Validity of accelerometer data in field team sports activities

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Contents

Preface

This is a web-friendly version of my Honours thesis, converted to an online format using the `bookdown` package in R.

The thesis was submitted in 2009 in partial fulfillment of the requirements for the Bachelor of Exercise and Sport Science (Honours) degree. The degree was conferred to me in 2010 by the School of Exercise and Nutrition Sciences, Deakin University, Australia.

The research team produced a conference paper from this study, which was presented at the 2010 International Conference on Biomechanics in Sport:

> Tran, J., Netto, K., Aisbett, B. and Gastin, P. 2010, Validation of accelerometer data for measuring impacts during jumping and landing tasks, *in Proceedings of the 28th International Conference on Biomechanics in Sports (2010)*, International Society of Biomechanics in Sports, Konstanz, Germany, pp. 1-4. **(link to full text)**

Modifications from the originally submitted thesis have been made as follows:

- Section ordering has been altered to take adavntage of the web format and produce a user-friendly document for better readability and easier navigation.
- In-text citations have been altered to an author-date style.
- No table of contents page has been rendered in this web format, since the left sidebar navigation inherently provides this.
- Most of the front matter, such as lists of table and figure captions, have been moved to the end of the thesis as part of the Appendices.

Abstract

Background. The application of accelerometers in sport and physical activity is widely reported and continues to grow rapidly. These devices are appealing for field use as they are small, lightweight, unobtrusive, provide a direct measure of accelerations in up to three directions, and can log data at high speed and store data over long periods of time. Accelerometers are often used in sports as an indirect measure of force during high intensity impact movements, usually occurring over a short period of time. Despite their pervasiveness in applied sports science and sports research, little is known about the validity of accelerometers in these settings. The current literature addressing accelerometer accuracy for quantifying team sport-related movements is scarce, and is not externally valid to the application of such technology in team sport contexts. Therefore, the purpose of this study was to address the following question: "In the context of their application in the field, do accelerometers provide an accurate measure of impact events that commonly occur in field team sports?"

Methods. Thirteen healthy adults (7 males and 6 females, age: 23.38 + 3.43 years, height: 172.6 + 10.6 cm, mass: 69.3 + 10.0 kg) were recruited for this study. Due to technical errors arising from equipment malfunction and subsequent data loss, the final sample was reduced to ten participants (age: 22.8 + 2.6 years, height: 174.8 + 9.2 cm, mass: 72.0 + 8.6 kg). Prior to data collection, each participant completed a familiarisation session to avoid any learning effects in relation to performance of the movement tasks. Following this, participants attended one 3.5 hour testing session, which was conducted in the Deakin University Motion Capture Laboratory. Participants were instrumented with one GPS-integrated triaxial accelerometer (SPI Pro, GPSports Pty Ltd, Australia) for all trials. Positional data for three reflective markers (one each to represent the movement of the monitor, pelvis, and left ankle) was recorded by the optical motion analysis laboratory cameras (Eagle-4, Motion Analysis, USA) for all trials, while a portable force plate (model ACG, Advanced Mechanical Technologies Inc., USA) was used during all jumping and landing tasks, to provide criterion measures for validation of two accelerometer variables (Y axis acceleration data, and vector magnitude calculated from triaxial data). The prescribed movement tasks were selected to replicate common field team sport movements. Each participant performed repeated trials of the movement tasks in the following order: drop landing (DLAND); countermovement jumping (CMJ); drop jumping (DJUMP); running (RUN); and cutting (CUT).

Results. *Force as the criterion measure:* Peak SPI_Y and SPI_VM values were significantly greater than VGRF/BW across the tasks. Moderate correlations ($r = 0.23 - 0.57$, $r2 = 0.05 - 0.32$; $p < 0.05$) were observed between the accelerometer variables and force for all jumping and landing tasks, except the second landing phase of the DJUMP task. Correlations were stronger in relation to VM values (average $r = 0.46$, average $r2 = 0.21$; $p < 0.05$) compared to when Y axis values were used (average $r = 0.38$, average $r2 = 0.15$; $p < 0.05$). Most %CVdiff values examining the Y axis acceleration data were below the acceptable limit of 20%, though DJUMP (2L) was slightly above this limit (%CVdiff = 21.1%). All %CVdiff values in relation to vector magnitude were all outside the acceptable limit. *Motion laboratory marker accelerations (at 60 Hz) as the criterion measures:* SPI_Y and SPI_VM peak acceleration values were significantly higher than all three markers, for all tasks. Mostly moderate to strong correlations ($r = 0.29 - 0.82$, $r2 = 0.08 - 0.67$; $p < 0.05$) were observed between the accelerometer variables and marker accelerations recorded during the jumping and landing tasks. However, correlations observed during the RUN and CUT tasks were sporadic. Aside from one extreme outlier, %CVdiff values calculated for both accelerometer variables were large and well above the acceptable limit. *Motion laboratory marker accelerations (at 120 Hz) as the criterion*

measures: SPI_Y and SPI_VM were significantly greater than peak acceleration values calculated for all three markers. However, correlations were rarely observed between peak accelerations measured during the DJUMP, RUN, and CUT tasks. Almost all %CVdiff values were considerably higher than the acceptable upper limit, for both accelerometer variables across all tasks. *Task and condition discrimination:* Both accelerometer measures were generally able to distinguish between conditions within a given task, except for the CUT task. In addition, both accelerometer variables were able to discriminate between jumping-based tasks (DLAND, CMJ, DJUMP) and running-based tasks (RUN, CUT).

Conclusions. The results of the present study suggest that accelerometers placed at the base of the neck, as they are commonly used in the field, do not provide an accurate measure of impacts experienced in the lower limbs during the performance of common team sport-related movements. This finding is primarily attributable to the distance of the monitor from the impact site, the effects of impact attenuation, and vibration of the monitor within its harness. Based on the results of the present investigation, it was concluded that accelerometer data was able to discriminate between jumping-based and running-based tasks. However, neither of the two accelerometer variables examined were sufficiently accurate to be used as indirect measures of peak force experienced on ground contact, or peak accelerations experienced at the ankle, pelvis, or base of the neck. Further investigation is recommended into the feasibility of different accelerometer placement sites and attachment methods (e.g., Velcro closures, adjustable straps), to minimize monitor vibration while addressing accessibility, athlete comfort, and safety factors in the context of team sports use.

Chapter 1

Introduction and Statement of Problem

1.1 Introduction

The application of accelerometers in sport and physical activity is widely reported and continues to grow rapidly. These devices are appealing for field use as they are small, lightweight, unobtrusive, provide a direct measure of accelerations in up to three directions, and can log data at high speed and store data over long periods of time (2, 21, 55).

Accelerometers are popular in physical activity interventions and research as they provide an objective measure of concurrent activity (2), allowing for the estimation of energy expenditure from recorded activity counts (12, 50). These monitors can also detect changes in duration and intensity of activity (25), and are capable of collecting and storing data over consecutive days (67). The use of accelerometers to estimate the energy cost of physical activity has been validated for level-ground and treadmill walking and running, but tends to be less accurate when assessing other lifestyle activities, such as those requiring predominantly upper body movements (73).

Increasingly, sports scientists are using accelerometers to assess sporting performance and physical demand (10), particularly in field team sports such as Australian football (10, 22), soccer (10), rugby union and rugby league (10, 35). Of particular interest in the team sport environment is the measurement of impacts (generally high-intensity movements or gameplay events involving a rapid change in acceleration). Accelerometers have also been used to measure injuries (8, 18, 32), test the quality of protective sporting equipment (11, 38, 65), and examine biomechanical movement patterns associated with physical activity (68), and prior injury (16). In these settings, accelerometers are used to provide an indirect measure of force, based on the relationship between force and acceleration as proposed by Newton's Second Law of Motion (33). However, despite their popularity, relatively few studies (21, 25, 39) have examined the validity of accelerometers for quantifying sporting movements.

The current validation literature is scant, providing mixed support for accelerometer use as an indirect measure of impacts. The inconsistency across this body of research is primarily attributable to considerable differences in study design, including differences in participant characteristics, activities completed, accelerometer placement, and data analysis. Moreover, the scope of the literature in this area has limited relevance to the elite sports environment, as many of these factors are not representative of the manner in which accelerometers are used in field team sports. Further, a broad range of field team sports activities have yet to be investigated in relation to accelerometer validation.

Given that their use in elite field team sports continues to grow rapidly, more research is required to examine the validity of accelerometers as they are used in this context. This will allow us to answer the question, "How accurate is a triaxial accelerometer for quantifying field team sports movements?" Until it is established that accelerometers provide true and consistent measures when assessing sporting movements, we cannot confidently draw conclusions on the data collected in these circumstances.

1.2 Aims

The aims of this study were:

1. To investigate the criterion validity of peak acceleration measures recorded by a triaxial accelerometer, using concurrently-measured peak force as the criterion measure, as assessed during team sport-related movement tasks.
2. To investigate criterion validity by comparing the peak acceleration measures recorded concurrently by a triaxial accelerometer and a high-speed infrared camera motion capture system, during team sport-related movement tasks.

This study examined one triaxial accelerometer that was integrated with Global Positioning System (GPS) technology. Specifically, a unit manufactured by GPSports (Canberra, Australia) was used, given the widespread use of these units in several elite field team sports (28).

1.3 Hypotheses

1. Peak accelerometer values will correlate strongly ($r > 0.80$) with peak force values, for all movement tasks.
2. Peak accelerometer values will correlate strongly ($r > 0.80$) with peak marker acceleration values (calculated from positional data recorded in a motion capture laboratory), for all tasks.
3. With regards to marker accelerations as the criterion measures, the strongest correlations will be observed between peak accelerometer values and peak accelerations of the marker positioned on the shoulder harness (top [TOP] marker). Correlations between peak accelerometer values and the peak middle [MID, representing the pelvis] and bottom [BOT, representing the ankle] marker accelerations will be weaker.

Chapter 2

Review of Literature

2.1 Introduction to accelerometer technology

A range of acceleration sensors exist, including strain gauge, piezoresistive, and capacitive (40), though the most common form of technology employed is the piezoelectric acceleration sensor (12, 40). These units utilize a piezoelectric element and a seismic mass within an enclosure (12). When the unit undergoes acceleration, the seismic mass causes the piezoelectric element to deform, causing displaced charge to build up on one side of the sensor, which generates a voltage signal that is proportional to the acceleration experienced by the unit (12, 66).

2.1.1 Acceleration data collection and filtering

Accelerometers measure acceleration, or the change in velocity over time (33, 72). This data is often reported in gravitational acceleration (g) values, where 1 g is equal to the acceleration of the body due to the force of gravity acting on it (-9.8 m.s-2) (12, 40, 72). Data may demonstrate positive acceleration or negative acceleration (more commonly referred to as "deceleration"). In physical activity contexts, data is often reported in activity counts, which are derived from accelerations through a process called "data filtering" (12). The manufacturer or user can define data cutoff points, such that all data within this range is given full weighting (e.g., 1 activity count = weighting of 1.0), and any data that falls outside this range, is given a lower weighting (less than 1.0) or is filtered out to reduce the number of counts that are not representative of the actual movement of interest (e.g., "activity" recorded if a unit shifts in its place) (7). In sporting environments, peak acceleration values corresponding with specific movement events are of greater interest than overall activity counts.

2.1.2 Accelerometer axes and orientation

Accelerometers can be classified as uniaxial, biaxial, or triaxial. Uniaxial accelerometers measure acceleration in a single axis (when monitors are attached to human participants, this is usually aligned with the longitudinal axis, with respect to the ground) (50). Biaxial accelerometers measure acceleration in two axes (55, 75), but are not commonly used due to the emergence of more sophisticated triaxial configurations. Triaxial accelerometers measure acceleration in three axes (55), most commonly aligned with the sagittal, transverse, and longitudinal axes when human participants are instrumented (12). Triaxial accelerometers are becoming more popular in sports and exercise research, due to their capacity to measure three-dimensional accelerations which may potentially improve the accuracy of data quantifying various movements occurring in multiple planes (e.g., lifestyle activities) (71).

2.1.3 Sampling rate

Although accelerometer sampling rates have been set as high as 3000 Hz in previous research (i.e., 3000 data points collected per second) (76), physical activity and sports researchers commonly use a sampling rate of 100 Hz (12). This allows 100 "pieces" of data to be collected per second. In addition, accelerometers can be configured to collect data in "epochs", which are manufacturer- or user-defined periods of time during which activity counts can either be totaled (13) or averaged (12), varying with different models and manufacturers. This function is more often utilized in physical activity settings, where an individual's energy cost over a period of days is of interest to the researcher (67). The setting of moderate-length epochs (commonly 1-minute) allows data collection to occur over consecutive days without exceeding the storage capacity of the monitors. In sports settings, data is usually recorded and downloaded in its raw format (raw acceleration data), without undergoing any filtering or compressing procedures.

2.1.4 Accelerometer range

Accelerometer range is important to consider in relation to the motion (human or mechanical) or event being tested. The sensing range of an accelerometer refers to the acceleration range over which a unit is capable of recording data, and is dependent on the accelerometer's sensor technology (63). Piezoelectric accelerometers tend to be popular for this reason, as this technology allows for the measurement of high impact events (e.g., + 100 g or greater) (63). Accelerometers used to analyze human movement commonly range between + 2-10 g when used to quantify walking and running events (40), though higher ranges have been reported with varying unit placement [e.g., two +70 g uniaxial accelerometers used by Elvin et al. (21) to measure tibial axial accelerations].

2.2 Use of accelerometers in physical activity monitoring

Although it will not be the focus of this review, it is worth briefly examining accelerometers in physical activity due to their extensive use in field interventions and research, and the volume of research that has examined the validity of accelerometers as a physical activity measurement tool. Physical activity researchers use activity counts (derived from accelerometer data) to assess the duration, frequency, and intensity of physical activity (25, 50), and to estimate energy expenditure (12, 46, 50) in laboratory and free-living conditions. These units are particularly popular as they provide direct, objective measures of physical activity (2, 46), are cost-effective compared to other activity assessment techniques [e.g., doubly labelled water method (12)], are small in size (12, 71), and place minimal burden on participants (25, 58). Commonly, participants wear an accelerometer continuously over the course of 3-7 days (67), at either the hip or waist (50). As estimators of energy expenditure, accelerometers have been found to be valid when assessing level-ground and treadmill walking and running, but these monitors tend to be less accurate when assessing other lifestyle activities, such as those requiring predominantly upper body movements (73). Recently, researchers (25, 39) have investigated accelerometer validity in regards to quantifying loads experienced by the body during impact-based activities. The key findings from these studies will be discussed in further detail in section 2.4.

2.3 Use of accelerometers in sports performance analysis and injury monitoring

Accelerometers are also popular as a performance analysis tool in elite sports (55), where it is often used to assess the physical demands of a session, supplying sport scientists with objective data to aid in the appropriate planning of recovery and training loads (19). This technology is also utilized in injury measurement (e.g., during head impacts) (4, 8, 18, 32, 51, 52, 62), quality testing of protective equipment (11, 38, 44, 65), and biomechanical assessment (31, 61, 68). As in physical activity, the portability of accelerometers is favourable in sport settings, permitting the measurement of movement in training and competition, where it is generally impractical (due to size, weight, and/or equipment design) to use other tools to take direct measures (such as force plates) (21).

2.3.1 Elite sports performance analysis

In elite sports, the use of accelerometers has grown rapidly in recent years, particularly in competitive team sports. Accelerometers are often integrated with GPS technology for use in many field team sports, as demonstrated by the prevalence of integrated GPS monitors currently used in the Australian Football League (10, 22), Australian National Rugby League (10, 35, 36, 42), A League Football (28), Professional Rugby Union and Super 14 Rugby (10, 28), and the English Premier League (10, 28). Despite the widespread application of such technology as reported by the manufacturer (28) and in general literature, there is a paucity of scientific literature acknowledging the use of GPS-integrated accelerometry in sports. Where GPS technology allows for the measurement of variables such as total distance run, time spent in various speed zones, and so on, accelerometers are used to log the frequency and intensity of "impact" events, such as tackles in Australian football (29). In addition, accelerometers record other physically-stressful (i.e., short-duration, high-intensity) events that require rapid changes in acceleration, such as sprinting, jumping and landing, and direction change movements (29). Though time-motion analysis studies have reported that high-intensity efforts represent only 2-6% of total game time in field team sports (15, 20, 64), these events are of interest to performance analysts and coaches alike for their contribution to the overall physical demand imposed on athletes (29), and their significance to competitive outcomes, given that these events often occur during crucial periods of a match (e.g., sprinting and changing direction to attack the try line in rugby) (64). For the purposes of this review, these common team sport movements requiring rapid acceleration and/or deceleration will be referred to collectively as impacts. In quantifying impact events, acceleration data is used as an indirect measure of the force acting on the body in a certain direction. This approach is based on Newton's Second Law of Motion (33, 57), which states that force (F) is equal to the product of an object's mass (m) and the object's acceleration (a), that is:

F = m x a

In an elite sporting environment, the athlete is the object. Over the short time period during which impact events occur, m remains constant [considering the body as a single mass particle (17)]. Therefore, force should be proportional to acceleration, thus providing the conceptual basis for using accelerometers in the field to indirectly assess force. Commonly, accelerometer data is used to identify the physical cost incurred by an athlete as a result of impact events experienced (42). This data has been used to monitor the frequency of impacts, and to calculate indices of physical demand such as "body load" (27). Increases in these variables indicate to the sport scientist that the athlete in question may require increased recovery time, decreased training load, or temporary cessation of activity (e.g., in-game substitutions) to rest and avoid injury (26). However, the validity of accelerometer data when used in this manner has not been widely investigated. Specifically, no literature has examined the integration of multiple technologies, such as the frequently utilized combination of GPS and accelerometry. Additionally, no studies have validated accelerometer data when such monitors are utilized in a similar manner to their use in field team sports settings.

2.3.2 Other uses in sporting contexts

Accelerometry-based monitors and multiple-monitor systems are often utilized for the purposes of injury measurement, quality testing of protective equipment, and injury research. Accelerometers have been used to assess head accelerations during impact events, occurring in actual and simulated gameplay, in sports such as soccer (51, 52, 62), field hockey (51), and American football (8, 18, 32, 51). Additionally, accelerometer technology is commonly used to assess the protective features of sporting equipment, especially protective headgear. The impact absorption characteristics of soft headgear and rigid helmets for a range of sports, including cricket (65), Australian football (38), soccer (44), and lacrosse (11), have been examined in this manner. Furthermore, biomechanical assessments have utilized accelerometry to provide insight into joint loads during physical activity (68), biomechanical factors that may predispose an individual to greater injury risk (41, 61), and the biomechanics of injured populations compared to non-injured populations (16).

Clearly, accelerometer use for investigating sport-related movements is varied and widespread, particularly within elite field team sport environments. Given the use of accelerometer technology for assessing physical demand in competitive team sports, with implications for the management of player wellbeing and subsequent performance, it is essential to determine the accuracy of the measurement tool itself. In order to confirm that such technology is valuable as a sports analysis tool, we must explore whether accelerometers provide a true measure of impacts by asking: how valid are accelerometers for quantifying short-duration, high-intensity efforts such as those that are commonly performed in sports? Specifically, how valid is accelerometer data when adhering to the way in which such monitors are set up and used in field team sports environments?

2.4 Accelerometer validity in sport settings

The literature examining accelerometer validity for measuring sport-related movements is limited. At the time of writing, only four published papers had investigated the criterion validity of accelerometers when quantifying such movements, of which three studies examined the relationship between force and acceleration (21, 25, 39), and the other investigated accelerometry in relation to optical motion analysis data (48).

2.4.1 Concurrent validity

In order to determine the accuracy of accelerometer data for quantifying impact events, the concurrent validity of the technology must be assessed. That is, the output of interest (in this case, accelerations measured by an accelerometer) must be compared to a "gold standard" or criterion measure (e.g., force) (56). A strong correlation and low error margin between these two variables thus establishes the validity of utilising acceleration data to quantify impact events.

At present, the literature is mixed in regards to the strength of any relationship between accelerometer data and force plate data. Janz et al. (39) observed no correlation between ground reaction forces (GRF) and activity counts during repeated drop jumping ($r = -0.15$). On the other hand, Garcia et al. (25) reported that summary activity count scores from all three accelerometers investigated (Mini-Motion Logger, Computer Sciences and Applications Inc. accelerometer, and BioTrainer) were moderately predictive of weight-adjusted vertical ground reaction force (VGRF), measured during a series of tasks including level-ground walking, running, continuous jumping, and drop landings ($r = 0.46$, 0.51, and 0.52, respective to each accelerometer model). Moreover, Elvin et al. (21) reported a strong correlation between peak GRF and peak tibial axial acceleration, measured during vertical jumps of easy (50% of maximum vertical jump height), moderate (75%), and challenging (95%) difficulty (average r2 = 0.812). These findings in particular suggest some promise for the use of accelerometers in measuring peak accelerations associated with impact events.

As aforementioned, only one study (48) has validated accelerometer data using motion capture acceleration data as the criterion measure. Using a portable system combining four pairs of uniaxial accelerometers with one rate gyroscope, Mayagoitia et al. (48) found strong correlations (coefficient of multiple correlations = 0.93-0.98) between the accelerometer data and accelerations calculated at the knee and shank from positional data. Despite some promising results, it is critical to note that, although these findings have been pooled for discussion in this review, making comparisons across these studies is difficult, due to considerable variations in methodology and data analysis, specifically in relation to 1) participant characteristics; 2) accelerometer placement; 3) setting, mode, duration and intensity of activity; and 4) data analysis procedures.

The participant characteristics of the study samples tested by Janz et al. (39) and Garcia et al. (25) were reasonably similar: both groups sampled children 6-11 years old, with almost equal representation of girls and boys. In contrast, both Elvin et al. (21) and Mayagoitia et al. (48) tested adult male participants. Accelerometer placement also varied, with Garcia et al. (25) and Janz et al. (39) attaching units at hip and waist sites, whereas Elvin et al. (21) aligned accelerometers with the fibular heads, while Mayagoitia et al. (48) used four uniaxial accelerometers arranged on the shank (lower leg) and thigh). Critically, these placement sites have limited relevance to accelerometer use in field team sports, as will be discussed in further detail below. Though each of these studies shared similarities in regards to the types of activities tested (e.g., jumping, walking, running), all three investigations varied considerably in their prescription of setting, mode, duration, or intensity of activity. For example, although both studies examined jumping tasks, Elvin et al. (21) examined moderate to high intensity countermovement jumps, while Garcia et al. (25) monitored continuous jumping activities performed in 1 min bouts. Similarly, although three studies (25, 39, 48) investigated accelerometer validity for quantifying locomotor activities, two studies (39, 48) employed treadmill-based locomotion into their protocol, while the other (25) implemented a circular, level-ground walking protocol. Furthermore, the data analysis strategies employed by these studies varied markedly. Only Elvin et al. (21) examined the relationship between peak VGRF and peak tibial axial accelerations, while the other three investigations (25, 39, 48) compared acceleration data in raw values or activity counts over short periods of time (1-3 minutes).

Many aspects of the field use of accelerometers in team sports are yet to be addressed by the validity literature. Therefore, the relevance of these findings to the application of accelerometers in sports performance analysis is debatable. As aforementioned, Elvin et al. (21) studied a sample population that may be comparable (recreational male athletes) to the elite athlete populations that are often instrumented with accelerometers in elite sport settings. However, the only high-intensity movement investigated thus far has been “challenging” vertical jumps (95% of maximum vertical jump height) (21); there is no published literature exploring the measurement of other common field team sport movements, such as sprinting, landing, or changes of direction. No studies have utilized accelerometers placed at the base of the neck, nor accelerometers that have been integrated with GPS units, both of which are commonly employed in elite sporting environments (9). Further, though impacts are of particular interest in team sport settings, only one study (21) has attempted to validate peak acceleration measures of team sport-related movements. Given the growing use of accelerometers for quantifying impact events, further inquiry is required to address the gaps in the existing body of knowledge regarding the accuracy of accelerometers. We must seek to answer the following question: do accelerometers provide a true measure of impact events that commonly occur in field team sports? It is essential that this broad question be explored in circumstances that are relevant to the context in which they are used, within the constraints of validity testing. Until the accuracy of accelerometer data is established, it remains difficult to draw appropriate conclusions regarding impacts based on acceleration data, as we cannot be sure that the accelerometers have collected true measures of these movement events.

2.5 Summary of main findings

It is apparent that accelerometers provide a popular means to assess physical activity and sporting performance in the field. In physical activity research and interventions, accelerometry-based monitors are primarily used to estimate energy expenditure. On the other hand, accelerometers are often used in sports as an indirect measure of force during high intensity impact movements, usually occurring over a short period of time. Despite their pervasiveness in applied sports science and sports research, little is known about the validity of accelerometers in these settings. The current literature addressing the accelerometer accuracy for quantifying team sport-related movements is scarce, and is not externally valid to the application of such technology in team sport contexts. Further research is required to investigate the validity of accelerometers in the context of field team sports, for quantifying a wider range of team sport-related impact movements.

Chapter 3

Methodology

3.1 Participants and recruitment

Thirteen healthy adults (7 males and 6 females, age: 23.38 + 3.43 years, height: 172.6 + 10.6 cm, mass: 69.3 + 10.0 kg) were recruited for this study. Participant inclusion was based on age (18-40 years), regular involvement (at least once per week) in an organized sport or physical activity that required athletes to perform the sporting movements prescribed in the present study (short-distance running, changes of direction, jumping, and landing movements), and no lower limb joint injuries sustained in the 6 months preceding testing. The first and second criteria were designed to address the external validity of the study design by testing a similar population to the population of interest (team sport athletes). The third criterion was set for safety reasons, due to the high impact nature of the movement tasks prescribed. Similarly, any participants that reported a history of any lower limb joint injury that required surgical treatment were excluded from undertaking the drop jumping task. Three of the thirteen participants were excluded from data analysis, due to accelerometer unit malfunction which resulted in lost data. Thus, the data from the remaining 10 participants were analysed for this study. Of these 10 participants, 9 individuals completed all five movement tasks, and 1 participant completed four movement tasks (excluded from drop jumping task due to history of operable lower limb joint injury). The study protocol was approved by the Deakin University Human Research Ethics Committee (see Appendix A.1). Informed consent was obtained from all participants prior to the commencement of testing.

3.2 Instruments

3.2.1 GPS-embedded accelerometer

To measure accelerations, participants wore a data-recording accelerometer unit, embedded within a GPS monitor (SPI Pro, serial no. ASP00725, GPSports Pty Ltd, Australia) for the duration of their trials. The same unit was used for all participants. The SPI Pro is a small, mobile phone-sized unit, housing a GPS unit and a triaxial accelerometer, and is designed to be worn in shoulder-mounted harnesses provided by the manufacturer (see Figure 3.1). The GPS unit was set to indoor mode, disabling the GPS function and allowing the accelerometer to collect data indoors. The GPS unit was orientated in the same direction for all participants, such that the Y axis of the accelerometer aligned with the longitudinal axis of the participant. The accelerometer sampled data at 100 Hz (i.e., 100 data points per second), and data was stored on-board the unit itself. Following each data collection session, accelerometer data from the SPI Pro unit was downloaded to a personal computer using the Team AMS proprietary software provided by the manufacturer (version 2.1.05 P2, GPSports Pty Ltd, Australia).

// FIGURE 3.1 GOES HERE //

3.2.2 Portable force plate

To provide one criterion measure against which to validate the accelerometer data, VGRF for all jumping and landing tasks were measured using a portable force plate (model ACG, serial no. 0687, Advanced Mechanical Technologies Inc. [AMTI], United States of America [USA]), sampling at 100 Hz. The portable force plate was calibrated using weight plates totalling 200 kg, which registered a force reading of 1978.2 N (0.83% greater than expected reading [1962.0 N], where a = 9.81 m.s-2). During data collection, the portable force plate was connected to a personal computer and operated through the AMTI Netforce software (version 2.4.0, AMTI, USA) provided by the force plate manufacturer. Data were saved to the hard drive after each trial.

3.2.3 Motion capture laboratory

All movement tasks were completed in the Deakin University Motion Capture Laboratory using twenty-four high-speed digital cameras (model Eagle-4, Motion Analysis, USA). This motion analysis system was used to capture the movement of three reflective markers placed on each participant (refer to section 3.4.2 Data Collection). The system was calibrated on the morning of each testing day, using a standard motion capture calibration protocol (30), with a reported positional error of 1 mm. During data collection, the system was operated and each trial recorded using Cortex motion analysis software (version 1.1.4.368, Motion Analysis, USA). The sampling rate of the motion capture laboratory was set at 120 Hz. Following each testing day, data were copied to a personal computer for further analysis.

3.2.4 Timing gates

Infra-red timing gates (Smartspeed, FusionSport Pty Ltd, Australia) were used for both the running and cutting tasks. During the running task, gates were placed at 0 m (starting line), 5 m, and 10 m (finish line), to capture the split times for each trial (see Figure 3.5). This data was used to determine whether the three self-selected running speeds (corresponding to a “moderate jog”, “stride run”, or “sprint”) were significantly different from one another. During the cutting task, gates were placed at 0 m (starting line), 5 m (trigger gate), and two possible finishing gates placed at 10 m. The two finishing gates were spaced 5 m apart from each other (i.e., 2.5 m to the left or right side of the straight line path through the 0-5 m gates) (see Figure 3.5). During data collection, the timing gate system was operated using the SmartSpeed software provided by the manufacturer (FusionSport, Australia), installed a handheld Personal Digital Assistant (PDA) device. Data was saved to the PDA hard drive, and then exported to a personal computer.

3.3 Preliminary assessment procedures

3.3.1 Familiarization session

Participants completed a 60-minute familiarization session prior to their respective data collection session. During this session, participants were provided instructions for the performance of each movement task, to reduce inter- and intra-participant variability (39).

3.3.2 Anthropometric assessments

To collect descriptive data, each participant’s height and weight were measured once, on the day on which they were scheduled to undertake testing. All participants were measured with shoes and socks off, wearing the same clothing as they would wear during data collection. Data was collected to the nearest 0.1 cm, and 0.1 kg using a stadiometer (PE27, Sportsforce, Australia) and electronic scales (model UC-321, serial no. 3030400011, A&D Mercury Pty Ltd, Australia).

3.4 Experimental design

This study used a quasi-experimental study design, incorporating repeated measures of each movement task measured in one session. Each participant completed their prescribed protocol in one 3.5 hour session. Movement tasks were completed in the following order: (A) drop landing, (B) countermovement jumping, (C) drop jumping, (D) running, (E) cutting. Tasks were completed in the same order for each testing session (see Figure 3.2). In total, six data collection sessions were conducted on three separate days (two sessions on each day).

// FIGURE 3.2 GOES HERE //

3.4.1 Pilot testing

There were initial plans to use a SPI Pro model monitor (GPSports Pty Ltd, Australia) for all data collection, including pilot testing. However, delivery of the SPI Pro unit from the manufacturer was delayed for 5 weeks. Given the broader time constraints of the project as a whole, it was decided that pilot testing would proceed with the use of one WiSPI unit (serial no. K07W0475, GPSports Pty Ltd, Australia). Pilot testing was conducted two weeks prior to data collection. One individual participated as the pilot testing participant (age: 23 years, height: 188.0 cm, weight: 76.0 kg), following a similar movement task protocol as prescribed for the data collection session. The WiSPI unit was configured to indoor mode to collect accelerometer data.

// FIGURE 3.3 GOES HERE //

Inspection of the pilot testing data revealed that the peak accelerometer data were consistently clipped during the majority of jumping and landing trials, due to the + 6 g range of the WiSPI accelerometer (see Figure 3.3). Therefore, it was decided that data collection would proceed with the one SPI Pro monitor instead, housing a triaxial accelerometer with a range of + 8 g.

3.4.2 Participant preparation

Participants were instructed to dress in tight-fitting lower-body clothing if possible (e.g., compression shorts or pants, running tights, etc.) and to avoid loose fitting upper body garments. During the data collection phase, each session began with participants arriving at the university to undertake the preparation phase, which included recording of descriptive data, harness fitting, and attachment of reflective markers. Three markers were attached to participants, corresponding with the following sites: posterior aspect of the shoulder-mounted harness, immediately superior to the integrated pouch sewn in to hold the GPS unit; sacrum, on the midline of the body; and the left lateral malleolus (see Figure 3.4). All reflective markers were secured with adhesive tape. Where necessary, reflective surfaces (e.g., reflective fabric on shoes) were covered either with fabric tape, or with black fabric foot bags, for ease of data post-processing. All participants completed a 5-minute warm up prior to the commencement of the movement tasks.

// FIGURE 3.4 GOES HERE //

3.4.3 Data collection

All trials were conducted indoors, in the Deakin University Motion Capture Laboratory. To avoid introducing inter-unit variability, only one specific SPI Pro unit was used for testing the performance of all movement tasks across all participants. During sessions in which more than one participant was being tested, the GPS unit was swapped from one participant to the next after the performance of each trial. Though platform heights of 30 cm, 40 cm, and 50 cm were utilized in the drop landing and drop jumping tasks, the actual elevated heights from the force plate were 25.5 cm, 35.5 cm, and 45.5 cm, due to the 4.5 cm height of the portable plate itself.

// FIGURE 3.5 GOES HERE //

Drop landing (DLAND): Participants completed 15 drop landing trials in total (5 trials from each of the three prescribed platform heights 30 cm, 40 cm, and 50 cm), with two minutes rest between trials to cater for full physiological recovery. Trial conditions (platform height) were randomized for each participant to account for any ordering effects. The front edge of the platform was placed 15 cm away from the back edge of the force plate. Participants were instructed to begin each trial by stepping up onto the platform, positioning their feet hip width apart, with their toes extended slightly past the front edge of the platform. Arms were held at 90^{o} of shoulder flexion for the entirety of each trial (see Figure 3.5). To begin the drop landing movement, participants shifted their body weight forward, and were instructed to land both feet on the force plate at approximately the same time, using their natural landing style. This protocol was selected based on drop landing tasks employed in previous research (60).

Countermovement jumping (CMJ):