will at least one investigator of the same sex as the participant(s) be present throughout the investigation?	Choose an item
22. Will participants be visited at home?	Choose an item

Researcher Safety

23. Will the researcher be alone with participants at any time?	Yes
If Yes, please answer the following questions:	
23a. Will the researcher inform anyone else of when they will be alone with participants?	Yes
23b. Has the researcher read the 'guidelines for lone working' and will abide by the recommendations within?	Yes

Methodology and Procedures

24. Please indicate whether the proposed study:

Involves taking bodily samples (please refer to published guidelines)	No
Involves using samples previously collected with consent for further research	No
Involves procedures which are likely to cause physical, psychological, social or emotional distress to participants	No
Is designed to be challenging physically or psychologically in any way (includes any study involving physical exercise)	Yes#
Exposes participants to risks or distress greater than those encountered in their normal lifestyle	No
Involves collection of body secretions by invasive methods	No
Prescribes intake of compounds additional to daily diet or other dietary manipulation/supplementation	No

Involves pharmaceutical drugs	No
Involves use of radiation	No
Involves use of hazardous materials	No
Assists/alters the process of conception in any way	No
Involves methods of contraception	No
Involves genetic engineering	No

Involves testing new equipment	No

Observation/Recording

25a. Does the study involve observation and/or recording of participants?	Yes
If **Yes**:	
25b. Will those being observed and/or recorded be informed that the observation and/or recording will take place?	Yes

Consent and Deception

26. Will participants give informed consent freely?	Yes

Informed consent

27. Will participants be fully informed of the objectives of the study and all details disclosed (preferably at the start of the study but, where this would interfere with the study, at the end)?	Yes
28. Will participants be fully informed of the use of the data collected (including, where applicable, any intellectual property arising from the research)?	Yes

29. Will participants be children under the age of 18 or participants who are incapable of making an informed decision for themselves? **If you have selected No, please go to Question 30. If you have selected Yes, please answer the following:**	No
a. Will consent be obtained (either in writing or by some other means)?	N/A
b. Will consent be obtained from parents or other suitable person?	N/A
c. Will they be informed that they have the right to withdraw regardless of parental/guardian consent?	N/A
d. For studies conducted in schools, will approval be gained in advance from the Head-teacher and/or the Director of Education of the appropriate Local Education Authority?	N/A
e. For detained persons, members of the armed forces, employees, students and other persons judged to be under duress, will care be	N/A

taken over gaining freely informed consent?	

Deception

30. Does the study involve deception of participants (i.e. withholding of information or the misleading of participants) which could potentially harm or exploit participants?	No
If **Yes:**	
31. Is deception an unavoidable part of the study?	Choose an item
32. Will participants be de-briefed and the true object of the research revealed at the earliest stage upon completion of the study?	Choose an item
33. Has consideration been given on the way that participants will react to the withholding of information or deliberate deception?	Choose an item

Withdrawal

34. Will participants be informed of their right to withdraw from the investigation at any time and to require their own data to be destroyed?	Yes

Storage of Data and Confidentiality

35. Will all information on participants be treated as confidential and not identifiable unless agreed otherwise in advance, and subject to the requirements of law?	Yes
36. Will storage of data comply with the Data Protection Act 1998?	Yes
37. Will any video/audio recording of participants be kept in a secure place and not released for any use by third parties?	Yes
38. Will video/audio recordings be destroyed within ten years of the completion of the investigation?	Yes
39. Will full details regarding the storage and disposal of any human tissue samples be communicated to the participants?	Yes
40. Will research involve the sharing of data or confidential information beyond the initial consent given?	No
41. Will the research involve administrative or secure data that requires permission from the appropriate authorities before use?	No

Incentives

42. Will incentives be offered to the investigator to conduct the study?	No
43. Will incentives by offered to potential participants as an	No

inducement to participate in the study?	

Work Outside of the United Kingdom

44. Is your research being conducted outside of the United Kingdom?	No
If **Yes**:	
45. Has a risk assessment been carried out to ensure the safety of the researcher whilst working outside of the United Kingdom?	Choose an item
46. Have you considered the appropriateness of your research in the country you are travelling to?	Choose an item
47. Is there an increased risk to yourself or the participants in your research study?	Choose an item
48. Have you obtained any necessary ethical permission needed in the country you are travelling to?	Choose an item

Risk Assessment

49. Has a risk assessment been carried out to ensure the safety of the researcher and participants involved in the study?	Yes

Information and Declarations

Checklist Application Only:
If you have completed the checklist to the best of your knowledge, and not selected any answers marked with an * or †, your investigation is deemed to conform with the ethical checkpoints. Please sign the declaration and lodge the completed checklist with your Head of Department/School or his/her nominee.

Checklist with Additional Information to the Secretary:
If you have completed the checklist and have only selected answers which require additional information to be submitted with the checklist (indicated by a †), please ensure that all the information is provided in detail below and send this signed checklist to the Secretary of the Sub-Committee.

Checklist with Generic Protocols Included:
If you have completed the checklist and you have selected one or more answers in which you wish to use a Generic Protocol (indicated by #), please include the Generic Protocol reference number in the space below, along with a brief summary of how it will be used. Please ensure you are on the list of approved investigators for the Generic Protocol before including it on the checklist. The completed checklist should be lodged with your Head of

Department/School or his/her nominee.

Full Application needed:
If on completion of the checklist you have selected one or more answers which require the submission of a full proposal (indicated by a *), please download the relevant form from the Sub-Committee's web page. **A signed copy of this Checklist should accompany the full submission to the Sub-Committee.**

Space for Information on Generic Proposals and/or Additional Information as requested:

All data collection methods to be used and activities to be undertaken fall under G00-P1.

The responsible investigator is a member of academic staff and some subjects will be university students. However, these will not be recruited directly by the RI but by the research student.

For completion by Supervisor

Please tick the appropriate boxes. The study should not begin until all boxes are ticked.

☒ The student has read the University's Code of Practice on investigations involving human participants

☒ The topic merits further research

☒ The student has the skills to carry out the research or are being trained in the requires skills by the Supervisor

☒ The participant information sheet or leaflet is appropriate

☒ The procedures for recruitment and obtaining informed consent are appropriate

Comments from supervisor:

Click here to enter text.

Signature of Applicant: Riyadh Alsaeed

Signature of Supervisor (if applicable): Dr. Matthew Pain