The Biomechanical Specificity of Running Drills to Sprint Performance

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A thesis submitted to the University of Limerick in fulfilment of the requirements of the degree of Doctor of Philosophy

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Submitted to the University of Limerick
Abstract

Title: The Biomechanical Specificity of Running Drills to Sprint Performance.

Drills are considered important in the coaching of correct sprinting technique as they establish the optimal movement and coordination patterns of sprinting. However, there limited of research on the kinematics and muscle activation of drills compared with sprinting. Therefore, the aims of this thesis were to advance the understanding of the movement and muscle activation patterns of drills and their specificity to the movement and muscle activations of sprinting. This research examined the optimisation of event specific technical training (i.e. drills) for sprinting based on kinematics and muscle activation patterns. This thesis consists of a series of linked studies examining coach and athlete practices and empirical studies comparing kinematics coordination and muscle actions between drills and sprinting.

Coaches (n = 209) were found to base sprint drill selections on what other coaches were doing rather than having a scientific rationale for selecting drills. The two most popular drills selected by coaches were the A-skip and heel flicks. These two drills formed the basis for further investigation of the A-skip and heel flicks throughout this thesis. To provide further insight on drills and sprinting, a kinematics study was conducted to determine the movement and coordination patterns of drills and compare these with movement the coordination patterns of sprinting. The results of this study found similarities of knee movement in heel flicks (RMSD 8°) between the knee angles, but difference in hip action. Similarities of hip action in A-skip were found but there were significant differences in knee action (RMSD 36°). Observations from the kinematics study were that further research was needed examining the muscle activations of the lower limb during sprinting, A-skip and heel flicks.

In examining the muscle activations of lower limb muscles during sprinting, there were various similarities and differences when comparing the drills to sprinting. Additionally, it was shown that there was large variability between participants (n = 16), this was apparent when examining the effect sizes which indicated some similarities and some large difference between drills. Small differences and large differences were found between sprinting and heel flicks in the right biceps femoris with a small effect size (0.304) and right rectus femoris with a large effect size (0.964). It should be noted that there were limitations to using surface EMG analysis to detect muscle activations; this is due the fact that different muscles can be used in many different ways to initiate the same action (muscle redundancy). The final study examined the optimal movement and muscle actions patterns using musculoskeletal computer simulation modelling model. The current model was validated based on comparisons between experimental muscle activity and model predictions of muscle activity. Near perfect correlations for kinematic data were noted between both experimental and computer simulation model data, 0.993 for the 5th metatarsal and 0.999 for the greater trochanter for the A-skip drill.

This thesis has provided information on coaches and athletes understanding of drills and their enhancement of technique. The experimental work has provided some valuable information on the movement and muscle activations of A-skip and heel flicks compared with sprinting. There are some similarities and differences observed when comparing A-skip and heel flicks drills to sprinting. Therefore, implementing both drills into a programme may be useful as they do replicate important movement and activation components of sprinting.
Authors Declaration

I hereby declare that the work contained in this thesis is my own, and was completed under the supervision of Prof. Andrew Harrison and Dr. Ian Kenny of the Department of Physical Education and Sport Sciences, University of Limerick. This work has not been submitted to any other university or higher education institution, or for any other academic award within this University.

Furthermore, within this thesis there is one published article:


______________________________________________

Niamh Whelan

______________________________________________

Prof. Andrew Harrison

______________________________________________

Dr. Ian Kenny
Acknowledgements

I would like to thank the following people who all contributed somehow to completing this thesis:

First and foremost, I would like to offer my sincerest gratitude to my supervisors Prof. Drew Harrison and Dr. Ian Kenny. Thank you for all your support and encouragement throughout my PhD research and write up process. A special thank you to Prof. Drew Harrison, your door was always open regardless of the problem. Thank you for reading my numerous chapter drafts and always providing useful guidance and feedback.

I would like to thank my parents Angela and John for all their help and encouragement throughout my life and particularly over the past few years. I will hopefully someday be able to pay you back for all you have done for me.

Past and current postgraduates of the PESS Department, you have all helped in your own little way in the completion of this thesis, whether that was academically or distracting me from the PhD with the many laugh out loud moments during lunch. Thank you for your guidance, opinions, memories and friendship.

Paul, thanks for being you and putting up with me even on the bad days.

This research would not have been possible without the financial backing from the Department of Physical Education and Sport Sciences I would like to and express my gratitude to the PESS department for funding this research.
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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 RM</td>
<td>1 Repetition maximum</td>
</tr>
<tr>
<td>2D</td>
<td>Two dimensional</td>
</tr>
<tr>
<td>3D</td>
<td>Three dimensional</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variation</td>
</tr>
<tr>
<td>COM</td>
<td>Centre of mass</td>
</tr>
<tr>
<td>EMG</td>
<td>Electromyography</td>
</tr>
<tr>
<td>fc</td>
<td>Frequency cut off</td>
</tr>
<tr>
<td>HIIT</td>
<td>High intensity interval training</td>
</tr>
<tr>
<td>LBF</td>
<td>Left biceps femoris</td>
</tr>
<tr>
<td>LGAS</td>
<td>Left gastrocnemius</td>
</tr>
<tr>
<td>LGM</td>
<td>Left gluteus maximus</td>
</tr>
<tr>
<td>LRF</td>
<td>Left rectus femoris</td>
</tr>
<tr>
<td>PAP</td>
<td>Postactivation potentiation</td>
</tr>
<tr>
<td>RBF</td>
<td>Right biceps femoris</td>
</tr>
<tr>
<td>RGAS</td>
<td>Right gastrocnemius</td>
</tr>
<tr>
<td>RGM</td>
<td>Right gluteus maximus</td>
</tr>
<tr>
<td>RMSD</td>
<td>Root, mean, squared difference</td>
</tr>
<tr>
<td>ROM</td>
<td>Range of motion</td>
</tr>
<tr>
<td>RRF</td>
<td>Right rectus femoris</td>
</tr>
<tr>
<td>RS</td>
<td>Resisted sprints</td>
</tr>
<tr>
<td>SEMIAM</td>
<td>Surface electromyography for the non-invasive assessment of muscles</td>
</tr>
<tr>
<td>SD</td>
<td>Standard deviation</td>
</tr>
<tr>
<td>SL</td>
<td>Stride length</td>
</tr>
<tr>
<td>SR</td>
<td>Stride rate</td>
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</table>
Submissions and publications related to this research

**Peer reviewed journal articles**


**Peer reviewed conference publications**

Chapter 1. Introduction
1.1 Background

1.1.1 General information on sprinting

Sprinting involves running over a short distance during a short period of time. During the Olympics and other major athletic events such as the IAAF World Championships and the European Championships, the 100 m sprint is perhaps the most widely anticipated event in the athletic schedule. Sprinting events make up a large component of the track and field programme and include events such as 100 m, 200 m 400 m and relays. Sprinting is also a significant component of other events such as long jump, and triple jump. It is largely incorporated into many other sports which involve running quickly to reach a target or goal, or catch an opponent. The 100 m sprint can be broken down into various stages. For the purpose of this thesis they will be referred to as the:

- Sprint start
- Acceleration – start acceleration and pick up acceleration
- Maximum velocity
- Deceleration

While there is a large body of research on sprinting, there are significant gaps in our understanding of how the muscles act to achieve maximal running speed (Howard et al. 2017 and Novacheck 1998). Furthermore, there is limited research on how to ensure the specificity of conditioning exercises and drills to improve running speed (Ross et al. 2001). Running drills are widely used in athletics and other sports to develop optimal sprint technique but there is limited evidence to link the muscle activations of the drills with muscle activations in the sprint. Research which has been conducted on execution of drills has suggested from the observations of athletes performing drills that, for example, the common heel flick drill does not appear to be consistent visually to the movement of sprinting (Harrison 2010). Harrison (2010) concluded that future research was necessary to determine the movement and muscle activations of drills such as heel flicks.

1.1.2 Authors Perspective

As the author of this thesis, I have had a keen interest in sprinting and sprinting technique. This relates largely to the fact that I am exposed to sprinting on a daily basis as an international athlete. Having experienced and witnessed many different and hugely varied sprint warm ups performed by international sprinters around the world, I
began to question “why are these athletes doing these drills and why are the drills used by athlete A so different to the drills used by athlete B”. It posed a requirement to delve a little deeper into the practice of drills and sprinting. In theory, the drill practice should relate to the movement of the end goal which in this case is sprinting (Harrison 2010). There is a large amount of research examining the kinematics of sprinting, the sprint start, acceleration, training for sprinting. Close examination of scientific literature reveals very little scientific research to date on drills and sprinting technique. The International Association of Athletics Federations published an instructional coaching book “Run! Throw! Jump!” (Thompson 2009) which has recommended various drills which include heel kick-up drills (heel flicks) ankling, high knees and high knees with extensions. Carr (1999) recommended high- knee march, high knees with extension of the lower leg, high knee skipping, high knee skipping with lower leg extension high knee running with leg extension seat kicks (heel flicks). According to Carr (1999) pp. 7-8 the drills mentioned above should be performed as follows:

- **High-knee march:** this drill should replicate marching forwards slowly. The athlete should lift each thigh to horizontal, and push up onto their toes with each step. The arms should work similarly to running with opposite arm forward to the leg thigh that is horizontal.

- **High-knee skipping with lower leg extension:** this drill is performed at a high intensity the athlete skips rather than walks. The athlete should lift their thigh to a horizontal position and then extend the leg. The arms should work similarly to running with opposite arm forward to the leg thigh that is horizontal.

- **Seat kicks:** The athlete kicks their heels towards their rear without making contact.

These sources provide a broad outline of commonly used drills but there is no scientific research of note on the specific link between the movements of drills and sprinting; clearly the literature has not addressed this. Inspection of web-based sources show a large amount of resources online on drills but there is currently no clear scientific rationale for using these drills. To date there is no scientific research which examines the drills used by athletes and coaches, why they use these drills, and whether the muscle activation and movement patterns of drills compare with sprinting. This research
bridges the gap in the implementation of drills and sprinting and to gain an understanding of why these drills are being used.

1.2 Thesis aims

The aims of this thesis are to advance the understanding of the movement and muscle activation patterns of drills and their specificity to the movement and muscle activations of sprinting. This research examines the use of drills for optimisation of sprint technique based on kinematics and muscle activation patterns.

1.3 Thesis objectives

1. Examine the extent of the scientific literature on drill type practices in sprinting.

2. To determine the drills selected by coaches and athletes for developing sprinting technique and why they select these drills.

3. To develop and implement a method for determining on–off events of muscle activity using activation level thresholds.

4. To investigate the kinematics of sprinting and sprinting drills using coordination patterns (angle-angle graphs).

5. To use this method to determine muscle activations during sprinting and sprinting drills.

6. To use a computer simulation model, 3D kinematic analysis and muscle activations in drills and correlate these with muscle activations of running drills.

1.4 Thesis structure

This thesis contains a series of linked chapter which examine drills and sprinting. The aim is to understand the movement and muscle activation patterns of sprinting and selective drills. The studies will examine the kinematics and muscle activations of sprinting and drills.

Chapter 1 provides a brief introduction to sprinting and outlines the primary aims of the thesis.
Chapter 2 presents a comprehensive review of the literature examining the phases of sprinting, focusing on the importance of various training modalities used for sprinting with an in-depth examination of drills used for sprint technique.

Chapter 3 provides descriptive information on coaches’ knowledge of drills. This chapter examines the range of sprint drills used by coaches, their knowledge on drills and the effect drills have on sprinting technique. The information collected in this chapter provided the rationale for the drills selected for further examination throughout this thesis.

Chapter 4 provides descriptive information on sprint athlete’s knowledge of drills. This chapter examines the range of drills used by athletes and their knowledge of drills.

Chapter 5 describes two pilot studies. This chapter firstly examines the use of the accelerometer feature in Delsys Wireless EMG sensors to predict heel strike events during running. Acceleration data were validated by comparing heel strike events with the same heel strike event on a force platform. Both force platform and Delsys wireless EMG were synchronised. The second part of this study is a follow up from the first pilot study and examines a test method for identifying on and off events of the lower limb muscles during maximal sprinting and identification of the key events of the running cycle using acceleration data.

Chapter 6 examined the kinematics of sprinting, compared with the kinematics of the A-skip and heel flicks. Movement patterns of the hip, knee and ankle were compared using angle time graphs and angle-angle diagrams.

Chapter 7 examined the muscle activity of sprinting and compares the activations to the muscle activations of selected sprint drills. The drills used were the two most popular drills selected by coaches in Chapter 3; A-skip and heel flicks. Muscle activations were detected using the methods outlined in Chapter 5 for identifying on and off events. Results will enhance our understanding of muscle activity of the lower limb during drills and sprinting and whether they are useful for sprint performance.

Chapter 8 examined and validated computer simulation predictions of kinematics and muscle activation of sprinting and drills and compares predicted data with the kinematics and muscle activation patterns of experimental data. The computer simulation model was valid kinematically and for muscle activations. This allowed
interpretation of data for muscles which could not be obtained by surface EMG that were predicted by the computer model to be analysed. Given the limitations of surface EMG, it is not possible to obtain EMG data of all muscles while running. Therefore, a computer simulation (ADAMS Lifemodeler) was used to predict optimised activation patterns.

**Chapter 9** summarises the key findings of the thesis and their practical implications. The limitations of the thesis and directions for future studies are also identified.
Chapter 2. Literature Review
2.1 General sprint information

Sprinting is a complex task and can be defined as the ability to run at maximal or near maximal speeds for short periods of time (Baughman et al. 1984). In track and field athletics, sprint races cover a range of distances from 60 m up to 400 m (Carr 1999). Success in any sprint event is evaluated based on the ability to cover a specific distance in the least possible time. Sprinting performance is determined by two main components, namely, stride length and stride frequency. Stride frequency is the rate at which an athlete completes a stride, and stride length is the distance travelled during a stride. A stride is defined as two consecutive steps (a step right and left) and comprises of support phase and a flight phase (Thompson 2009). Running speed can be defined as the rate of change of distance (Knudson 2003) and acceleration can be defined as the rate of change in velocity with time (Griffiths et al. 2006). Speed in running is defined as stride length by stride rate (SL×SR) and acceleration is dependent on the resultant horizontal force acting on the athlete. Cronin et al. (2006) stated that the ability of athletes to accelerate rapidly in running depends on several factors including running technique and the capability for force production in the lower limb muscles. There are many aspects to a sprinter’s training programme and these include but are not limited to sprint technique, sprint track sessions (speed and speed endurance), flexibility, resistance exercises, resisted sprints and plyometrics.

2.2 Breakdown of sprint phases

Sprinting is a multi-phase event but the number of phases and the names of each phase appear to differ within the scientific community and amongst track and field coaches. Mero et al. (1992) divided the 100 m sprint into four phases: the sprint start, the acceleration phase, the constant speed phase and finally the deceleration phase. Similarly, Jones et al. (2009) divided the sprint into four phases: the block-start, the acceleration or pick-up phase, the maintenance and the final deceleration. In contrast, Delecluse et al. (1995a) divided the 100 m sprint into three specific performance phases. The first phase which is over the initial 10 m required the athlete to generate high accelerations, in the second phase from 10 to 36 m the acceleration is continued and in the final phase 36-100 m the maximum speed is maintained. Mackala (2007) researched the various phases of a 100 m sprint using the force velocity curve of elite and novice male sprinters. The novice sprinters had personal best performances which
ranged from 11.18 seconds to 10.78 seconds for the 100 m. The study proposed an advanced structure for the phases of the 100 m sprint; these include the initial accelerations phase (0-20 m), the extended acceleration phase (20-40 m) (this phase is often called the second acceleration phase or pick up), the initial peak velocity phase (40-50 m), the velocity regulation phase 1 (50-60 m), the velocity regulation phase 2 (60-70 m), the maximum velocity phase (70-80 m) and finally the deceleration phase (80-100 m). Various factors can affect the duration and distance of the phases, these include: strength, motivation, fitness, technique, wind speeds, track surfaces and temperature (Nigg & Yeadon 1987; Stafilidis & Arampatzis 2007).

2.3 Phases

After reviewing the literature on the phases of the sprint, there appear to be inconsistencies in the literature with respect to the number and naming of phases. For the purpose of this thesis, the phases will be referred to as follows throughout the thesis:

- **Sprint start**: this phase refers to the time in which the athlete is in the blocks to the instance of block clearance after the gun is fired.

- **Acceleration**: this phase begins when the athlete leaves the blocks and ends when maximum velocity is reached. The acceleration phase and can be further divided into:
  - Starting acceleration
  - Pick up acceleration

- **Maximum velocity**: this phase/event occurs from the end of the acceleration phase and the beginning of the deceleration phases and is the instant at which the athlete has reached their top speed.

- **Deceleration**: this phase begins after the instant in which the athlete has reached their maximum velocity and involves the athlete trying to maintain speed.

2.3.1 Sprint start

The transition from the start to acceleration is hugely dependent on the execution of the first step and the length of that first step (Coh et al. 2006). The sprint start is a complex
motor task which is characterised by large forces that are exerted in a horizontal direction (Fortier et al. 2005). The starting block phase refers to the time in which the athlete is in contact with the blocks and in the set position (Mero et al. 1992). Once the athlete is in the set position, the athlete must then react to the starters’ gun. Reaction time has been defined as the time which elapses between the sound of the starters’ gun and the moment the athlete is able to exert a certain pressure against the starting blocks (Mero et al. 1992).

### 2.3.2 Starting acceleration

The starting acceleration phase refers to the athlete’s execution of their first step and the first 10 m of the sprint (Delecluse 1997; Slawinski et al. 2010). Figure 2.1 presents the phases of the sprint start and the block acceleration adapted by Hay (1983). During the starting acceleration phase, the athlete has longer ground contact times. Longer ground contact enables the athlete to produce force, which allows the athlete to produce a greater impulse (Wild et al. 2011). As the sprint progresses, ground contact times have been found to decrease; Salo et al. (2004) observed contact times over the first four steps to decrease, with an average first step contact time of 0.200 s, second step 0.173 s and steps three and four decreased to 0.159 s and 0.135 s.

### 2.3.3 Kinematic parameters of the sprint start and starting acceleration

There are many biomechanical aspects to the sprint start including the configuration of the set position, and kinematics of the lower limb in set and during block acceleration. Ciacci et al. (2016) examined the kinematic differences of the first and second step of a competitive 100 m race. Participants were male and female and ranged from national level to world-class athletes. Differences were observed in kinematics between the levels of the athlete’s, overall, the faster athletes were found to assume a set where their centre of mass was closer to the ground and with greater knee flexion. The first two steps of the elite athletes were associated with longer contact time and shorter flight times. The study concluded that athlete’s sprint start kinematics were only partially affected by the sex but were more affected by the athlete’s performance level (previous sprint times). Slawinski et al. (2010) compared the major kinematic parameters of six elite and six well-trained male athletes and found no significant difference in the average reaction time between each group. The results showed that elite athlete’s started quicker than the well-trained athletes with an average gain of 0.09 s at 10 m. The elite
athletes were also found to have greater explosive strength; these allowed the athletes to have a higher rate of force development and a higher velocity from the block phase to the second step. The study concluded that coordination and strength were key factors that could be improved to help the well-trained athlete run quicker.

2.3.4 Pick up acceleration

The acceleration phase is the entire distance in which an athlete is increasing speed from the start (Jefferys 2013). The distance required for the acceleration phase is also dependent on an athlete’s sex and their maximum speed (Jefferys 2013). Athletes with high maximum speed achieved their maximum acceleration later in the race and required longer acceleration distances compared with slower athletes. Research suggests various distances for the acceleration phase 0-40 m (Mackala 2007 & Yu et al. 2016); while Delecluse et al. (1995a) states that the acceleration phase is 10 m-36 m. During the acceleration phase, ground contacts are shorter, flight time increases and there is an increase in stride length. Jefferys (2013) examined the phases of world recorded holder Usain Bolt during the Olympic final in Beijing and reported that the athlete achieved 73% of this maximum velocity at 10 m, 85% at 20 m, 93% at 30 m and 96% at 40 m.

2.3.5 Stride parameters during entire pick up phase.

Nagahara et al. (2014) examined the association between the rates of changes in step length and step frequency during the entire acceleration phase of maximal sprinting on 21 male sprinters performing a 60 m maximal effort sprint from starting blocks. The smallest number of steps to complete the 60 m sprint was 22 steps. For sprinting to be effective, it is imperative that the athlete accelerates initially by increasing their stride frequency; this changes in the middle of the acceleration phase to increasing their stride length and then changes to either step length or step frequency in the latter part of the acceleration phase (Nagahara et al. 2014). The study concluded for acceleration to be effective, step frequency should be increased for the first three steps and step length should be increased in the middle section from the 5th step to the 15th step.

Nagahara et al. (2014b) examined the changes in kinematics during the acceleration phase for a 60 m sprint. The study investigated whether there are changes in acceleration during the entire acceleration phase. Twelve male sprinters participated in the study and performed two maximum effort sprints over 60 m. Linear and angular kinematics of segments were calculated. The study detected two transitions during the
entire acceleration of maximum sprint and this justified the division of the acceleration phase into three key phases, i.e. initial, middle and final acceleration phases. Transition one was detected from the 3rd to the 6th step and this transition was recognised by changes in the athlete’s kinematics; the foot contacted the ground in front of the centre of gravity, the knee joint began to flex during the support phase and step frequency did not increase. The second transition was detected from the 10th to the final step and was recognised by no changes in posture and the initiation of a decrease in the hip-joint movement. During the initial acceleration phase the athlete’s running speed and stride length increased rapidly. Stride frequency increased until the fourth step and then remained constant throughout the acceleration phase.

Morin et al. (2012) examined the mechanical variables of the 100 m sprint for four sprinters and nine non-specialists. Mechanical variables included; stride parameters, force velocity profiles and resultant ground reaction forces of the participants. The participants performed a six seconds maximal sprint on a treadmill and a 100 m sprint on a standard synthetic track. The 100 m sprint performance was monitored using a radar system to measure the participants forward running velocity. The sprint was performed on a treadmill, which allowed continuous recording of the athlete’s ground reaction forces and step kinematics. Results showed higher levels of acceleration and overall performance (time to complete) are associated with the following; a velocity orientated force-velocity profile which can be explained by the athlete’s ability to apply ground reaction forces with a forward orientation during the acceleration phase and finally an increased step frequency causes a shorter contact time which is associated with increased acceleration.

2.3.6 Maximum velocity

The maximum velocity phase is the instant at which the athlete has reached their top speed. This phase is characterised by the athlete running upright and tall. Seagraves et al. (2009) reported that there is a high correlation in the performance and success of 100 m with the level of velocity maintained during the maximum velocity phase of the race. Sprinters usually achieve maximum velocity around 40 – 60 metres during a 100 metre sprint. This phase can be further divided into two phases; the first part of this phase is where the athlete maintains their maximum velocity for approximately 20 metres, followed by a slight decrease in velocity and then the deceleration phase (Brewer 2017). During this phase the ankle and knee angles reduce while the foot is in contact with the
ground (stance phase) (Wild et al. 2011). The use of the A-skip can be useful during this phase to help to reduce the braking impulse and contact time while maximising the propulsive forces (Wild et al. 2011). This is achieved by emphasising the “paw back” as the foot contacts the ground during this drill. A number of studies have examined the maximum velocity phase in comparison to the acceleration phase (Atwater 1982; Wild et al. 2011; and Weyand et al. 2000). Contact time gradually decreases as an athlete continues to accelerate and reach the maximum velocity phase (Wild et al. 2011). Atwater (1982) noted differences in mean contact time between the first steps at the start of the 100 m and the mean contact time at maximum velocity. Mean contact times for the first four steps were 0.19, 0.179, 0.164 and 0.152 seconds, while the mean contact time during the maximum velocity had decreased to 0.111 seconds. Contact times for the maximum velocity phase have typically ranged from 0.09 – 0.12 seconds (Atwater, 1982; Kuitunen et al. 2002; Mann 1985; Wild et al. 2011). It has been suggested by Wild et al. 2011 that when examining faster sprinters in comparison to recreational sprinters the greatest difference is the faster sprinters ability to apply greater vertical forces during the maximum velocity phase. This allows the athletes to achieve effective impulses and the flight time needed to reposition their swing leg with a shorter contact time. Faster athletes during this phase are able to spend less time in contact with ground while maintaining stride length (Weyand et al. 2000).

2.3.7 Deceleration

The deceleration phase occurs as the athlete begins to fatigue and this phase is defined as the time when maximal-velocity effort cannot be sustained (Freeman 2015). This phase is observed in the latter part of the 100 m and is characterised by an increase in ground contact and flight times. The deceleration phase can be easily distinguished on the velocity time graph as a sharp decrease in velocity from the peak (Mero & Komi 1987). Decreases in stride rate and a slight increase in stride length are associated with this phase (Mero et al. 1992). Bezodis et al. (2011) have suggested that during the deceleration phase of the sprint, there is a reduction in velocity due to a decrease in stride rate. This study used group and single subject analysis, when using single subject analysis the fastest sprinters were found to maintain their running velocities by increasing their stride length to account for the decreases in stride rate.
2.4 Training to improve sprint performance

Since the 100 m sprint is divided into several phases, it is important to focus training specifically developing each phase. The various sections of the 100 m which can be worked on in training are; starting acceleration, pick up acceleration, maintaining maximum speed and reducing the rate of loss of maximum speed (Dick et al. 2014). Various methods of training can be used to help an athlete develop their start, acceleration, or their maximum velocity. In the following section, an outline of some of the training modalities incorporated into sprinters training programmes will be discussed.

2.4.1 Non-specific resistance based exercises

Sprinting performance is dependent on in part an athlete’s muscular strength. Resistance training can be implemented into a sprinter’s program to improve an athlete’s sprint performance. Examples of resistance training include: Olympic lifting, resisted sprints training and plyometric training. Resistance training has been found to increase muscular strength and power and when used in conjunction with sprint training allows the athlete to apply a greater impulse with each step, which in turn can increase the athlete’s running velocities and acceleration and their overall sprint time (Blazevich 2002; Kraemer et al. 2006; Ratamess et al. 2007). The squat and the power clean have been shown to correlate highly with sprinting performance (Ross et al. 2001; Ross et al. 2009). However; it would be unwise to interpret this as strength in the athlete equals improved performance in the athlete. Not all individuals who produce excellent squat and power clean are excellent sprinters and similarly there are many elite sprinters who do not produce excellent performances in squat and power cleans (Young 2006). While strength is correlated with sprinting this does not mean improvements in sprint times (Young 2006). Cronin et al. (2007) reviewed the literature on the magnitude of strength development necessary for improved running speed and concluded that after an extensive review of the literature there were significant strength gains without significant improvements in speed.

2.4.2 Specific resistance exercises – resisted sprints

Resisted sprint training techniques are used by sprinters to improve speed and acceleration in running (Harrison et al. 2009). Towing a weighted sled, tyre, speed parachute or some other device over a set distance (Lockie et al. 2003), running uphill
or wearing a weighted vest (Harrison et al. 2009) are examples of resisted sprint training. According to Harrison et al. (2009) resisted sprints training will over time, lead to an increase in stride length during normal unresisted running, this is achieved by increasing the strength and power of an athlete. Resisted sprint techniques have been found to increase neural activation and muscular force output of the leg (Cronin et al. 2006) and this can lead to increases in stride length over time. Towing a weighted device such as, sleds have been found to be the most popular method of resistance for the enhancement of sprint performance. The kinematic mechanisms responsible for these enhancements include changes in: step length, step frequency, contact time, flight time (Lockie et al. 2011). However, the majority of studies conducted on resisted sprints training have used team players as participants and not sprinters (Bevan et al. 2010; Crewther et al. 2011; Kilduff et al. 2007; Lockie et al. 2013; McBride et al. 2005; Yetter et al. 2008). Sprinters were used as participants in studies conducted by Alcaraz et al. (2008), Weber et al. (2008) and Cronin et al. (2008).

Previous research has examined the use of resisted sprints training and its effect on sprinting kinematics (Cronin et al. 2006; Cronin et al. 2008; Hrysomallis 2012; Alcaraz et al. 2008; Lockie et al. 2003). Cronin et al. (2006) investigated the effects of weighted vests and sled towing on sprint kinematics. The participants performed five types of sprints – one unresisted sprint (baseline measure), two with a weighted vest (15% and 20% of body weight) and two towing a weighted sled (15% and 20%). It is important to note that there was no post unresisted run and the effect of resisted sprints on sprint performance cannot be therefore determined. The results showed that for all trials the time to 10 m was significantly slower when compared to the baseline measure. The time to 10 m for the towing was significantly slower when compared to the vest trials. There was an increase in stride length through the acceleration phase for both resisted trials. Stride frequency decreased by between 2.7% – 6.1% for the resisted sprint. Stance phase duration decreased with resistance while swing phase duration increased. Joint kinematics results showed that trunk angle lowered significantly for the weighted vest trials, indicating that the subject was more upright while trunk angle increased when towing the sled. Thigh and knee angles with towing were significantly higher when compared with both baseline and weighted vest. Alcaraz et al. (2008) conducted a similar study comparing the kinematics of unloaded sprinting at maximum velocity to sprinting while towing a weighted sled, towing a parachute and wearing a
weighted belt. All three devices reduced the average running velocity when compared to unloaded sprinting and the study concluded that the decrease in velocity was due to the decrease in stride length and stride frequency. The most substantial change was found in the runs with the sled and parachute. There was an increase in the angle of trunk lean, only the sled produced a statistically significant increase- the shank was less upright at touchdown, which lead to a slightly shorter landing distance.

Lockie et al. (2003) investigated the effects of resisted sled towing on the sprint kinematics of athletes who participated in team sports towing a weighted sled loads of 12.6% and 32.2% of their body mass over a distance of 15 m. The results of their study found that horizontal hip velocity decreased with increasing load. The stride lengths of the participants during both loaded trials were significantly different when compared to the unloaded sprint. Mean stride length dropped by approximately 10% for the load one and by 24% for the load two trials concluding that increases in towing resistance significantly reduced stride length. Stride frequency data suggested that increases in towing resistances from load one and load two led to greater reductions in stride length compared with stride frequency. For first step contact time there was only a significant difference in load two which decreased by about 40% when compared to the unloaded sprint. Therefore, it appears that a greater resistance than load one is needed to significantly reduce flight time. Contact times for both loaded runs increased, therefore as resistance is increased, contact time with the ground is lengthened considerably. There were significant differences found for hip flexion and range of motion variables for the loaded runs. Clearly, from the above, resisted sprints caused a change in running kinematics but this change is dependent on the weight used. It is emphasised in the literature that a weight of 10-15% of body weight is the optimal load to have a training effect and anything above this seriously disrupts the movement pattern i.e. a change in velocity below 90%. However, in a recent study Cross et al. (2017) examined the present optimal loading in sled sprinting using a mixture of recreational sports athletes and highly trained sprinters as participants. The study concluded the optimal loading conditions for maximal power are greater than the current recommendations from previous literature. The study suggested that optimal loading for recreational athletes ranged from 69% -91% of body weight and 70%-76% of body weight for the sprinters. The study indicated that further research in greater sled loads was necessary.
2.4.3 Plyometric training

Plyometric training is based on development of the effectiveness of the stretch shortening cycle which enhances the muscles ability to produce maximal force in the shortest amount of time (Saez De Villarreal et al. 2012). Plyometrics refer to exercises which are designed to enhance muscle contractile performance mainly through jump training. During plyometric exercises, the muscle tendon lengthens during an eccentric contraction phase and is followed immediately by a shortening concentric contraction. Plyometric exercises are useful in improving athlete’s’ strength and speed (Starkey 2013). Exercises that use the stretch shortening cycle stimulate neuromuscular changes and enhance the muscles ability to respond quicker to rapid and slight changes in muscle length (Radcliffe & Farentinos 2015). Two-foot ankle hops, squat jumps, box jumps, bounding, single leg hops, stadium hops and spilt squat jumps are examples of popular plyometric exercises. It is important that the plyometric exercise should be specific to the competitive movement, since this allows for a greater transfer of the training effect to performance (Delecluse et al. 1995b; Rimmer & Sleivert 2000; Sale & MacDougall 1981). When examining plyometrics the exercises should be specific to sprinting a plyometric exercise which appears to be similar to sprint are bounding plyometrics. Bounding requires the athlete to move powerfully in the horizontal plane (Rimmer & Sleivert 2000). There are a number of studies which have implemented plyometrics interventions with field based athlete’s such a rugby and soccer players as participants.

Rimmer and Sleivert (2000) examined the effect of sprint specific plyometric program on a players’ sprint performance. Twenty-six rugby players participated in an eight week training study. Prior to study the participants performed a 40 m sprint. Those who achieved a time of less than six seconds were permitted to participate in the study. Participants were randomly allocated to either a plyometric, sprint or control group. The participants performed sprints over 10 m and 40 m distance before and after training. Some examples of the exercises performed by the plyometric group were double –leg tuck jump, single leg hop, alternated leg bound, sprint bound and speed jumps. The results showed a significant improvement in the plyometric groups’ sprint time when compared to the control group but there was no significant difference between the plyometric group and the sprint group. The plyometric intervention had the greatest effect on the players’ initial acceleration 0-10 m this is similar to the findings in
Delecluse et al. (1994). Ground contact time was found to decrease at 37 m by 4.4% in the plyometric group only. The study concluded that the effects of a sprint specific plyometric training program can improve sprint performance over distances up to 40 m, this improvement is no greater than improvement observed with standard sprint training. The specific plyometric program was implemented in to athletes training program and was executed every other day after the strength or speed training session.

Research by Mackala and Fostiar (2015) examined the effect of short high-intensity plyometric program on explosive power of male sprinters. The participants were trained individuals who were training at least five times a week and were in a pre-competition phase at the time of the testing procedure. The participants completed a two week training program which consisted of six plyometric training sessions. Initial tests required the participant to perform a maximum sprint (flying 20m) and 1 x 60 m sprint from blocks, following this a number of explosive tests were performed and included squat jumps, countermovement jumps, standing long jump and standing triple jump. The plyometric program consisted on single and double leg exercises for example squat jumps, double leg tuck jumps, double leg hurdle hops, single-leg hopping, and sprint single-leg hopping. The results of this study found improvements in the participants’ explosive power with increased in height jumped and distance jumped. Improvements in 20 m sprint were observed as decreases in stride frequency (contact time). This study concluded that plyometric exercises can be used as a short-term strategy that can help improve explosive power.

2.4.4 Combined resistance training studies

Lockie et al. (2011) examined various speed training protocols on sprint acceleration kinematics. Participants were allocated one of the following groups free sprint training n = 9, resisted sprints n = 9, plyometric training n=9 and weight training n = 8. The training intervention involved two 60 minute training sessions over a six week period. Prior to participating in the study participants participate in two days of pre testing to get baseline measures. Day one included an acceleration assessment and a power assessment. The acceleration assessment involved four 10 m sprints which were filmed and timed. The power assessment involved bounding, counter movement jumps and drop jumps. On day two the participants strength was assessed this involved a three repetition maximum squat. During the intervention of six weeks the participants in the free resistance running and the resisted running programs increased their total running
distance weekly. The resisted sprints group towed a load that was 12.6% of their body mass. Those in the weight training group performed exercises which involve bilateral movements – squat standing calf raises and unilateral movements- step ups cable hip flexion. The plyometric group also performed bilateral movements – box jumps, double-leg hurdle hops and unilateral movements- alternate leg bounds, single-leg forward hops, drop jumps were also included in the plyometric program. The results of this study found that all athletes’ improved in 0-10 m sprint there was an increase in velocities. The plyometric and weight training groups had the most significant improvements with effects sizes of 0.42 for the plyometric and 1.41 for the weight training group. Step length was found to increase across all training groups. All the groups except the weight training group improved their drop jump height in the post-test indicating an improvement in reactive strength index in these participants. The study concluded that all four types of training were important aspects in a training program to help improve an athlete or players sprint acceleration.

Delecluse et al. (1995) also researched the effects of different types of resistance training (plyometrics and weight). The study analysed the effect of specific strength training, high resistance and high velocity on sprint performance. The high velocity program involved plyometric exercises and the high resistance training involved free weights and machine exercises. 78 participants participated in the study which involved an intervention program for nine weeks. The participants were assigned to one of the following four experimental groups - high velocity, high resistance, A-Sprint control group and a passive control group. All participants performed a 100 m sprint prior to beginning study as a baseline measure. The study concluded that the high velocity plyometric program is effective in improving the initial acceleration of the 100 m and in turn has an improved effect on the final sprint time when compared. High resistance training resulted in a clear gain in strength but did not improve sprint times.

Wild et al. (2011) examined the biomechanical comparisons of acceleration and maximum velocity phase and made recommendations of strength training exercise which could be useful to improve these phases. The study recommended two different phases of resistance exercises - general preparatory exercises which involves lower limb strength training such as the squats, deadlifts cleans and variations of lunges. These exercises are important for developing strength but specialised preparatory exercises are necessary for specific phases of sprinting. Specialised preparatory exercises vary from
resisted sprint exercises (high load sled towing) and plyometric exercises (hurdle jumps and drop jumps) to strength based exercises (jerks, squat jumps, steps ups, medicine ball dive throws and overhead medicine ball throws). Additionally strength was categorised into one of the two phases of sprinting the acceleration and maximum velocity. The study stated that during training periods strength exercises should have similar contact times and forces close to those of sprinting. Plyometric exercises which focus on fast stretch shortening cycles have been found to have similar contact times to the contact times seen during the acceleration and the maximum velocity phases.

2.4.5 Speed endurance training

Speed endurance training can be defined as high intensity exercise while maintaining speed. Training speed endurance combines speed work with an endurance session. Endurance training sessions involve repeated bouts of sprinting with short recoveries. Physiological adaptations of speed endurance training include – improvements in delivery and use of oxygen at the exercising muscle and an improvement in the muscles capacity for high intensity exercise. This type of exercise involves effective removal of lactic acid from the muscle which is dependent on aerobic metabolism. Endurance training will enable the athlete to recover faster from high intensity training bouts and also perform a higher sprinting in training session (Dick et al. 2014). Speed endurance training has been extensively used as part of a sprinter’s training programme and research on the effectiveness of this type of training has increased. Speed endurance training has more recently been referred to in the literature as High Intensity Interval Training (HIIT).

2.5 Technique

Correct technique is imperative to performance; poor technique can be a limiting factor in an athlete’s speed development. Sprinting technique is dependent on the athlete’s ability to improve the coordination of the muscles used to produce a movement pattern. The athlete’s ability to coordinate the muscles efficiently and quickly has a direct impact on the performance outcome in the case of sprinting the time it takes to complete a 100 m (Cissik 2002). Technique is trainable and is an essential component to sprinting. Cissik (2002) discussed sprint technique, sprinting was divided into two phases the support phase and the recovery phase. The support phase began when the foot made contact with the ground and ended when the foot is no longer in contact with
the ground. The recovery phase began when the foot is no longer in contact with the ground and lasted until the foot makes contact with the ground again. Drills are a valuable part of an athlete’s training and can help the athlete to learn and refine key aspects of running skill, and more specifically, develop sprinting technique (Cissik, 2004). McFarlane (1993) p.57 stated “Practice makes perfect only if practiced perfectly”.

2.5.1 Drills

Drills are considered important in the coaching of correct sprinting technique as they help establish the movement and coordination patterns of sprinting. Coaches will often breakdown a skill into its component parts simplifying sprinting technique. These component parts can be practiced in isolation in the form of specialised sprinting drills. A variety of running drills are used to help develop the movement and coordination patterns of sprinting (Harrison 2010). Some examples of drills used include ankling drills, butt kicks and A drills (Cissik 2002). These exercises which are also referred to as isolation drills are often prescribed to an athlete to aid specific parts of sprinting. Development of speed involves technical skill in the form of specific drills which are designed to isolate and combine joints to mimic a series of sensations that help establish the exact motor pathways of sprinting. McFarlane (1993) states that A-Sprint or high knees can help develop proper sprint technique. This exercise emphasises a high knee lift, keeping hips tall, and cocking the ankle with an active foot landing (pull-push clawing). Using drills to decompose sprinting technique are therefore part of a whole-part-whole learning strategy. Whole-part-whole involves breaking a skill into specific smaller parts in this case drills and relating the drills back to the movement of sprinting (Harrison 2010; Reid et al. 2010; Reid et al. 2013). For successful implementation of this approach, it is important for the drills to closely replicate the movements and activations of sprinting. Information on drills has failed to provide a clear and unequivocal description of how the drills should be implemented to improve sprint performance.

While there is very limited scientific literature on sprint drills, there are many information sources online which provide details on drills used for sprinting. It is important that the drills used by athletes should closely match the movements of sprinting (Harrison 2010; McFarlane 1993). The IAAF recommends ankling, high
knees, heel kick up and high knees with extension to help develop the athlete’s basic running skills (Thompson 2009). The guidelines for high knees are: that the thigh is parallel to the ground, for the heel flick drill the athlete is told to dorsi flex the foot (bring the toe up) and the heel up. Griffiths (2006) suggested that stride length and stride frequency can be improved by using the A and B drills during training, suggesting that the A-drill helps the athlete to bring their knees up high. The aim of this drill is to mimic sprinting but the movement is slowed down to a walking pace. The B-drill is similar to the A-drill but requires the athlete to fully extend the knee of the free leg. A computer simulation analysis by Thelen et al. (2005) of sprinting showed that during late swing phase, the hamstrings muscles are highly active during this phase; the movement involves flexion at the hip and extension at the knee. Similar studies by Heiderscheit et al. (2005), Higashihara et al. (2010), and Yu et al. (2008) used 3D kinematic analysis to examine the movements and activations of sprinting have confirmed that hamstrings are highly active during the late swing and stance phases. Research would suggest that heel flicks mimics knee flexion during the early swing phase of sprinting (Harrison, 2010) since inspection of the sprinting action indicates that immediately after toe-off, the knee and hip joints appear to flex as the knee moves through the swing phase.

To gain an insight into the drills being used, a desk-based search of existing academic databases (Web of Science and Sports Discus) was completed. The search terms included, “sprinting drills”, “sprinting drills athletics”. No relevant articles were found with this search. A manual search of the journals was then conducted on journals including the Journal of Sports Science, the Strength and Conditioning Journal, Journal of Strength and Conditioning Research) and the Journal of Coaching Education. For an article to be considered relevant, it had to provide information on drills used for sprinting and/or running. This search provided a limited number of peer reviewed articles on running drills. Due to the small number of appropriate articles, the search was supplemented with an online search using a generic search engine. Consequently, the majority of the information obtained on drills was from internet sources such as YouTube™, and coaching websites. Following a detailed review of the drills most commonly used, a comprehensive list of drills and their various names was formed. This list was then carefully examined to determine duplicate drills and their names and a
A definite list of the top ten drills according to the available literature was derived (Table 2.1).

**Table 2.1 Drill description/alternative names for the 10 most commonly used drills and coaching points for each drill.**

<table>
<thead>
<tr>
<th>Core Drill</th>
<th>Alternative Name</th>
<th>Description/Coaching points</th>
</tr>
</thead>
</table>
| **A-March**      | High step walking, walking drill                      | • Push up onto toes of supporting leg with each step  
|                  |                                                       | • Involves triple extension of hip, knee and ankle.  
|                  |                                                       | • Drive knee of the other leg to hip level (thigh parallel to the ground)  
|                  |                                                       | • Foot of knee drive leg should be “cocked” dorsiflexed                                                                                                 |
| **A-Sprint**     | High knee running- leg cycling, high step jogging, high knees, high knee drills using ladders | • Running at low intensity with focus on knee lift, that foot is dorsiflexed and moving forward                                                                 |
| **A-skip**       | Pull throughs, claw back, skip claw, pawing drill    | • Similar to A-March but once knee is at hip level “claw” back  
|                  |                                                       | • Need to stay on balls of feet for this exercise                                                                                                       |
| **1, 2, 3 knee lift/Quick Step** | 3 step fast foot (left or right), 2 step and alternate fast feet | • Begin with jogging very slowly  
|                  |                                                       | • Explosively exaggerate one stride with a high knee drive  
|                  |                                                       | • Done alternatively left and right leg                                                                                                                  |
| **Bounding**     | Straight bounding, outside bounding, inside bounding  | • Similar to run with emphasis on driving the knees up and really exploding off the ground                                                                 |
| **Heel flicks**  | Butt kicks, heel kicks, bum whackers, flicks, seat kicks, Flick backs | • Kick heels up to butt while moving forward                                                                                                               |
| **Backward running** | No alternative name                                 | • Normal running action just performed backwards  
| **B-Skip**       | No alternative name                                   | • Similar to A-skip but once knee is at hip level extend leg straight out                                                                                  |
| **B-Run**        | No alternative name                                  | • Push up onto toes of supporting leg with each step  
|                  |                                                       | • Drive knee of the other leg to hip level and extend knee (straightening leg)                                                                         |
| **Straight leg bounds** | Foreleg extensions, straight leg, leg extensions, straight leg shuffle | • Run forward keeping legs straight                                                                                                                      |
2.6 Conclusions

This literature review has considered research on sprinting kinematics during the various phases of sprinting - start, pick up, acceleration, maximum velocity and deceleration. The review demonstrates a lack of scientific research on drills with the majority of available information based on anecdotal evidence or observations of what other coaches and athletes are performing. There is a clear need to examine the drills used by coaches and athletes in more depth. Specifically, there appears to be a need to further examine the following:

- How athletes and coaches use drills, in terms of what drills they use and their reasoning for using drills. This will be addressed through a questionnaire sent to qualified coaches and national and international athletes.

- How drills compare with sprinting in terms of movement and coordination patterns. An examination of the movement and coordination patterns of selected drills compared with the movement and coordination pattern of sprinting.

- The muscle activation and movement pattern during drills and sprinting and whether there are similarities in the timings of the muscle activations during selected drills and sprinting.

From the above, it is anticipated that this information will begin to bridge the gap in the research on drills. It is the aim of this thesis to increase knowledge and understanding of the drills and provide athletes and coaches with relevant information on drills and how they relate to sprinting.
Chapter 3. An Insight into Coaches’ Knowledge and Use of Sprinting Drills to Improve Sprinting Technique and Performance.

3.0 Abstract

Coaches’ knowledge of drills and their specificity to sprint movement patterns and muscle activations has become increasingly important. Drills are used to encourage the development of optimal movement and coordination. They are prescribed to help the athlete develop sprint technique and it is generally assumed that the drills are the parts within a whole-part-whole learning strategy. Previous literature has suggested some drills may be questionable as they may not replicate the muscle activations or movement pattern of sprinting (Harrison 2010). 209 coaches completed an online questionnaire which examined coaches’ choice of drills; reasons for using drill and reasons for changing drills used. The results were analysed using qualitative and quantitative methods. Results showed that coaches believed that drills are vital part of training to improve performance but that they should be specific to sprinting technique.

3.1 Introduction

Research on coaching and coach knowledge has become increasingly popular, especially in track and field sprinting (Jones et al. 2009). Traditionally, coaches have emphasised the need for consistency in movement production (Hay & Reid 1988), therefore maximum sprint performance may be seen as an idealised, invariant pattern. To simplify the learning of sprint technique or reduce its dimensionality, coaches often decompose a skill into its component parts. These component parts can be practiced in isolation in the form of specialised running drills. Coaches and athletes often use a variety of running drills to encourage the development of optimal movement and coordination patterns (Harrison 2010). These exercises, or “isolation drills” are often prescribed to help the athlete to practise specific parts of the running skill, therefore it is assumed that the drills are the parts of a whole-part-whole learning strategy, where the whole skill is decomposed into constituent parts (Hay & Reid 1988; Hunter et al. 2004). For this approach to be successful, it is important that the part practice relates closely to desired sprint movements and Activate the muscles in patterns that are consistent with sprinting. From a pedagogical perspective, the use of varied part practices is well justified, provided the movement parts (drills) accurately mimic the component within the whole skill. Davids et al. (2001) and Reid et al. (2010) have shown that skill decomposition can have poor learning consequences if the key characteristics of the part
practice change significantly when the decomposed part practices are performed in isolation. These studies concluded that the major goals for research in skill acquisition appear to be: (1) to achieve a better understanding of the information–movement relationship that constrains movement system components; (2) to focus on the implications of manipulating various constraints in the learning environment; (3) to improve understanding of how to organise practice regimens and break down sport tasks for the purposes of practice (Davids et al. 2001; Reid et al. 2010). It is hoped that this thesis will contribute to number three in terms of skill acquisition, to improve understanding of how to organise practice regimens and break down sport tasks for the purpose of practice (Davids et al. 2001; Reid et al. 2010). This will be done by improving the understanding of drills which breakdown the skill of sprinting into part practices.

It appears then that isolation drills are valuable and can aid in learning and help refine key aspects to develop sprinting technique (Davids et al. 2001). Drills are considered important as they establish the optimal movement and coordination patterns of sprinting. Despite this, information on isolation drills and various sprinting practices has failed to provide a clear and unequivocal description of how the practices/drills should be implemented to improve sprint performance or the reasons why certain practices may be effective and conversely, why other practices may not. While it is important that part practices mimic the correct sprinting technique, they should also invoke the appropriate muscle activation patterns. Drills that do not mimic the movement pattern or muscle activations of sprinting could be considered questionable (Hunter et al. 2004). A common example of a sprint drill which could be considered questionable is the use of heel flicks (See Figure 3.1 - 3.11). It is believed this drill mimics the knee flexion during the early swing phase of sprinting (Harrison 2010) since inspection of the sprinting action indicates that immediately after toe-off, the knee and hip joints appear to flex as the knee moves through the swing phase. Studies using computer simulation and 3D kinematic analysis of sprinting show that during late swing, which involves hip flexion and knee extension, the hamstring muscles are highly active and are lengthening (Higashihara 2010; Harrison 2010; Yu et al. 2008; Thelen et al. 2005; Heiderscheit et al. 2005). This suggests that heel flicks along with some other drills (straight leg bounds, running backwards and B-drills) which are widely used by coaches and athletes to improve sprinting technique, could be classed as questionable
since the movements and muscle activations may not be consistent with the sprinting action (Hunter et al. 2004).

The peer reviewed scientific literature reveals very limited research on isolation drills in sprinting. Recent research has examined the technical knowledge of coaches with respect to the different phases of a sprint (Jones et al. 2009) and coaches’ understanding of the important characteristics of sprinting (Higashihara et al. 2010). Jones et al. (2009) examined the technical knowledge of expert sprint coaches using semi structured in-depth interviews. The coaches were asked about their understanding of race phases and technical constructs for sprinting. Thompson et al. (2009) investigated expert sprint coaches and their technical knowledge of sprinting. Thompson’s study found that the characteristics of ground contact provided the greatest similarity between the coaches’ responses and the relevant sprint literature. However, in relation to arm action coaches believed that the arms play a vital role in sprinting while the research literature shows that it is of little importance other than somewhat helping to maintain balance. Overall, both studies concluded that coaches appeared to rely on their experience rather information from research on sprint techniques to develop their knowledge of the technical constructs in sprinting (Jones et al. 2009; Thompson et al. 2009).

Clearly, there appears to be a gap between the research-based knowledge on sprinting technique and what coaches implement while coaching their athletes to improve performance. While research on sprint drills appears to be very limited, anecdotal evidence suggests that a wide variety of drills are used extensively by coaches in a wide range of track and field events. Sprinting drills may be an important aspect of learning correct sprinting technique through establishment of optimal movement patterns and coordination, but there is a need for research to establish the range of drills used by athletic coaches and examine coaches’ rationale for using those drills. Therefore, the aims of this investigation were: 1. to determine the range of drills commonly used by track and field coaches with a particular focus on the coaching of sprint events; 2. to examine the reasons that coaches provide for selecting drills. Since drills are often seen as part practices as they mimic the movement or muscle activations, the analysis of the data considered the extent to which coaches prescribed potentially questionable drills. It is expected that the data obtained from this study will provide important insights on the practices of sprint coaches and athletes and their understanding of the learning process.
3.2 Methods

3.2.1 Participants

Participants were Irish based coaches of various qualification levels (n=209). The courses ranged from level 0 to level 3 (the highest athletic coaching qualification in Irish Athletics; recognised as equivalent to IAAF Level 4). Ethical approval was obtained for the University Research Ethics Committee. Coaches were contacted via a third party source, Coaching Ireland. Inclusion criteria for participation in the questionnaire were: coaches had to be qualified athletics coaches (coaching qualification levels 0 to 3) and had to be coaching a sprint event (i.e. sprinting, hurdles, long and/or triple jump). The exclusion criteria were: coaches who were not qualified athletics coaches and/or did not coach a sprint event. Both inclusion criteria were met by all the coaches who completed the questionnaire since they were contacted indirectly via the Coaching Ireland national database of qualified athletics coaches. The coaches were only registered on the Coaching Ireland database because they had completed an Athletics Ireland coaching course, secondly the Coaching Ireland database had information on the events that these qualified coaches were coaching therefore only coaches who were coaching sprint events received an invitation to participate in the questionnaire.

3.2.2 Questionnaire development

As a first step in preparing the questionnaire, a desk based search of existing academic databases (Web of Science and Sports Discus) was completed. The search terms included “sprinting drills”, “sprinting drills athletics”. No relevant articles were found with this search. Therefore, the majority of the information obtained on drills was from internet sources such as YouTube™, and coaching websites. Following a detailed review of the drills most commonly used, a comprehensive list of drills and their various names was formed this aided in the development of answer options within the questionnaire. This list was then examined to determine duplicate drills and names and a definitive list of the top ten most frequently used drills according to the available literature was derived. The questionnaire was piloted with a small sample to ensure clear and easy understanding. Following piloting and final refinement, the questionnaire consisted of 16 questions including closed and open (i.e. textual response) questions.
To gain an understanding of which drills the coaches incorporated into their training sessions, a list of drills described using picture sequences (Figure 3.1-3.5) were provided to supplement several tick the box questions for the coaches. While the coaches were asked to select the drills they used in sprint sessions from the prescribed list, they were also able to name and describe additional drills not included in the questionnaire and their reasons for using these drills. The coaches were also asked to identify three key drills they would use to help an athlete improve their sprinting technique. This provided further insight into the most commonly used sprint drills for developing performance. Survey Monkey™ analysis tools were used for text analysis and to identify the key themes in the textual responses. Drills (Figure 3.6-3.11) were designated as “questionable drills” since the movement patterns and/or expected muscle activations do not appear to mimic the movement pattern and/or muscle activation sequences in sprinting (Harrison, 2010, Thelen et al. 2005 and Yu et al. 2008).

<table>
<thead>
<tr>
<th>Frame Number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A-March</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 3.1 Picture sequence of A-march drill.
A-Sprint

Figure 3.2 Picture Sequence of A-sprint drill.

A-skip

Figure 3.3 Picture sequence of A-skip drill.

Quick Step

Figure 3.4 Picture sequence of quick Step drill.
Bounds

Figure 3.5 Picture sequence of bounds drill.

Heel Flicks

Figure 3.6 Picture sequence of heel flicks.

Backward Running

Figure 3.7 Picture sequence backward running drill.*
B-skip

Figure 3.8 Picture sequence of B-skip drill.

B-March

Figure 3.9 Picture sequence of B-March drill.*

Straight Leg Bounds

Figure 3.10 Picture sequence of straight leg bounds drill. *

* Indicated that the drill was potentially questionable.
These drills have been indicated as potentially questionable drills based on the research of Harrison (2010) which pointed out that drills such as heel flicks do not appear to be consistent with the movement pattern of sprinting. This is because during the swing phase of sprinting, the knee does not flex before the hip is flexed. In reality, the knee flexion occurs simultaneously with hip flexion. Further, Harrison (2010) suggested that during sprinting, the hamstrings are not likely to be active immediately following toe off and therefore the practice of heel flick drills may implement inappropriate muscle activation patterns. Drills such as B-skips, straight leg bounds and backwards running were also highlighted as potentially questionable drills due to inappropriate movement patterns (Harrison, 2010).

3.2.3 Data collection

Information was collected using the finalised online questionnaire. Participants were invited by email via the Coaching Ireland data base to participate in the investigation via a link to the questionnaire on Survey Monkey™.

3.2.4 Data analysis

The data were analysed using a combination of descriptive statistics (percentages, means and frequencies of responses). Histograms were used to display the data trends. The textual responses were analysed using a thematic approach adapted from a seven stage process by Braun and Clark (2006). This involved: familiarisation with the data, generating initial codes, searching for themes, reviewing these themes and defining and naming the themes. The coaches were invited to provide comments after some of the questions. In one such question, the coaches were asked to select the drills they used in sprint sessions from a prescribed list and they were also given the opportunity to name and describe additional drills not included in the questionnaire. These additional drills were categorised according to the nature of the movements involved and are presented in Table 3.2. The Survey Monkey™ analysis tools were used for textual analysis. This tool identified recurrent themes (i.e. the most frequently used words) in the coaches’ responses.
3.3 Results

3.3.1 Coaches’ experience

The results of the survey indicated that 339 coaches commenced the survey; but 209 coaches completed the survey correctly. The loss of 40% of the data was due to incomplete questionnaires i.e. the questionnaire was started, but not all questions were completed by the coaches. Coach qualification levels ranged from ‘athletic leader’ to National level 3. Most of the athletics coaches had a national level 3 qualification (n=93) while 35 had a level 3 qualification and had selected sprints and hurdles as one of their coaching disciplines. All coaches used drills within their training sessions (n=209). Figure 3.11 shows the percentages of coaches who prescribed each of the ten drills illustrated with picture sequences in Figure 3.11. Table 3.1 describes the proportion of coaches selecting questionable drills in relation to their coaching qualification level.

Table 3.1 Percentage of coaches who selected at least one questionable according to their coaching level.

<table>
<thead>
<tr>
<th>Coaching Level</th>
<th>% Who selected at least one questionable drill</th>
<th>% who did not select any of questionable drills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 3 (7%)</td>
<td>80</td>
<td>20</td>
</tr>
<tr>
<td>Level 2 (23%)</td>
<td>82</td>
<td>38</td>
</tr>
<tr>
<td>Level 3 (44%)</td>
<td>73</td>
<td>27</td>
</tr>
</tbody>
</table>
Figure 3.11 Drills used by coaches in order of most popular.

Figure 3.12 The reasons coaches considered drills were important.
Figure 3.13 The reasons coaches provided for changing drills.

Figure 3.14 coaches influences in making changes to sprint drills.

Figure 3.13 and 3.14 provide information on the reasons why coaches changed the drills they were using and the influences in terms of making the changes to the drills. This question was put to coaches to gain an understanding of whether they were open to changing the drills they used based on information that was currently available to them? Of the coaches that participated in the questionnaire, 91% had changed the drills they used. The ways in which they had changed drills involved omitting a drill, adding a new one, progressing/modifying the drill or changing the focus of the drill. The influences in terms of coaches changing drills were
information they received from other coaches, information they found on the internet and information they had received at seminars. Information from coaches was the biggest factor that influenced changes in the drills used.

3.3.2 Textual response analysis

The textual responses of the coaches provided additional information on the drills most commonly used by sprint coaches and in particular, their reasons for selecting them. Table 3.2 provides a summary of these additional drills which are categorised according to the nature of the movements involved.

The textual analysis using Survey Monkey™ analysis tools identified the thirteen most important words and phrases of the coaches’ responses; these are shown in Figure 3.14.

![Table 3.2](image)

Figure 3.15 Textual analysis showing the thirteen most important words and phrases that coaches used when asked to select three drills they would select to help an athlete with their sprint performance.

Table 3.2 Summary of additional drills which are categorised according to the nature of the movements involved.

<table>
<thead>
<tr>
<th>Skips</th>
<th>Variations of A-skips</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee Drive for height</td>
<td>Single leg skips</td>
</tr>
<tr>
<td>Knee Drive for speed</td>
<td>Claw back</td>
</tr>
<tr>
<td>Skipping laterally</td>
<td>Double A-skip</td>
</tr>
<tr>
<td>Backward skip</td>
<td>Sideways movements</td>
</tr>
<tr>
<td>Skips with open arms</td>
<td>Carioca (Crossovers)</td>
</tr>
<tr>
<td><strong>Body weight exercises/stretches</strong></td>
<td>Side step</td>
</tr>
<tr>
<td>Lungs – lunge walk, lateral lunge walk</td>
<td>Sideways running</td>
</tr>
<tr>
<td>Squats - air squats</td>
<td>Back to front side run</td>
</tr>
<tr>
<td>Skip and scoop</td>
<td>Sideways jogging</td>
</tr>
<tr>
<td>Stretching while walking</td>
<td><strong>Walking drills</strong></td>
</tr>
<tr>
<td><strong>Plyometric</strong></td>
<td>Stationary A-march</td>
</tr>
<tr>
<td>Squat jumps</td>
<td>Walking on toes</td>
</tr>
<tr>
<td>Bunny hops</td>
<td>Walking on heels</td>
</tr>
<tr>
<td>Double leg bound</td>
<td>Heel lifts</td>
</tr>
<tr>
<td>Kangaroo hops</td>
<td><strong>Hurdle and ladder drills</strong></td>
</tr>
<tr>
<td>Star jumps</td>
<td>SAQ drills</td>
</tr>
<tr>
<td>Frog hopping</td>
<td>Micro hurdles</td>
</tr>
</tbody>
</table>
Single leg hops
Side to side long bounding
Vertical jumps on spot
Two legged bounds (Forward and back)
Frog hopping
Single leg hops
Side to side long bounding
Vertical jumps on spot
Two legged bounds (Forward and back)

The key points from the textual analysis (illustrated by sample text in italics) showed that:

- Coaches believe drills are an integral and important part of training and should be practiced frequently. “Drills are vital part of training I believe one day per week should be spent solely on drills.”

- Coaches believe drills help develop correct sprinting technique and should be linked to movements similar to sprinting. “Drills are specific to the running action and must mimic it closely”

- Coaches believe drill practice is very important for young athletes. “You couldn’t do enough drills with young athletes but the drill has to be broken down at an early stage so that they can learn it properly as more often than not you see a lot of drills being done wrong....”

- Coaches believe that drills should mimic sprinting “..... I believe that they are the important two for sprint running they mimic sprint running the most”.

- Coaches’ sources of information on which drills to use, generally stemmed from what other successful coaches were doing rather than why drills were actually specific to sprinting. “I feel we (coaches) just listen to other coaches and try the same, however, sometimes we do not know why we are doing a particular drill and if we are doing them correctly, I believe that the top coaches should be providing videos on AI (Athletics Ireland) website that we can look at and telling us the focus that we should be looking for.

- Finally there is need/desire from coaches for more information to be made available on which drills to use. “The hardest question I have to answer is: what do I
teach next, it would be good to have a little book of drills that gave progression and a method to evaluate what drill suits what athlete”.

- The general responses of coaches can be effectively summarised in a single quote from one of the coaches: “I think drills are a really important part of the technical training of my athletes, however, it is important that they are done correctly & work on a specific part of the technique of their event. If the drill is not specific and not conducted correctly, it will reinforce bad technique rather than foster good technique. I believe it is easier to change an athlete’s overall technique with the use of drills as they are only practising a section of ‘the whole’ rather than having to try and alter everything at the same time”

From the results in Figure 3.14 some additional comments from coaches provided further information on why they changed the drills:

**Athlete rationale**- Feedback from the athlete, athlete injury (limited drills), challenge athlete observation of the athlete (more able to do certain drills), athlete not transferring, drills into running technique, athlete progression, athlete had matured and developed (more able to do certain drills).

**Source information**- elite athletes, coaching courses, college, books, DVD, athletics Ireland workshops.

**Other rationale**- experimentation, variability (keeping the session fresh, keeping the athlete interested), gaining in own personal knowledge, drills not working.

### 3.4 Discussion

The aims of this study were: (1) to determine the range of drills commonly used by coaches with a particular focus on the coaching of sprint events and (2) to examine the reasons that coaches provide for selecting drills.

#### 3.4.1 The range of drills commonly used

From the current analysis, the majority of coaches believed that drills were very important for sprint performance and improving technique. The majority of coaches believed that drills should be specific to the sprinting action. The results of the closed questions showed that several drills were considered important by most coaches and these included: A-skip, A-march and A-Sprint (Figure 3.12). Visual inspection of these movement patterns revealed that these drills appeared to mimic the sprint movement pattern of sprinting (Higashihara 2010; Harrison 2010; Yu et al. 2008; Thelen et al.
2005; Heiderscheit et al. 2005); however, further experimental work is needed to determine the exact muscle activation pattern of the drills. From the textual and quantitative analysis of the data, the most popular drill selected by coaches was the A-skip; this was closely followed by heel flicks (Figure 3.12). According to Harrison (2010), the heel flick drill emphasises hamstring activation during and immediately after toe-off to mid-swing phase. There is currently no research on the muscle activation patterns of the lower limb during drills. Research on sprinting has suggested that the hamstrings are most active in sprinting from the late swing phase until toe-off (Harrison 2010; Heiderscheit et al. 2005; Higashihara 2010; Thelen et al. 2005; Yu et al, 2008). This suggests that the activation pattern of sprinting may be different from the activations of the hamstrings during the heel flick drill. There is a noticeable lack of research which directly examines the levels of similarity in the kinematics and muscle activation patterns of drills and sprinting. The coaches’ additional comments about other drills they used provided further insight into the range and variety of drills being used by coaches to develop sprint technique. The additional comments identified a wide range of exercises including, variations of A-skips, skips to plyometric exercises and sideways movements (see Table 3.2). Coaches appeared to incorporate plyometric training with their drills. Plyometric training does not necessarily have to mimic sprinting, but these exercises effectively train fast and slow stretch shortening cycle response, condition the athlete and help reduce injury prevalence (Hunter et al. 2004). When the coaches were asked which three drills they would prioritise if they had a limited amount of time, the two most popular answers were the heel flick and the quick step. Clearly on the basis of these responses, some potentially questionable drills are highly prioritised by coaches.

3.4.2 Coaches’ reasons for selecting drills

Analysis of the data on coach reasons for selecting drills showed that most coaches believed sprint drills were important for technique, strength, balance and warm up (Figure 3a). The need for drills to have similar movement patterns was highlighted by coaches, but some stated that drills needed to be implemented at the optimal time and movement patterns should be similar. For example, one coach most effectively summarised this link between drill performance and technique, stating:
“The limiting factors of speed are primarily technique, therefore you can only sprint as fast as your technique will allow………”

Although coaches appear to be using many drills, the results showed that coaches provided limited justification for using these drills (Figure 3.12). While it would be expected that drills should be similar to sprinting in movement pattern and muscle activation, the results of Figures 3.12 and 3.13 and the text analysis show that coaches’ knowledge of muscle activations and movement patterns appears to be limited. While some coaches mentioned the need for similarity between drill and sprint movement patterns, there was no mention of muscle activations in any of the questionnaire responses. Based on the responses, it appears that coaches primarily base their drill choice on what other successful coaches and athletes do, rather than having a scientific rationale for their decisions. This may be due to the limited amount of scientific research available on kinematics and muscle activations of sprinting drills. This lack of understanding of research is illustrated in the quote of one coach who stated, contrary to the findings of research (Harrison 2010; Heiderscheit et al. 2005; Higashihara 2010; Yu et al, 2008; Thelen et al. 2005).

“Butt kicks and high knees, I believe that they are the important two for sprint running they mimic sprint running the most”.

Since the available evidence of muscle activations in sprinting shows limited hamstring activation during the early to middle swing phase of sprinting (Harrison 2010; Heiderscheit et al. 2005; Higashihara 2010; Yu et al, 2008; Thelen et al. 2005). It appears that the coach may have an understanding of movement but limited knowledge of muscle activations in sprinting.

3.5 Conclusions

The main findings of this study were that A-skips were the most popular drill selected by the coaches. This was closely followed by heel flicks. Coaches believed that drills are a very important aspect of technical training, but it is important that these drills are done correctly and that they mimic sprinting. The reasons for selecting drills were primarily based on what other coaches were doing rather than scientific evidence on coaching practice. Based on the results of this study, it is clear that there is no
substantive scientific rationale for coaches’ selection of drills. This is possibly due to the current lack of research available on drills and how they relate to sprinting technique. This study has provided an insight into the knowledge of coaches, the range of drills used by coaches and why they are using these drills. The drills used by athletes and their reasons for using these drills, remains unclear. Further studies are therefore necessary to gain an insight into athletes’ use of drills and their reasons.
Chapter 4. An Insight into Athlete’s Knowledge and Use of Sprinting Drills to Improve Sprinting Technique and Performance.
4.1 Introduction

4.1.1 Athlete coach relationship

The athlete coach dynamic is an important aspect of an athlete’s development and progression (Jowett and Cockerill, 2003; Jowett, 2003; Jowett and Chaundy, 2004; Jowett 2005; Jowett, 2009) since the way in which a coach instructs their athlete may help or hinder the athlete’s learning of a skill. Jowett et al (2003) examined the nature and significance of the athlete-coach relationships for 12 Olympic medallists and reported that the athlete coach relationship was very important. One athlete made a comment about their role and the role of the coach stating that:

“...my role as an athlete was to follow my coach’s instructions and my coach’s role was to provide me with effective instructions......”

(Jowett et al. 2003 p.323)

4.1.2 Coach instruction and attentional focus

A coach can implement three main types of performance related communication during competition or training, 1. Cues, 2. Verbal instruction and 3. Feedback (Benz et al. 2016). Instructions from coaches can either focus the athlete internally, externally or can be neutral. The coach’s instructions and what an athlete focuses on in training are imperative for athletic development and performance. Research suggests that an athlete performs a skill better if their attentional focus is focused externally (Wulf 2013). Wulf (2013) found that of the studies reviewed 80 experiments reported significant advantages when the participant’s attention was externally focused compared to internally focusing the participants attention.

Porter et al. (2015) examined low skilled sprinters and their 20 m sprint times following various forms of focus cues and found that the athletes ran significantly faster when instructed to focus on external cues. The external cue instructed the athlete to focus on “driving forward as powerfully as possible while clawing the floor with your shoe as quickly as possible”. This was compared with an internal coaching cue which instructed the athletes on “driving one leg forward as powerfully as possible while moving your other leg and foot down and back as quickly as possible as you accelerate”. Similar findings were found in studies by Wulf and Prinz (2001) and Wulf et al. (2001) which reported that external instructions have been shown to be effective for both low and
high skilled athletes when compared to internal focus instructions. Research findings have suggested that verbal instructions and cues have benefits on an athlete’s focus of attention, learning a skill and improving that skill almost immediately (Benz et al. 2016). Despite the research on the benefits of external focus, coaches appear to ignore this information and not implement these instruction practices. In track and field athletes, an effective coaching relationship has been associated with elite athlete performance (Jowett et al. 2002).

Porter et al. (2010) used USA track and field athletes as participants. These athletes were competing at the national outdoor championships. The athletes completed a survey which asked questions about what their coach got them to focus on during training and competition. Athletes focused on specific body parts and how they move or should not move. Results showed that 84.6% of the athletes believed that the instructions they received during training promoted an internal focus of attention rather having an external focus of attention. This was also seen during competition; 69% of the athletes reported that during competition they also focused on internal cues. To enhance the execution of drills, the coach must be aware of what suits their athlete best and whether or not to give their athletes external, internal or neutral coaching instructions (Brady et al. 2017). External instruction directs the attention of the athlete to the effects of their movement, while internal instructions direct the attention of the athlete to some internal aspect of their own actions (Sheppard et al. 2008). In using internal and external instructions for coaching the A-skip, an external instruction would be to “claw the ground back”, while an internal instruction would focus on joint action for example, “focus on extending the support leg”.

4.1.3 The role of drills in developing sprint technique

Coaches play a major role in developing an athlete’s technical ability. Their instructions to athletes on technical aspects of their training can have an impact on the athlete’s performance of that skill (Benz et al. 2016). In sprinting, drills have been found to play a vital role in helping an athlete develop their sprint technique and performance. Research has suggested that a coach can immediately improve their athlete’s performance by simply changing how they instruct or give feedback to the athlete (Wulf 2007). Drills are prescribed to encourage optimal movement patterns and coordination specific to sprinting. To help simplify learning a skill is often broken into its
component parts. Coaches believe that drills play a vital role in technically training for sprinting but these drills must be done correctly and mimic sprinting (Whelan et al. 2016). These components can be practiced in isolation in the form of specific running drills. Coaches often prescribe exercises of “isolation drills” to help the athlete practice specific parts of the running skill. This learning strategy is known as whole-part-whole learning and involves decomposing the whole skill into constituent parts. Whelan et al. (2016) reported that the most popular drill selected by coaches were the A-skip followed by heel flicks. Coaches based their selection of drills based off what other coaches were doing rather than having a scientific rationale for selecting the drills. It is the role of the coach and athlete to ensure that the practice parts relate closely to the desired sprint movement patterns and activation patterns that are consistent with sprinting.

4.1.4 Rationale and aims

Athletes are prescribed a variety of running drills to help improve their sprinting technique. It is interesting to note whether the athlete understands why they are doing the drills prescribed to them by their coach. There is a lack of research demonstrating athlete’s knowledge about drills and their preferred choice. It is important to gain an understanding of what drills athletes are using and their reasoning for selecting these drills. Therefore the aims of this investigation were: to determine the range of drills commonly used by athletes in sprint events, to examine the reason that the athletes provided for why they used these drills, and finally to compare athlete responses to the coaches’ responses in Chapter 3.

4.2 Methods

4.2.1 Participants

Participants were international and national level athletes (N = 49) from Ireland (82%), the United Kingdom (16%) and United States of America (2%). All participants competed in sprint, hurdle or jump events, distance athletes were not asked to participate in this study. Participants were recruited via various methods such as squad lists and direct contact as a fellow athlete. All the participants were contacted via email and asked to participate in a short questionnaire. Ethical approval was obtained from the local University Research Ethics Committee.
4.2.2 Questionnaire development

The questionnaire development and picture sequence (see Figure 3.1-3.11) were similar to those used in Chapter 3. The athlete’s questionnaire consisted of questions directly about the athlete for example the level in which they competed and how often a week did they train. The remainder of the questions used for the athlete questionnaire were identical to those used in the coaches’ questionnaire.

4.2.3 Data collection

The questionnaire was piloted with a small sample of athletes to ensure clear and easy understanding. Following piloting and final refinement, the questionnaire consisted of 16 questions including closed and open (i.e. textual response) questions. Information was collected using the finalised online questionnaire. Participants were contacted directly via email to participate in the investigation via a link to the questionnaire on Survey Monkey™

https://www.surveymonkey.net/create/?sm=Ey4Tn2D4ss_2F2F3kJujwn91L6CavgGptOjof_2B5aOGVvFs_3D

4.2.4 Data analysis

The data analyses in this study were identical to those used in Chapter 3 the coaches questionnaire study. Additionally responses from the coaches on their drill selection (Figure 3.11) were compared with the athlete’s response for drill selection.

4.3 Results

4.3.1 Quantitative analysis

The results of the survey indicated that 49 athletes commenced and completed the survey correctly. Athletes’ levels ranged from national 57.2% (making a final at their national championships) to international level 42.8% (competed for the country at underage – youth, junior and under 23 or senior level) with some competing at the Olympics London, 2012 & Rio, 2016. All the athletes used drills within their training session.
Table 4.1 Drills selected by athletes in order of most popular. A-skip, A-Sprint and A-March were the most popular drills selected by the athletes.

<table>
<thead>
<tr>
<th>Answer Options</th>
<th>Number of Responses</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-skip</td>
<td>45</td>
<td>91.8%</td>
</tr>
<tr>
<td>A-Sprint</td>
<td>38</td>
<td>77.5%</td>
</tr>
<tr>
<td>A-March</td>
<td>37</td>
<td>75.5%</td>
</tr>
<tr>
<td>Quick step</td>
<td>35</td>
<td>71.4%</td>
</tr>
<tr>
<td>B-Skip</td>
<td>26</td>
<td>53.1%</td>
</tr>
<tr>
<td>Bounding</td>
<td>24</td>
<td>49.0%</td>
</tr>
<tr>
<td>Heel flicks</td>
<td>22</td>
<td>44.9%</td>
</tr>
<tr>
<td>Straight leg bounds</td>
<td>22</td>
<td>44.9%</td>
</tr>
<tr>
<td>B-March</td>
<td>20</td>
<td>40.8%</td>
</tr>
<tr>
<td>Backward running</td>
<td>10</td>
<td>20.4%</td>
</tr>
</tbody>
</table>

Table 4.2 When in training athletes use drills and the reasons athletes thought drills were important.

<table>
<thead>
<tr>
<th>When in training are drills used by athletes</th>
<th>Why do athletes think drills necessary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Answer Options</td>
<td>Number of Responses</td>
</tr>
<tr>
<td>Dynamic warm up</td>
<td>33</td>
</tr>
<tr>
<td>After stretching pre training Drills session</td>
<td>29</td>
</tr>
<tr>
<td>End of training</td>
<td>9</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 4.1 A comparison of athlete and coach responses.

Table 4.1 provides information on the drills selected by athletes in order of popularity. Almost all the athletes who participated in the questionnaire selected A-skip (91.2%) as the most popular drill. This was followed by A-Sprint (77.55%) and A-March (75.5%). The least popular drill selected by the athletes was backwards running (20.4%). Table 4.2 illustrates the reasons why athletes believed drills were important and when in training do they use drills. Over half the athletes (57%) who participated in the questionnaire believed drills were important for technique. The two most popular times for when drills were used were as a dynamic warm up (67.4%) and after stretching prior to the main training session (59.2%). Figure 4.1 depicts the difference in drills selected by the athletes and coaches (Chapter 3 Figure 3.11). It is interesting to note that both the athletes and coaches selected A-skip as the most popular drill. However, the athletes and coaches differed in their selection of the second most popular drill. Athletes selected the A-Sprint while the coaches selected heel flicks. B-March and backwards running were the two least popular drills selected by both the athletes and coaches. This indicates that of the 49 athletes and 209 coaches that those drills (B-March and backwards running) are not widely implemented into a drill programme. The textual analysis using Survey Monkey™ analysis tool identified the nine most important words.
and phrases of the athletes responses when asked which three drills do they think are the most important. These responses can be seen in Figure 4.2.

<table>
<thead>
<tr>
<th>Quick Step</th>
<th>Butt Kicks</th>
<th>Run</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heel Flicks</td>
<td>B skipping</td>
<td>Knee Lifts</td>
</tr>
<tr>
<td>High Knees</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 4.2 Textual analysis showing the thirteen most important words and phrases that athletes used when asked to select three drills to help an athlete with their sprint performance.

4.3.2 Textual analysis

The key points from the textual analysis (illustrated by sample text in italics showed that:

- Coaches play a major role in determining the drills athletes perform. The athletes relied on their coaches to make the changes necessary to the drills they were doing. When asked why changes were made to the drills they used 8.3% stated it was based off information found on the internet, 91.7% stated it was based off information from another coach and 16.7% changed the drills used based on information from a seminar. The coaches’ influence was very apparent in the following comments from athletes on why they changed drills they were doing. “no idea - coach's decision”, “Coach decision” “Information from my coach” “coach experience”.

- Some athletes have a greater understanding of the need for drills with one stating the change was made “To help improve running biomechanics”.

- Athletes do have an understanding that correct technique i.e. drills should be closely linked to the movements similar to drills and that drills should mimic sprinting “I was advised against doing the B skip as it wasn't specific to sprinting and emphasised the lower leg swinging forwards, instead of down and back.”

“I removed a few drills from previous years as some did not reflect the actual running motion and were training in bad habits that were somewhat effecting my overall running technique i.e. for me, quick step was more training my non
lifted leg to shuffle with a low knee while my main focus was on my lifted leg. (if that makes sense)"

“I think the march is important as it mimics the running action and educates the muscle memory”

“the technical drills that work on body sprint position, that adapt behaviour in running technique”

- When athletes were asked what drills the thought were the most important there was a variety of answers (see Figure 4.2). When looking at the textual response the following were the most common combinations of the three drills:
  
  “A-skip, A-Sprint and A-March”
  “A-Sprint, A-skip, and Quick step
  “A-skip, A-March, Bounding”

4.4 Discussion

The aims of this investigation were: to determine the range of drills commonly used by athletes in sprint events, to examine the reason that the athletes provided for why they used these drills, and finally to compare athlete responses to the coaches’ responses in Chapter 3.

4.4.1 Range of drills commonly used

From the current analysis, the majority of athletes believed that drills are important for improving their sprint technique and sprint performance. Some athletes believed that the drills they are doing should closely mimic sprinting action. The three drills that athletes deemed to be the most important were: the A-skip, A sprint and the A march (Figure 4.1). It is interesting to note that when coaches were asked the same questions, the coaches selected A-skip, heel flicks and A sprint (Whelan et al., 2016). The movement pattern of the A drills appears to visually mimic the movement pattern of sprinting. Heel flicks according to Harrison (2010) have been reported to emphasise hamstring activation during and immediately after toe-off to the mid-swing phase, however, research suggests that the hamstring is most active in sprinting from the late swing phase until toe-off (Thelen et al. 2005; Heiderscheit et al. 2005; Higashihara et al. 2010; Yu et al. 2008). It should be noted that when discussing the movement and activation patterns that there is no current scientific research on the muscle activations of drills and
further research should be conducted to determine the muscle activations of drills. The findings of the current study suggest that the athletes and coaches differ slightly when selecting the most important drills for improving sprint performance. The athletes who completed this study believe that the A drills (A-skip, A-Sprint and A-March) are the most important drills selected, however, this is different when compared to the coaches responses who believe that the A-skip is the most important with heel flicks drills ranked as the second most important drills for aiding sprinting technique and performance. The results indicate that athletes do have an understanding that correct technique when performing drills should be closely linked to the movements similar to drills and that drills should mimic sprinting “I was advised against doing the B skip as it wasn't specific to sprinting and emphasised the lower leg swinging forwards, instead of down and back.”

The results also showed that some athletes are influenced by what their coach tells them to do, with some stating that the reason for changing drills was because their coach told them to change it. The results of this study are similar to the findings of Jewett et al. (2003) which further highlighted the importance of the athlete coach relationship with the statement made by an Olympic medallist about their coach “my role as an athlete was to follow my coach’s instructions and my coach’s role was to provide me with effective instructions……” (Jewett et al. 2003 p.323). The most interesting finding from the current study is the difference between coach and athlete selections of the most important drills. It appears that in this sample there is a mix of athletes who follow the instructions of their coaches without any further thought, while other athletes put considerable thought into the selection of practices. The coach plays a major role in how athletes learn a skill, drills are a fundamental part of sprinting and it is important that the coach provides the right instructions and cues for the athlete to learn the drill correctly.

4.5 Conclusion

The main findings of this study were that A-skips were the most popular drill selected by the athletes. This was closely followed by A-Sprint and A-March. The results showed that athletes are aware that drills should mimic sprinting patterns. Athletes are predominantly using drills because their coach told them to do those drills. While the findings from Chapter 3 indicate that coaches are selecting the drills used based on what other coaches are doing rather than having a scientific rationale for selecting drills. It is
the responsibility of both coach and athlete to question the drills being used and to have a scientific rationale for using those drills. However, as stated in Chapter 2 there is currently limited scientific research available to coaches and athletes on drills. The resources that are available are not based on a scientific rationale but largely on the drills that successful coaches and athletes are using. The findings from Chapter 3 and Chapter 4 show that athletes and coaches are aware that drills should mimic the movement pattern of sprinting. It is the aim of this thesis to provide coaches and athletes with scientific information on drills. Further studies within this thesis will investigate the kinematics of sprinting and two drills namely, the A-skip (most popular drill selected by both coaches and athletes) and heel flicks (second most popular drill selected by coaches).
Chapter 5. Developing methods of analysis for determining foot contacts and electromyography thresholds for on and off events, using Wireless EMG.
5.1 General introduction

This chapter is the first step in determining the feasibility and effectiveness of the instrumentation being used for the main study. Two pilot studies were completed to determine effective analysis techniques for electromyography (EMG) and acceleration data. The demands of this thesis require developing analysis methods to identify foot contacts and muscle activity. It is important to have a reliable technique to identifying foot contact events, foot switches which have been used to determine foot contacts are not hugely reliable. The analysis of muscle activations events has been examined using various threshold methods for example using 1, 2 or 3 times the standard deviation of a quiet phase as a threshold to determine when the muscle is active and when the muscle is not active (Hodges & Bui, 1996). For this research it is necessary to develop a method for determining EMG on and off events. The equipment used for this thesis is the Delsys Trigno Wireless EMG system which records both EMG activity and acceleration data. This system has the potential to provide solutions for both EMG and acceleration data by mounting one of the Delsys sensors to the leg. There is a need to evaluate the Delsys sensors in terms of EMG and acceleration data to determine if it is suitable for future thesis studies. The aims of these studies were:

Pilot study 1: To develop and test a method for identifying peak impact accelerations using the Delsys Trigno system during running and comparing the timing of this event with the initial contact on the force platforms.

Pilot study 2: To develop and test a method for identifying on and off activities of lower limb muscles during maximal sprinting and to identify the key events of the running cycle. Secondly to explore a new method for identifying 50% maximum muscle activation thresholds during maximal sprinting and to identify the key events of the running cycle.

5.2 Introduction pilot 1

Sprinting performance is determined by stride rate and stride length, however, there are many other components that influence sprinting including muscle action. In a movement task as complex as sprinting a large group of muscles must be activated at the appropriate times and intensities (Ross et al. 2001). A gait cycle can be divided into the stance and the swing phase. The stance phase can be defined as when one foot
comes in contact with the ground (initial contact) and ends when the same foot contacts the ground again. The stance phase ends when the foot is no longer in contact with the ground. As the toe leaves the ground (toe-off) the swing phase begins (Novacheck 1998). Determining the phase of initial contact can be done using force platforms. Force platforms provide a valid method for measuring initial contact (foot strike) during running. The use of force platforms however, is not practicable for outdoor situations as they are fixed in the ground and are therefore non-portable. It may not be possible in some indoor situations where a force platform is not installed. Recent developments in wireless inertial sensors may enable the determination of key events in running gait outside a laboratory environment. Accelerometers are useful for field based testing as they are portable, lightweight, and can be used for extended periods (Kavanagh et al. 2006). Various studies have used force platforms and accelerometers to try determine foot contact events during walking and running (Lee et al. 2010; Auvinet et al. 2002; Sinclair et al. 2013) and sprinting (Purcell et al. 2005). Purcell et al. (2005) developed and tested a method for determining foot ground contact time during the acceleration phase of maximal sprinting using data obtained from a force platform and an accelerometer. Contact time was determined using the minima of the anterior–posterior axis accelerations and on the X and Z axis accelerations which experienced a local minima and maxima respectively around the event of toe-off. Lee et al. (2010) used an inertial sensor placed on the sacrum to examine stride, step and stance durations at various walking and running frequencies. Tibial accelerations were examined in the anterior-posterior direction to identify foot-strike events. Acute positive peaks in anterior-posterior acceleration indicated foot-strike. The results indicated there was less than 0.020 seconds difference between force platform and accelerometer identified foot-strike events, indicating a strong similarity between both methods. Despite many studies on identifying foot strike events there is a need to establish the appropriate methods for determining foot strike events using acceleration data from the Delsys system.

5.3 Methods pilot 1

5.3.1 Participant characteristics

Seven national and international sprinters (three males, four females with a mean age of 22.28 ± 2.24 years; stature 1.69 m ± 0.11 m; and body mass 60 kg ± 8.93 kg) were recruited from within a training group in the University of Limerick. Volunteers were
recruited via attending the groups training session and informing them of the testing procedures. All participants were physically active and injury free and completed one testing session. Ethical approval for the study was granted from the university research ethics committee, and written consent was obtained from all participants. Before taking part in the study, all participants completed a physical activity questionnaire and provided informed consent in writing.

5.3.2 Measurement devices

Participants underwent this testing procedure once. All participants completed their own warm up followed by a series of familiarisation trials prior to the testing. For the testing protocol a Delsys Trigno Wireless EMG System Natick MA, USA and an AMTI force platform (OR6-5, Advanced Mechanical Technology, Inc., Watertown, MA, USA) were used to obtain ground reaction force and accelerometer data. The force platform sampling frequency was 1000 Hz while the accelerometer sampled at 148.15 Hz. Systems were synchronised using an external source, Delsys Trigger Module (SN: 1345). Due to the differences in sampling rate between the systems, there was an expected delay between the two systems of up to 7 ms. A Delsys Trigno Wireless triaxial accelerometer device was secured to the participant’s right leg (shin bone) to record the tibial accelerations during the running trials.

5.3.3 Running procedures

Participants completed ten runs across a force platform. The participants were instructed to step with their right foot on an AMTI strain gauge force platform (AMTI ORG-5; AMTI, Watertown, MA, USA). Each run was followed by a 30 s recovery.
5.3.4 Data analysis

The force platform data were analysed to determine the instant of foot contact. This was determined by finding the instant where there was an increase in the vertical ground reaction force above a threshold of 5 N. Previous research has indicated that a minor anterior acceleration peak (i.e. peak impact acceleration) occurs after the foot-strike event and a major peak occurs soon after toe-off, (Purcell et al. 2005). All three axes were analysed but the Z axis (anterior-posterior) data provided the most appropriate indicator when compared to the force platform and was also the easiest to identify the peak accelerations. A number of acceleration trials were firstly filtered to determine the appropriate frequency cut off for acceleration data. The acceleration data were filtered from 6 Hz to 12 Hz. Using a frequency cut off of 10 Hz provided smooth data and also allowed to determine gait events. The Z axis accelerometer data were filtered using a low pass Butterworth filter with a frequency cut off (fc) of 10 Hz (Winter, 2009) and the time occurrences of peak acceleration were recorded and compared to the force platform data. The timings of the Z axis peak impact acceleration event accelerometer data were
compared to the force platform data foot-strike event. The average maximum and minimum difference between the times on the force platform foot-strike event and the peak impact accelerations via the tibial-mounted accelerometer were calculated. An interclass correlation coefficient (ICC) and a Pearson R were calculated together with Bland and Altman (1986) limits of agreement (LoA) to determine the levels of agreement between the peak impact acceleration and foot-strike events.

5.4 Results pilot 1

Table 5.1 provides information on the maximum and minimum differences between the time of heel strike on the force plate and the minor peak in the acceleration data. The data demonstrates that peak tibial impact acceleration provided a very good estimate of foot impact with maximum and minimum differences ranging from -0.017 to +0.015 s when compared with force platform data. Interclass correlation coefficient (ICC) a Pearson R and limits of agreement (LoA) are also presented in table 5.1 to determine the levels of agreement between the peak impact acceleration and foot-strike events. The ICC and Pearson R values of >0.99 indicate that there are very high correlations between the force platform foot-strike event and peak impact acceleration in the anterior-posterior axis Figure 5.2 provides an exemplar graph illustrating anterior-posterior accelerations compared with the initial contact on the force platform. There is a large acceleration forward as the foot lands (heel strike), as the foot comes off (Toe-off) there is the biggest acceleration forward. Initial contact according the force platform was 2.64 s and 2.625 s according to the accelerometer-based method (difference of 0.015 s)

Table 5.1 Average minimum, maximum, Upper LoA, Lower LoA, Intraclass Confidence Interval and Pearson R comparisons of force platform and accelerometer data

<table>
<thead>
<tr>
<th>Maximum Difference (s)</th>
<th>Minimum Difference (s)</th>
<th>Upper Limits of Agreement (s)</th>
<th>Lower Limits of Agreement (s)</th>
<th>Intraclass Confidence Interval</th>
<th>Pearson R (r)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.015</td>
<td>-0.017</td>
<td>0.038</td>
<td>-0.012</td>
<td>&gt;0.99</td>
<td>0.999</td>
</tr>
</tbody>
</table>
5.5 Discussion pilot 1

The purpose of this study was to develop a method for determining or approximating foot-strike during running using an accelerometer device (Delsys Trigno Wireless). The results show that the use of accelerometers provides a means to accurately determine peak tibial impact accelerations in a laboratory setting. The data demonstrated that peak tibial impact acceleration provides a very good approximation to foot impact with average maximum and minimum differences between acceleration and force platform data of -0.017 s to + 0.015 s. In analysis of running gait, peak tibial impact acceleration may be used to normalise the gait cycle data. The ICC and Pearson R values of >0.99 indicate that there are very high correlations between the force platform foot-strike event and peak impact acceleration in the anterior-posterior axis. These data show that the accelerometer based peak impact reading provides close estimates of initial contact/foot-strike during running. While the peak impact acceleration may not be an
identical event to foot-strike, it does occur regularly in the gait cycle and occurs within 20 seconds of the foot-strike event. The data in this experiment agrees closely with the findings of Purcell et al. (2005). According to Purcell et al. (2005) the level of agreement increased with running speed. This is due to the association of larger accelerations being generated with increased speed. While previous studies consider the minima and maxima accelerations of the anterior-posterior axis (Purcell et al. 2005; Auvine et al. 2002), the minor peak before the subsequent major peak in anterior-posterior acceleration was an easily identifiable event when compared to the force platform vertical ground reaction force. The second purpose of this study was to develop a method of determining an approximation of a foot-strike event to aid with future studies in which participants will be maximally sprinting. It should be noted that while this event may not exactly coincide with foot-strike, it can provide a useful approximation to this event. Therefore, in practical situations, running gait cycles could be effectively normalised using consecutive peak tibial impact acceleration events rather than consecutive foot-strikes.

5.6 Limitations

The pilot study had some limitations. The Delsys Trigno Wireless sensor acceleration maximum sampling frequency of 148 Hz limited the precision for detection of events from the acceleration data. This sampling frequency could provide difficulties in determining foot strike events as the speed of the movement increases (i.e. during maximum sprinting). This did not appear to be a problem in the current pilot study due to the sampled runs being conducted at slow and not maximum speeds. The speed of the sampled runs was limited due to the location of the force platform (in a laboratory space) and therefore it was impossible for the participants to run at maximum speed.

5.7 Conclusion pilot 1

This study found that a single accelerometer positioned on the anterior tibia provided an effective technique to identify key events in the running gait cycle. The peak impact acceleration approximated foot-strike to within ± 0.017 s. The findings from this study provide a means of key gait event data collection and analysis outside the laboratory.

5.8 Introduction pilot 2

There are many studies which have looked at the activations of the lower limb muscles during sprinting (Howard et al. 2017; Novacheck 1998; Mero & Komi 1994; Mero et al. 

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Determining the onset of muscle activity has been used across various EMG studies. A common method for determining the onset of activity is the use of a threshold which is derived from the baseline signal amplitude characteristics using the mean and standard deviation (Hodges & Bui 1996). A body of research on the injury of the hamstrings has focused on the activations of the hamstring during maximal sprinting for both the stance and swing phase (Yu et al. 2008; Chumanov et al. 2012; Higashihara et al. 2010; Thelen et al. 2005; Chumanov et al. 2011; Chumanov et al. 2007). Despite many of these studies there is a need to establish appropriate threshold methods for determining on and off events during sprinting. The aims of this study were to use an appropriate method for identifying on and off activities of lower limb muscles and to explore a new method for identifying 50% maximum muscle activation thresholds during maximal sprinting.

5.9 Methods pilot 2

5.9.1 Participant characteristics

Six sprinters (4 males, 2 females (age 22 ± 2.6, mass 70 kg ± 13 kg, height 1.74 m ±0.09 m) participated in this study. The participants ranged from 100 m sprinters to 400 m hurdlers. All participants were of a national (qualified for the national final in Ireland) or international level (selected in their discipline to represent Ireland). At the time of testing all participants were injury free and had been participating in sprinting sessions at least three times a week for the last six months. Ethical approval for the study was granted from the university research ethics committee, and written consent was obtained from all participants. Before taking part in the study, all participants completed a physical activity questionnaire and provided informed consent in writing.

5.9.2 Experimental procedures

Kinematic data was recorded using a Casio (EX-F1) high speed camera 240 Hz. The camera was placed in the middle of the flying 20 m zone (at the 10 m line between 2 cones). Delsys Trigno Wireless EMG™ were placed on both the right and left side of the participants. Electromyography (EMG) data were recorded at 2000 Hz and acceleration data were recorded at 148.15 Hz. Sensors were placed using SEMIAM electrode placement guidelines on the shin bone (accelerometer), rectus femoris (EMG), medial gastrocnemius (EMG), and the biceps femoris (EMG). The rectus femoris, lateral gastrocnemius and biceps femoris were selected for the following reasons:
1. Based on previous research by Mero and Komi (1987) which selected the gastrocnemius, biceps femoris and rectus femoris.

2. Each muscle has been identified as contributing to the execution sprinting (Mero and Komi, 1992).

3. The muscles selected are the most superficial muscles in each of the areas and also the easiest to identify for sensor placement.

<table>
<thead>
<tr>
<th>Table 5.2 Sensor placement and muscle identification information</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Muscle</strong></td>
</tr>
<tr>
<td>Medial gastrocnemius</td>
</tr>
<tr>
<td>Biceps femoris</td>
</tr>
<tr>
<td>Rectus femoris</td>
</tr>
</tbody>
</table>

5.9.3 Running procedures

After completing their own preferred warm up, all participants performed three maximal sprints using a flying start. This required the participant to gradually build up their speed and be at maximum speed between two cones which were 20 m apart in distance. Recovery between the trials was up to 10 minutes or when the athlete felt they were fully recovered.

5.9.4 Data analysis

Accelerometer data were analysed based on methods previously used (5.3 methods). The Z axis accelerometer data were filtered using a low pass Butterworth filter with a frequency cut off (fc) of 10 Hz. The data were visually inspected by graphing the data points in Microsoft Excel (See Figure 5.3). A large peak acceleration in the graph indicated the foot landing (heel strike); and a second peak acceleration indicated the foot coming off (toe-off) (Purcell et al. 2005). This process was used to estimate the
point in time in which heel strike and toe-off occurred. These time points made it possible to ascertain muscle activity during certain events in the running cycle. The EMG data were analysed using the following steps using Excel:

**Rectified**

The Raw EMG data were full wave rectified to a single polarity frequency which in this case was positive. The purpose of rectifying a signal is to ensure the raw signal does not average zero, due to the raw EMG signal having positive and negative components (Robertson *et al.* 2014).

**Low Pass Filter**

The EMG data were filtered using a low pass Butterworth filter with a frequency cut off (fc) of 10 Hz to remove baseline drift any DC offset (Robertson *et al.* 2014). EMG data were filtered at 10 Hz to create a smooth linear envelope.

**Threshold**

Thresholds of three times the standard deviation of a quiet phase during the activity were used. EMG activity above this threshold classed as active or on and below the threshold classed as inactive or off. The threshold of three times the standard deviation of a quiet phase appeared too low as all the muscles were active throughout the full sprinting cycle (Hodges & Bui, 1996).

**Normalised**

The EMG data were normalised firstly against time from heel strike to heel strike (one full running cycle). The data were also normalised against the highest peak during the running cycle. This normalisation approach was used rather than normalising to maximum voluntary isometric contractions based on the findings of Suydam, Manal and Buchanan, (2017) which demonstrated that ballistic tasks such as sprinting provided more reliable data using normalisation to peak EMG signal in the activity compared to normalisation to constrained maximum voluntary contractions. One of the justifications for this was that sprinting permitted the body to perform natural unconstrained movements. EMG signals above 50% were characterised as highly active and below the 50% threshold was characterised as active. The use of the 50% threshold is based on analysis techniques used by Howard *et al.* (2017).
5.10 Results pilot 2

The results for determining heel strike which is step one of the data analysis process can be seen in the exemplar graph (Figure 5.3). Heel strike is determined using previously used methods outlined in pilot 1 of the filtered acceleration data. There is a large acceleration forward which indicates the foot landing this can be seen in the graph as the smaller peak which occurs at 4.5 seconds; the second larger peak acceleration occurring at 4.82 seconds indicates the foot coming off the ground finally the smaller peak can be seen again at 5.06 seconds this indicates a full running cycle (heel strike to heel strike). From Figure 5.3 a running cycle is determined heel strike to heel strike (4.5 -5.06 s). The EMG activity of the rectus femoris can be seen in Figure 5.4 during this time period. Figure 5.4 shows a large amount of activity throughout the sprint cycle. For this reason a more detailed method of determining muscle activity was used (Figure 5.5). The EMG data seen in Figure 5.5 is normalised against time and also against the highest peak during the running cycle. Activity > 50% was characterised as a high level of activity during sprinting. The exemplar graph gives a greater understanding of EMG activity during sprinting and indicates high levels of activity for each of the muscles at various stages of the sprint cycle.
Figure 5.3 Exemplar graph illustrating anterior-posterior acceleration accelerometer data filtered at 10 Hz during near maximal sprinting.

Figure 5.4 Exemplar graph illustrating EMG of the rectus femoris of the right leg filtered at 12 Hz during a known period of heel strike to heel strike (from acceleration data above).
Figure 5.5 Exemplar graph illustration normalised EMG data. Above 50% was characterised as highly active.

The average results for each individual athlete using the above methods are shown in table 5.2. The on and off column indicates the period of time for each individual in which the muscles were active above three times the standard deviation threshold of a quiet phase. For all the participants this activity begins early in the cycle. The on 50% and off 50% columns gives a greater insight into the activity of each muscle and pinpoint periods where there is a high level of activity during the cycle. Figure 5.6 gives a visual example of the average muscle activity for the group during a maximal sprinting running cycle. The graph shows that all three muscles are active throughout heel strike the swing phase the muscle activity is then low towards the end of the sprint cycle (below 3*SD threshold). All the muscles groups have two bouts of high activity <50% during the sprint cycle. The highest activity for the gastrocnemius can be seen at the beginning of the cycle and as the toe begins to leave the ground. The biceps femoris initially is active during mid heel strike and shortly after toe-off. The rectus femoris is highly active for the longest period from mid heel strike to just after toe-off. Table 5.3
provides information on the average EMG profile for all six participants. The average EMG activity has two periods of activity >50% of the maximum muscle activation thresholds during maximal sprinting for all three muscles. Table 5.4 provides information of the group average percentages of on and off above threshold and on and off above 50% of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle (heel strike to heel strike). Figure 5.6 is an exemplar graph of the data outlined in table 5.4. Figure 5.6 provided graphical information on the percentages of on and off above threshold (3*SD) and on and off above 50% of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle average group (heel strike to heel strike).
Table 5.3 Individual average percentages of time on and off above threshold and on and off above 50% of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle (heel strike to heel strike).

<table>
<thead>
<tr>
<th>Muscle</th>
<th>3* SD Threshold</th>
<th>50% Threshold</th>
<th>50% Threshold</th>
<th>50% Threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>On 3* SD Thresh.</td>
<td>On 50% Thresh.</td>
<td>Off 50% Thresh.</td>
<td>Off 50% Thresh.</td>
</tr>
<tr>
<td><strong>Participant 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastrocnemius (%)</td>
<td>5.3</td>
<td>73.3</td>
<td>27.7</td>
<td>46.0</td>
</tr>
<tr>
<td>Biceps Femoris (%)</td>
<td>2.7</td>
<td>71.3</td>
<td>7.7</td>
<td>27.3</td>
</tr>
<tr>
<td>Rectus Femoris (%)</td>
<td>16.0</td>
<td>100.0</td>
<td>43.7</td>
<td>59.0</td>
</tr>
<tr>
<td><strong>Participant 2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastrocnemius (%)</td>
<td>0.7</td>
<td>95.3</td>
<td>17.0</td>
<td>34.7</td>
</tr>
<tr>
<td>Biceps Femoris (%)</td>
<td>0.0</td>
<td>100.0</td>
<td>3.3</td>
<td>24.0</td>
</tr>
<tr>
<td>Rectus Femoris (%)</td>
<td>2.3</td>
<td>80.7</td>
<td>31.3</td>
<td>45.0</td>
</tr>
<tr>
<td><strong>Participant 3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastrocnemius (%)</td>
<td>7.0</td>
<td>82.0</td>
<td>12.0</td>
<td>45.0</td>
</tr>
<tr>
<td>Biceps Femoris (%)</td>
<td>6.0</td>
<td>94.0</td>
<td>11.5</td>
<td>43.0</td>
</tr>
<tr>
<td>Rectus Femoris (%)</td>
<td>0.0</td>
<td>100.0</td>
<td>34.0</td>
<td>51.0</td>
</tr>
<tr>
<td><strong>Participant 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastrocnemius (%)</td>
<td>4.0</td>
<td>69.8</td>
<td>4.2</td>
<td>24.0</td>
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<td>Biceps Femoris (%)</td>
<td>18.7</td>
<td>75.0</td>
<td>21.0</td>
<td>41.7</td>
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<tr>
<td>Rectus Femoris (%)</td>
<td>0.7</td>
<td>71.3</td>
<td>21.7</td>
<td>40.0</td>
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<tr>
<td><strong>Participant 5</strong></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Gastrocnemius (%)</td>
<td>8.0</td>
<td>82.3</td>
<td>13.3</td>
<td>30.7</td>
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<tr>
<td>Biceps Femoris (%)</td>
<td>0.7</td>
<td>69.7</td>
<td>0.0</td>
<td>10.7</td>
</tr>
<tr>
<td>Rectus Femoris (%)</td>
<td>0.7</td>
<td>76.3</td>
<td>17.3</td>
<td>33.0</td>
</tr>
<tr>
<td><strong>Participant 6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gastrocnemius (%)</td>
<td>0.0</td>
<td>70.5</td>
<td>16.5</td>
<td>47.0</td>
</tr>
<tr>
<td>Biceps Femoris (%)</td>
<td>0.0</td>
<td>80.5</td>
<td>9.5</td>
<td>19.0</td>
</tr>
<tr>
<td>Rectus Femoris (%)</td>
<td>0.0</td>
<td>64.5</td>
<td>5.0</td>
<td>16.5</td>
</tr>
</tbody>
</table>
Figure 5.6 Graphical representation of percentages of on and off above threshold (3*SD) and on above 50% threshold of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle for participant 4 (heel strike to heel strike).

Table 5.4 Group average percentages of on and off above threshold and on above 50% of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle (heel strike to heel strike).

<table>
<thead>
<tr>
<th>Average Group</th>
<th>On</th>
<th>Off</th>
<th>On 50%</th>
<th>Off 50%</th>
<th>On 2</th>
<th>Off 2</th>
<th>On 2 50%</th>
<th>Off 2 50%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectus Femoris (%)</td>
<td>2.73</td>
<td>63.57</td>
<td>23.80</td>
<td>38.50</td>
<td>51.00</td>
<td>77.50</td>
<td>57.70</td>
<td>74.40</td>
</tr>
<tr>
<td>Biceps Femoris (%)</td>
<td>4.40</td>
<td>71.90</td>
<td>8.30</td>
<td>24.53</td>
<td>61.50</td>
<td>83.75</td>
<td>45.00</td>
<td>59.33</td>
</tr>
<tr>
<td>Medial Gastrocnemius (%)</td>
<td>3.60</td>
<td>66.23</td>
<td>15.73</td>
<td>36.47</td>
<td>76.50</td>
<td>99.50</td>
<td>50.67</td>
<td>63.00</td>
</tr>
</tbody>
</table>
5.11 Discussion pilot 2

The purpose of this study was to develop and test a method for identifying on and off activities of lower limb muscles and to identify the key events of the running cycle. Exploring a new method for identifying >50% maximum muscle activation thresholds during maximal sprinting was used. The exemplar data (Figure 5.6) for the group average show that the rectus femoris was active throughout contact and early swing phase 0.67-71.33% and then the muscle activity is low (below 3*SD threshold). The gastrocnemius is very active in the early stages during heel strike and off during the swing phase. Finally, the biceps femoris is active during the contact phase and early swing. Highest activity can be observed during the contact phase. From the average acceleration data toe-off was found to occur at 51% of the running cycle. The rectus femoris and the biceps femoris have similar muscle activity when looking at the threshold above 3*SD threshold, but are very different when looking at the activity above the 50% threshold. The rectus femoris is active above the SD threshold from 3.3-82% and the biceps femoris is active from 4.7-81.7. Both muscles are active

![EMG Profile of Lower Limb Muscles During a Maximal Sprint Average Group](image)

Figure 5.7 Graphical representation of percentages of on and off above threshold (3*SD) and on above 50% of the rectus femoris, biceps femoris and gastrocnemius during one full running cycle for average group (heel strike to heel strike).
throughout the contact phase and in to the swing phase and have a period of quiet coming into heel strike. When looking at the activity above 50% threshold of the normalised data the rectus femoris and biceps femoris appear to be working in cocontraction which involves the simultaneous contraction of agonist and antagonist muscles around a joint. The rectus femoris has two bursts of high activity these occur immediately before toe-off (25.5-40.6%) and during the mid-swing phase (56.7-73.6%). The biceps femoris is highly active shortly after heel strike occurs (8.8-27.6%) and again coming into toe-off and during the very early swing phase (37.5-48.5%). The gastrocnemius has longer periods of activity for both thresholds (above 3*SD and the 50% threshold). The gastrocnemius is active throughout the contact and early swing phase 4.2-78.9% it then has a period where there is little to no activity and then is active for the rest of the running cycle. The gastrocnemius is highly active shortly after heel strike and again at toe-off as the foot leaves the ground. The final aim of this study was to use the acceleration data to identify the key events of the running cycle heel strike and toe-off. From the average acceleration data toe-off was found to occur at 51% of the running cycle. However, research has suggested that the toe-off events during sprinting is estimated to occur at 30% of the sprint cycle (Howard et al. 2017a). When comparing the current acceleration data to previous research it is apparent that the method used to estimate heel strike and toe-off is flawed.

5.12 Conclusions

The main aim of this study was to develop and test a method for identifying on and off activities of the lower limb muscles. The methods used were 3*SD of a quiet phase of EMG data to establish the time in which the muscles were active during a sprint cycle. Following this method identifying >50% maximum muscle activation thresholds during maximal sprinting were used. This method established the high levels of muscle activity which were < 50%, which highlights periods of relatively strong muscle activation. The method pinpoints the muscle activity to a percentage of the sprint cycle rather than just indicating simplistic on off thresholds. The step by step process of analysis is easy to use and graphically is simple to interpret. The methods used to analyse EMG muscle activity in this study will be used and explored further in this thesis. The methods outlined in this chapter for establishing sprint events (heel strike and toe-off) using acceleration data are flawed. Different methods for determining heel strike and toe-off events will be used and investigated in future studies reported in this thesis.
Chapter 6. Analysis of kinematic patterns in athletics practices- maximal sprinting and A-skip and Heel Flicks
6.1 Introduction

Kinematic analysis provides a description of motion without regard to causes i.e. it does not take into account the forces that cause the movement (Novacheck 1998; Robertson & Caldwell 2014). Kinematics describes and quantifies the linear and angular positions of the body, along with their time derivatives (Robertson & Caldwell, 2014). Sprinting kinematic variables include speed, time, stride length and stride frequency. Beneficial effects on running time over 10 m sections can be achieved through increased stride length, longer flight time and a shorter ground contact time (Lockie et al. 2015). Therefore, many studies have examined kinematics parameters such as stride length and stride frequency during the various phases of sprinting, sprint start (Delecluse 1997; Slawinski et al. 2010; Wild et al. 2011; Salo et al. 2004; Ciacchi et al. 2016), and pick up phase (Hunter et al. 2004, Jefferys 2013; Nagahara et al. 2014; Nagahara et al. 2014b; Morin et al. 2012;).

6.1.1 Research using angle–angle diagrams to illustrate movement patterns

In sprinting, the patterns of movement provide important data which can be expressed as angle-angle diagrams (Novacheck 1998) and coordination structures. Angle-angle graphs illustrate the coordinated movement of two segments by plotting one versus the other at coincident time points (Robertson & Caldwell 2014). Therefore, angle-angle diagrams allow for speed variations, by removing time-based fluctuations. Since these graphs plot the relative positions of the joint/segments, they can retain the same coordination patterns (i.e. similar shapes) at different speeds. They emphasise the relationships between angles more clearly than separate joint/segment angle-time plots, i.e. cannot be examined from angle time graphs (Grieve 1968). Coordination patterns examine more than one parameter simultaneously and can be presented as continuous or discrete forms relative phase, i.e. angle vs angular velocity. The importance of coordination is widely established as a significant component when learning and analysing a skill, but there remains limited research which examines continuous signals such as coordination patterns (angle-angle and angle versus angular velocity graphs) during sprinting.

While there is a limited amount of research on coordination patterns during sprinting and drills, several studies have examined coordination patterns during distance running. Cavanagh (1990) examined knee-rearfoot kinematics using angle-angle diagrams to
compare the movement of the lower extremity with various types of footwear and running at various running speeds ranging from 3.4 ms\(^{-1}\) to 5 ms\(^{-1}\). The study concluded that there were adaptations in timing and velocity patterns at the knee in the sagittal plane kinematics to the shoe perturbations. The study by Cavanagh (1990) showed that the range of motion in the lower limb is velocity dependent. As the speeds increased, the angle-angle diagram became larger in all directions but maintained the same shape. Kivi and Alexander (1997) presented angle-angle diagrams for sprinting A and B drills and found that the coordination patterns for sprinting were different when compared to both the A and B drills. An increased range of motion was found at the hip during sprinting which resulted in a larger more rounded shape of the angle-angle graph (Figure 6.1). This is similar to the findings of Cavanagh (1990), who showed that the speed of movement of sprinting would be considerably quicker than the movement of the drills and would result in a larger more rounded shape and therefore a greater range of motion in the joints.

### 6.1.2 Sprinting kinematics – angle-angle diagrams

Kivi and Alexander (1997) described the events that occurred at the hip and knee during sprinting for one stride (heel strike to heel strike). As the foot leaves the ground (toe-off) there is a steep vertical slope, this represents the recovery of the knee (knee flexion) with little to no changes in the angle at the hip. During the swing phase the leg is being pulled forward behind the body and the hip begins to flex. In the final stage of the sprint cycle as the foot prepares to make contact with the ground maximum knee extension occurs prior to maximum hip flexion. There were slight variations in the maximum knee flexion between participants; this was due to some participants during the recovery phase flexing maximally at the knee while others did not. The large proportion of the loop on the left hand side of the axis (Figure 6.1) indicated a greater range of hyperextension of the hip.
6.1.3 Drill kinematics – angle-angle diagrams

Kivi and Alexander (1997) also examined an angle-angle diagram for the A-drill and B-drill. The A-drill in comparison to sprinting, was found to be more linear in shape. Flexion at the hip and knee were found to occur simultaneously. The knee flexed while bringing the heel to the buttocks. The flexion movements were closely followed by hip and knee extension as the foot made contact with the ground. In comparison to sprinting, there was no flexion of the knee during the stance phase and only a small proportion of the loop appeared on the left hand side of the graph, which indicated only a small amount of hyperextension at the hip, this occurred just prior to toe-off. The B-drill appeared to be similar in shape when compared to the A-drill but in comparison the B-drill it assumed a more oval shape rather than a linear shape. Hip and knee flexion occurs at similar times and brings the thigh to approximately vertical and the heel to the buttocks. In comparison the A-drill, knee flexion ends prior to hip flexion and knee extension occurs prior to hip extension as the foot prepares to contact the ground. This difference may be due to the B-drill having a phase where the leg in straightened prior to the foot coming back in contact with the ground. There is a small angle of hyperextension which occurs in the late foot contact phase.
Figure 6.2 Angle-angle diagram of the hip and knee of the right leg during the A-drill (Kivi and Alexander 1997 p. 107).

Figure 6.3 Angle-angle diagram of the hip and knee of the right leg during the B-drill (Kivi and Alexander 1997 p. 109).

Other notable results were that there was greater trunk flexion during sprinting when compared with the A and B drills; this is most likely due to higher knee lift rather than...
greater trunk lean. There were significant differences in the hip angle between the drills and sprinting, there were similarities in hip angle when comparing the A-drill with the B-drill. The greatest amount of knee flexion occurred during sprinting but there was no significant difference between sprinting and the drills. Finally there was a significant difference in the ankle angle between all three trials. The study concluded that there were differences between all three trials (sprinting, A-drill and B-drill). The A-drill was found to be performed at a higher frequency when compared with the other two trials. There were longer contact ground times during drills when compared with sprinting.

Cappadona (2013) conducted a study to examine the kinematic differences if any between two commonly used sprint drills the A and B skip and maximal sprinting. For the kinematic analysis of the study only five of the twelve participants were used this was due to marker issues. Four of the five participants analysed were experienced (at least five years varsity experience) and one was inexperienced (junior varsity or under four years experience). Joint angles for the ankle, knee and hip for flexion and extension during a cycle were determined. The study by Cappadona (2013) found that there was a significant difference in hip flexion between all three trials (sprint, A-skip and B-skip). Maximum hip flexion was significantly higher for the drills when compared with sprinting. There were no significant differences, between the three trials for peak knee flexion this is similar to the findings reported by Kivi and Alexander (1997). Knee flexion was at its greatest during the sprinting trials. The study reported no significant differences between the three trials in mean ankle flexion. Significant differences were found between experienced and inexperience participants for step rate of sprinting and the drills. The study concluded that the A and B skip were not effective as a sprint biomechanics tools for sprinting. Experienced athletes were more efficient at performing drills. It is important to note that this study is limited by its sample size only five participants were used in the kinematic data analysis due to marker issues; this is a relatively low sample size and not representative of anything other than being a few individuals. From the group of five participants four were categorised as experienced and one was categorised as inexperience, this does not allow for a great comparison between the two levels of experience. Review of this study demonstrates a clear need for a more robust investigation of the kinematics of drills and sprinting. The movement and coordination patterns of the hip, knee and ankle will be compared using angle time graphs and angle-angle diagrams. Angle-angle diagrams are useful in capturing
simultaneous coordination of two joints and provide the relative movement of two joints. Therefore, the aim of this study is to examine the kinematics of sprinting, compared with the kinematics of the A-skip and heel flicks.

6.2 Methods

6.2.1 Participant characteristics

A group of 15 sprinters (8 Males and 7 Females) participated in this study (age 22 ± 3.4, mass 69 kg ± 9.4 kg, height 1.76 m ± 0.09 m). The participants ranged from national level athletes which were defined as making the final of their national championships and international level athletes represented their country at a major championship – European Championships (Zurich and Amsterdam), World Juniors (Poland) and Olympics (London, 2012 and Rio, 2016). At the time of testing, the participants were injury free and had been participating in sprinting sessions at least three times a week for the last 6 months. Ethical approval for the study was granted from the University Research Ethics Committee, and written consent was obtained from all participants. Before taking part in the study, all participants completed a physical activity questionnaire and provided informed consent in writing.

6.2.2 Experimental procedures

Testing of the participants took place over two days. On day one the participants performed a number of drills – A-skip and heel flicks. These drills were used based on the results found in Chapter 3; A-skip and heel flicks were the two most popular drills selected by coaches. The participants performed three repetitions of each drill. On day two the participants performed three maximal sprints.

6.2.3 Drills

The drills data collection took place in a sports hall with the participant wearing flat running shoes. Kinematic data were collected using a Basler 210 Hz camera. Contact time and flight time were collected using 10 m of Optojump Next, this information was used to determine a running cycle. The camera for the drills was placed 5 m from where the Optojump was placed. Eight retro reflective markers were placed on various bony landmarks – 5th metatarsal, lateral malleolus, calcaneus, lateral epicondyle, greater trocanter of the hip, lateral scaphoid, lateral condyle and acromion process. To reduce error, the same trained biomechanist placed markers for day one and day two. The
participants muscle activities were recorded using 10 Delsys Trigno Wireless EMG™ sensors. The sensors were placed on both the right and left side of the participants. Sensors were placed using SEMIAM electrode placement guideline on the shin bone (acceleration), rectus femoris, medial gastrocnemius, biceps femoris and gluteus maximus. EMG data were recorded at 2000 Hz and acceleration data were recorded at 148.15 Hz.

6.2.4 Sprinting

The sprint data were collected on day two and the testing session took place on an indoor 60 m running track with the participants wearing their own sprint spikes shoes. The participant completed their own preferred warm up prior to sprinting which consisted of stretching, drills and stride. Stride parameter, kinematic data and EMG data were all collected as previously on day one. The Optojump was placed 40 m into the sprint, this allowed the participant to accelerate to top speed by the time they reached the Optojump zone. The camera was placed 10 m perpendicular to the Optojump measurement zone. The camera was positioned to obtain one full stride of the participant (right initial contact to right initial contact) running at maximum speed. The participants were instructed to gradually build up speed and be at maximum speed when they reached the Optojump measurement zone (40 m). Recovery between the trials was up to 10 minutes or when the athlete felt they were fully recovered.

6.2.5 Data analysis

Kinematic data were tracked for each trial using MaxTRAQ™ auto and manual tracking software. Three trials for sprinting, A-skip and heel flicks were tracked for one cycle running cycle (initial contact of right to initial contact of right). The data were saved as MaxTRAQ™ ASCII files. The files were saved in this format so that they could be used in MaxMATE™ motion analysis toolbox for Microsoft Excel™. The MaxMate software tools allowed for analysis and graphical representation of: positions, angles, displacements and velocities of markers during trials. The aim of this study was to investigate the movement and coordination patterns of A-skip, heel flicks and sprinting. Joint angle time along with angle-angle graphs provide an effective means of analysing movement patterns and inter-joint coordination. For the purpose of this study, angles were analysed. Raw kinematic data were filtered using a Butterworth filter (6 Hz) and interpolated using MaxMATE™ software. For kinematic data a frequency cut off of 6
Hz is appropriate for gross segment movements such as sprinting (Winter 1990). The positions of each marker against time were plotted and the angles of the ankle, hip and knee for each trial were calculated. The ankle angles were calculated using the 5th metatarsal, lateral malleolus and lateral epicondyle, the knee angles were calculated using the lateral malleolus, lateral epicondyle and the greater trocanter, and finally the hip angles were calculated using the lateral epicondyle, greater trocanter and acromion process. The angle data were then exported to excel. The time to complete each trial and exercise varied from participant to participant. The data were normalised by splining the data using a Matlab programme to 201 rows per trial (data were interpolated). The average of the three trials was calculated for each participant. Overall group ensemble mean and standard deviations were generated for all of the participants for each exercise.

6.3 Results

Figure 6.4 a-c illustrates the mean ensemble of the ankle angle during one cycle 0 – 100% (heel strike to heel strike) for sprinting, A-skip and heel flicks. The group average ±SD was also included to highlight the differences between participants above and below the average. There appears to be the greatest amount of variability (size of the standard deviation) of the ankle angle during sprinting. Figure 6.4 d depicts the difference between the average ankle angle during sprinting, A-skip and heel flicks. During heel flicks and A-skip there appears to be very little movement of the ankle for both exercise. During the A-skip the ankle angle is between 117° and 125° through the whole cycle. The ankle during heel flicks is slightly lower than A-skip, the ankle angle is between 114° and 122°. The ankle angle during sprinting is different in comparison to the drills there is flexion just after toe-off, the ankle angle is between 103° and 122°.

Figure 6.5 a-c illustrates the mean ensemble of the knee angle during one cycle 0 – 100% (heel strike to heel strike) for sprinting, A-skip and heel flicks. The group average ±SD was also included to highlight the variability between participants. Heel flicks have the most notable variability around the mean for knee angle. Figure 6.5 d depicts the difference between average knee angle during sprinting, A-skip and heel flicks. There is phase distortion during the A-skip; an extended ground contact time is followed by flexion and extension. The movement pattern of the knee during the cycle is similar for heel flicks and sprinting with the angle of the knee being only slightly
higher during the cycle in comparison to the angle of the knee during sprinting. For the knee angle when comparing the three exercises there is movement related similarities but differences in timings can be seen in the A-skip drill.

Figure 6.6 a-c illustrates the mean ensemble of the hip angle during one cycle 0 – 100% (heel strike to heel strike) for sprinting, A-skip and heel flicks. The group average ±SD was also included to highlight the variations around the mean between participants. When examining the hip angle during A-skips there the most notably variability about the mean is observed. Figure 6.6 d depicts the difference between comparison of average hip angle during sprinting, A-skip and heel flicks. Visually there appears to be notable differences in the movement patterns during for each of the exercises. In comparison to A-skip and sprinting there is the smallest amount of movement at the hips during heel flicks, the hip angle during the cycle is between 147° and 165°.

Figure 6.7 illustrates the angle-angle diagram of the hip and the knee of the right leg during sprinting, A-skip and heel flicks. These data show some similarities in shape between sprinting and heel flicks. The range of movement of the heel flicks plot is smaller than the sprinting plot; there is less range of motion observed at the hip and knee during heel flicks. There are similarities between the heel flicks and sprinting plots when observing the shape of the plots, there are very similar gradients. The heel flicks plot is contained within the movement of sprint; there is little movement during heel flicks that goes beyond the sprint. During sprinting there is a larger range of motion observed at the knee then there is during the A-skip. There are differences observed in the coordination of each exercise. The sprint is smooth in shape; however, a steep vertical gradient is observed during the A-skip and the drill appears to be somewhat jerky. The sprinting angle-angle graph is exaggerated in size in comparison to the A-skip and heel flicks this may be due to the speed in which the drills are performed. These results are similar to the finding of Cavanagh (1990) which showed that as the speeds increased, the angle-angle diagram became larger in all directions but maintained the same shape.

Table 6.1 provides information on the root mean squared difference between sprint and A-skip and sprint and heel flicks. Pooled variation of sprint and A-skip combined variation and sprint and heel flicks combined variation is also included. The pooled variation provides variation across the group during two exercises. In examining the
RMSD value between sprint and A-skip a large value of 35.5° is observed, this is seven times the size of the pooled variation which indicates that there is a large difference between the knee angle during A-skip and the knee angle during sprinting. There is a very small RMSD value observed in the knee angle between sprinting and heel flicks.
Figure 6.4 a-d Mean ensemble of the ankle angle during one stride during sprinting, A-skip and heel flicks
Figure 6.5 a-d Mean ensemble of the knee angle during one stride during sprinting, A-skip and heel flicks.
Figure 6.6 a-d Mean ensemble of the hip angle during one stride during sprinting, A-skip and heel flicks.
Figure 6.7 Angle-angle diagram of the hip and knee of the right leg during the sprint, A-skip and heel flicks.
Table 6.1 root mean square differences between sprint and A-skip and Sprint and heel flicks and pooled variation for sprint and A-skip and sprint and heel flicks.

<table>
<thead>
<tr>
<th></th>
<th>Root Mean square difference</th>
<th>Pooled Variation (SD)</th>
<th>Root Mean square difference</th>
<th>Pooled Variation (SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sprint vs A-skip</td>
<td>Sprint &amp; A-skip</td>
<td>Sprint vs heel flicks</td>
<td>Sprint &amp; heel flicks</td>
</tr>
<tr>
<td>Knee</td>
<td>35.5°</td>
<td>5.4°</td>
<td>7.7°</td>
<td>8.8°</td>
</tr>
<tr>
<td>Hip</td>
<td>12°</td>
<td>8.0°</td>
<td>19.0°</td>
<td>3.6°</td>
</tr>
</tbody>
</table>
6.4 Discussion
There is a limited amount of research which compares the kinematics of sprinting using angle-angle graphs with the kinematics of drills. Studies by Kivi and Alexander (1997) and more recently by Cappadona (2013) have examined the kinematics of sprinting compared with the A and B drills, but concluded that further research in this area was necessary to gain a better understanding of the kinematics of drills and sprinting. The main aim of this study was to gain an understanding of the kinematics of drills and sprinting, the A-skip and heel flicks, and compare these findings by examining the coordination patterns of the ankle, hip and knee during each exercise.

6.4.1 Differences in timings- heel flicks and A-skip
The findings of this research suggest that the angle at the hip and ankle during heel flicks appear to remain constant with very little change in the angle throughout the cycle. This is in comparison to sprinting where there is a noticeable decrease in the internal angle at the ankle and knee followed by an increase as the right foot makes contact with the ground. There appears to be differences in timings for the A-skip most notably for the knee angle. When examining the pattern throughout the cycle there appears to be movement related similarities. There is a decrease in the knee angle during the cycle but this appears to be out of phase in comparison to the knee angle during sprinting (Figure 6.5d). There is a large amount of the cycle (0 - 40%) where the knee is extended and nearly straight, this indicates a longer ground contact for A-skip in comparison to sprinting. There appears to be a phase distortion when comparing the A-skip with sprinting.

6.4.2 Angle-angle diagram comparing sprinting with A-skip and heel flicks.
The A-skip and heel flicks are smaller in amplitude in x and y axis when compared to sprinting which appears exaggerated in size (Figure 6.7). There are similarities in the shape during all three exercises but the sizes are different. This may be due to the changes in the speed in which each of the exercises are performed. The A-skip and heel flicks drills are performed at a slower more controlled rate when compared to the speed that sprinting is performed. Cavanagh (1990) examined the changes in speed on the angle of the knee and hip during running, this study examined the movement of different drills compared with sprinting. The results of the current study are similar to the finding of Cavanagh (1990) which showed that as the speeds increased during
running, the angle-angle diagram became larger in all directions but maintained the same shape. Although different exercises are being performed the findings are the same – sprinting which is performed at the highest speed has the largest angle-angle graph in all directions when compared to the drills.

6.4.3 Heel flicks vs Sprinting / A-skip vs Sprinting

When comparing the sprint and heel flicks (Figure 6.7), there is large horizontal movement during sprint and there is a much larger range of motion (ROM) in the hip angle. The main difference between heel flicks and sprinting is found in the hip angle, as there is very little movement in the hips during heel flicks, and this is in contrast to the large amount of movement at the hip during sprinting. The knee angle during both exercises is similar but there is a slight reduction in the knee angle during heel flicks when compared to sprinting throughout the whole cycle. These data show that the knee action during heel flicks is very similar to the knee movement during sprinting. This similarity is apparent when examining the RMSD of 7.7° and pooled variation of 8.8° (Table 6.1) which indicated only small differences between the knee movement during heel flicks and sprinting. The opposite is seen during the A-skip (Figure 6.7), the movement at the knee appears to be different this may be due to the longer ground contact seen during the A-skip. The difference for knee during the A-skip and sprinting has a much larger difference of 35.5° (Table 6.1). In examining the RMSD information against the pooled variations there is a large difference observed of seven times the pooled variation. While the hip action is closer during A-skip when compared to sprinting with a difference of 12° (Table 6.1). Neither drill fully mimics the movements of the hip and knee during sprinting.

6.4.4 Practical implications

Heel flicks show similarities in knee movements when compared to sprinting, although overall movement is slightly reduced throughout the whole movement. By contrast, hip range of movement is quite different in heel flicks as there is a large ROM seen at the hip during sprinting, while there is little movement at the hip during heel flicks. The opposite effect is seen during the A-skip where there are similarities in the movement of the hip and differences in the movement of the knee during the drill. As previously discussed in Chapter 3 and 4, drills are part of a whole-part-whole learning and are done as isolation drills which allows the athlete to practice specific parts of sprinting, this is
providing that the drill being performed replicates the whole skill. When compared to sprinting neither drill (A-skip and heel flicks) are not identical in movement pattern but there are some similarities observed. Therefore based on kinematic data analysis, implementing both into a programme may be useful as they do replicate some important movement components of sprinting. A-drill which may closely replicate the knee action during heel flicks and the hip action during the A-skip should be included. This could be in the form of a variation of the A-skip (Figure 6.9), currently the coaching cues for the A-skip as outlined in table 2.1 are:

- Push up onto toes of supporting leg with each step
- Involves triple extension of hip, knee and ankle.
- Drive knee of the other leg to hip level (thigh parallel to the ground)
- Foot of knee drive leg should be “cocked” dorsiflexed

A variation of the A-skip where the emphasis is on performing the skip by stepping over the opposite leg and pulling back could involve the following coaching cues:

- Push up onto toes of supporting leg with each step
- Involves triple extension of hip, knee and ankle.
- When driving knee of the other leg to hip level-emphasis stepping over the opposite leg.
- Foot of knee drive leg should be “cocked” dorsiflexed.
Further research on the kinematics of performing this A-skip variation would be necessary. When examining sprinting visually, there is a noticeable flick of the heel towards the buttocks which would explain why the heel flicks are similar in movement pattern to sprinting. However, it has not been determined if this movement occurs because short duration, ground reaction force induces a bouncing effect on the foot off the ground or because the hamstring muscles have activated to induce knee flexion.

6.4.5 Number of drills analysed

While this body of work comprised extensive and novel investigations and provided an insight into the kinematics of drills compared to sprinting, it is not without its limitations. As outlined in the literature review (Chapter 2), there are a large number of drills being used by coaches and athletes (Table 2.1). This was further reinforced in Chapters 3 and 4 which revealed that a large percentage of coaches used many different
drills in their training programmes. The A-skip and heel flicks drill were selected for further analysis in this research based on their popularity amongst coaches who participated in the questionnaire. Four other drills, A-Sprint, A-March, B-skip, and straight leg bounds which were selected by the coaches and athletes in Chapter 3 and Chapter 4, were collected at the time of data collection for this study. However, time constraints prevented analysis of these additional drills. For future study, it is recommended that an in-depth examination of a wider range of drills is completed to gain a clear understanding of the most appropriate drills to use to enhance sprint performance.

6.5 Conclusion

The main findings of this study are there are some similarities in movement patterns between sprinting and the two selected drills. Neither the A-skip nor heel flicks fully mimic the hip and knee movements which are observed during sprinting. The knee angle during heel flicks is very similar to the knee movement during sprinting. This is apparent in the small RMSD value comparing the knee angle during heel flicks and sprinting. The results of this current study demonstrate kinematic similarities and differences when comparing the A-skip and heel flicks with sprinting. A drill which could incorporate the movement of the knee during heel flicks and the movement of the hip during the A-skip could better mimic the movement pattern of sprinting. Further research is necessary to gain an understanding of this suggested drill, and other drills (A-March and quick step and B drills). Since movements are determined by muscle actions, it is important to determine the patterns of muscle activations for the movements of the knee and hip which are outlined in this chapter. An investigation of the muscle activity of the lower limb muscles will be conducted to provide some additional insight into the coordination of the lower limb actions during sprinting and drills.
Chapter 7. Examining the muscle activity of sprinting and comparing the activations to the muscle activations of selected sprint drills (A-skip and heel flicks).
7.1 Introduction

7.1.1 Information on drills

Drills are considered important in the coaching of correct sprinting technique as they establish the optimal movement and coordination patterns of sprinting (Harrison 2010). Drills are valuable part of an athlete’s training and can help the athlete to learn and refine key aspects of running skill, and more specifically, develop sprinting technique (Cissik 2004). Harrison (2010) investigated the biomechanical factors in sprint training including an investigation of sprint drills. Harrison (2010) suggested that drills are designed to help the athlete to practice specific parts of the running skill using a whole-part whole learning strategy. Previous research on sprint drills have investigated the kinematics of the A and B drills and compared with the kinematics of maximal sprinting (Kivi & Alexander 1998; Cappadona 2013). Kivi and Alexander (1998) concluded that there were differences in range of motion at several joints and peak angular velocity during the A and B drills when compared to sprinting. There were no differences in range of motion at the knee between the drills and sprinting. The frequency (number of steps) of the drills differed and the A-drill was performed at a greater step frequency than sprinting. The B-drill was performed at a slower frequency than sprinting. The sprinters were in contact with the ground for longer during the drills when compared with sprinting. Cappadona (2013) concluded that the A and B drills do not mimic the movement pattern of sprinting and recommended that the A and B drills be used as a warm up drill but not to improve sprinting biomechanics. There is currently no research on the muscle activations of the lower limb during drills. Therefore, studies which have examined the muscle activation of the lower limb will be discussed.

7.1.2 Previous research using EMG to detect activations of muscles during a running cycle-hamstrings

The hamstrings are at their highest recruitment when sprinting and there is a high eccentric resistance required from the hamstrings to decelerate the rapid leg swing (both knee extension and hip flexion) (Wiemann & Tidow 1995). Several studies have examined the phase (stance or swing) in which the hamstrings are most active and most susceptible to hamstring strains. These studies have analysed the muscle activity of the hamstring muscles using raw EMG and 3D data capture to produce a musculoskeletal model. The participants were required to run at various intensities of their maximum on
a treadmill (Chumanov et al. 2012; Higashihara et al. 2010; Thelen et al. 200; Chumanov et al. 2011; Chumanov et al. 2007) or track (Yu et al. 2008). There are differences in EMG activity between treadmill and overground running (Baur et al. 2007). The onset of activation is considerably delayed between treadmill and overground running. The onset of muscle activation occurs earlier in treadmill running when compared to overground running (Baur et al. 2007). The raw EMG showed that the hamstrings were active during the stance, middle swing and late swing phase. The maximum activation of the hamstrings occurred during the late swing at all running velocities. As speed increased the activation of the biceps femoris increased during mid-swing and late swing of the sprinting gait cycle. (Yu et al. 2008; Chumanov et al. 2012; Higashihara et al. 2010; Thelen et al. 2005; Chumanov et al. 2011; Chumanov et al. 2007). The hamstrings activity was two to three times greater during the mid to late swing phase than during the late stance phase and early swing phase (Yu et al. 2008). In a study by Chumanov, EMG sensors were placed on the hamstrings, the biceps femoris, and medial hamstrings (semitendinosus, semimembranosus). The results were similar to previous studies for the hamstring muscles that during the mid to late swing hamstring activity increased. Similarly, in studies which looked at lower limb muscles during sprinting, the hamstring muscles were found to be active during foot contact and late swing (Mero et al. 1992; Mero & Komi 1987). After take-off when the heel is moved towards the hip there was not much EMG activity in the biceps femoris (Mero et al. 1992). However, in a study conducted by Wiemann and Tidow (1995) they found that the hamstrings activity began as the free leg entered the back-swing phase and activity continues during the whole support phase (stance phase) right up to beginning of the forward-swing phase (early swing phase).

7.1.3 Previous research using EMG to detect activations during running - other muscle groups

In the studies by Chumanov et al. (2012, 2011, 2007) muscle activity of the hamstring to detect hamstrings strains were examined. Additional EMG sensors were placed on vastus lateralis, rectus femoris, medial gastrocnemius, tibialis anterior, gluteus medius, and gluteus maximus. This study provided some insight into the muscle activity of some other lower limb muscles and found that during the pre-swing/early swing phase the rectus femoris and tibialis anterior activity were at their highest. During the late swing- pre-activation (coming into stance) the gluteal muscles and medial gastrocnemius activity increased. In a study by Wiemann and Tidow (1995) the vastus
muscle was found to be highly active only during the concentric part of the support phase. After touchdown most of the vastus muscle activity decreased rapidly. Gluteus maximus activity was found to begin at the same time as the hamstring muscles activity but activity stops in the middle of the support phase. In a review study by Mero et al. (1992) the study concluded that during the maximal sprinting phase EMG activity was considerably lower in the propulsion phase when compared to the breaking phase. There was a high level of activity in all lower limb muscles (gluteus maximus, rectus femoris, biceps femoris, gastrocnemius, and tibialis anterior) before foot contact. It is important that the leg extensors are highly activated and stiff prior to and at the moment of contact. Minimum activity of the lower leg was found to occur during the flight phase of sprinting. In a review paper by Howard et al. (2017a) 18 studies (some of the findings have been previously discussed), muscle activity during running and sprinting were examined. The study found that the hamstrings were active during the stance phase and the late swing phase. The quadriceps muscles were also active during the stance phase and the rectus femoris had two bursts of activity during the early and late swing phase. The gastrocnemius was found to be active during the stance phase and the late swing while the gluteus maximus was active during the stance and late swing phase. Activation during the late swing phase indicates pre-activation preparing for initial contact. Howard et al. (2017a) provided a useful graphical representation of the muscle activations of the lower limb muscles during sprinting which is easy to understand and interpret and is similar to the findings of the studies outlined previously (Figure 7.1).

7.1.4 EMG techniques to determine on-off events

Electromyography is the study of muscle electrical activity and can provide valuable information about the control and execution of movements (Robertson et al. 2014). Various methods can be used to analysis an EMG signal such as peak to peak amplitude, average EMGs, root mean squared amplitude and linear envelopes. EMG signal vary in both the positive and negative voltage direction. To compute an average representation of amplitude over a period of time the signal must be rectified. Rectifying the signal involves converting all the negative values to positive values. An EMG envelope gives an estimate of the ‘volume’ of the EMG activity (Robertson et al. 2014). Researchers seek to identify when the muscle activity begins and ends; a linear envelope can be used to identify onset and offset of muscle activation. Hodges and Bui (1996) examined various visual and computer based methods for determining onset and offset of muscle activity. Hodges and Bui (1996) used a threshold method which classified activity as above 1, 2, and 3 standard deviations beyond the mean of a baseline activity. Howard et al. (2017a) used a similar technique in identifying onsets
and offsets of muscle activity during the shot put. An initial threshold of three times the standard deviation of a quiet phase was used to detect muscle activity of the lower limber during shot put. A second threshold which involved timings normalised 0-100% of the cycle time and normalised to maximum peak in the signal. A higher muscle activation threshold was used to determine signals exceeding 50%.

7.1.5 Identification of gaps in the literature

After extensive research on this area and issues highlighted by Howard et al. (2017a) there appear to be some gaps in the research. There are few studies that have examined EMG activity in full speed running. Previous research which has examined EMG activity during sprinting have used both treadmill and tethered EMG systems (Chumanov et al. 2012; Higashihara et al. 2010; Thelen et al. 2005; Chumanov et al. 2011; Chumanov et al. 2007). Yu et al. (2008) examined over ground sprinting using a wireless EMG system while Baur et al. (2007) examined and compared running on a treadmill and running overground. There is lack of clarity about the phasic muscle activity in sprinting and the levels of activity related to gait cycle in sprinting. There are no published data on EMG activity in drills and no information which examines the similarity of muscle timings in drills and sprinting. Therefore, the aims of this study were to identify the timings of muscle activity of sprint drills (A-skip and heel flicks) and compare these activations to the timings of muscle activations during sprinting. This study will provide coaches and athletes with information on whether these sprint drills mimic the muscle activations of sprinting.

7.2 Methods

7.2.1 Participant characteristics

A group of sixteen sprinters (8 males and 8 females) participated in this study (age 22.7 ± 3.3 years, mass 69.7 kg ± 9 kg, height 1.76 m ± 0.09 m). The participants ranged from national level athletes which were defined as making the final of their national championships and international level athletes represented their country at a major championship – European Championships (Zurich and Amsterdam), World Juniors (Poland) and Olympics (London, 2012 and Rio, 2016). At the time of testing the participants were injury free and had been participating in sprinting sessions at least three times a week for the last 6 months. Ethical approval for the study was granted from the University Research Ethics Committee, written consent was obtained from all
participants. Before taking part in the study, all participants completed a physical activity questionnaire. The drills data collection took place in a sports hall with the participant wearing non spiked training shoes and dark tight fit clothing. The sprint data were collected on day two and the testing session took place on an indoor 60 m running track with the participants wearing sprint spike and dark tight fit clothing. To reduce error, the same trained biomechanists placed sensors for day one and day two.

7.2.2 Measurement devices

For this chapter EMG data were analysed. Optojump data and kinematic data were used to identify timings of initial contact to initial contact. The kinematic data were recorded using a Basler camera which was synchronised with the Delsys Wireless EMG system. This meant that the time stamp on the visual corresponded with the same time point in the EMG data.

7.2.3 Data collection drills

Stride parameters (contact time and flight time) were collected using 10 m of Optojump Next. Kinematic data were collected using a Basler (reference camera), the camera for the drills was placed 5 m from where the Optojump was placed. The camera was positioned to obtain 3-4 reps (initial contact to initial contact) of each drill for each trial. Eight retro reflective markers were placed on various boney landmarks – 5th metatarsal, lateral malleolus, calcaneus, lateral epicondyle, greater trocanter of the hip, lateral scaphoid, lateral condyle and acromion process. The participant’s muscle activities were recorded using ten Delsys Trigno Wireless EMG ™ sensors. The sensors were placed on both the right and left side of the participants. Sensors were placed using Surface electromyography for the non-invasive assessment of muscles (SEMIAM) electrode placement guidelines on the right and left rectus femoris, medial gastrocnemius, biceps femoris and gluteus maximus (outlined in Table 7.1). EMG data were recorded at 2000 Hz and the accelerometers which were placed on the shin bone were recorded at 148.15 Hz.
Table 7.1 Sensor placement and muscle identification information

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Placement description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medial Gastrocnemius</td>
<td>The electrode must be placed at 1/3 of the line between the head of the fibula and the heel</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>The electrodes must be placed at 50% on the line between the ischial tuberosity and the lateral epicondyle of the tibia</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>The electrodes must be placed at 50% on the line between the sacral vertebrae and the greater trochanter. This position corresponds with the greatest prominence of the middle of the buttocks well above the visible bulge of the greater trochanter.</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>The electrodes must be placed at 50% on the line from the anterior spina iliac superior to the superior part of the patella.</td>
</tr>
</tbody>
</table>

The, medial gastrocnemius, biceps femoris, gluteus maximus and rectus femoris were selected for the following reasons:

1. Based on previous research by Mero and Komi (1987) which examined the gastrocnemius, biceps femoris, gluteus maximus and rectus femoris.

2. Each muscle has been identified as contributing to the execution sprinting (Mero and Komi, 1992).

3. The muscles selected are the most superficial muscles in each of the areas and also the easiest to identify for sensor placement.

7.2.4 Data collection sprinting

Stride parameter, kinematic data and EMG data were all collected as previously, on day one. The Optojump was placed 40 m into the sprint to ensure the athlete was running at maximum speed when entering the capture zone. The camera was placed 10 m away from where the Optojump was positioned. The camera was positioned to get one stride of the subject (right initial contact to right initial contact) while the participant ran at maximum speed. Recovery between the trials was up to 10 minutes or when the athlete felt they were fully recovered.
7.2.5 Experimental procedures

Testing of the participants took place over two days. On day one, the participants performed a number of drills – A-skip, and heel flicks. The participants performed three repetitions of each drill. On day two, the participants performed three maximal sprints.

Figure 7.2 Delsys Wireless EMG sensors placement – tibia bone, rectus femoris, lateral gastrocnemius, biceps femoris, and gluteus maximus

7.3 Data analysis

7.3.1 Event identification

The visual data were used to identify when the participant’s foot first came in contact with ground for the selected repetition of the drill and when the right foot came in contact with the ground for sprinting. In Chapter 5 the acceleration data from the shin bone sensor placed on the participants were used to identify heel strike to heel strike as visual data were not recorded. The initial contact of the right foot were recorded and the repetition (how many foot contacts occurred before the selected initial contact).
Following this, the Optojump data contact time and flight time of the right and left were used to determine the end time of the repetition (See Table 7.1).

7.3.2 Sprint cycle phases identification

The key phases in the sprint cycle were adapted from previous research (Novacheck 1998; Yu et al. 2008; Howard et al. 2017a) and the phases defined as follows:

1. The Early Stance (Braking) Phase: This phase begins as the foot makes initial contact (IC) and ends at the mid-stance phase, estimated at 0 – 15% of the cycle.
2. The Late Stance (Propulsion) Phase: This phase begins at the mid-stance phase and ends at the toe-off (TO), estimated at 15 – 30% of the cycle.
3. The Early & Middle Swing (Recovery) Phase: This phase begins at TO and ends roughly two thirds of the way through the swing phase, estimated at 30 – 77% of the cycle.
4. The Late Swing (Pre-activation) Phase: This phase begins roughly two thirds of the way through the swing phase and ends at the IC, estimated at 77 – 100% of the cycle.

(Howard et al. 2017a)

The estimated percentages for a sprint cycle outlined above were used to identify each of the phases of the early, middle and late swing phase (30% - 100%). Heel strike and toe-off events were identified directly using the optojump and visual data and the additional information from Howard et al. (2017a) were used to estimate muscle activation timings during the swing phase of the cycle. There is no information available for drills and toe-off and heel strike events. From the data collected for the current study average toe-off and heel strike events are represented in Table 7.1. This information was calculated using Optojump (contact times and flight times) and visual (the time point at which the right foot leaves the ground and the time point that the right foot makes contact with the ground. During sprinting toe-off is estimated to occur at 30% of the sprint cycle (Howard et al. 2017a); during the A-skip heel flicks this occurs slightly later at 32% and 34%. During sprinting the event of heel strike is estimated to begin at around 77% of the sprint cycle (Howard et al. 2017a), this event occurs later during A-skip and heel flicks with both having group averages at 82%.
Table 7.2 Identification of toe-off and heel strike events during A-skip and heel flicks for one stride – heel strike to heel strike (0-100% of the cycle).

<table>
<thead>
<tr>
<th>Event</th>
<th>A-skip</th>
<th>Heel Flicks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Right toe-off (%)</td>
<td>Right heel strike (%)</td>
<td>Right toe-off (%)</td>
</tr>
<tr>
<td>Average Group</td>
<td>32</td>
<td>82</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.96</td>
<td>8.45</td>
</tr>
</tbody>
</table>

7.3.3 Initial EMG analysis

All the EMG signals were analysed using the following steps in Excel. The Raw EMG data were full wave rectified to a single polarity frequency which in this case was positive. The purpose of rectifying a signal is to ensure the raw signal does not average zero, due to the raw EMG signal having positive and negative components. The EMG data were filtered using a low pass Butterworth filter with a frequency cut off (fc) of 10 Hz (Howard et al. 2017b) to remove baseline drift and DC offset. The EMG signals were cropped to the duration of initial contact to initial contact and then normalised firstly against time from initial foot contact of the right to initial foot contact of the right (one stride). The data were also normalised against the highest peak value of the linear envelope (Millivolts) during the running cycle.

7.3.4 Identifying onset and offsets

A double threshold method was implemented to identify the onset and offset of each of the muscles (Kamen & Gabriel, 2010; Hodges & Bui, 1996). A threshold of 3 times the standard deviation of a quiet phase during the activity was previously used in Chapter 5 (Di Fabio, 1987; Hodges & Bui, 1996; Kamen & Gabriel, 2010). For the majority of the sprint trials, there was no quiet phase. For this current study the minimum threshold for periods of muscle activity were defined as above 10% of the normalised data. When the signal dropped below 10% for more than 40 ms this was characterised as a period of inactivity. Periods of high activity were defined as signal above 50% (Howard et al. 2017b)
7.3.5 Statistical analysis

The average of the three trials was calculated for each participant. Overall group ensemble mean and standard deviations were generated for all of the participants for each exercise. The timings of key events and muscle activation timings between sprint and drills the whole group and for males and females and were evaluated using Cohen’s d effect sizes. Hopkins (2002) has recommended that this statistical method which is an interpretation of magnitude differences is the principal means to test hypotheses. Due to the small sample size (n = 16) this statistical analysis was used. Based on Cohen’s (1977) magnitude differences, the following were used to determine the scale of difference between sprinting and A-skip and sprinting and heel flicks:

- $dz < 0.2$ (trivial no difference)
- $dz > 0.2$ - $< 0.5$ (small difference)
- $dz > 0.5$ (moderate difference)
- $dz > 0.8$ (large difference)

Figure 7.3 Optojump and Basler camera set up on 60 m sprint track.
7.4 Results

Table 7.3 provides exemplar data which was used to calculate one stride for sprint, A-skip and heel flicks. The initial contact time was obtained from video footage. Initial contacts were determined as the time in which any part of the foot was seen to contact the ground. Using Optojump data for the selected visual stride contact time and flight time were added to the initial contact time and this provided a final time. Initial contact of the right foot to initial contact of the same right foot represented one stride and 0-100% of the cycle. Tables 7.4-7.6 provides information on group mean and standard deviations of on and off events for the timings of muscle activity above 10% and 50% during sprinting. Data is expressed as percentage of gait cycle and indicates the % time in which the muscle activity is above 10% and 50%. What is interesting to note across all three of the exercises- sprint, A-skip and heel flicks is that there is a large amount of within subject variability, this is seen by the high numbers of the standard deviations observed. This indicates that within the group of 16 athletes that the times in which each of the lower limb muscles are active can vary from participant to participant.

7.4.1 Group sprint analysis

Figure 7.4a illustrates the muscle activations of all eight muscles during sprinting for 16 participants. The Right Rectus Femoris (RRF) was active during the early and late stance phase and remains active shortly after right toe-off (14% to 36%). It had a second burst of high activity during the mid-swing phase (53% to 71%). The RRF has a final burst of activity in the late swing phase as the right foot prepares to come in contact with the ground again (86% to 96%). The Right biceps Femoris (RBF) is highly active during the late stance phase to shortly after the right toe leaves the ground coming into the early swing phase (24% to 43%). The RBF is active again during the mid and late swing phase from the instant the left foot left the ground (63% to 84%). There is a second burst of high activity of RBF during the late swing phase as the right foot prepares for initial contact (88% to 99%). The Right Gastrocnemius (RGAS) and Left Gastrocnemius (LGAS) appear to be active as each foot is in contact with the ground and shortly after toe-off. The RGAS is active from the early to late stance phase (11% to 33%) while the LGAS is highly active from 28% to 57%. The RGAS has a second burst of high activity during the mid to late swing phase from 72% to 99% as the right foot prepares for initial contact. The LGAS also has a second burst of high activity from
73% to 87% as the left toe comes off the ground. The Right Gluteus Maximus (RGM) has similar activations during early to late stance phase when compared to the RBF (24% to 43%). The RGM is highly active before and shortly after right toe-off. The RGM also has a period of high activity during the mid to late swing phase (60% to 74%) and again during the late swing phase as the right foot prepares for initial contact (77% to 95%). The Left Rectus Femoris (LRF) is active during the late stance phase to the beginning of the mid-swing phase (24% to 40%). The LRF is highly active during the mid to late swing phase (56% to 73%) and finally during the late swing phase as the right foot prepares for initial contact after left toe-off (82% to 100%). The Left biceps Femoris (LBF) is active before the RBF early in the sprint cycle during the late stance phase and it is active from a longer duration (19% to 54%). The LBF has a long duration of high activity after left toe-off during the late swing phase from 80% to 96%. The Left Gluteus Maximus (LGM) is active during the late stance phase before toe-off and into the early to mid-swing phase (17% to 45%). The LGM is highly active during the mid to late swing phase (67% to 82%).

7.4.2 Group A-skip analysis

Figure 7.4b illustrates the muscle activity of eight muscles during the A-skip drill. During the A-skip drill all the muscles are highly active after right toe-off there is no muscle that had a burst of high activity early in the cycle. The RRF is highly active immediately after right toe-off to the early swing phase (31% to 41%). The RRF has a second burst of active during the mid-swing phase (54% to 64%) and has a final burst of high activity during the late swing phase as the left foot begins to leaves the ground (76% to 86%). The RBF has short bursts of high activity going from the early swing phase to the mid-swing phase (37% to 43%) and during the mid to late swing phase (61% to 70%). The RBF has a final burst of high activity during the late swing phase after left toe-off from 80% to 89%. The RGAS has three short bursts of high activity during the swing phase up to shortly after left toe-off (37% to 49%, 56% to 67% and 76% to 86%). The RGM is highly active during the mid-swing 38% to 50%, the late swing 68% to 79% and finally during the late swing phase as the right foot prepares for initial contact 91% to 97%. The LRF has two bursts of high activity these occur during the early swing phase shortly after right toe-off (31% to 39%) and during the late swing phase just as the left toe begins to leave the ground (71% to 80%). The LBF has three bursts of high activity these occur during the early swing phase shortly after right toe-
off to the beginning of the mid-swing phase (35% to 50%). The LBF is highly active during the mid to late swing phase just before the left toe leaves the ground (66% to 78%). This muscle has a final burst of high activity during the late swing as the right foot prepares for initial contact from 86% to 94%. The LGAS has two bursts of high activity during the early to mid-swing phase from 40% to 58% and during the late swing phase to shortly after left toe-off (71% to 84%). The GM has three bursts of activity during the mid-swing phase (47% to 57%), the mid to late swing phase (65% to 79%) and during the late swing phase after left toe-off as the right foot prepares for initial contact (81% to 89%).

7.4.3 Group heel flicks analysis

Figure 7.4c illustrates the muscle activity of eight muscles during the heel flicks drill. Similar to the A-skip drill the heel flicks drill has no activity before right toe-off except for the LRF and LGAS which have high levels of activity during the late stance phase just before right toe-off (27%). All the muscle have two bursts of high activity during this drill and all the activity occurs during the early to mid-swing phase of the drill except for the RGM and RGAS which have high muscle activity during the late swing phase as the right foot prepares for initial contact. The RRF is highly active shortly after right toe-off to the start of mid-swing phase (37% to 52%) and is highly active during the mid to late swing phase to left toe-off (68% to 80%). The RBF is highly active shortly after toe of to the beginning of the mid-swing phase (34% to 46%) and is highly active again during the mid to late swing phase to just after left toe-off (60% to 81%). The RGAS has two bursts of high activity and begins shortly after right toe-off to the beginning of the mid-swing phase (34% to 49%), it is highly active during the latter part of mid-swing phase throughout the late swing phase to just before initial contact (65% to 91%). The RGM has two bursts of activity and activations similar to the RBF. The muscle activity begins in the early swing phase immediately after right toe-off to the beginning of the mid-swing phase (31% to 46%). There is a second burst during the mid to late swing phase to right initial contact (65% to 100%). The LRF is highly active during the late stance phase just before right toe-off and during the early swing phase (27% to 43%), it has a second burst of activity during the mid to late swing phase (53% to 77%). The LBF is highly active during the early swing phase (34% to 42%) and during the mid to late swing phase (45% to 79%). The LGAS is highly active during the late stance phase just before right toe-off to during the early and mid-swing phase from
27% to 37% and 44% to 57%. The LGM is highly active during the early swing phase shortly after right toe-off (32% to 42%). This muscle is active during the mid to late swing phase just before left toe-off from 54% to 78%.

7.4.4 Effect sizes

Table 7.7 provides effect sizes which were calculated to compare the timings (% of cycle) of the first burst of high activity for the biceps femoris and rectus femoris muscles. Effect sizes were used to determine and compare the size of the difference in timings of muscle actions between drills and sprint. Having similar effect sizes does not necessarily mean similar actions. Examination of the effect sizes provided inconsistent results. There were small, moderate and large differences observed when comparing sprinting with heel flicks and A-skip. Small differences (dz >0.2-<0.5) were found in the timings of the first burst of high activity of the left rectus femoris for both comparisons (A skip and sprinting 0.374, heel flicks and sprinting 0.332). There was a large difference (dz > 0.8) observed in the timing of the first burst of high activity for the right rectus femoris for heel flicks and sprinting 0.964. Moderate differences (dz > 0.5) were observed in the left biceps femoris for both A-skip and heel flicks (A skip and sprinting 0.688, heel flicks and sprinting 0.548).

*A comparison between males and females was also conducted. However, it was not included in the main document as there were only some differences observed between males and females. This comparison did not shed any further light on the difference in muscle activation timings between males and females. Male and female comparisons and summary of the muscle activation timings can be viewed in Appendices G.
Table 7.3 Exemplar table for subject 2 illustrating how the timings of initial contact to initial contacted were calculated using visual data and Optojump data of contact time and flight time during sprint, A-skip and heel flicks. This data provided information to establish a cycle (0-100%) for one stride for each participant.

<table>
<thead>
<tr>
<th>Participant 2</th>
<th>Right initial contact (s)</th>
<th>Contact time (s)</th>
<th>Right toe-off (s)</th>
<th>Flight time (s)</th>
<th>Left foot contact (s)</th>
<th>Contact time (s)</th>
<th>Left toe-off (s)</th>
<th>Flight time (s)</th>
<th>Right foot contact (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprint 1</td>
<td>2.52</td>
<td>0.114</td>
<td>2.634</td>
<td>0.139</td>
<td>2.773</td>
<td>0.113</td>
<td>2.886</td>
<td>0.166</td>
<td>3.052</td>
</tr>
<tr>
<td>Sprint 2</td>
<td>2.51</td>
<td>0.119</td>
<td>2.629</td>
<td>0.135</td>
<td>2.764</td>
<td>0.12</td>
<td>2.884</td>
<td>0.158</td>
<td>3.042</td>
</tr>
<tr>
<td>Sprint 3</td>
<td>2.655</td>
<td>0.123</td>
<td>2.778</td>
<td>0.149</td>
<td>2.927</td>
<td>0.111</td>
<td>3.038</td>
<td>0.15</td>
<td>3.188</td>
</tr>
<tr>
<td>A-skip1</td>
<td>1.605</td>
<td>0.205</td>
<td>1.81</td>
<td>0.14</td>
<td>1.95</td>
<td>0.241</td>
<td>2.191</td>
<td>0.098</td>
<td>2.289</td>
</tr>
<tr>
<td>A-skip2</td>
<td>1.615</td>
<td>0.232</td>
<td>1.847</td>
<td>0.138</td>
<td>1.985</td>
<td>0.209</td>
<td>2.194</td>
<td>0.74</td>
<td>2.934</td>
</tr>
<tr>
<td>A-skip3</td>
<td>1.885</td>
<td>0.214</td>
<td>2.099</td>
<td>0.112</td>
<td>2.211</td>
<td>0.255</td>
<td>2.466</td>
<td>0.389</td>
<td>2.855</td>
</tr>
<tr>
<td>Heel Flicks 1</td>
<td>2.55</td>
<td>0.189</td>
<td>2.739</td>
<td>0.105</td>
<td>2.844</td>
<td>0.185</td>
<td>3.029</td>
<td>0.14</td>
<td>3.169</td>
</tr>
<tr>
<td>Heel Flicks 2</td>
<td>2.4</td>
<td>0.197</td>
<td>2.597</td>
<td>0.097</td>
<td>2.694</td>
<td>0.193</td>
<td>2.887</td>
<td>0.117</td>
<td>3.004</td>
</tr>
<tr>
<td>Heel Flicks 3</td>
<td>1.885</td>
<td>0.193</td>
<td>2.078</td>
<td>0.098</td>
<td>2.176</td>
<td>0.184</td>
<td>2.36</td>
<td>0.117</td>
<td>2.477</td>
</tr>
</tbody>
</table>
Table 7.4 Group mean and standard deviations for on and off events for the timings of muscle activity above 10% and 50% for group during sprinting. Data is expressed as percentage of gait cycle and indicated the % time in which the muscle activity is above 10% and 50%.

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Group Mean above 10% ± SD Sprint</th>
<th>Group Mean above 50% ± SD Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Burst 1</td>
<td>Burst 2</td>
</tr>
<tr>
<td></td>
<td>Threshold On</td>
<td>Threshold Off</td>
</tr>
<tr>
<td>Right RF</td>
<td>1.1 ±2.5</td>
<td>45.1 ±36.5</td>
</tr>
<tr>
<td>Right BF</td>
<td>2.4 ±5.0</td>
<td>48.3 ±24.9</td>
</tr>
<tr>
<td>Right GAS</td>
<td>4.0 ±7.8</td>
<td>55.8±30.9</td>
</tr>
<tr>
<td>Right GM</td>
<td>3.0 ±6.0</td>
<td>46.3 ±29.1</td>
</tr>
<tr>
<td>Left RF</td>
<td>0.4 ±1.6</td>
<td>51.4 ±27.6</td>
</tr>
<tr>
<td>Left BF</td>
<td>3.9 ±3.9</td>
<td>56.1 ±27.5</td>
</tr>
<tr>
<td>Left GAS</td>
<td>3.7 ±5.2</td>
<td>58.1 ±24.4</td>
</tr>
<tr>
<td>Left GM</td>
<td>4.4 ±6.7</td>
<td>68.8 ±28.8</td>
</tr>
<tr>
<td>Right RF</td>
<td>14.0 ±12.3</td>
<td>36.2 ±18.2</td>
</tr>
<tr>
<td>Right BF</td>
<td>24.9 ±19.8</td>
<td>46.6 ±25.4</td>
</tr>
<tr>
<td>Right GAS</td>
<td>11.2 ±17.1</td>
<td>32.6 ±21.8</td>
</tr>
<tr>
<td>Right GM</td>
<td>24.3 ±23.5</td>
<td>43.4 ±26.3</td>
</tr>
<tr>
<td>Left RF</td>
<td>23.7 ±16.4</td>
<td>40.3 ±20.5</td>
</tr>
<tr>
<td>Left BF</td>
<td>19.5 ±12.0</td>
<td>44.7 ±19.0</td>
</tr>
<tr>
<td>Left GAS</td>
<td>27.8 ±12.4</td>
<td>57.0 ±18.9</td>
</tr>
<tr>
<td>Left GM</td>
<td>17.5 ±10.2</td>
<td>45.0 ±18.2</td>
</tr>
</tbody>
</table>
Table 7.5 Group mean and standard deviations for on and off events for the timings of muscle activity above 10% and 50% for group during A-skip. Data is expressed as percentage of gait cycle and indicated the % time in which the muscle activity is above 10% and 50%.

### Group mean above 10% Threshold (A-skip)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Burst 1</th>
<th></th>
<th>Burst 2</th>
<th></th>
<th>Burst 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold On</td>
<td>Mean ± SD</td>
<td>Threshold Off</td>
<td>Mean ± SD</td>
<td>Threshold On</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Right RF</td>
<td>3.0 ±6.2</td>
<td>64.2 ±27.7</td>
<td>65.1 ±14.9</td>
<td>78.2 ±13.1</td>
<td>87.1 ±14.1</td>
<td>99.4 ±1.3</td>
</tr>
<tr>
<td>Right BF</td>
<td>2.3 ±5.0</td>
<td>49.7 ±30.6</td>
<td>62.9 ±21.8</td>
<td>73.5 ±15.2</td>
<td>89.1 ±12.9</td>
<td>94.6 ±6.2</td>
</tr>
<tr>
<td>Right GAS</td>
<td>4.0 ±5.4</td>
<td>39.9 ±28.3</td>
<td>43.2 ±13.5</td>
<td>72.1 ±17.0</td>
<td>78.6 ±19.4</td>
<td>91.6 ±19.8</td>
</tr>
<tr>
<td>Right GM</td>
<td>6.3 ±10.1</td>
<td>44.0 ±23.1</td>
<td>49.4 ±14.5</td>
<td>73.3 ±15.7</td>
<td>80.8 ±8.8</td>
<td>96.4 ±5.9</td>
</tr>
<tr>
<td>Left RF</td>
<td>2.4 ±3.5</td>
<td>55.5 ±25.9</td>
<td>58.7 ±16.9</td>
<td>70.5 ±16.1</td>
<td>86.1 ±10.6</td>
<td>90.0 ±13.3</td>
</tr>
<tr>
<td>Left BF</td>
<td>4.8 ±9.3</td>
<td>23.3 ±33.3</td>
<td>51.0 ±22.5</td>
<td>90.3 ±15.4</td>
<td>67.3 ±20.9</td>
<td>87.9 ±18.7</td>
</tr>
<tr>
<td>Left GAS</td>
<td>14.0±18.2</td>
<td>61.9 ±25.3</td>
<td>48.5 ±18.0</td>
<td>73.3 ±22.7</td>
<td>83.9 ±19.4</td>
<td>92.5±12.5</td>
</tr>
<tr>
<td>Left GM</td>
<td>11.9±15.9</td>
<td>57.7 ±30.0</td>
<td>58.3 ±22.1</td>
<td>75.9 ±18.1</td>
<td>82.1±16.8</td>
<td>91.6 ±14.9</td>
</tr>
</tbody>
</table>

### Group mean above 50% Threshold (A-skip)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Burst 1</th>
<th></th>
<th>Burst 2</th>
<th></th>
<th>Burst 3</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Threshold On</td>
<td>Mean ± SD</td>
<td>Threshold Off</td>
<td>Mean ± SD</td>
<td>Threshold On</td>
<td>Mean ± SD</td>
</tr>
<tr>
<td>Right RF</td>
<td>30.8 ±19.4</td>
<td>41.3 ±21.8</td>
<td>54.4 ±23.4</td>
<td>63.7 ±23.2</td>
<td>76.3 ±24.1</td>
<td>86.1 ±18.7</td>
</tr>
<tr>
<td>Right BF</td>
<td>36.7 ±15.2</td>
<td>42.9 ±21.8</td>
<td>61.1 ±22.4</td>
<td>70.3 ±23.2</td>
<td>79.7 ±11.0</td>
<td>88.9 ±9.5</td>
</tr>
<tr>
<td>Right GAS</td>
<td>36.5 ±27.7</td>
<td>48.6 ±28.3</td>
<td>55.6 ±23.8</td>
<td>67.3 ±22.7</td>
<td>75.5 ±17.0</td>
<td>85.8 ±16.2</td>
</tr>
<tr>
<td>Right GM</td>
<td>37.8 ±19.5</td>
<td>50.3 ±20.1</td>
<td>68.1 ±22.2</td>
<td>79.3 ±20.2</td>
<td>90.5 ±7.6</td>
<td>96.5 ±3.5</td>
</tr>
<tr>
<td>Left RF</td>
<td>31.4 ±17.7</td>
<td>39.0 ±24.3</td>
<td>71.4 ±22.6</td>
<td>76.9 ±24.1</td>
<td>77.2 ±9.4</td>
<td>79.8±11.4</td>
</tr>
<tr>
<td>Left BF</td>
<td>34.9 ±21.3</td>
<td>50.3 ±24.0</td>
<td>65.6±14.0</td>
<td>77.8 ±19.2</td>
<td>85.6 ±10.4</td>
<td>94.4 ±9.3</td>
</tr>
<tr>
<td>Left GAS</td>
<td>40.0 ±19.2</td>
<td>57.8 ±17.9</td>
<td>70.5 ±19.5</td>
<td>79.7 ±21.5</td>
<td>81.58±8.07</td>
<td>83.8 ±6.4</td>
</tr>
<tr>
<td>Left GM</td>
<td>46.8 ±16.3</td>
<td>56.7 ±21.4</td>
<td>65.2 ±17.5</td>
<td>79.0 ±16.5</td>
<td>80.9 ±19.8</td>
<td>89.0 ±17.6</td>
</tr>
</tbody>
</table>
Table 7.6 Group mean and standard deviations for on and off events for the timings of muscle activity above 10% and 50% for group during heel flicks. Data is expressed as percentage of gait cycle and indicated the % time in which the muscle activity is above 10% and 50%.

### Group mean above 10% Threshold (Heel Flicks)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Burst 1 Threshold On</th>
<th>Threshold Off</th>
<th>Burst 2 Threshold On</th>
<th>Threshold Off</th>
<th>Burst 3 Threshold On</th>
<th>Threshold Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right RF</td>
<td>12.1±10.0</td>
<td>46.6±31.0</td>
<td>53.9±7.3</td>
<td>77.2±13.1</td>
<td>77.7±13.5</td>
<td>94.9±16.3</td>
</tr>
<tr>
<td>Right BF</td>
<td>13.9±10.2</td>
<td>50.0±22.8</td>
<td>59.6±12.4</td>
<td>75.6±12.8</td>
<td>89.1±9.0</td>
<td>100.0±</td>
</tr>
<tr>
<td>Right GAS</td>
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<td>52.2±21.4</td>
<td>58.3±15.0</td>
<td>59.5±15.7</td>
<td>88.8±6.4</td>
<td>89.9±13.7</td>
</tr>
<tr>
<td>Right GM</td>
<td>11.0±13.7</td>
<td>56.1±26.7</td>
<td>62.2±17.2</td>
<td>77.2±15.6</td>
<td>86.6±9.8</td>
<td>100.0±</td>
</tr>
<tr>
<td>Left RF</td>
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<td>69.9±29.8</td>
<td>49.7±19.0</td>
<td>81.4±16.6</td>
<td>79.6±7.3</td>
<td>98.3±3.5</td>
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<tr>
<td>Left BF</td>
<td>14.3±9.2</td>
<td>59.3±26.2</td>
<td>63.0±18.3</td>
<td>75.0±13.6</td>
<td>86.9±2.7</td>
<td>95.5±5.5</td>
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<tr>
<td>Left GAS</td>
<td>20.1±17.9</td>
<td>67.2±24.6</td>
<td>55.7±25.5</td>
<td>78.3±18.4</td>
<td>74.2±21.4</td>
<td>94.0±14.6</td>
</tr>
<tr>
<td>Left GM</td>
<td>13.5±14.9</td>
<td>66.3±29.9</td>
<td>70.7±25.1</td>
<td>85.5±19.8</td>
<td>89.0±</td>
<td>100.0±</td>
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</tbody>
</table>

### Group mean above 50% Threshold (Heel Flicks)

<table>
<thead>
<tr>
<th>Muscle</th>
<th>Burst 1 Threshold On</th>
<th>Threshold Off</th>
<th>Burst 2 Threshold On</th>
<th>Threshold Off</th>
<th>Burst 3 Threshold On</th>
<th>Threshold Off</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right RF</td>
<td>37.0±22.2</td>
<td>49.8±28.2</td>
<td>52.2±25.1</td>
<td>68.3±25.5</td>
<td>68.8±24.9</td>
<td>80.4±25.6</td>
</tr>
<tr>
<td>Right BF</td>
<td>34.0±22.7</td>
<td>46.1±20.1</td>
<td>59.6±21.0</td>
<td>77.9±15.9</td>
<td>79.0±16.1</td>
<td>80.9±29.0</td>
</tr>
<tr>
<td>Right GAS</td>
<td>33.7±20.4</td>
<td>49.2±17.2</td>
<td>64.6±24.3</td>
<td>71.1±27.3</td>
<td>71.1±28.9</td>
<td>90.9±13.8</td>
</tr>
<tr>
<td>Right GM</td>
<td>30.9±21.5</td>
<td>45.8±22.9</td>
<td>64.9±24.1</td>
<td>88.2±12.1</td>
<td>96.0±9.3</td>
<td>100.0±</td>
</tr>
<tr>
<td>Left RF</td>
<td>27.0±20.5</td>
<td>43.1±21.1</td>
<td>52.6±20.0</td>
<td>59.8±21.6</td>
<td>77.2±12.2</td>
<td>78.0±11.7</td>
</tr>
<tr>
<td>Left BF</td>
<td>33.7±19.6</td>
<td>41.9±22.5</td>
<td>45.1±15.0</td>
<td>62.8±17.1</td>
<td>78.3±10.1</td>
<td>79.3±8.5</td>
</tr>
<tr>
<td>Left GAS</td>
<td>27.5±21.8</td>
<td>37.2±23.0</td>
<td>44.0±23.4</td>
<td>56.8±25.6</td>
<td>69.0±18.9</td>
<td>70.3±19.1</td>
</tr>
<tr>
<td>Left GM</td>
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<td>72.5±27.1</td>
<td>73.2±24.5</td>
<td>78.0±28.3</td>
</tr>
</tbody>
</table>
Figure 7.4 The muscle activation timings of the lower limbs for the group during sprinting (a), A-skip (b) and heel flicks (c) across the gait cycle.
Table 7.7 Effect sizes comparing group timings (% of cycle) of the first burst of high activity (above 50%) for biceps femoris, rectus femoris, during sprint and A-skip and sprint and heel flicks

<table>
<thead>
<tr>
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<th>Effect Size (Cohens d)</th>
</tr>
</thead>
<tbody>
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<td>Right Biceps Femoris</td>
</tr>
<tr>
<td>Sprint/A-skip</td>
<td>0.499</td>
</tr>
<tr>
<td>Sprint/Heel Flicks</td>
<td>0.304</td>
</tr>
</tbody>
</table>

7.5 Discussion

Studies on muscle activity of the lower limb muscles during sprinting using wireless EMG systems are limited. There is currently no research on the timings of muscle activations of lower limb muscles during drills (A-skip and heel flicks). The aims of this study were to identify the timings of muscle activations of sprint drills (A-skip and heel flicks) and compare these timings of activations to the timing of muscle activations during sprinting.

7.5.1 Previous research findings compared with this study findings sprint

When examining the timings of muscle activations during sprinting compared to previous research there are some similarities. The results of this investigation showed that the phasic muscle activity data for biceps femoris is highly active during the late stance phase to shortly after the right toe leaves the ground coming into the early swing phase. The biceps femoris is active again during the mid to late swing phase as the left toe begins to leave the ground. There is a final burst of high activity during the late swing phase as the right foot prepares for initial contact these findings are consistent to findings in previous research (Yu et al., 2008; Chumanov et al. 2012; Higashihara et al. 2010; Thelen et al. 2005; Chumanov et al. 2011; Chumanov et al. 2007). These studies found that the hamstrings were active during the stance, middle swing and late swing phase. As speed increased the activation of the biceps femoris increased during the mid-swing and late swing of the sprint cycle. Howard et al. (2017a) concluded that the hamstrings were highly active during the stance phase and the late swing phase. According to Mero et al. (1992) and Mero & Komi (1987) the biceps femoris is active shortly after heel strike and throughout the stance phase. After take-off when the heel is moved towards the hip there was not much EMG activity in the Biceps femoris (Mero et
al. 1992 and Mero & Komi 1987). The findings of Mero and Komi (1987) were consistent with the results of the current study. The biceps femoris appears active shortly after toe-off during the early swing phase and then has a period of quiet and is active again during the mid to late swing phase. The results of this current investigation found that the rectus femoris is active during the early and late stance phase and remains active shortly after right toe-off. It has a second burst of high activity during the mid-swing phase. The rectus femoris had a final burst of activity in the late swing phase as the right foot prepares to come in contact with the ground again. According to Wiemann & Tidow (1995) the rectus femoris during the pre-swing/early swing phase are at its highest recruitment. The rectus femoris is highly active during the concentric phase of the support (Chumanov et al. 2012). The rectus femoris in this current study is highly active during both the contact phase and swing phase. The gastrocnemius appears to be active as each foot is in contact with the ground and shortly after toe-off. The gastrocnemius is active from the early to late stance phase. There is a second burst of high activity during the mid to late swing phase as the right foot prepares for initial contact. Research has suggested that the gastrocnemius is active while the foot is in contact with ground during the stance phase (Mero & Komi, 1987). Mero and Komi (1987) stated that there is a second burst of activity during the late swing phase as the lower limb pre-activates as it is about to make contact with the ground (Mero & Komi, 1987). The results of this investigation show that the gluteus maximus was highly active during the early to late stance phase. This muscle active during the mid to late swing phase. There is a final burst of activity during the late swing phase as the right foot prepares for initial contact. These findings are similar to those found by Howard et al. (2017a) which states the gluteus maximus has peak activity during foot strike and early stance, high activity was also found during the late swing phase.

### 7.5.2 Muscle redundancy

There are limitations to using surface EMG analysis to detect muscle activations as there are many possible ways a muscle will activate for one movement. This is known as muscle redundancy which is as a problem where there are many possible muscle action solutions to complete a task. This is because of the number of degrees of freedom and the infinite number of muscle activation patterns that can be used to achieve a goal or skill (Hirashima & Oya 2016), therefore, an individual participant could use different activation patterns to complete the same task. The results observed in tables 7.3-7.5
indicate that the muscle activation timings of the individual participants can vary from participant to participant. Muscle activation timings appear to be very individual. There is large within subject variability observed in sprint, heel A-skip and heel flicks, this is seen with by the large standard deviations (mean ± SD values).

7.5.3 Group comparison sprint Vs drills

To date there is currently no research which examined the muscle activation timings of drills. Therefore, there are no muscle activation timings to compare to the results of this study. A visual examination of the results (Figure 7.4a, 7.4b, 7.4c) highlights some similarities and differences between the exercises. During sprinting the rectus femoris has a burst of activity during the stance phase, there is no burst of activity for A-skip or heel flicks during the stance phase. Both A-skip and heel flicks have bursts of activity during the early to mid-swing phase shortly after right toe-off while sprinting has a burst of activity during the mid-swing phase. All three exercises have a burst of high activity during the late swing phase. Similar to the rectus femoris the biceps femoris is active during the stance phase for sprinting and is not active during this phase for A-skip and heel flicks. The biceps femoris is active from stance phase to the early to mid-swing phase ending at 43%, during A-skip there is short burst which ends during the early to mid-swing phase at 43% and finally there is also a burst during heel flicks which ends in the early to mid-swing phase ending at 46%. During all three exercises there is activity during the mid to late swing phase, sprinting (63%-84%), A-skip (61%-70%) and heel flicks (60%-80%). Both sprinting and A-skip have late final bursts of activity as the muscle pre activates to prepare for initial contact. The gastrocnemius is active during sprinting when the foot is in contact with the ground during the stance phase. A-skip and heel flicks have no bursts of high activity during this phase. Both A-skip and heel flicks have bursts of activity during the early to mid-swing phase which is not seen in the sprint. All three exercises have bursts of activity during the mid to late swing phase as the muscles pre-activate to prepare for initial contact. The RGM was active during the stance phase for sprinting, this was not the case for A-skip and heel flicks. All three exercises have high levels of activity during the mid to late swing phase as the muscles pre activate to prepare for initial contact. There appears to be some similarities between the timings of sprinting when compared to the drills but the duration of the activity and timings differ. This may be due to sprinting being maximal and the drills being sub-maximal.
The effect size comparisons were used to interpret the sizes of the difference between muscle activation timings between sprint and A-skip and sprint and heel flicks. When comparing the size of the difference between sprint and drills it can be observed that there are some similarities but also some large differences when examining some of the effect sizes. When the sprint and A-skip is compared the size of difference is observed as a moderate difference when examining the right biceps femoris, left biceps femoris and right rectus femoris and the size of the difference is small for the left rectus femoris. Comparison of sprinting with heel flicks indicates small differences in activity in the right biceps femoris and left rectus femoris. There is a notable difference in the left biceps femoris and a large difference in the right rectus femoris. Small differences were observed when comparing sprint and heel flicks in the biceps femoris (ES 0.304) but also large differences observed when comparing heel flicks and sprinting in the rectus femoris (ES 0.964) between sprinting and drills.

7.6 Limitations

While this body of work comprises of extensive and novel investigations providing an insight into the use of drills muscle activations of drills compared to sprinting, it is not without its limitations.

7.6.1 Separate testing days for sprinting and drills

Data collection of EMG in sprint and drills took place on two separate days; this is an unavoidable limitation to this study. Ideally, the testing would have taken place over one day. One day of testing was originally trialled, however, due to the time required to complete the testing session, availability of the indoor track facility, changes to footwear from drills to sprint, the need to avoid questionable drills being performed after maximum sprint, and sensors falling off it was decided to complete the testing of drills and sprinting separately. These constraints challenged the reliability of the EMG measures because of variations in sensor placement, and skin conductivity. To limit the sensor placement issue the participants were tested within a week of the first testing session. Since the area where the sensors were placed was shaved, this area was still visible for the second day of testing therefore reducing the amount of variation in sensor placement across testing sessions. The aim of this study was to examine the timing of muscle activations (when in the gait cycle muscle activity above 50% occurred) and not to examine the size of the EMG signal. Timing of events using EMG is not likely to be adversely affected by the variations in skin conductivity across testing sessions.
7.6.2 Equipment availability

Equipment availability impacted on some of the parameters collected. Firstly, at the time of data collection for this study only ten of the sixteen Delsys wireless EMG sensors were available and working. There were battery, recording and range problems with six sensors. Therefore, only one muscle from each of the main lower limb muscles (calf, hamstring, quadriceps and gluteals) were analysed. The additional two sensors were placed on the shin bone to detect foot strike events using the methods outlined in Chapter 5; however, the Optojump and visual data provided a more accurate account of foot contacts.

7.6.3 Muscle redundancy

Due to the limitations of surface EMG, it was not possible to obtain EMG data of all the muscles, particularly the deeper lying muscles when participants were performing the drills and sprinting. Measures to obtain deep lying muscle could not be obtained. There are limitations to using EMG analysis to detect muscle activations for specific movements since there are many possible ways that muscles can activate to achieve the same movement outcome. This is known as muscle redundancy (Hirashima & Oya 2016), therefore, an individual participant could use different activation patterns to complete the same task.

7.7 Conclusions

The findings of this research on the muscle activations of drills was not fully conclusive. Muscle activations of the lower limb during sprinting in this study appeared to correspond to the findings of previous literature. Comparing the similarities of muscle activations between drills and sprinting was inconclusive due to high levels of participant variability, the maximal nature of sprinting, the submaximal nature of drills and muscle redundancy issues. Therefore, more research is necessary on muscle activation during drills and further investigation of other drills and deep lying muscles is recommended. Since information on deep lying muscles cannot be obtained using surface EMG, the use of a musculoskeletal modelling may provide information on deep lying muscles in a non-invasive way. An investigation of the muscle activity of the deeper lying muscles during sprinting and drills using a musculoskeletal model is therefore recommended.
Chapter 8. Validation and application of a simulation model for sprinting and drills of an elite sprinter in ADAMS Lifemodeler
8.1 Introduction

Musculoskeletal modelling is a method which is used to understand biomechanical aspects of the human body (Wibawa et al. 2016). A musculoskeletal model simulates the human body in static and dynamic conditions and can be divided into two groups: forward and inverse dynamic models (Damsgaard et al. 2006). Forward dynamics compute the motion based on a predicted muscular activation while inverse dynamics computes the muscle activation based on a specific task (the motion) (Damsgaard et al. 2006). Simulation can provide capabilities not generally offered by an experimental approach (Thelen et al. 2003). Forward dynamic simulation offers a methodology for determining the relationship between multi-joint movement and muscle excitation during motion (Thelen et al. Anderson 2006). Musculoskeletal model studies have examined the lower extremity during normal walking (Thelen et al. 2005; Neptune et al. 2004; Wibawa et al. 2016), and activity of the hamstrings during sprinting (Thelen et al. 2005; Chumanov et al. 2007; Schahe et al. 2012).

8.1.1 Hamstring muscle activity using musculoskeletal models

Musculoskeletal models have been used to examine the effects of maximal sprinting on the hamstring muscles (Thelen et al. 2005; Chumanov et al. 2007; Schahe et al. 2012). Thelen et al. (2005) used a computer simulated model to examine the effects of running speed and tendon compliance on the muscle and tendon contributions to length excursions and mechanical work (Thelen et al. 2005). In the study by Thelen et al. (2005) a musculoskeletal computer model was used to simulate and investigate the mechanics of the biceps femoris long head during the swing phase in sprinting. Whole body kinematics were collected for one adult male (single subject analysis) while sprinting on a high-speed treadmill, the kinematic data were used to drive the computer simulated model. Representative EMG data were collected on five adult males during high-speed treadmill sprinting and used to validate the model predictions of muscle excitation timing. The model allowed estimations of muscle excitation for deep lying muscle for example the psoas muscle, which cannot be assessed using surface EMG. The study found that when compared to the experimental EMG the model estimations of muscle excitation closely agreed. The biceps femoris was substantial stretched during the swing phase of sprinting. This finding indicated that during the swing phase there is a potential of injury to occur in the biceps femoris. The study concluded that the model was a valid method for predicting kinematics and muscle excitation.
Schahe et al. (2012) investigated why the hamstring muscles are vulnerable to acute strains during sprinting, hamstring mechanics during overground maximal sprinting were examined. A musculoskeletal model was used to calculate muscle strain, velocity, power and work for the hamstrings. 3D kinematic data and ground reaction forces were collected and used to drive the musculoskeletal model. A generic and a participant specific musculoskeletal model were generated via OpenSim. Joint kinematics and lower limb joint movements for the entire sprint cycle were computed by conducting an inverse dynamics approach. The main findings from this study were that the hamstring muscles all reached peak force during the late swing phase. The biomechanical load differed for all the hamstring muscles with the biceps femoris generating the largest peak strain. The study concluded that as the hamstrings all reach peak force during the late swing phase that this phase is when the hamstring muscles are at the greatest risk of injury.

8.1.2 Musculoskeletal models – sprinting and jumps

Wibawa et al. (2016) compared muscle activity predicted by an Anybody musculoskeletal model with experimental EMG of ten participants during walking, one legged jumps and side jumps of eight lower limb muscles. The results showed that the model muscle excitation when compared to the experimental muscle had varied Pearson R correlations which ranged from -0.2 to 0.8 during each exercise. For the walking trial the biceps femoris and lateral gastrocnemius were reported to have to have the highest correlations between the model and experimental data, with biceps femoris having a r value of 0.7 and lateral gastrocnemius having a r value 0.79. Four muscles vastus medialis, vastus lateralis, lateral gastrocnemius and tibialis anterior during the one-legged hop had the highest correlations ranging from 0.65 to 0.71. Finally, the vastus medialis, vastus lateralis had the highest correlations (r = 0.8) when comparing the experimental with the model muscle excitation.

8.1.3 Aims

The present study advances the work presented in Chapter 6 and 7 by developing and validating a computer simulation model of sprinting and various running drills (A-skip, and heel flicks). The aims of this study were to compare kinematics, and muscle activation patterns of sprinting with kinematics and muscle activations in running drills. Given the limitations of surface EMG, it is not possible to obtain EMG data of all
muscles while running. Therefore, a computer simulation (ADAMS Lifemodeler) was used to predict optimised activation patterns. ADAMS Lifemodeler is software which allows for virtual human modelling and simulation.

### 8.2 Methods

#### 8.2.1 Participant characteristics

This study employed single subject analysis to compare the kinematics coordination and muscle activations of sprinting with the kinematics and muscle activations in running drills (Stergiou 2004; Dufek et al. 1995; Bates 1996; Schache et al. 2009). Statistical methods of human movement tend to combine biomechanical data measured from repeated trials from a group (Newell & Corcos 1993). Many biomechanical studies employ the measure of average performance within a group of individuals and then generalise this information to a larger population, without taking into account individual performances (Stergiou & Scott 2005). The use of single subject analysis as an experimental method provides varied responses to interventions with increased sensitivity to change compared when to group analysis. Scholes and McDonald (2012) concluded that single subject analysis when compared to group analysis provided a better detection of individual changes. This was despite there being within and between variability across trials. This is an important consideration when detecting differences in knee function, whether using group or single-subject approaches.

One male participant participated in this study (22 years, 1.84 m, 78 kg). The participant was a national level 100 m and 200 m sprinter. At the time of testing the participant was injury free and had been participating in sprinting sessions at least three times a week for the last six months. Ethical approval for the study was granted from the University Research Ethics Committee, and written consent was obtained from the participant. Before taking part in the study, the participant completed a physical activity questionnaire.

#### 8.2.2 Experimental procedures

Whole body kinematics were recorded using 52×12 mm diameter retro-reflective markers. The markers were placed on various anatomical landmarks (see table 8.1). 17 retro reflective were used as plug-in for ADAMS Lifemodeler to drive inverse dynamics computation (see table 8.1), and two additional markers were attached to the participant
The additional markers were used to validate the model whereby three-dimensional trajectory data collected experimentally for these markers were not used to drive the computer model as the original 17 markers did. Rather, their three-dimensional data were compared to three dimensional trajectory data produced for the same anatomical landmarks by the model (Kenny et al. 2006). All trials were captured using a twelve camera 3D motion analysis system (500 Hz, MAC Eagle, Motion Analysis Corporation Inc., Santa Rosa CA., USA). The capture volume (Length: 7.5m; width: 1.25m; height 2.25m) was located on an indoor 60 m athletics track. 14 Delsys Trigno Wireless EMG™ sensors were placed on both the right and left side of the participant (See table 8.3). Sensors were placed using SEMIAM electrode placement guideline. EMG data were recorded at 2000 Hz.

8.2.3 Running procedures

As seen in the previous studies Chapter 6 and Chapter 7, the testing procedures took place over two days. Testing over two days was due to a number of reasons; the use of some of the drills were potentially questionable did not want them to compromise sprinting technique therefore they were performed on a different day, facility constraints, time constraints - changing footwear from runners to spikes meant changing marker from one shoe to the other. The participant wore dark tight fit clothing and their own appropriate footwear for sprinting and performing drills.

Day 1

After completing their own preferred warm up as they normally would before training, the participant performed three repetitions of the following drills A-skip, A-Sprint, heel flicks and straight leg bounds (for this chapter A-skip and heel flicks will be examined). The Participant performed each of the drills through the 3D camera set up (see Figure 8.2 & 8.3)

Day 2

After completing their own preferred warm up and drills, the participant performed three maximal effort sprints over a distance of 60 m. Recovery between the trials was up to ten minutes or when the athlete felt they were ready to sprint again this was to ensure that the participant were fully recovered for each maximal sprint. The participant performed each of the sprints through the 3D camera set up (see Figure 8.2 & 8.3).
Table 8.1 Plug in gait markers for computer simulation model

<table>
<thead>
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<th>Marker Code</th>
<th>Marker Name</th>
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<th>Marker Name</th>
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</thead>
<tbody>
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<td>RASI</td>
<td>Right anterior superior iliac spine</td>
<td>LASI</td>
<td>Left anterior superior iliac spine</td>
</tr>
<tr>
<td>RPSI</td>
<td>Right posterior superior iliac spine</td>
<td>LPSI</td>
<td>Left posterior superior iliac spine</td>
</tr>
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<td>RTHI</td>
<td>Right thigh cluster</td>
<td>LTHI</td>
<td>Left thigh cluster</td>
</tr>
<tr>
<td>RKNE</td>
<td>Right knee</td>
<td>LKNE</td>
<td>Left knee</td>
</tr>
<tr>
<td>RTIB</td>
<td>Right shank cluster</td>
<td>LTIB</td>
<td>Right shank cluster</td>
</tr>
<tr>
<td>RANK</td>
<td>Right ankle</td>
<td>LANK</td>
<td>Left ankle</td>
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<td>RHEE</td>
<td>Right heel</td>
<td>LHEE</td>
<td>Left heel</td>
</tr>
<tr>
<td>RTOE</td>
<td>Right toe</td>
<td>LTOE</td>
<td>Left toe</td>
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<tr>
<td>SACR</td>
<td>Sacrum</td>
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Table 8.2 5th metatarsal and greater trochanter markers used to validate model.

<table>
<thead>
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<th>Marker Code</th>
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<th>Marker Code</th>
<th>Marker Name</th>
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</thead>
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<td>LMH5</td>
<td>Fifth Metatarsal Head</td>
</tr>
<tr>
<td>RFT</td>
<td>Femur Greater Trochanter</td>
<td>LFT</td>
<td>Femur Greater Trochanter</td>
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</table>
Figure 8.1 Anterior and posterior view of 52 retro-reflective marker placements.

Table 8.3 Sensor placement of Delsys Trigno Wireless EMG™ left and right sides.

<table>
<thead>
<tr>
<th>Left Side</th>
<th>Right Side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gastrocnemius medial head</td>
<td>Gastrocnemius medial head</td>
</tr>
<tr>
<td>Gastrocnemius lateral head</td>
<td>Gastrocnemius lateral head</td>
</tr>
<tr>
<td>Biceps femoris</td>
<td>Biceps femoris</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>Semitendinosus</td>
</tr>
<tr>
<td>Vastus lateralis</td>
<td>Vastus lateralis</td>
</tr>
<tr>
<td>Rectus femoris</td>
<td>Rectus femoris</td>
</tr>
<tr>
<td>Gluteus maximus</td>
<td>Gluteus maximus</td>
</tr>
</tbody>
</table>
Figure 8.2 MAC 3D camera positioning on indoor sprint track.
Figure 8.3 Visual representation of application of subject anthropometrics, soft tissues, muscles and inverse dynamics and for simulation model.
8.3 Data processing

To run the computer simulation model effectively 17 markers were needed as plug-ins for the ADAMS Lifemodeler software and the additional two markers (5th metatarsal and greater trochanter) which were used for validation of the model. These markers were chosen representing movement of fast and relatively slow body parts respectively, providing both large and small reference angular and velocity data points. Cortex 5 (Motion Analysis Corporation, Santa Rosa, CA, USA) was used to track and export the coordinate data. Each trial for each exercise (sprint, A-skip, heel flicks) were visually analysed and the best trial which had all markers seen throughout trial for each exercise was analysed. Gait events were defined as foot contact of the right leg to foot contact of the right leg and were visually determined. Once the trials were tracked for one cycle the data were exported to MS Excel and formatted, each file was then converted to a systematic licence file (.SLF). This ASCII file contains information tailored to the individual which is biofidelic and single subject and included: anthropometrics, joints, posture and motion capture data. The file is organized in data blocks (adapted from LifeMOD™ Technical Manual, 2005). The .SLF files for each exercise were then imported into ADAMS Lifemodeler.

8.3.1 Modelling techniques

ADAMS Lifemodel™ was used to recreate the data captured using the MAC system. Modelling techniques and data analysis were adapted from techniques used by Kenny et al. (2008). The base segment set comprised of 19 segments:

- Head
- Neck
- Upper torso
- Lower torso
- Right/left scapula
- Right/left upper arm
- Right/left lower arm
- Right/left hand
- Right/left lower leg
- Right/left foot.  

(Kenny et al. 2008 p. 39)
The model was originally scaled for the participant’s height and body mass (1.84m, 78kgs). In this study, the model was constructed with a total of 42 degrees of freedom. Kinematic data were used to create the inverse dynamics simulation which replicated the sprint, A-skip and heel flicks. Inverse dynamics involves computing moments and forces from recorded motion (Hamill, Selbie and Kepple, 2004). Trainable passive joints and muscle contractile elements were added which were then trained in an inverse-dynamics simulation. During this process the muscles learned shortening/lengthening patterns (Kenny et al. 2008). A biofidelic model representative of the participant’s musculoskeletal system and inertial parameters were created. A full lower body set of 118 muscles were generated with 45 lower leg muscles. The muscles elements transmitted tension force only. For inverse dynamics muscle tendon forces consisted of training elements. Ligaments were passive spring/dampers and muscle (Kenny et al. 2008). Physiological cross-sectional area, resting load and maximum tension/stress were defined for each muscle. With this approach, muscles replicated the desired motion of the body, while staying within the physiological limit of the muscle by producing the necessary forces. Physiological limits for each muscle included: physiological cross-sectional area (pCSA), resting load (Fresting), and maximum tissue stress (Mstress). The assumption was that if enough muscles were included, the calculated muscle forces would be very close to the actual force values (Kenny 2006).

### 8.3.2 Data analysis

Validation of a model is normally achieved by a comparison of model predicted results with data obtained experimentally for the same condition. For this current study validation was carried out for kinematics and kinetics. Kinematic data were compared using Pearson R correlations and root mean squared differences, and relative and absolute comparison of experimental and modelled theoretical data. Kinetic data were compared using experimental EMG compared with the model’s predicted activity. Kinematics data were validated using additional markers the 5th metatarsal and greater trochanter tracked during the experiment. These markers were not used to drive the model and were replicated virtually on the model. Their modelled trajectories were recorded during the inverse dynamics simulations. Kinetic data were compared using experimental EMG and the models predicted muscle force-time history. The experimental EMG and predicted EMG data were analysed using the techniques in Chapter 6 (rectified, filtered, normalised, on-off events above 10% and 50%). The on-
off events above 50% were compared between the experimental and predicted. EMG experimental and theoretical data were compared using Pearson’s R correlations. Due to the model predictions incorporating little muscle resting tension in the predicted muscle activity when compared with experimental data which has small ‘resting’ fluctuations of muscle activity, a second comparison was performed. This was a comparison between the model predictions and experimental EMG data above the 50% activation threshold using Pearson’s R. Thus, errors associated with resting tension were removed.

8.4 Results

Results are presented in two sections; firstly, for kinematic data validation measures, and secondly for kinetic EMG data validation and simulation of muscle activity. Table 8.4 provides information on the correlations between experimental data and computer simulation model predictions for kinematics of the 5th metatarsal and greater trochanter. The closer to 1.0 the correlation, and smaller the RMSD difference (m) the better the model is a predicting the correct movements for drills and sprinting. Table 8.4 shows near perfect correlations between both experimental and computer simulation model data, 0.993 for the 5th metatarsal and 0.999 for the greater trochanter for the A-skip drill. This information provides excellent validity between real life movement and movement predictions by the computer simulated model for sprint, A-skip and heel flicks.

<table>
<thead>
<tr>
<th>Exercise</th>
<th>Pearson Correlation (r)</th>
<th>Root Mean Square Difference (m)</th>
<th>Pearson Correlation (r)</th>
<th>Root Mean Square Difference (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5th Metatarsal</td>
<td>Greater Trochanter</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sprint</td>
<td>0.987</td>
<td>0.086</td>
<td>0.999</td>
<td>0.040</td>
</tr>
<tr>
<td>A-skip</td>
<td>0.993</td>
<td>0.085</td>
<td>0.999</td>
<td>0.085</td>
</tr>
<tr>
<td>Heel Flicks</td>
<td>0.995</td>
<td>0.090</td>
<td>0.999</td>
<td>0.098</td>
</tr>
</tbody>
</table>

Figure 8.5 shows the muscle activity for lower limb muscles during sprint, A-skip and heel flicks for EMG experimental data and computer simulation model predictions. As seen in Chapter 6 EMG activity above the 50% threshold indicates high muscle activity. When comparing the computer model EMG predictions and experimental EMG visually there appears to be some similarities. The experimental data appears to have many bursts of activity in some cases for example in the lateral gastrocnemius during A-skip in comparison to the computer simulation model predictions. The model data appears to
have very little resting tension in the muscles and only shows activity when the model predicts the body needs it. This is based on the optimised model overcoming inertial parameters of segments. This is in comparison to the experimental EMG where in reality there are small fluctuations of muscle tension before the muscle activity reaches its peak. Figure 8.6-8.8 provides graphical representation for experimental EMG and predicted EMG of four lower limb muscles the rectus femoris, biceps femoris, gastrocnemius, gluteus maximus during sprinting, A-skip and heel flicks. Two Pearson’s R correlations were performed on these data, r1 indicates correlation values for the full cycle heel strike to heel strike and r2 indicates correlations of events above 50%. The correlations between experimental EMG and predicted EMG for the full cycle r1 are low (r1= 0.12 - 0.36). There appears to be some strong to moderate correlations when comparing the experimental EMG with the predicted EMG for r2 correlations of events above 50% (0.41 - 0.78) for all the muscles for sprinting, A-skip and heel flicks, except for one the gastrocnemius activity during heel flicks with a correlation value of -0.33 (Figure 8.8). There are some similarities in terms of peaks and patterns but there appears to be differences in timings and phase differences. The timings of the predicted EMG are inconsistent; some timings are very similar when compared visually with the experimental EMG for example the biceps femoris during sprinting (Figure 8.6). Some have peaks before the experimental EMG for example the rectus femoris during heel flicks (Figure 8.8) and some have peaks after the experimental EMG for example the gluteus maximus during the A-skip (Figure 8.7).

Computer simulations predictions for the gluteus minimus, psoas, soleus, and tibialis anterior were also included as this information cannot be examined using surface EMG sensors. Figure 8.9 – 8.11 provides graphical representation of predicted muscle activity which cannot be reached by surface EMG for gluteus minimus, psoas, soleus and tibialis anterior during sprinting, heel flicks and A-skip. The same methods were used as in Chapter 6 for indicating different events in the cycle from heels strike to heel strike 0 – 100%. Figure 8.9 indicates that during sprinting all four muscles are highly active above 50% during the initial contact. The gluteus minimus has a second burst of activity during the mid-swing phase and a final burst of activity as the foot prepares to make contact with the ground. Figure 8.10 indicates that during the A-skip the tibialis is active for all of the initial contact and after toe-off. The psoas is active in the late swing phase as the foot prepares to make contact with the ground. The gluteus minimus is
active during early contact and again during late swing and the soleus is active for a brief period of time early in the cycle while the foot is in contact with the ground. Figure 8.11 indicates that during heel flicks the psoas is highly active while the right foot is in contact with the ground and again as the foot prepares to make contact with the ground. The gluteus minimus is highly active after toe-off and during the mid-swing phase and has a final small burst of activity during the late swing phase. The tibialis anterior is active during the early to mid-swing phase and has a second burst during the late swing phase. The soleus is not highly active above 50% at any stage of the cycle.
Table 8.5 Comparison of experimental EMG activity above the 50 % threshold (which indicates high levels of muscle activity) with model predicted muscle activity.

<table>
<thead>
<tr>
<th>Muscles</th>
<th>Above 50% Experimental EMG</th>
<th>50% Model Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sprint (%)</td>
<td>A-skip(%)</td>
</tr>
<tr>
<td>Semitendinosus</td>
<td>61-83</td>
<td>5-9</td>
</tr>
<tr>
<td>Biceps Femoris</td>
<td>0-5</td>
<td>41-47</td>
</tr>
<tr>
<td></td>
<td>58-100</td>
<td>88-100</td>
</tr>
<tr>
<td>Rectus Femoris</td>
<td>19-49</td>
<td>33-38</td>
</tr>
<tr>
<td></td>
<td>80-100</td>
<td></td>
</tr>
<tr>
<td>Vastus Lateralis</td>
<td>53-69</td>
<td>90-97</td>
</tr>
<tr>
<td>Lateral</td>
<td>41-52</td>
<td>0-5</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>23-31</td>
<td></td>
</tr>
<tr>
<td></td>
<td>41-48</td>
<td></td>
</tr>
<tr>
<td></td>
<td>83-100</td>
<td></td>
</tr>
<tr>
<td>Gluteus Maximus</td>
<td>0-9</td>
<td>92-98</td>
</tr>
<tr>
<td></td>
<td>61-100</td>
<td></td>
</tr>
<tr>
<td>Gluteus Minimus</td>
<td>No EMG sensor</td>
<td>No EMG sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Psoas</td>
<td>No EMG sensor</td>
<td>No EMG sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soleus</td>
<td>No EMG sensor</td>
<td>No EMG sensor</td>
</tr>
<tr>
<td>Tibialis Anterior</td>
<td>No EMG sensor</td>
<td>No EMG sensor</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
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<td></td>
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<td></td>
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</tbody>
</table>
Figure 8.4 Graphical representation of experimental muscle activity vs model predicted activity for the rectus femoris (a), biceps femoris (b), lateral gastrocnemius (c) and gluteus maximus (d) during sprinting.
Figure 8.5 Graphical representation of experimental muscle activity vs model predicted activity for the rectus femoris (a), biceps femoris (b), lateral gastrocnemius (c) and gluteus maximus (d) during the A-skip drill.
Figure 8.6 Graphical representation of experimental muscle activity vs model predicted activity for the rectus femoris (a), lateral gastrocnemius (b) and gluteus maximus (c) during the heel flick drill.
Figure 8.7 Computer simulation model muscle predictions for deep lying muscles that cannot be examined by surface EMG experimentally (gluteus minimus, psoas, soleus and tibialis anterior) during sprinting.
Figure 8.8 Computer simulation model muscle predictions for deep lying muscles that cannot be examined by surface EMG experimentally (gluteus minimus, psoas, soleus and tibialis anterior) during A-skip.
Figure 8.9 Computer simulation model muscle predictions for deep lying muscles that cannot be examined by surface EMG experimentally (gluteus minimus, psoas, soleus and tibialis anterior) during heel flicks.
8.5 Discussion

8.5.1 Previous research

The aims of this study were to compare kinematics, and muscle activation patterns of sprinting with kinematics and muscle activations in running drills. Given the limitations of surface EMG, it is not possible to obtain EMG data of all muscles while performing drills and sprinting. Measures to obtain deep lying muscle can be invasive for the participant, a computer simulation (ADAMS Lifemodeler) can be used to predict optimised activation patterns. There is some limitation with using computer simulation to predict muscle activity of the deep lying muscles. There are many possible ways a muscle will activate for one movement. This is known as muscle redundancy which is a problem where there are a large number of possible solutions. This is because of the number of degrees of freedom and the large number of muscle activation patterns that can be used to achieve a goal or skill (Hirashima & Oya 2016). An individual participant could use different activation patterns to achieve the same goal or skill. For example if one person is performing a biceps curl they may activate different muscles at different times when compared to someone else performing the same movement.

Previous research has been conducted using musculoskeletal models to determine hamstring kinematics and muscle activity during sprinting (Thelen et al. 2005; Chumanov et al. 2007; Schahe et al. 2009). These studies concluded that the use of musculoskeletal models is a valid method to predict the activity of the hamstrings during sprinting and that the hamstring muscles specifically the biceps femoris is at the highest risk of an acute strain injury during the late swing phase of sprinting. There is a limited amount of research which have compared experimental EMG with model predicted activity. The results of this study indicate that the musculoskeletal model used is kinematically and kinetically validated. There are moderate to strong correlations for many muscles. Therefore the current model produces optimised muscle activation that firstly closely mirrors surface EMG activation timing, and secondly can be used to investigate other muscle activity.

8.5.2 Model Validation

There are differences between the model and the experimental data, the model data appears to have very little resting tension in the muscles and only shows activity when
the model predicts the body needs it. This is in comparison to the experimental EMG where in reality there are small fluctuations of muscle tension before the muscle activity reaches its peak. The results indicated a combination of correlation values. When examining the full cycle (0-100) for sprinting there is a combination of negative correlations and moderate to strong correlations between the predicted model activity and the experimental model activity. Visually there appear to be similar patterns between the two, but there is a phase related difference between the predicted and experimental data. There are differences in the timings and durations of the maximum peaks but there are high Pearson’s R values for the biceps femoris and gluteus maximus when examining the peaks in isolation. Results for the A-skip and heel flicks indicated larger differences between the model and the experimental EMG. Both A-skip and heel flicks had negative and low correlation values during the whole cycle (0-100). The correlation values of the maximum peaks in isolation during the cycle, however, have moderate to high Pearson R values. The results suggest that the model is predicting an optimal solution but in reality there are different ways to activate muscles for the same movement. Visual patterns appear similar but there is a notable difference in timings, durations and there is a phase related difference. The high and low correlations for different muscles and different exercises are similar to the findings of Wibawa et al. (2016) the study concluded that muscle activity predictions showed higher correlations values and a better validation for side jumping and forward hopping in comparison to normal walking. The possible reason for the difference between the higher correlations seen in sprinting when compared to drills might be because sprinting is a maximal exercise whereas drills is a submaximal exercise. Submaximal exercises allow for a higher possibility of more than one solution of muscle activity for the movement.

8.6 Limitations

8.6.1 Separate testing days for sprinting and drills

As outlined in Chapters 6 and 7, data collection for sprinting and drills took place on two separate days. This is a limitation to this study which affected marker and EMG sensor placement. A single day of testing was not feasible due to a number of reasons – the set-up time for the 3D cameras was extensive, track availability, changes to footwear from drills to sprinting, markers and sensors falling off.
8.6.2 Time to use ADAMS Lifemodeler

The time available to use ADAMS Lifemodeler was also limited due to licence availability. Once activated, the software could only be used for 30 days. Time was needed to become familiar with how the software worked and how to set up the data correctly so it was inputted into the ADAMS Lifemodel correctly to build the musculoskeletal model. Building the model to work involved many trials. Although the musculoskeletal model was kinematically validated, there were still some flaws in the built model particularly in the predicted EMG. The limitations above however, meant that there was not time to attempt to rectify those flaws.

8.7 Conclusions

It was the aim of this study to develop and validate a computer simulation model of sprinting and A-skip and heel flicks. The current model is kinematically and kinetically validated based on comparisons between experimental data and model predictions. The musculoskeletal model in this current study provided information on the activations of muscles which could not be obtained using surface EMG. However, care is needed when interpreting model kinetics due to optimised solutions. Mathematically modelling is a very useful tool to analyse kinematics and kinetics. Due to the limited amount of time constructing this model future research should conduct a more in-depth analysis using musculoskeletal modelling of sprinting and drills. Further research should also examine what the joints are doing during sprinting and drills by examining the forces generated by the joint. Joint net torques would give more consistent insight into the movements of the joints during maximal sprinting and drills.
Chapter 9. Thesis Conclusions and implications
9.1 General discussion

This thesis aimed to develop greater knowledge and understanding of the drills being used by athletes and coaches by firstly, examining coaches’ and athlete’s knowledge and secondly, experimentally examining the kinematics and muscle activity of drills and sprinting. As outlined in Chapter 1, sprinting involves running over a short distance during a short period of time. Sprinting is a major event in athletics track and field and is largely incorporated into many sports. While there is a large body of research on sprinting, there are significant gaps in our understanding of the how the muscles act to achieve maximal running speed (Novacheck 1998). Furthermore, there is limited research on how to ensure the specificity of conditioning exercises and drills to improve running speed (Ross et al. 2001).

Development of speed involves technical skill in the form of specific drills which are designed to isolate and combine joints to mimic a series of sensations that help establish the exact motor pathways of sprinting. Drills are a valuable part of an athlete’s training and can help the athlete to learn and refine key aspects of running skill, and more specifically, develop sprinting technique (Cissik, 2004). Drills are considered important in the coaching of correct sprinting technique as they establish the movement and coordination patterns of sprinting (Harrison 2010). Coaches often breakdown a skill into its component parts thereby simplifying sprinting technique. These component parts can be practiced in isolation in the form of specialised sprinting drills. A variety of running drills are used to help develop the optimal movement and coordination patterns of sprinting (Harrison 2010). While running drills are widely used in athletics and other sports to develop sprint technique, there is limited evidence to link the muscle activations of the drills with muscle activations in the sprint. The development of running speed presents a complex challenge which requires a coherent model for sprint running that describes performance, muscle actions and can be used to predict appropriate training exercises and ensure optimal specific conditioning. This research helps to refine this model by providing information on the kinematic and muscle activation specificity of drills which are commonly used in athletics.

9.2 Key findings

The aims of this research were to advance the understanding of the movement and muscle activation patterns of drills and their specificity to the movement and muscle
activations of sprinting. This research examined the use of drills for optimisation of sprint technique based on kinematics and muscle activation patterns. The studies from this research have provided useful information on coaches and athletes understanding of drills and their enhancement of technique. The experimental work has provided some valuable information on the movement and muscle activations of A-skip and heel flicks compared with sprinting. The key findings were:

1. There is a vast amount of research on the various stages of sprinting and the training mechanisms used to enhance sprinting performance including, strength, plyometrics, and speed endurance training. However, there appears to be very little research on the technique and the specificity of drills and sprinting. This is despite the fact that drills are extensively used by coaches. The majority of information used by coaches is largely based on anecdotal evidence and observations of what other coaches are doing rather than scientific evidence.

2. Both coaches and athletes believed that drills are important and that they should closely mimic the movement pattern of sprinting. A-skip and heel flicks were the two most popular drills selected by coaches, while athletes believed that A-skip and A-sprint were the two most popular drills. The most popular drills selected by coaches (A-skip and heel flicks) were further investigated in this research.

3. The methods of identification of thresholds >50% maximum muscle activation levels of the lower limb muscles can be used to assess the timings of the muscle activity. The muscle activity was normalised to a percentage of the cycle rather than just indicating simplistic on-off thresholds. This provided a more informative analysis of muscle activity during key phases of the cycle, for example, during the stance or swing phase. This step-by-step process of analysis is easy to use and is graphically easy to interpret.

4. Heel flicks more closely matched sprinting than previously anticipated. Information on the movement and coordination patterns of the knee during heel flicks and sprinting appeared to be very similar throughout the movement with an 8° RMSD between the knee angles of the two exercises. Examination of the hip angle during heel flicks indicated that hips remained relatively level throughout the whole cycle while the hip action in sprinting appeared to have
increases and decreases in ROM during the cycle. Based on kinematic data analysis, implementing both A-skip and heel flicks into a programme may be useful as they do replicate some important movement components of sprinting. The A-drill which may closely replicate the knee action during heel flicks and the hip action during the A-skip should be included. This could be in the form of a variation of the A-skip (Figure 6.9). Further research on the kinematics of performing this A-skip variation is recommended.

5. Information on the muscle activity of the lower limb of the group during drills provided inconsistent results. This was apparent in the large standard deviation values (Table 7.4-7.6) and range of effect sizes (Table 7.7). This may be due to muscle redundancy whereby individuals can activate muscles in different ways to perform the same movement. To attempt to eliminate this issue, further research should examine at EMG activity using single subject analysis.

There is limited research which has been conducted on sprinting drills. This research has only begun the biomechanical exploration of drills and provided some information on the movement and muscle activations of only a few of the more commonly used drills by coaches and athletes. More research on drills is necessary since these practices are widely used but the specificity to sprinting is not well understood. Future research should extend the examination of the joints actions during sprinting and drills by examining the kinetics of the joint actions. In particular, examination of the net joint torques could potentially provide more insight into the movements of the joints and the effect of muscle action during maximal sprinting and drills.

### 9.3 Future recommendations

The present thesis contributes to enhance the knowledge of the research on the use of drills for sprinting performance. While this thesis has addressed a series of research questions, it is clear that various limitations exist within this present work and therefore further investigation is recommended.

- Future work should consider other drills for example A-Sprint, A-March, B-Skip and straight leg bounds, and examine coordination and muscle activation
patterns. While this study has determined the coordination of muscle activation patterns of the A-skip and heel flicks, these two drills are only a small part of a large group of drills used by athletes and coaches. The best way to perform these drills to enhance sprint technique should also be further examined.

- The results of Chapter 6 are of particular interest and the results suggest that incorporating the movement of the knee during heels flicks and the movement of the hip during A-skips could mimic the movement pattern of sprinting. A variation drill which combines these two elements (see Figure 6.9) should be further investigated to determine if the movement and muscle activation patterns are similar to sprinting and if this variation drill is useful for sprint performance.

- Chapter 3 examined the most popular drills used by coaches and the rationale for why these drills were selected. This chapter concluded that the A-skip and heel flicks were the two most popular drills selected by coaches and that drills used were based on what other coaches were doing rather than a scientific rationale. Further study of how these drills are being coached to the athletes is recommended to enhance understanding of the process of how drills are coached and whether they are being coached to athletes effectively.

- Once the appropriate drills for sprint performance are determined, a drills intervention study would provide useful information for the correct drill practices necessary to enhance sprint performance. This intervention would firstly involve collecting pre-test information for each athlete, this could include sprinting coordination and muscle activation patterns along with joint torques and stride parameters such as stride length and stride frequency. Following the pre-test an invention would be implemented. This would involve the correct coaching of the appropriate drills with athletes over a six week period. The sessions would include coaching the drills correctly prior to a track training session along with one technical session dedicated solely to performing drills. Data would be collected post intervention to examine the effects of the correct coaching of appropriate drills for sprint performance and if the drills intervention had an effect on sprinting parameters.

- This research examined the coordination and muscle activation patterns of drills and compared this information with sprinting. Joint torque analysis was not in the scope of this thesis. When examining muscle activations patterns it is apparent from this thesis that how people activate muscles for a specific
movement can vary from individual to individual. A joint torque is the measurement of force about a fixed point for example the knee joint (James & Williams, 2014). Joint torque represents the effective outcome of muscular effort around the joints. It can be more representative of muscle effort/tendency as joint torques are not contaminated from errors that occur when examining muscle activations i.e. crosstalk. The use of joint torques could eliminate the issues of muscle redundancy and give a clearer picture of the joint actions during drills and sprinting. Examining joint torques could also provide a greater understanding of the movement of the knee during sprinting. As outlined in Chapter 6, when examining sprinting qualitative visual examination of sprinting reveals a noticeable flick of the heel towards the buttocks which would explain why the heel flicks are somewhat similar in movement pattern to sprinting. However, it has not been demonstrated whether this movement happens because the foot bounces upwards off the ground due to the ground reaction forces during impact, or is caused by the hamstring muscles activating to induce knee flexion.
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