The effect of starting velocity on maximal acceleration capacity in elite level youth football players.

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Abstract

Due to advancements in performance monitoring technology (GPS & Accelerometry), practitioners are able to measure accelerations and decelerations with a view to quantifying their impact on training load in team sports. In practice, the magnitude of these accelerations has typically been categorized into low, moderate and high threshold bands (similar to often-quoted speed and distance parameters).

Research suggests a value of greater than 2.78 $m.s^{-2}$ (Varley and Aughey, 2013) as a high acceleration threshold, based on data measuring maximal acceleration capacity from a standing start.

However, there has only been one study to our knowledge that directly examines the effect of starting speed on the capacity to maximally accelerate (Sonderegger et. al, 2016). Further, the research fails to examine accelerations, measured via GPS or Accelerometry in football specific context.

Therefore, the aim of this study is to quantify, via GPS and Accelerometry, the impact of different commencement

velocities on the maximum voluntary acceleration capacity of individuals during maximum efforts. A secondary aim of the study is to analyse more dynamic situations involving a stretch-shortening cycle by determining the impact of changing entry speed and deceleration on the acceleration capacity of individuals making maximum voluntary efforts.

Fifteen male football players from the Development Squad of a Scottish Premier League club took part in the study during the pre-season phase of the 2015/2016 season.

Subjects wore Catapult OptimEye X4 10-Hz GPS units with in-built tri-axial accelerometer, gyroscope and magnetometer sampling frequencies of 100-Hz

The players were asked to complete three different running tests that would require them to accelerate maximally from either a standing start position, from five increasing run-in speeds or after a period of deceleration.

The data collected for analysis was; peak acceleration at point of change of pace & peak deceleration at point of deceleration.

These were measured by both Doppler GPS method and from the Vector of the tri-axial accelerometer data.

The results showed that peak accelerations achieved during progressively increasing starting velocities were 2.34±0.35, 1.85±0.31, 1.5±0.26, 1.12±0.18 and 0.92±0.21 m.s^{-2} (Doppler derived values). Accelerations were reduced to 1.42±0.57, 0.83±0.51, 0.61±0.26, 0.47±0.37 and 0.33±0.32 m.s^{-2} (Doppler derived values) when the effort was preceded by a rapid deceleration after similar entry speeds.

The reduction in observed acceleration with increased running speed will be important in situations where the context changes player behaviour, such as in; pitch-dimensions, number of players and relative playing area. The consequences of this misinformation may be that players initiate an acceleration effort and pay metabolic cost but get further load applied because that effort was not recorded. This could potentially result in training overload.

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Abbreviations

AFL	Australian Football League
ATT	Attacker
C DEF	Central Defender
C MID	Central Midfielder
CMJ	Counter Movement Jump
FB DEF	Full-Back Defender
FJ	Free Jump
GK	Goalkeeper
GPS	Global Positioning System
HI	High Intensity
HIR	High Intensity Running
HSR	High Speed Running
MIR	Moderate Intensity Running
SD	Standard Deviation
SE	Standard Error
W MID	Wide Midfielder

1. Introduction

1.1 Overview of football:

Soccer is a high-intensity intermittent sport consisting of repeated periods of high speed running, sprints, tackles and jumps interspersed with periods of low activity (walking or jogging at low speed). Typically, a football match is played with 11 players versus 11 (10 outfield + 1 Goalkeeper on each team) on pitch dimensions that range from 45-90 m width and 90-120 m length (FIFA, Laws of the Game 2015/16). At both professional and amateur level, most teams are scheduled to play one game per week, however it is common in the modern era for many teams to compete in 2 games or even 3 matches in 7 days. The structure and management of the training programme around soccer match play has, as a result, become crucial to achieve peak performance in matches and competition. Therefore, in recent years there has been a large focus on how sport science can positively impact on structuring and evaluating the training programme, particularly at the elite level.

Understanding the physical characteristics that underpin football performance is of great importance. Consequently, performance monitoring has become an important part of the training process allowing practitioners to fully understand the physical impact of both training sessions and match play and thus helping to make a positive impact on the training programme in optimising efficiency and reducing the risk of injury.

1.2 Performance monitoring:

With the advent of performance monitoring techniques that allow us to monitor the physiological characteristics of training, sports scientists can instruct the coaches and athletes to train 'smarter' - to get a better understanding of the physical impact of training and of the balance between fitness gain and fatigue. Examining this training process is essential to understanding why we measure the 'training load'. By measuring the training load, we are looking for a dose-response relationship with the outcome parameter. The dose, or the training 'load', is the prescribed exercise, and the response, in the case of football or soccer, is the associated gain in fitness or fatigue or the risk in injury. By examining this dose-response relationship or ‘training load’ in this manner, we can improve our knowledge of how individuals respond to a particular training mode.

Impellizzeri et. al (Impellizzeri, Rampinini and Marcora, 2005) conceptualize this training process well in the following diagram (Figure 1), showing how internal, external and individual characteristics, all come together to form the overall training load.

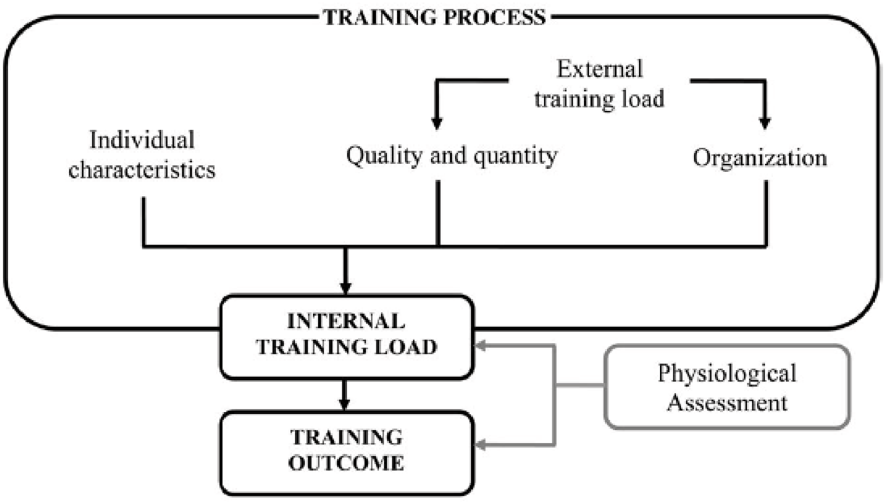

Figure 1. The Training Process (Impellizerri et al., 2005)

Measuring the training load is particularly difficult in sports like soccer, because different exercise prescriptions lead to different physiological and mechanical demands, and within that there are inter-individual responses to these demands (Bangsbo, Mohr and Krustrup, 2006).

The measurement of training load is often described as either internal or external. Understanding what physical factors impact the training load is crucial. Physical exertion can be dominated by metabolic stress, by exerting the different energy systems (e.g. aerobic or anaerobic). It can be dominated by biomechanical stress and be static and explosive in nature (e.g. jumps or power lifting moves), or it can be both combined metabolic and biomechanical stress, involving slow to moderate speed activity with repeated periods of high speed and power. Understanding how to monitor their relative contribution is of great importance.

Initially sports scientists looked to monitor the heart rate response to training (described as the *internal* response). Intensity of exercise has been measured objectively using HR (Heart Rate) due to its linear relationship with oxygen consumption (Bot and Hollander, 2000). Despite heart rate monitoring being able to provide valuable feedback on the physiological response to training stimulus and the impact of exercise on the cardiovascular system and aerobic capacity, there are limitations with using heart rate solely as a performance monitoring tool. Mainly, heart rate monitoring does not provide much information about the external load or pick up the muscular load required in short and sharp explosive movements such as jumping or accelerating over 0-5m. In addition, due to a lag in the heart rate response to periods of high speed bursts, heart rate monitoring fails to categorize the quantity of efforts made.

Therefore, to gain a more holistic picture of the true impact of training and match play in soccer, researchers and practitioners looked to assess the external loading. In more recent history, the use of automated camera systems has brought to the fore the use of distances and breakdowns of the velocities at which these distances are covered. This method has enabled the determination of positional differences (Di Salvo et al., 2007), levels of play (Mohr, Krustrup, and Bangsbo, 2003) and match-to-match variation (Gregson et al., 2010). Even more recently, the invention and subsequent use of GPS (Global Positioning Systems) technology has revolutionised the way we track, monitor and examine the external loading in sports and has since become an extremely important and widely used tool.

1.3 GPS:

Research and understanding of sports performance has advanced with the introduction of time motion analysis and GPS. Global positioning satellite-based systems typically utilize a network of 24 satellites in orbit around the Earth. Each satellite is equipped with an atomic clock that emits, at the speed of light, the exact time and the position of the satellite (Macleod et. al, 2009). The GPS receiver compares the time emitted by each satellite signal. The lag time, measured by the receiver, is translated into distance by trigonometry. By calculating the distance to at least four satellites, the exact position and altitude of the receiver on the Earth's surface can be determined (Townshend, Worringham, & Stewart, 2008). Townshend and colleagues (2008) have argued that an increase in the accuracy of the non-differential variant of the GPS technology is important because non-differential systems are lighter, smaller, cheaper, and require less complex data collection procedures, which means non-differential GPS technology could have useful applications in many sporting contexts.

The technology allows users to track the distance covered by the athlete and the distance in relative speed zones – be it, walking, jogging, running or sprinting.

Several companies have begun to market GPS technology for sports performance across many sports and recreational activities; cycling, jogging, swimming or use within team sport. The wearable technology market is now larger than ever with mobile phones, watches and even clothing garments containing GPS technology capable of tracking distances covered among other variables.

The leading companies on the market in measuring team sports are Catapult Sports (GPSports, Playertek) and Statsports. The validity and reliability of these units (5Hz & 10Hz) to measure distances covered has been well established (Coutts & Duffield, 2010) It appears that the units are relatively accurate for covering total distance and as the speeds increase the units can accurately measure this – however it has been shown that validity and reliability may drop as the speed of movement increases. The units are available at different sampling frequencies, typically from 5-Hz to 10-Hz.

As of July 2015, FIFA, the governing body of Soccer, approved the wearing of GPS units in competitive match play in soccer, so long as the respective domestic Leagues allowed. However, despite its success, GPS technology also has its limitations, particularly when extrapolating solely distance parameters to equate to player load. For example, covering a greater total distance doesn't always necessarily mean an overall greater training load. Using distance parameters such as high-speed distance or sprint distance, set by arbitrary or even individualised speed thresholds is convenient, but not ideal. Due to the structure of training sessions, in small sided games (SSG's) for example, it is important for coaches and practitioners to understand that the relative distance covered will alter dependent on the duration, size of the pitch and the number of players. If a pitch is small or the relative pitch area per player is small, the players simply don't have enough space to move into to get to the speeds required for the technology to register it as ‘high speed’ for example. It is also important to understand the conditions placed on the training and games that are being played. Small sided possession games will differ with the addition of goalkeepers and goals at each end as the game has a directional element. Observational data suggests that players will naturally sit zonal in their positions and will generally attack towards one end and defend another. This generally creates more linear based shuttle running scenarios and thus will have an impact on the distances covered and the relative starting speeds at which the players move from.

Across playing positions in general match-play, we will also see differences in the GPS outputs. Full-backs and wide players in soccer will generally be required to cover more high speed and sprint distance, central midfielders often cover the greatest total distance whereas central defenders and attackers generally cover less total distance. All-be-it this is dependent on systems, formations and the nature of the game played (Bradley et al. 2011). However, in possession-based games where players are tasked with keeping possession of the ball for their team within a designated pitch area & where there are few conditions set by the coaches about player position, players tend to move more freely around and therefore can achieve greater average speeds within games as they try to evade their marker and gain possession of the ball or move to receive a pass.

Therefore, the main criticisms of the velocity-based distance measures of training load via GPS are; 1. Movements that don't create vertical displacement are not accounted for and 2. Activity isn't considered high intensity until it breaches a certain speed threshold, despite accounting for accelerations that do not result in top speed are just as, if not more, energetically demanding (Gaudino et al., 2013; Osgnach et al., 2010).

This has led to the development of both accelerometery-derived load and metabolic-power calculations, both of which are available from the latest GPS technology suppliers within their software.

Thus, using GPS to provide simple time motion analysis is limited in providing a full understanding of the training load during an individual training session and match play. We recognise that a large contribution to the total player load will come from short, sharp, explosive movements that don’t get recorded from the distances covered. As a result, recognising the accelerations performed are of huge importance and monitoring such efforts is made possible by the addition of inertial sensor technology to the GPS units (e.g. tri-axial accelerometers, gyroscopes and magnetometers).

1.4 *Accelerations*

As our understanding of football training and the effect of different elements of the drills and their physical outputs increases, the associated research has begun to look more at biomechanical loading during sporting activity. Due to improvements in the technology measuring these movements (with accelerometers sampling at 100-Hz) researchers and sports scientists are beginning to understand these movements to a greater extent.

Current GPS units contain tri-axial accelerometers allowing them to measure a vector magnitude by calculating the total acceleration across three axes; x, y and z. To explain, when a unit is stationary they will measure 0G across the x and z plane but a gravitational force of -1G (or 9.8m.s^{-1}) in the y (vertical) axis due to the Earth's standard acceleration due to gravity. Unlike GPS receivers it is widely accepted that the greater frequency of an accelerometer is beneficial given that they are attempting to capture all movement and force going through the unit. There are currently 100 Hz tri-axial accelerometers integrated into the newest GPS units, measuring up to 16G on each axis.

In physics terms, acceleration is defined as the rate of change (or derivative with respect to time) of velocity. It is thus a vector quantity with dimension length/time^2. Acceleration is measured in meters per second^2 (m.s^{-2}). Thus, to accelerate an object is to change its velocity, which is accomplished by altering either its speed or its direction in relation to time. In this strict mathematical sense, acceleration can have positive and negative values (deceleration).

Accelerations in football are extremely common - with reports that players may change speed or direction around 1000 to 1500 times per game (Reilly, *Science and Soccer*, 2003). Since we know that these movements are common, and because we have established that the GPS technology and the training drills we prescribe don’t always allow high speeds to be recorded, the monitoring of accelerations and short explosive movements and change of pace has taken on greater importance. Indeed, when you consider match play in football – it is often a change of pace or acceleration that has preceded a match winning action – and, therefore, training and monitoring accelerations must be importantly considered.

Traditionally, an individual’s maximal acceleration capacity has been monitored during typical speed testing using light gates by asking the player to sprint 20 - 40m as fast as they can and examining the time taken to cover the first 5m. There is a well-established link between maximal acceleration capacity and players max speed (Little & Williams, 2005). However, not all maximal accelerations lead to maximal speed efforts in training and in games – due to the space limitations of the pitch dimensions or coming into contact with opposition players (Akenhead et al., 2014)

Now, with the introduction of accelerometer technology within the GPS units, we can examine the number and magnitude of acceleration efforts in training and in matches. As explained, the technology works by using a tri-axial accelerometer that measures the movement across 3 planes – x, y and z (or to the side, forward and up). We can use these values collectively to look at a vector quantity of acceleration or simply use the Doppler based acceleration value which uses the change in speed measured by GPS (i.e. comparing distances covered during the time dictated by sampling frequency).

In practice, the magnitude of these accelerations have typically been categorized into low, moderate and high (similarly to the often quoted speed and distance parameters). The establishment of these thresholds is interesting in that it appears much of the research has come from varying high intensity intermittent sports (e.g. in Hockey, Rugby League, AFL) (Aughey, 2011)

Research suggests a value of greater than 2.78 $m.s^{-2}$ (Varley and Aughey, 2013) as a high acceleration threshold (based on data measuring maximal acceleration capacity from a standing start and predicting a range of 80-90%). With Dwyer and Gabbett, (2012) suggesting that a sprint be defined as any movement that reaches or exceeds the sprint threshold velocity for at least 1 second and any movement with an acceleration that occurs within the highest 5% of accelerations found in the corresponding velocity range. However, it is unclear how often soccer players accelerate maximally from a standing start within match play or within training and so understanding how the measurement of acceleration is affected by non-standing starts should be of general interest (since it is the initiation of any effort that may be the important aspect for training load). If we truly want to understand training load, then we must take into consideration all movements and not just those set above an arbitrary acceleration or velocity threshold.

The initiation of any effort will be important for understanding training load and consequently it is not appropriate to just consider the distance covered. This assertion is logical if we consider, by way of example, the power lifting action in strength and conditioning environments. During a clean, or a snatch, while the movements are extremely powerful and fast and require significant effort, the athlete does not move across the surface of the lifting platform. The triple extension action involved in this exercise is a foundation to the acceleration effort and is why training these movements have become common practice for strength and conditioning coaches to include in programmes designed to improve acceleration and maximum speed. Therefore, if the action is transferrable to prescribe an appropriate training load but the athlete is not covering any distance then it is apparent that there is a limitation in any system that purely monitors movement displacement. It is the initiation of effort, independent of speed over the ground or the distance over the ground covered that will contribute to the overall training load.

Additionally, it is relevant to consider the stretch–shortening cycle in relation to monitoring acceleration capacity. The stretch–shortening cycle (SSC) of muscle function comes from the observation that body segments are periodically subjected to impact or stretch forces. Running, walking and hopping are typical examples in human locomotion of how external forces (e.g. gravity) lengthen the muscle. In this lengthening phase the muscle is acting eccentrically, then a concentric (shortening) action follows. The true definition of eccentric action indicates that the muscles must be active during stretch. This combination of eccentric and concentric actions forms a natural type of muscle function called the stretch–shortening cycle (SSC) (Komi, 2008). Its principles lie in Newtons third law that every action must produce an equal and opposite reaction. The principles of the stretch shortening cycle have led to the formation of plyometric training by strength and conditioning coaches. Plyometrics is often the term now applied to exercises that have their roots in Eastern Europe, where they were first known simply as “jump training”. The actual term plyometrics is based on Latin origins, *plyo* + *metrics*, interpreted to mean “measurable increases”.

For an exercise to be truly plyometric, it must be a movement preceded by an eccentric action. This results not only in stimulating the proprioceptors sensitive to rapid stretch, but also in loading the serial elastic components (the tendons & cross-bridges between the muscle fibres) with a tension force from which they can rebound (Chu, 1998).

The reason the stretch-shortening cycle is important in relation to monitoring training load is that it is likely to influence the individuals' acceleration capacity and therefore can be applied as an experimental intervention to assess the measurement of training load. From a static start (where the athlete is held at the start), there is no significant stretch shortening cycle action during a maximal acceleration, however, there could be improved acceleration capacity if a stretch shortening action is created before acceleration (i.e. rocking in the blocks or swaying from a standing start). These types of movements would be common within football with landing from jumps, decelerating maximally and re-accelerating again to change pace with maximal changes of direction. Thus, understanding their impact is important again if we aim to provide a more holistic approach to the training load concept.

1.5 *Research Proposal*

Firstly, and most importantly - in football it has been observed that players are rarely moving from a standing start (Akenhead et. al 2013) therefore, quantifying maximal accelerations based on thresholds defined from standing start maximal efforts could be flawed. Current GPS technology applies thresholds in their software for high accelerations based on literature obtained from testing maximal accelerations from a standing start position or from accelerations observed within match-play (Aughey, 2011; Dwyer & Gabbett, 2012) Research suggests a value of 2.78m.s^{-2} is appropriate (Varley & Aughey, 2013) across team sports, despite this value having been obtained from sports where the nature of the game is different in such that players more than often are at a standing start and accelerate maximally to try and break the opposition line. Therefore, in terms of examining player load and the impact of accelerations, we could be under-estimating the true ‘effort’ by players simply because the magnitude of acceleration that they complete isn’t reaching the set threshold (despite the initiation of the observed response being physically demanding for them).

Therefore, the aim of this study is to quantify the impact of different commencement velocities on the maximum voluntary acceleration capacity of individuals making maximum efforts. Furthermore, in more dynamic situations where a stretch-shortening cycle is introduced, the aim of the study is to determine the impact of changing entry speed and deceleration on the acceleration capacity of individuals making maximum voluntary efforts.

We hypothesise that initial running speed will have a detrimental effect on the capacity to maximally accelerate. However, the introduction of a sudden deceleration, could produce a stretch-shortening cycle action that may ‘boost’ the acceleration capacity and improve the change of pace effect.

2. Systematic Literature Review

2.1 Rationale

The use of GPS technology to monitor performance in team sports has evolved considerably over the past decade. With these advancements in performance monitoring technology, coaches, researchers, and sports scientists are now able to use in-built accelerometer data to support in quantifying training load with the aim of giving a more accurate description of the high intensity activities involved within soccer and other team sports.

Researchers believe that the ability to increase velocity or accelerate is decisive in critical activities such as being first to the ball, moving into space before an opponent and creating and stopping goal-scoring opportunities during team sports (Carling et. al 2008) (Reilly et. al 2000). To date, most of the research on the use of GPS technology within soccer has mainly focused on distance parameters such as the total distance or high intensity running (Bradley et. al, 2009 & 2011; Aughey, 2011), while acceleration data remains relatively unexplored.

While researchers may agree that the athletes starting velocity will influence the subsequent acceleration effort, as yet, there has been only one piece of research to our knowledge that considers precisely what effect that the initial velocity has on the athletes’ capacity to maximally accelerate (Sonderegger et.al, 2016).

The aim of this proposed research is therefore not only to further examine the effect of starting velocity on the ability to maximally accelerate in elite-level soccer players, but also to determine which method of determining and quantifying the magnitude of accelerations may be most reliable. Not only that, this research also aims to examine the effect on a player’s capacity to maximally accelerate after performing a movement more specific to the demands of football, such as a sudden deceleration.

The following literature review examines the available research into the use of GPS as a performance monitoring tool with regards to accelerations. It will go on to review the available research on quantifying training load when considering accelerations and their impact on fatigue, and look at how some studies have categorized accelerations into low, medium, and high intensity thresholds. It will also review the effect of altering different aspects of small-sided games, a commonly prescribed training activity, as this is important in understanding the range of velocities involved in soccer which could impact on the players starting speed.

2.2 Methods

The eligibility criteria for inclusion within the literature review was that the sport was a field-based intermittent, high intensity (HI) team sport (Soccer, AFL, Field Hockey, Rugby) including either male or female participants and both adult & youth teams with participants greater than age 16 years.

The search was conducted using the electronic databases available through PubMed, Web of Knowledge, MEDLINE and Google Scholar.

The search strategy involved the input of a number of key words into each of the databases.

The key words used for the search were as follows:

1. GPS AND (Team Sport) (Soccer) (Football) (AFL) (Rugby) (Field Hockey)

2. GPS AND Accelerations

3. Accelerations Team Sports

4. GPS AND Accelerometry

5. Accelerations AND Soccer

6. Accelerations AND Team Sports

7. Accelerations OR Velocity AND (Team Sports) (Soccer)

The selected appropriate studies were identified by title and abstract, mainly that they included the use of GPS and/or Accelerometery and examined movement demands within soccer or another field based sport. Review Studies were not included. Studies that were selected in the initial search were then read and analysed in full and inclusion within this literature review was based on whether they would give detail on how GPS has been used to determine training load within team sports and or how the use of Accelerometery data is now adding to the current base of research in attempting to better understand the movement demands of team sports and the concept of training load, particularly in soccer.

2.3 Study Summary

Profile of Subjects

Mainly, two sports were analysed during the review of the literature, a number of which focussed specifically on soccer and the other across AFL (Australian Rules Football). The majority of the subjects analysed within the literature were of elite status, with one or two studies using well-trained but sub-elite, semi-professional or youth players. Of all the studies analysed, all subjects were Male and all were all greater than 16 years old. This is consistent with the profile of subjects used within this study.

GPS devices

The majority of the research examined used GPS devices from the main suppliers; being either Catapult sports or GPSports. The frequency of GPS units most commonly cited were 10Hz units with some of the earlier research using 5Hz devices. One paper analysed used a Local Position Measurement (LPM) system. The accelerometers examined within the research were sampling at 100Hz. This is consistent with the GPS devices used within our study.

Validity & Reliability of GPS Devices

Aughey looked to compare both 5 Hz and 10 Hz GPS Units with regards to measuring accelerations. Aughey noted that 10-Hz GPS devices can at least accurately determine that an acceleration or deceleration has occurred (Aughey, 2011). This has implications for the analysis of team sports as researchers can determine the number of accelerations or decelerations undertaken by athletes during training or in match play. However, it was further noted that the accuracy of measuring these changes in velocity during the deceleration efforts was poor. This is worth noting regarding our own proposed research.

Acceleration Thresholds

A number of the studies reviewed categorized accelerations into low, medium and high intensity bands. The categorization of these can be seen in the table below (Table 1).

Author(s)	Categorization of Acceleration(s)
Goralczyk et al (2003)	~3m.s^{-2} maximal acceleration from static start
Farrow et al (2008)	>4m.s^{-2} as a maximal acceleration
Wisbey et al (2010)	>1.11m.s^{-2} as a moderate acceleration
Varley & Aughey (2013)	>2.78 m.s^{-2} as a maximal acceleration
Castellano & Casamichana (2013)	1.0-1.5, 1.5-2.0, 2.0-2.5, >2.5m.s^{-2} intensity categories
Barron et al (2014)	Zone 1 (0-2), Zone 2 (2-4), Zone 3 (4-5), Zone 4 (5-20) m.s^{-2}
Hodgson et al. (2014)	Low (1-2), Moderate (2-3), High (>3) m.s^{-2}

Table 1: Absolute acceleration thresholds from current literature

Controlling the Entry Speed

Two studies that were reviewed had previously used a protocol to control player running speed to a prescribed value.

In the study by Aughey (2011) the participants were asked to produce an acceleration effort from a range of starting velocities common within team sports (1.0 - 6.0 $m.s^{-1}$). Participants were given a radio device to hold throughout each trial which provided feedback through different audio cues. The subjects would hear a low sounding pitch if their starting speed was too low, a high pitch if they were running too fast and silence if they were running at the correct prescribed speed. The subjects would then hear an alternating pitch once they had maintained constant velocity at the prescribed speed for a minimum of 2 seconds at which they were informed to accelerate maximally for several seconds before then decelerating to a complete stop.

Sonderegger et.al (2016) used a paced runner who received short auditory signals through a headset which ensured that players met the targeted initial running speed before acceleration. Markers were placed on the pitch every 5m that indicated the target distance covered between two auditory signals. Players on each side of the paced runner adopted the target running speed. The players maintained this target running speed for 25±40 m and at an arbitrary time point, the paced runner blew a whistle, which signalled the players were to accelerate maximally from that point.

2.4 Main findings

To fully understand accelerations and their effect on soccer performance, it is important first that we understand their physical definition and how they interact with other key performance measures. Research by Little and Williams (2005) was one of the first to examine this area.

Little & Williams acknowledged that the capacity of soccer players to produce varied high-speed efforts had previously been established to impact on soccer performance (Luhtanen 1994). They defined Acceleration as the rate of change in velocity that allows a player to reach maximum velocity in a minimum amount of time. This research noted that although the average sprint distance in match-play is small, at around 17m (Bangsbo 1994), players often initiate sprints when already moving at moderate speeds (Young et. al 2001a; Young et. al 2001b). The purpose of Little and Williams study was to determine the extent to which max speed, acceleration and agility were distinct physical attributes in professional soccer players.

106 male professional soccer players from the English league teams took part in the Little & Williams study. GPS and inertial sensor technology was not available at the time of this

research, and so acceleration was calculated using a 10m test involving sprinting 10m as fast as possible from a stationary start position (same method as previously used by Wilson et al 1993). According to the results of this study, it appeared that acceleration, maximum speed, and agility were relatively independent attributes in professional soccer players.

At the time, no criterion test existed for acceleration, maximum speed and agility and it was suggested that further research is needed to address this issue if research concerning sprint performance was to progress in a coherent manner. The findings suggested that testing procedures for acceleration, maximum speed and agility should be utilised in sports science support with elite soccer players. They proposed that the specificity of acceleration, maximum speed and agility that they observed may be attributed to differences in the musculature recruited; in the requirements of strength to be developed at specific muscle lengths; in the requirements for strength to be developed in either shortening or lengthening contraction modes; or in the complex motor control and coordination of several muscle groups.

With the introduction of GPS technology, research on accelerations could progress. Perhaps one of the most important pieces of literature reviewed is that of Aughey in 2011, despite their research coming from Australian Football as opposed to Soccer.

The authors noted that commercially available GPS units, sampling at 5-Hz, which could enhance the ability to measure short duration, high intensity activities, were heavily used within Australian football. It should also be noted that Australian football differs from soccer in several aspects, not solely including the fact that unlimited substitutions are allowed during matches, however there are also many performance aspects that are similar to that in soccer.

The Aughey 2011 study used 5-Hz GPS devices to record player movement. Running performance was expressed per period of the match divided into low intensity activity (0.1-4.17 $m.s^{-1}$), high intensity running (4.17-10 $m.s^{-1}$) and maximal accelerations (2.78–10m.s-^{2}). It was found that maximal acceleration performance was reduced towards each rotation of the second half of matches. The study also found that both high intensity running and maximal accelerations are reduced later in games, indicative of significant fatigue in players.

The aim of the Aughey research was to quantify player work rate in Australian football with 5-Hz GPS devices and express player work rate per unit of game time played. 18 elite Australian footballers took part in the study and data was collected from the 18 players between 1 and 17 occasions from 29 individual matches. The player work rate measurements were calculated via Catapult GPS devices. The number of maximal (>2.78 $m.s^{-2}$) changes in velocity (i.e. accelerations) was calculated from GPS data using the manufactures 'Sprint' software. The quantification of acceleration thresholds here differs from the only other studies to use acceleration data from GPS. One study counted accelerations of greater than >1.11 $m.s^{-2}$ as moderate accelerations (Wisbey et al 2010) and another counted accelerations >4 $m.s^{-2}$ as maximal accelerations (Farrow et al 2008). The Aughey study however, noted that world class sprinters accelerate at a rate of approximately 6 $m.s^{-2}$ in the first second of a race and subsequent to that first second, acceleration occurs at a maximum rate of approximately 2 $m.s^{-2}$.

Furthermore, it was found that elite team sport athletes accelerated from a standing start at a maximal rate of approximately 3 $m.s^{-2}$ (Goralczyk et al 2003). In pilot testing by the same author, trained but sub-elite team sport athletes accelerated maximally at a rate between 2.5 and 2.7 $m.s^{-2}$ measured using via laser technology and timing gates. Finally, it was noted that these elite Australian Rules football players only tended to accelerate maximally in matches from a moving start, an observation by (Aughey et al 2008). It is therefore suggested by Aughey, that 4 $m.s^{-2}$ is too high a threshold for elite team sport athletes, backed up by (Goralczyk et al 2003) and (Arsac & Locatelli 2002) and so a rate of between 2.7 $m.s^{-2}$ and 3 $m.s^{-2}$ is appropriate. Based on this and the observation of >1000 GPS files from elite Australian rules football matches and training sessions, it would appear that 2.78 $m.s^{-2}$ is an appropriate threshold for maximum acceleration in elite Australian football players.

The Aughey study stated that for the first time, they have characterized the number of maximal accelerations players undertake during matches and reported a decline in this ability in the latter stages of a match. It is perhaps not surprising that this ability is impaired as to accelerate is extremely physically demanding especially from low commencement velocities and therefore it is likely to induce significant fatigue. Furthermore, the researchers also agreed that accelerations are associated with key elements of the game, including the ability to accelerate towards or away from a tackle or move into space to receive the ball. Notwithstanding that the measurement of accelerations using GPS technology is potentially less reliable, than the measure of say, total or high intensity running distance (Jennings et al 2010), this may reflect an important indicator of fatigue. They proposed that further work was therefore needed to determine the reliability and validity of GPS for measuring these accelerations.

Unsurprisingly then, this proposed research was carried out. It is critical to establish the reliability of using GPS devices for measuring accelerations for my proposed research to be valid. Therefore, the research by Varley and Aughey in 2013 is an important piece of literature that gives credit to this.

The researchers agreed that the ability to increase velocity or accelerate (Little and Williams definition, 2005) is decisive in critical activities such as being first to the ball, moving into space before an opponent and creating and stopping goal-scoring opportunities during team sports – also agreed by (Carling et al 2008) & (Reilly et al 2000). In addition, they believed that to accelerate is more energetically demanding than constant velocity movement (an observation by research from Osgnach et al 2010) but to date no method has been satisfactorily validated for the measurement of these accelerations in team sports. They acknowledged that quantification of the acceleration and deceleration demands of team sports would add great value to the existing body of knowledge if a satisfactory measurement tool was available. Little was then known about the ability of GPS to measure these qualities but the use of GPS technology to quantify the physical demands (in terms of distances etc.) of team sports athletes was commonplace during training and match play (all backed up by research from Aughey 2011, Brewer et al 2010, Coutts et al 2010, Duffield et al 2009, Farrow et al 2008, Wisbey et al 2010).

The aim of this piece of research (Aughey, 2011) therefore was to determine the validity and reliability of 5- and 10-Hz GPS devices for measuring instantaneous velocity during the acceleration, deceleration and constant velocity phases of straight line running.

In this study (Aughey 2011), 3 sub-elite team sport athletes were used. As the primary measure of this study was the raw GPS data, the number of participants did not reflect the sample size as it is the number of samples collected and trials undertaken that were of most importance. An important point to note from the Aughey, 2011 study was the experimental protocol and their methods in controlling the speed of running. The participants were asked to perform straight line running along a marked white line. Each trial required the participant to establish and maintain a constant running velocity before performing an acceleration effort and finally decelerating to a complete stop. In total, 80 straight line running trials were undertaken. The subjects wore either two 5-Hz or two 10-Hz GPS Catapult devices on their back, in the standard position between the scapulae. The participants were asked to produce an acceleration effort from a range of starting velocities common within team sports (1.0 - 6.0 $m.s^{-1}$), an important point to note for the design of my own proposed research. Participants were provided with instant feedback on their velocity during each of the trials. A computer was connected to a laser and using custom software, instantaneous velocity data was obtained during each run. The participants were also given a radio device to hold throughout each trial which provided feedback through different audio cues. The subjects would hear a low sounding pitch if their starting speed was too low, a high pitch if they were running too fast and silence if they were running at the correct prescribed speed. The subjects would then hear an alternating pitch once they had maintained constant velocity at the prescribed speed for a minimum of 2 seconds at which they were informed to accelerate maximally for several seconds before then decelerating to a complete stop.

It was noted that higher starting velocities improved the measurement accuracy for detecting accelerations with both the 5- and the 10-Hz devices. – perhaps due to lower acceleration rates. This study was the first to determine the validity and reliability of 5- and 10-Hz GPS units for measuring instantaneous changes in velocity. It was also noted that participants reached a maximum speed of ~7.5 $m.s^{-1}$. Incidentally, similar top speeds have been reported in team sports athletes including elite soccer players (~7.6 $m.s^{-1}$) (Bradley at al 2009) and also in Australian Footballers (~8.6 $m.s^{-1}$) (Young et al 2001a).

Aughey noted that 10-Hz GPS devices can at least accurately determine that an acceleration or deceleration has occurred. This has implications for the analysis of team sports as researchers can determine the number of accelerations or decelerations undertaken by athletes during training or in match play. However, it was further noted that the accuracy of measuring these changes in velocity during the deceleration efforts was poor. This is worth noting regarding our own proposed research.

GPS accuracy was negatively affected by a high rate of change in velocity when decelerating. Although an increased sampling rate, i.e. the 10-Hz devices, improved this accuracy, researchers may simply be limited to reporting the occurrence of decelerations as opposed to attempting to quantify their magnitude in terms of distance and duration.

The Aughey (2011) study was limited too in its specificity to team sport movement demands as athletes often change direction, whereas only linear running was recorded. Therefore, importantly, it was suggested that future research should investigate the validity and reliability of GPS technology for measuring changes in velocity during non-linear movements and changes of direction.

And so, with the establishment of reliable and valid acceleration measurements from GPS technology, research moved forward and sports scientists and researchers began trying to measure these accelerations and examine what effect they had or what impact they had on performance.

In terms of gaining an understanding of different training modes, and being able to understand what effect that they might have on the physical demands and acceleration profile on soccer players, it is important to examine the research on small-sided games. Small-sided games are a commonly used training tool within soccer training and in terms of my proposed research, I was interested to examine whether altering different aspects of small-sided games would influence the speed at which the players move, thus potentially altering their starting velocity and perhaps then their acceleration capacity.

Therefore, the paper by Castellano & Casamichana in 2013 was one of the first to do this in terms of training and match data in soccer.

The aim of this study (Castellano & Casamichana, 2013) was to compare small-sided games and friendly matches with respect to the number of accelerations in different intensity ranges. The study used 27 semi-professional soccer players from the Spanish third division. The data collected from friendly matches was gathered from seven separate 11-a-side games whereas the small-sided game data was gathered over a 5-week period from 9 different training sessions and the formats varied from 3v3, 5v5 and 7v7. The relative pitch area per player was kept constant at 210m^2 and the width to length ratio was also maintained constant throughout. Each small-sided game lasted 4 minutes, with 3 repetitions and 2 minutes recovery (3x4mins:2mins). The study used 10 Hz Catapult GPS devices and specifically the accelerometer data. This study monitored each of the accelerations recorded within different intensity ranges. These ranges were as follows; 1.0-1.5 $m.s^{-2}$, 1.5-2.0 $m.s^{-2}$, 2.0-2.5 $m.s^{-2}$ and >2.5 $m.s^{-2}$.

The categories therefore were not established per the maximal accelerations achieved by the players used within the study. Instead, the researchers referred to the study by Aughey in 2011 that found that semi-pro team sport athletes achieve maximal acceleration values above 2.5 $m.s^{-2}$. The numbers of accelerations were normalised and made relative to per hour of activity. The Castellano study found that there were significant differences between small-sided games and friendly matches in all but one of the acceleration intensity ranges, with the exception being the highest category (>2.5 $m.s^{-2}$). This research was the first study in the soccer context to compare small-sided games and friendly matches with respect to the number of accelerations. The results showed that the number of accelerations was higher during small-sided games used as part of the training regime than it was in full size, 11v11 friendly matches. The researchers suggested this could be due to a greater neuromuscular fatigue and increased metabolic cost during the matches, therefore limiting the amount of accelerations due to fatigue (but the authors did not recognise the increased player contacts that would arise from smaller pitch game play as an important factor here).

However, what the Castellano study did highlight is that, when monitoring player performance, it is important to consider accelerations. Within small-sided games as part of training, accelerations occur very frequently whereas high intensity and sprint distance could remain low (this is most likely due to the small pitch dimensions and lack of space to run in to in order to reach higher speeds). Therefore, the failure to quantify accelerations correctly could lead us to underestimate the amount of high intensity activity engaged in by players, a statement agreed with by the research from Varley & Aughey in 2013.

Hodgson et al (2014) aimed to quantify the time-motion characteristics and technical demands of small-sided games played on small, medium and large pitch sizes using the Catapult GPS system that allowed assessment of acceleration and deceleration patterns. The study used 8 male soccer players who each played 4x4 minute with 3 minutes recovery on a small (20x30 m), medium (40x30 m) and large (50x40 m) pitch size. For this study, accelerations were organized or categorized as low (1-2 $m.s^{-2}$), medium (2-3 $m.s^{-2}$) and high (>3 $m.s^{-2}$). The researcher was interested at looking at the distance covered within these acceleration zones. i.e. the distance spent accelerating at low, medium or high intensity. The results from this study showed that the total distance covered in the different acceleration zones ranged from 230±111 to 356±72m.

The Hodgson et. al (2014) study provides more data demonstrating the acceleration patterns observed in small sided games and showing that they are relatively greater than those observed during professional match play on larger pitch sizes. With that in mind, the researchers suggested that small-sided games might offer a density type conditioning stimulus with regards to accelerations and decelerations.

Akenhead et al (2014) stated that recent advances in technology have increased the location sampling rate of GPS allowing a greater level of precision and increased ability to account for discrete movement over short distances (backed up by the paper by Varley et al 2012). These advances allow for a more precise study of the high intensity activities that are thought to better characterise soccer specific fitness. (Mohr, Krustrup and Bangsbo, 2003). Additionally, this higher frequency technology allows the acceleration demands to be more accurately quantified (Varley et. al 2012). This research also agreed that there is a greater energy cost and muscular demand with acceleration movements and that previous time-motion analysis research may have underestimated the physical demands of soccer (Osgnach et al 2010, Varley & Aughey 2013).

Within this study (Akenhead et al 2014), the pitch sizes gave a relative pitch area per player of 60, 120 and 200 m^2 respectively. The participants wore 10 Hz Catapult GPS units which allowed the assessment of distance covered accelerating and decelerating in addition to the typical time motion analysis variables (i.e. total distance, high speed distance, sprint distance). Acceleration was calculated as the change in instantaneous velocity over time. The distance covered during low, moderate and high accelerations was recorded along with the total (≥ 1 $m.s^{-2}$) acceleration and deceleration distance covered. The Akenhead et al. (2014) study was novel as at that time, no published data existed on the variability in distance covered in acceleration and deceleration categories within small-sided games. The results showed that the total distance covered in acceleration ranges were both higher on a medium and large sized pitch when compared to the small size pitch. It is well established within the research that altering the pitch size affects both the physical and technical demands of small sided games. This study therefore provides support for the use of small-sided games as a mode of training particularly with focus on accelerations. Osgnach (Osgnach et al, 2010) emphasised the importance of monitoring accelerations in soccer due to the metabolic and neuromuscular demands being high, even when the average speed is low. Data from 11v11 games show that the average acceleration distance is approximately 9.7 m every minute of a 90-minute match. However, as the acceleration demands from the medium sized pitch in this study was a higher value than this, it was suggested that the small-sided games may offer a density type condition stimulus with regards to accelerations.

With the smaller pitch size (20x30m), it was suggested that this reduced the active playing area and required the players to make faster decisions and execute skills with higher frequency – as shown by the technical analysis within this study. However, the potential for players to frequently accelerate and/or attain a high running speed is compromised and this could be why we see less efforts overall, particularly at the higher ranges. However, it could also be due to the initial starting velocities influencing the capacity to accelerate. This was acknowledged by the researchers as they stated that there remains a degree of error. The study was unable to distinguish between acceleration movements commencing from different speeds, suggesting that they have different mechanical and physiological consequences. For example, an acceleration of 2 $m.s^{-2}$ resulting in a change of velocity from 0 $m.s^{-1}$ to 2 $m.s^{-1}$ will pose a different physical demand than an acceleration resulting in a change of speed from 2 to 4 $m.s^{-1}$. Whilst they were not able to accurately characterise the incidence of different starting speeds, by reporting the distance covered in the acceleration ranges as opposed to the time spent, it is suggested that they have been able to proportionally discriminate between acceleration movements at high and low speeds.

The importance of acceleration movements in football is an area that warrants further research. The ability to repeat acceleration efforts is an important ability to train, particularly if these are the movements that may impact fatigue in football.

Furthermore, researchers and sports scientists are using the accelerometer derived data to try and better establish player loading and training load. One of the first papers to establish this was from Barron et al in 2014. This study aimed to investigate the acceleration, deceleration, and tri-axial player load during competitive youth football. External loads are the variables manipulated to induce internal stress and include the number, duration and velocity of activities and acceleration or deceleration movements (Lovell & Abt, 2013). They also acknowledged that recently, at the elite level, highly portable global positioning systems (i.e. the GPS devices) have been adopted to monitor training activities. Also, they supported the statement that successful performance is not simply related to high speed movement but to the ability to accelerate, defined as the rate of change in velocity (Little & Williams, 2005) and that accelerations are energetically demanding tasks (Osgnach 2010) again linked to game changing movements (e.g. beating an opponent to the ball, intercepting a pass or creating a scoring opportunity). They quoted that “The integration of accelerometers and GPS has enabled measurement of these movements with the total mechanical stress experienced by the player, recorded during quick changes in direction, jumping and collisions" (Barret et. al, 2014).

The summation of acceleration/deceleration movements in each anatomical plane provides an estimate of the total body load (x –sideways, y – forwards, z – vertical). They claimed that research into soccer is limited, but in Australian football; it was found that 8 times as many accelerations were performed when compared to maximum sprint efforts (Varley and Aughey, 2013). Again, interestingly, maximum accelerations do not always precede a maximum velocity movement and failure to describe this activity or these movements would underestimate external load (Osgnach et al 2010, Akenhead et al 2013). What was novel was that it also appears that these high acceleration movements are dependent on playing position; where studies show that central defenders completed fewer maximal acceleration efforts when compared to wide defenders. The Barron research used 38 well trained sub-elite youth soccer players who each competed in 8 home English college fixtures and wore 10Hz Catapult GPS units with accelerometer sampling at 100Hz. The acceleration categories for this study were categorized according to the manufactures 'Sprint' software default settings and were as follows. Zone 1 (0 to 2), zone 2 (2 to 4), zone 3 (4 to 5), zone 4 (5 to 20 $m.s^{-2}$) . This study profiled the positional acceleration and deceleration characteristics and 'Player Load' during competitive youth soccer for the first time. Previous observations about acceleration profiles within the research are, as we have seen, mixed. Variation in playing formation produces different activity profiles and logically different acceleration/deceleration profiles (Bradley et al 2009).

It was found that between halves, there were no reductions in the highest rates of acceleration or decelerations. Similar findings were reported by Akenhead et al (2013) and Wehbe et al (2014) and could suggest the idea of a pacing strategy. Agreeing that accelerating is more energetically demanding than constant velocity movement (Osgnach et al 2010) - reducing low and moderate acceleration efforts may preserve the capacity to perform high level changes in velocity.

In profiling the external characteristics of competitive youth football and for the first time by identifying differences in maximal acceleration and deceleration activity and tri-axial player load, this study (Barron et al, 2014) produced data that could be combined with video analysis to improve the interpretation and usefulness of findings.

Sonderegger noted that the fact that acceleration decreases with increasing initial running speed is ignored and therefore introduces a bias. Therefore, percentage acceleration was calculated as the ratio of the maximal acceleration of the action and the maximal voluntary acceleration that can be achieved for a particular initial running speed in an aim to remove this bias (Sonderegger et. al, 2016).

In the Sonderegger study, seventy-two highly trained junior male soccer players (17.1 ± 0.6 years) completed maximal sprints from standing and three different constant initial running speeds defined as; (trotting: ~6.0 $km.h^{-1}$; jogging: ~10.8 $km.h^{-1}$; running: ~15.0 $km.h^{-1}$).

The results from that study showed that the maximal acceleration was 6.01 ± 0.55 $m.s^{-2}$ from a standing start, 4.33 ± 0.40$m.s^{-2}$ from trotting, 3.20 ± 0.49 $m.s^{-2}$ from jogging and 2.29 ± 0.34 $m.s^{-2}$ from running. Importantly, the maximal acceleration correlated significantly with the initial running velocity (r = ±0.98).

Sonderegger proposed to classify high-intensity actions as accelerations >75% of the maximal acceleration, corresponding to acceleration values of >4.51 $m.s^{-2}$ initiated from standing, >3.25 $m.s^{-2}$ from trotting, >2.40 $m.s^{-2}$ from jogging, and >1.72 $m.s^{-2}$ from running.

The main findings from the Sonderegger study were that the use of percentage acceleration avoids the bias of underestimating actions with high and overestimating actions with low initial running speed. Furthermore, percentage acceleration allows determining individual intensity thresholds that are specific for one population or one single player.

However, limitations of the Sonderegger study were that it wasn't carried out using current GPS and Accelerometry units from the main suppliers. Furthermore, it also failed to highlight what impact more dynamic or football specific movements, such as a deceleration may have on the consequent acceleration.

In conclusion, this literature review has examined the use of GPS technology within team sports and demonstrated that accelerations are a vital performance aspect to measure when assessing overall training and match loading on a player. The literature agrees that there is still more to explore within this area of research. The research conducted here will add to the current research available as it further highlights the effect of starting velocity on the capacity to measure maximum acceleration using current GPS and Accelerometry technology and additionally, will distinguish between different methods of measuring these accelerations. Furthermore, it will examine to what extent a sudden deceleration may impact acceleration capacity – an area yet to be explored within the literature. The data generated and its analysis will help researchers and sport scientists better understand the limits on applying discrete acceleration thresholds and promote individualisation of GPS parameter thresholds that will improve our overall understanding and quantification of the training load concept.

3. Methods

3.1. Participants

Fifteen male football players from the Development Squad of an elite Scottish Premier League club took part in the study during the pre-season phase of the 2015/2016 season in Scotland. The players covered a range of playing positions (GK, FB Def, W Mid, C Mid, Att). The subjects had a mean age of 17.4±0.6 years, with a mean height of 176±8 cm and weight of 72±6 kg. Their physical profile along with sports science testing history in standard speed and power tests can be seen in Table 2.

Testing took place between July and August 2015 at the clubs training ground. In total, each subject completed a minimum of 22 trials giving a total of 330 GPS data traces available for analysis. Any efforts in which the participants did not meet the required test protocol were ruled out and participants were asked to complete the test again once fully recovered. Weather conditions were consistent throughout the trials (dry, no wind), with testing taking place outdoors on a 4G artificial surface. All players wore their regular football boots which were best suited to the surface. Players were all familiar with the surface having trained and played on it frequently.

Speed			Power		Yo-Yo IR2
0-5m	0-10m	0-20m	Counter-Movement Jump (CMJ)	Free Jump (FJ)	
Time (s)			Height (in)		(m)
1.03±0.03	1.8±0.06	3.01±0.08	21.1±1.61	25.3±1.96	980±130

Table 2: Physical Profile of subjects including sports science testing history (+/- Standard Deviation (SD)) across Speed, Jumps and Yo-Yo IR2 (Repeatability).

Ethical approval was granted for this study by the College of Medical, Veterinary & Life Sciences Research Ethics Committee at the University of Glasgow. All participants were given a briefing by the researcher and an information sheet before providing written consent for their data to be included in the study.

3.2. GPS Units

Catapult OptimEye X4 10-Hz GPS units (Catapult Innovations, Australia) were worn in vests designed by Catapult Sports with a padded pouch for the unit located in the back. When placed in the vest, the unit sits in the upper thoracic region of the spine between the scapulae – See Figure 2.

Figure 2. Example Position of GPS Unit wore in vest across participants back.

The GPS units, measuring (96mm x 52mm x 14mm, & weighing 67 g) have tri-axial accelerometer, gyroscope and magnetometer sampling frequencies of 100-Hz. Participants were all familiar with wearing the GPS units as they are worn regularly during training. Each unit was assigned to a player for the duration of the season and so for each trial, players wore the same unit.

3.3. Test Protocol

The players were asked to complete 3 different running tests that would require them to accelerate maximally from either a standing start position, from a controlled run-in speed or after a period of deceleration.

The first test required the players to complete a maximal acceleration effort over 20m from a standing start. Players assumed a static start position with two foot points of contact and were instructed to run whenever they felt ready – *there was no reactions cue or stimulus to "go!" for the participant.* See Figure 3.

The second test required the players to complete a maximal acceleration effort from a range of different run in speeds. The selected speeds were 3, 4, 5, 6, & 7 $m.s^{-1}$ respectively. These speeds were selected to match the different speeds players would often achieve in training and in match play as indicated from the previous literature (Bradley et al. 2009).

The selected speeds in km.hr^{-1} translated as – 10.8, 14.4, 18, 21.6 & 25.2 km.hr^{-1}. Our own speed thresholds currently set on the system for monitoring training for velocity bands were <14 km.hr^{-1} – running, 14-21 km.hr^{-1} – fast running, 21-24 km.hr^{-1} – high intensity running, >24 km.hr^{-1} – sprinting.

Finally, the third test required the players to complete a maximal acceleration in a 'Hollow' type sprint test. Typically, 'Hollow sprints' involve the performance of two sprints interrupted by a short 'hollow' period of recovery that might include walking or jogging. However, in our experimental design we instructed the participant to decelerate within a 2m zone, after a controlled run-in speed of between 3 and 7 m.s^{-1} as before, and on exiting the deceleration zone they were instructed to maximally re-accelerate again.

In total, each player completed a minimum of 22 maximal efforts over the course of the tests. The players completed these tests on different days and in a randomly selected order in an aim to reduce the impact of a learning or training effect. For each testing trial, a consistent and standardized warm up protocol led by the researcher was used which consisted of 15 minutes of dynamic movements, stretching and finishing with 3 sub-maximal 20m linear efforts. The GPS units were switched on before the warm up to allow time for the GPS signal to be picked up before the start of testing. The distances for each trial were measured using a steel tape.

For trial 1 the subjects were asked to perform the maximal 20 m sprint from a standing start. The players stood behind the scheduled start marker and were instructed to run in a forward direction for 20 m as fast as they could. Each player performed a minimum of 2 maximal efforts and each was recorded for subsequent data analysis. See Figure 3.

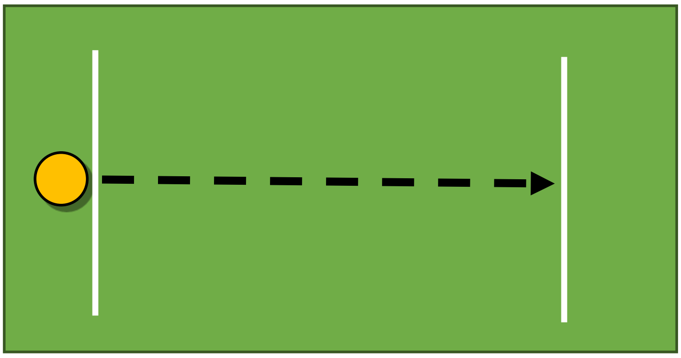

Figure 3: 20m maximal acceleration from a standing start. The circle illustrates the starting position and the distance between the white lines is 20 m.

For trial 2, we wanted to simulate non-standing start conditions and run-in speeds of 3, 4, 5, 6 & 7 $m.s^{-1}$. To do so, marker cones were placed at intervals of 3 m, 4 m, 5 m, 6 m, & 7 m respectively and each player was instructed that they had 1s to travel between each marker cone, before reaching the final marker cone signalled by a different colour where they were instructed to accelerate maximally from that point to 20 m. See Figures 4a & 4b. The players were given the 1 second time intervals by the researcher calling out elapsed seconds from a stop-watch (*i.e*. “1, 2, 3, 4” *etc.*). The players speed, acceleration, and distance covered were recorded on the GPS devices and subsequently analysed. Each player performed 2 efforts at each of the controlled speed run in. The players were given sufficient recovery times between efforts (2mins).

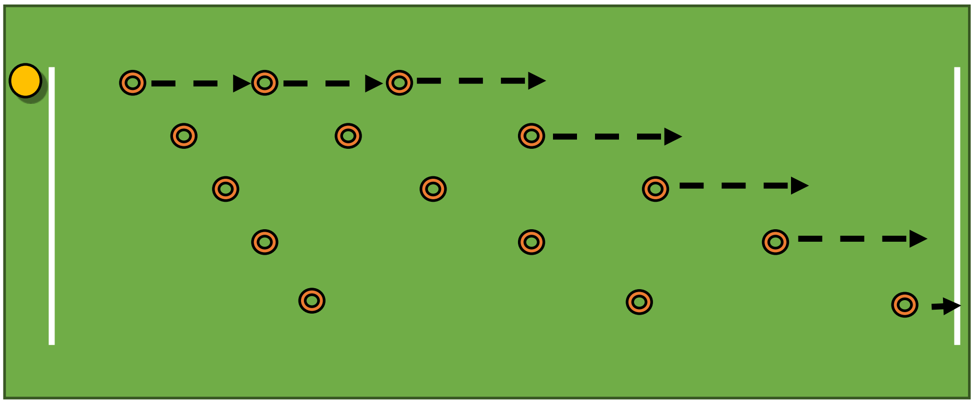

Figure 4b: Controlled speed entry protocol. The full circle illustrates the starting position with the entry speed controlled by passing the open cones at 1 s intervals. The total distance covered was dependent upon the point of initiating the 20 m sprint.

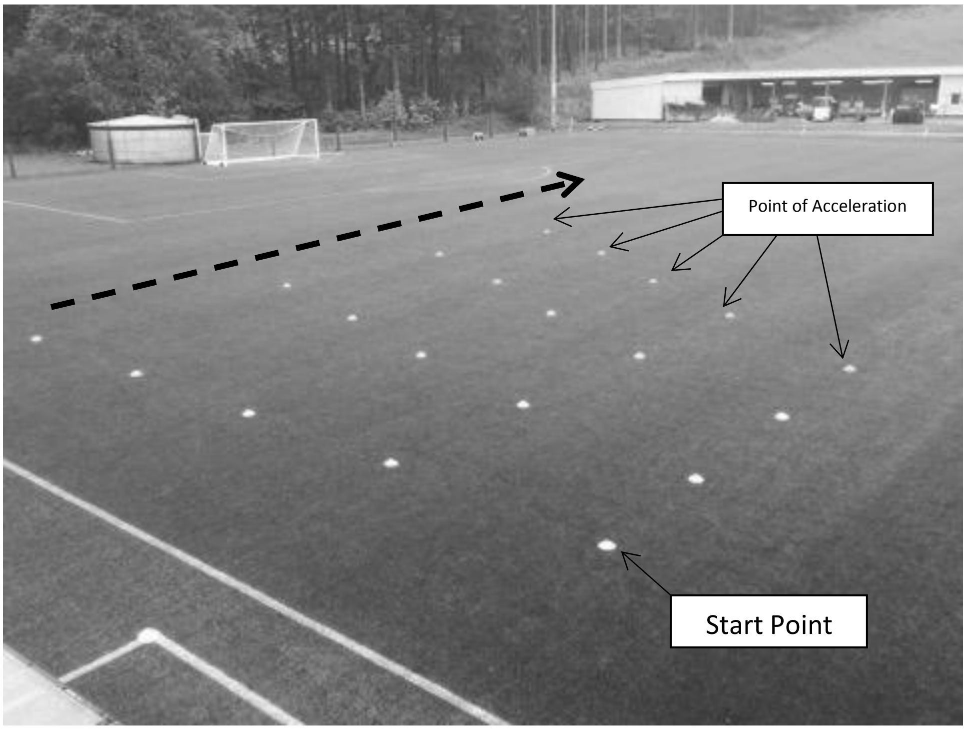

Figure 4a: Controlled speed entry set-up.

For trial 3, the players were asked to repeat the same controlled speed conditions as in trial 2, but this time a 2m deceleration zone was introduced at the end of the controlled speed run-in. The players were again instructed to travel through each marker cone at 1s intervals before decelerating within the 2m zone and maximally re-accelerating on exiting the zone. (See Figure 5a. & 5b.) The players speed, acceleration, deceleration and distance covered were recorded on the GPS devices and subsequently analysed. Each player performed 2 efforts at each speed zone 3-7 $m.s^{-1}$. Again, the players were given sufficient recovery times between efforts (2mins).

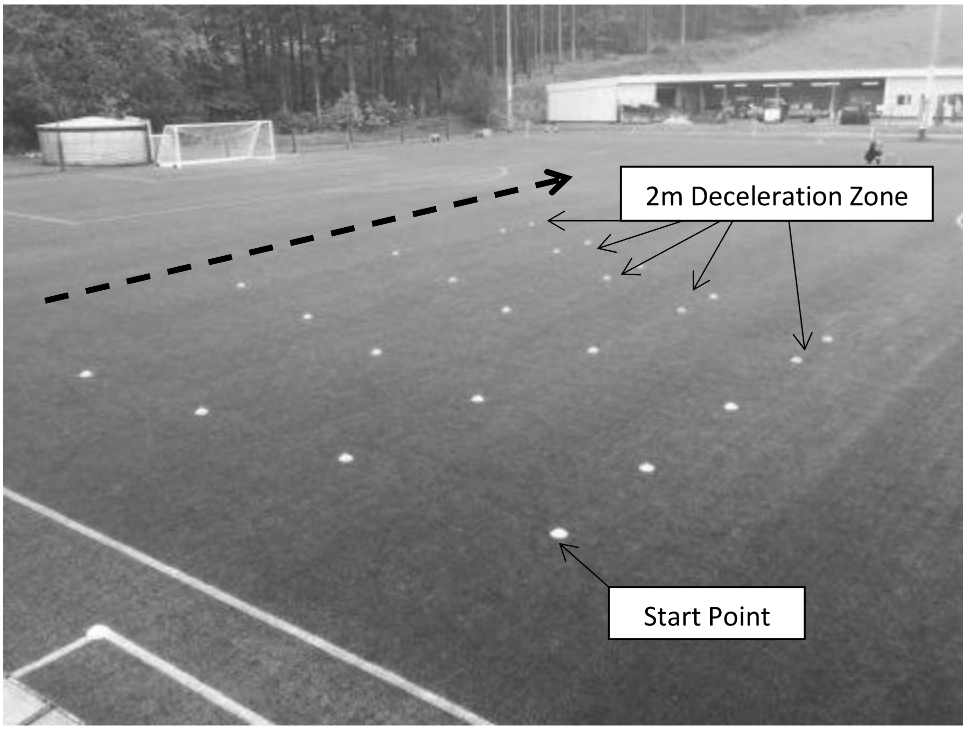

Figure 5a: 'Hollow Sprint' Test set-up.

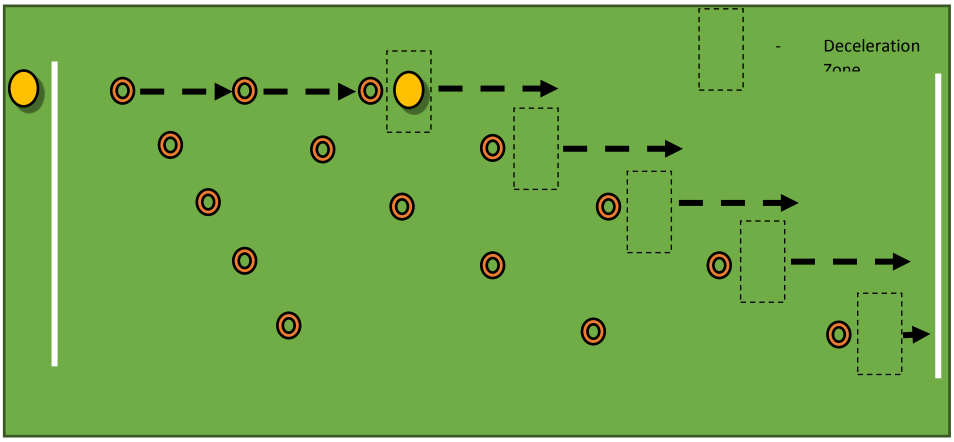

Figure 5b: Controlled speed running as indicated in trial 2, with a rapid deceleration indicated by the black dotted box and a re-acceleration indicated from the full circle within the deceleration zone.

3.4. GPS Variables

The data collected for analysis was; distance covered, speed at run-in, start speed and final speed.

Peak acceleration at point of change of pace & Peak deceleration at point of deceleration was measured by both Doppler GPS and from the Vector of the tri-axial accelerometer data.

3.5. Data Analysis

After testing, the raw data was downloaded from the GPS units using the suppliers mass USB device in the charging box, to the proprietary software (Catapult Sprint 5.1). The Raw Data CSV. File Microsoft Excel 2010 (Microsoft, California, USA) reports for each run were exported and the analysis of each trace was completed within the Sprint software. Analysis of the trace was completed by locating the static start point (0 $m.s^{-1}$) for each trace and the point at which the velocity went above this was assumed to be the commencement of movement. For trial 1 (static start acceleration) – peak acceleration over 0-1 m, 0-2 m, 0-5 m and 0-10 m was analysed as well as the time-based range 0-0.1 s, 0-0.2 s, 0-0.5 s, 0-1.0 s, 0-1.5 s and 0-5 s. For trial 2 (controlled speed run-in), the velocity and acceleration at set distances was analysed, equivalent to the marker cone intervals for 3-7 $m.s^{-1}$ (*i.e.* at 9 m for 3 $m.s^{-1}$ and at 21 m for 7 $m.s^{-1}$ and measured peak acceleration and change of pace after this point (at the points that the players were instructed to act in the protocol). The same approach was used for trial 3 (The hollow sprint test), taking into consideration the 2 m deceleration zone to analyse the magnitude of deceleration and provide a subsequent point for re-acceleration.

All data is presented as mean ± standard deviation (SD) or standard error (SE) as indicated and effect sizes are stated where appropriate.

Statistical analyses were conducted in “SPSS Version 22.0 for Windows (SPSS Inc, Chicago, IL, USA). One-way ANOVA and Tukey confidence interval tests were performed and one sample t-tests and Mann-Whitney tests were used for post hoc analysis. Effect sizes were calculated using Cohen’s *d* test [ES=(Δ mean)/pooled SD] (Cohen, 1988) and magnitude of effect was stated using the ranges reported by Batterham and Hopkins (2006) and Hopkins (2009).

4. Results

Figures 6 and 7 show data obtained for peak acceleration from a standing start position in each of the subjects, achieved after the first 5m and first 1.5s, respectively. Peak acceleration recorded by Doppler method and vector method for each effort was compared. Each subject (n=15) completed 2 maximal voluntary efforts & both were presented for analyses.

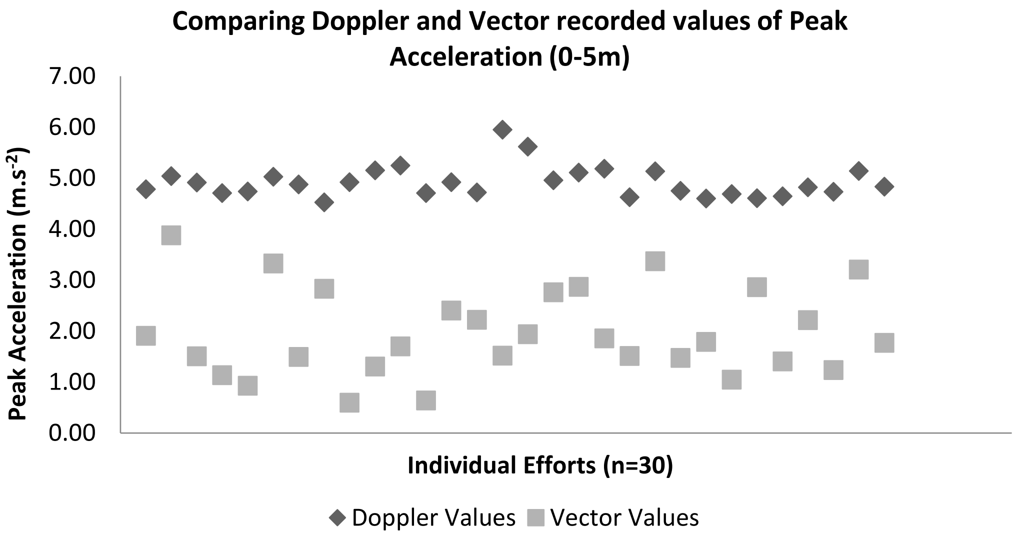

Figure 6: Graph displaying the recorded peak accelerations for each subject (2 Efforts) by both Doppler and vector method ($m.s^{-2}$) within the first 5m of a 20m standing start maximal effort

Figure 6 shows individual data points for each of the 15 subjects across 0-5m. The Doppler acceleration measured was higher than that for the accelerometer vector (4.9±0.31 vs 1.96±0.85, respectively $p<0.05$) ($m.s^{-2}$) Effect Size (ES) = 5.06

Similarly, Figure 7 shows individual data points for each of the 15 subjects across 0-1.5s. The Doppler acceleration measured was also higher than that for the accelerometer vector (4.67±1.04 vs 2.04±0.97, respectively $p<0.05$) ($m.s^{-2}$) ES = 2.56

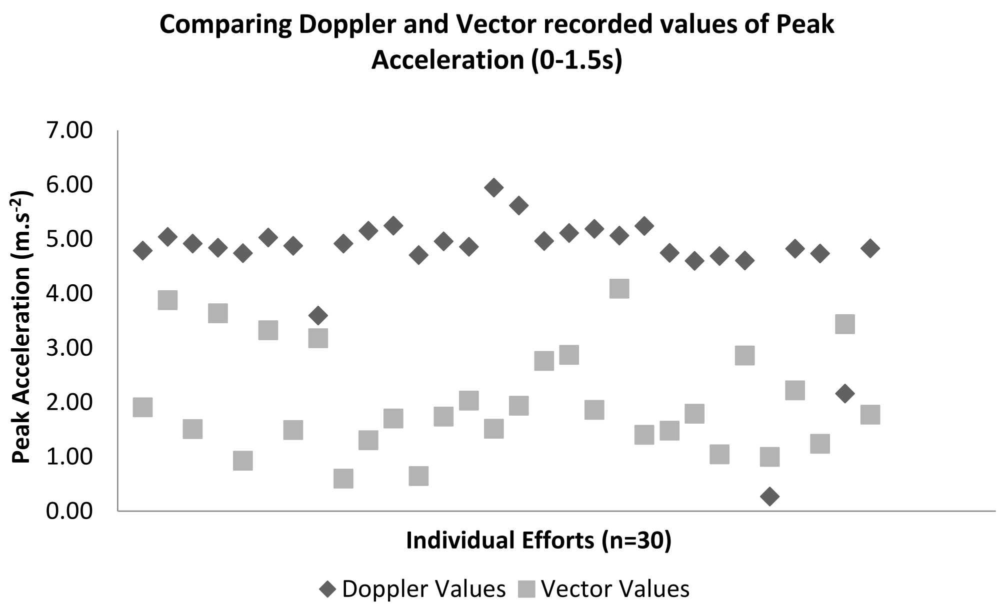

Figure 7: Graph displaying the recorded peak accelerations for each subject (2 Efforts) by both Doppler and vector method ($m.s^{-2}$) within the first 1.5s of a 20m standing start maximal effort

Doppler measures of acceleration were significantly higher than the vector derived measures of acceleration with the mean difference between Doppler and Vector recorded acceleration data 2.97±0.86 $m.s^{-2}$ for 0-5 m and 2.64±1.43 $m.s^{-2}$ for 0-1.5s, ($p<0.05$)

To establish the effect of the commencement running velocity on the subsequent maximal acceleration capacity, the testing protocol aimed to simulate a 3, 4, 5, 6 & 7$m.s^{-1}$ entry before a maximal voluntary acceleration.

The intended entry speed was not always achieved and the true mean recorded entry speeds for both Trial 2 (Controlled Run-In) and Trial 3 (Hollow Test) are shown in Figure 8.

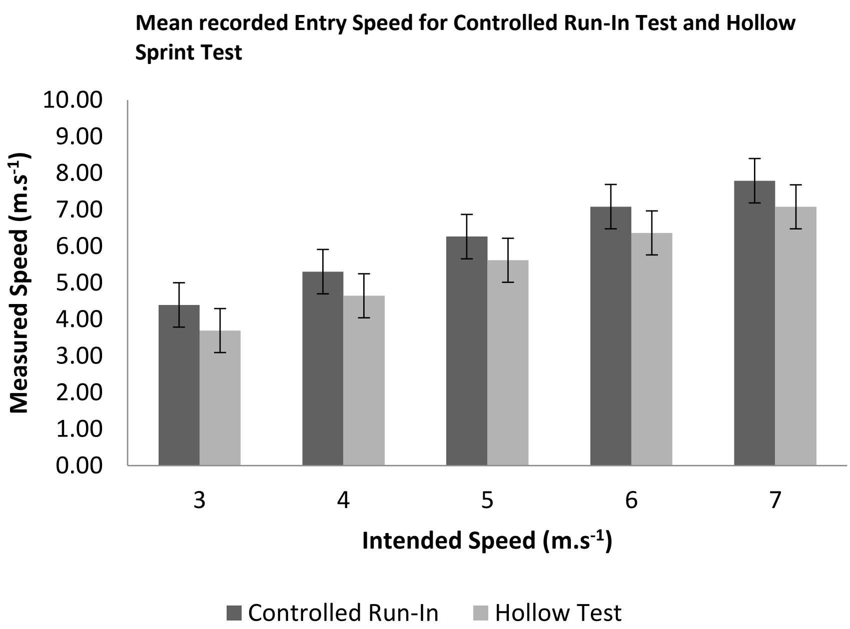

Figure 8: Chart showing the intended run-in speeds ($m.s^{-1}$) (*x-axis*) versus the actual group mean (n=15) measured run-in speeds ($m.s^{-1}$) (*y-axis*) with standard error in both the controlled run-in test and the hollow sprint test.

While the intended commencement velocity for each test protocol was 3, 4, 5, 6, & 7 $m.s^{-1}$, for trial 2 (*controlled run-in*) the recorded entry speeds were 4.39±0.52, 5.30±0.6, 6.26±0.31, 7.08±0.41 and 7.79±0.33 $m.s^{-1}$, respectively. Whereas the mean recorded entry velocities obtained during the conditioning phase to trial 3 (*Hollow Test*) were in fact 3.69±0.24, 4.64±0.26, 5.62±0.25, 6.36±0.38 and 7.08±0.36 $m.s^{-1}$, respectively.

Therefore, for trial 2 (Controlled run-in) the speed of entry was always measured higher than that prescribed. In this case, it was measured as 4.39±0.52 $m.s^{-1}$ for a prescribed speed of 3 $m.s^{-1}$, 5.30±0.6 $m.s^{-1}$ for a prescribed speed of 4 $m.s^{-1}$, 6.26±0.31 $m.s^{-1}$ for a prescribed speed of 5 $m.s^{-1}$, 7.08±0.41 $m.s^{-1}$ for a prescribed speed of 6 $m.s^{-1}$ and 7.79±0.33 $m.s^{-1}$ for a prescribed speed of 7 $m.s^{-1}$

For trial 3 (Hollow Sprint Test) the speed of entry was also always measured higher than that prescribed. In this case, it was measured as 3.69±0.24 $m.s^{-1}$ for a prescribed speed of 3 $m.s^{-1}$, 4.64±0.26 $m.s^{-1}$ for a prescribed speed of 4 $m.s^{-1}$, 5.62±0.25 for a prescribed speed of 5 $m.s^{-1}$, 6.36±0.38 for a prescribed speed of 6 m.s^{-1} and 7.08±0.36 m.s^{-1} for a prescribed speed of 7 m.s^{-1}

To examine the acceleration capacity at the point where the instruction to change velocity was given, the peak acceleration from both the Doppler and vector method was recorded. The results obtained are shown in Figure 9.

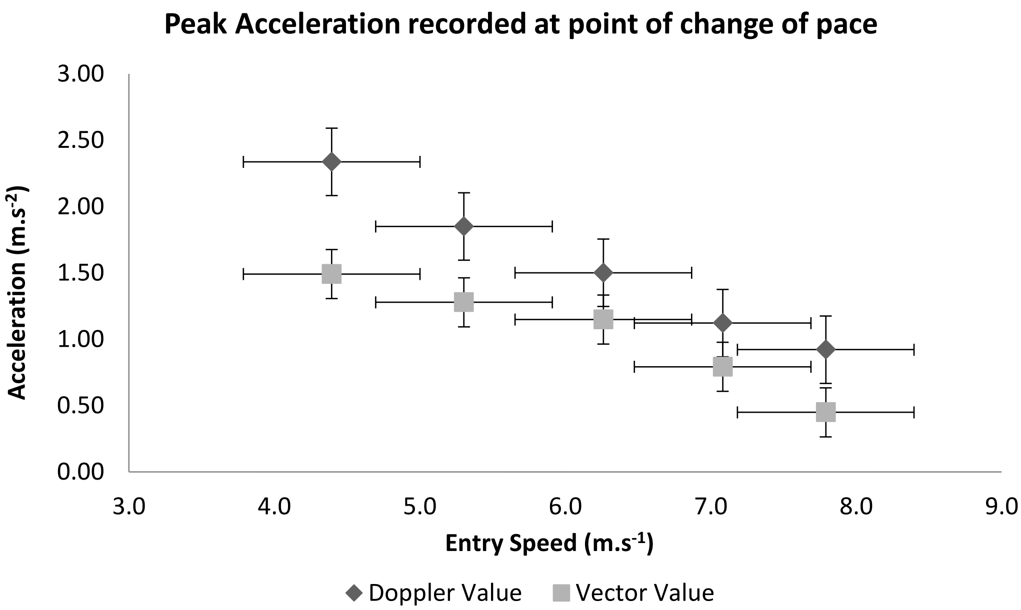

Figure 9: Graph displaying the mean measured peak acceleration ± SE from Doppler and vector methods at the point of change of pace at the corresponding mean recorded entry speed (m.s^{-1}) ± SE

Figure 9 demonstrates that independent of the measurement technique, as starting velocity increases, the maximal acceleration observed is reduced. Peak accelerations observed from the presented starting velocities were 2.34±0.35 $m.s^{-2}$ at 4.39 $m.s^{-1}$, 1.85±0.31 $m.s^{-2}$ at 5.30 $m.s^{-1}$, 1.5±0.26 $m.s^{-2}$ at 6.26 $m.s^{-1}$, 1.12±0.18 $m.s^{-2}$ at 7.08 $m.s^{-1}$ and 0.92±0.21 $m.s^{-2}$ at 7.79 $m.s^{-1}$ measured by Doppler and 1.49±0.24 $m.s^{-2}$ at 4.39 $m.s^{-1}$, 1.28±0.27 $m.s^{-2}$ at 5.30 $m.s^{-1}$, 1.15±0.16 $m.s^{-2}$ at 6.26 $m.s^{-1}$, 0.79±0.65 $m.s^{-2}$ at 7.08 $m.s^{-1}$ and 0.45±0.32 $m.s^{-2}$ at 7.79 $m.s^{-1}$ measured by vector method.

The vector of acceleration was significantly lower than Doppler measurement at all prescribed velocities (2.34±0.35 vs 1.49±0.24 at 4.39 $m.s^{-1}$ $p<0.05$, 1.85±0.31 vs 1.28±0.27 at 5.30 $m.s^{-1}$ $p<0.05$, 1.5±0.26 vs 1.15±0.16 at 6.26 $m.s^{-1}$ $p<0.05$, 1.12±0.18 vs 0.79±0.65 at 7.08 $m.s^{-1}$ and 0.92±0.21 vs 0.45±0.32 at 7.79 $m.s^{-1}$ $p<0.05$). *(T-Test)*

As observed in a static start, the vector values appear to be lower than the recorded Doppler based values. The observed differences between methods in measured acceleration (Doppler – vector) were 0.85±0.45, 0.57±0.45, 0.35±0.27, 0.33±0.22 and 0.47±0.26 $m.s^{-2}$, respectively.

To assess whether the capacity to maximally accelerate was influenced by a prior sudden deceleration, it is important to establish what effect the entry speed had on the magnitude of deceleration.

Figure 10 demonstrates that as the entry speed increases, the magnitude of deceleration also increases. The mean Doppler based deceleration values achieved were 0.29±0.35, 0.53±0.34, 0.84±0.37, 1.15±0.49 and 1.52±0.49 $m.s^{-2}$ for corresponding run-in speeds of 3.69±0.24, 4.64±0.26, 5.62±0.2, 6.36±0.38 and 7.08±0.36 $m.s^{-1}$, respectively.

The vector derived deceleration values were 0.1±0.08, 0.21±0.14, 0.48±0.19, 0.69±0.24 and 1.11±0.27 $m.s^{-2}$ for the corresponding run-in speeds of 3.69±0.24, 4.64±0.26, 5.62±0.2, 6.36±0.38 and 7.08±0.36 $m.s^{-1}$, respectively.

As before, the vector of acceleration (deceleration in this case) was significantly lower than Doppler measurement at all prescribed velocities (0.29±0.35 vs 0.1±0.08 $p<0.05$, 0.53±0.34 vs 0.21±0.14 $p<0.05$, 0.84±0.37 vs 0.48±0.19 $p<0.05$, 1.15±0.49 vs 0.69±0.24 $p<0.05$ and 1.52±0.49 vs 1.11±0.27 $p<0.05$) ($m.s^{-2}$) *(T-Test)*

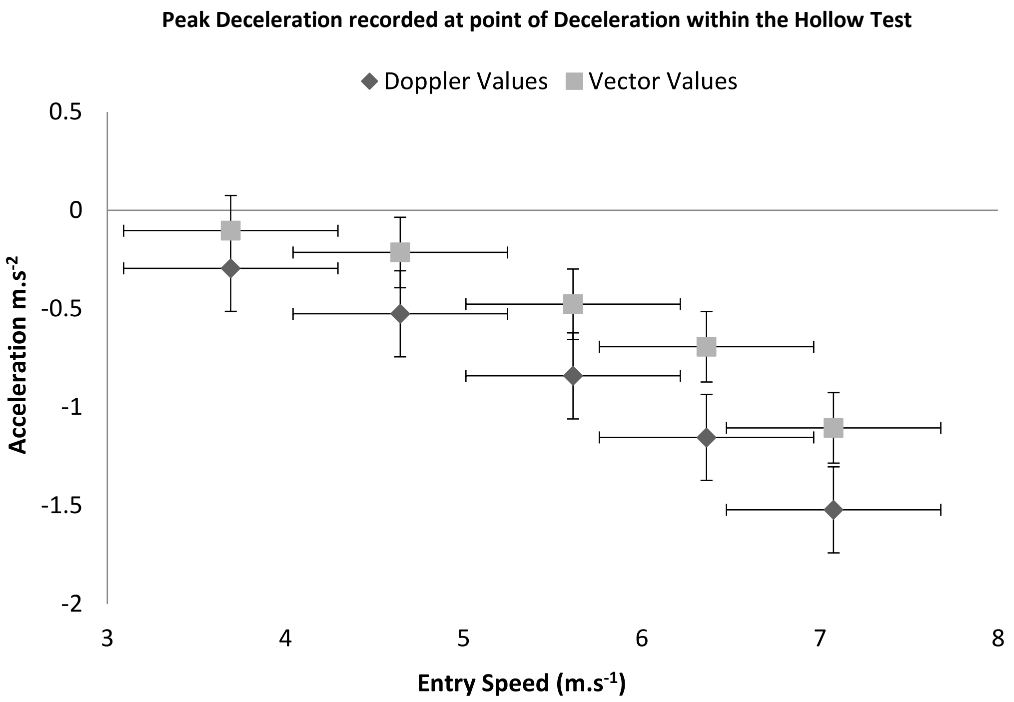

Figure 10: Graph displaying the mean measured peak deceleration ± SD by both Doppler and vector methods at the point of deceleration after the corresponding mean recorded entry speed within the hollow test.

The non-linear deceleration within the prescribed zone will obviously have an impact on the running speed immediately prior to the re-acceleration. These data are presented in Figure 11.

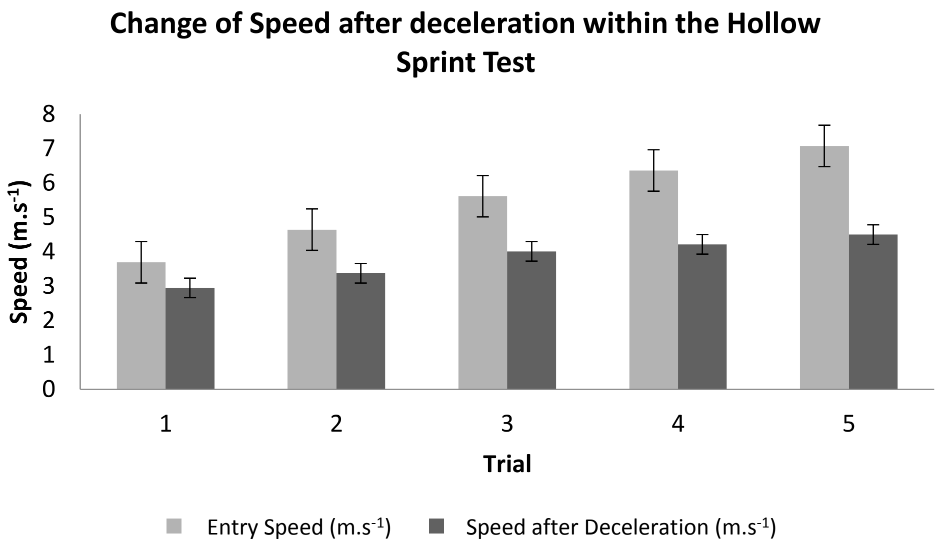

Figure 11: Chart showing the entry speed and speed after the deceleration phase of the hollow sprint test (±SE).

Figure 11 shows that as the speed of entry increased across trials 1-5 in line with the 3, 4, 5, 6, & 7 $m.s^{-1}$ entry speed target, the magnitude of the resultant deceleration increases. The speed at the point of re-acceleration therefore increases. The final speed being reduced by 0.74 $m.s^{-1}$ in trial 1 and increasing to a 2.6 $m.s^{-1}$ reduction in trial 5.

To examine the influence of these revised starting velocities and the effect of the deceleration on the capacity to re-accelerate; we again examined the peak acceleration at the point of re-acceleration, in line with the test protocol. These data are shown in in Figure 12.

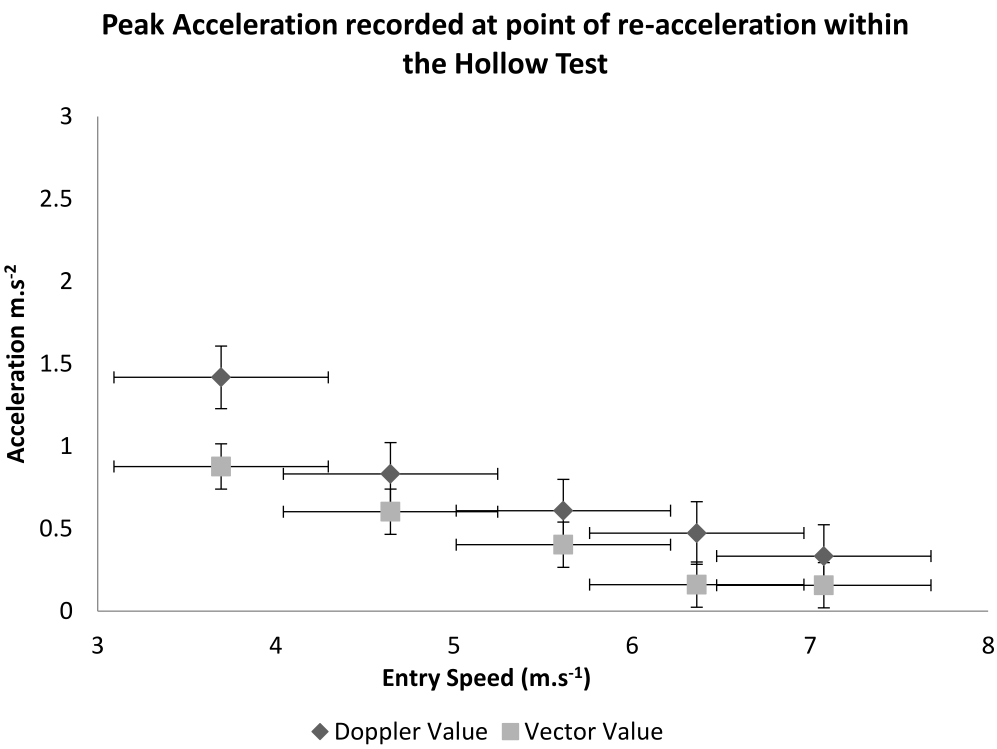

Figure 12: Graph displaying the mean measured peak acceleration ± SD by both Doppler and vector methods at the point of re-acceleration after the corresponding mean recorded entry speed within the hollow test.

As with the controlled speed test, this data shows that as speed of entry increases, maximal acceleration capacity is reduced. The peak accelerations achieved as entry speed increased were 1.42±0.57, 0.83±0.51, 0.61±0.26, 0.47±0.37 and 0.33±0.32 $m.s^{-2}$ for Doppler and 0.88±0.28, 0.6±0.4, 0.4±0.17, 0.16±0.07 and 0.16±0.06 for the vector derived data respectively.

To illustrate the relationship between the speed of entry, magnitude of deceleration and their effect on the capacity to re-accelerate, mean values are plotted for these variable in Figure 13 and Figure 14.

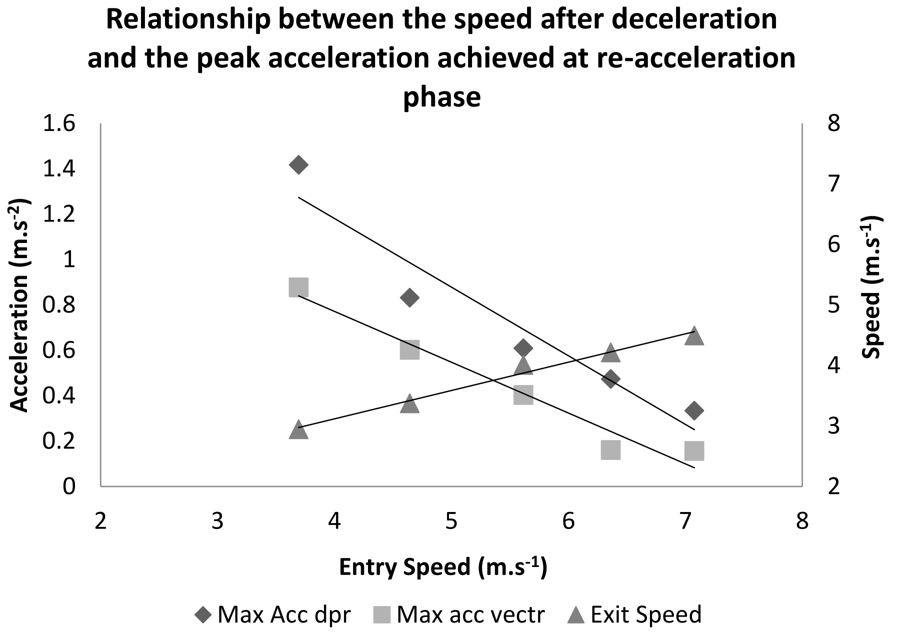

Figure 13: Graph showing the mean recorded entry speed and the speed recorded after deceleration within the hollow test. It also shows the peak acceleration recorded by both Doppler and vector methods that was achieved at the point of re-acceleration.

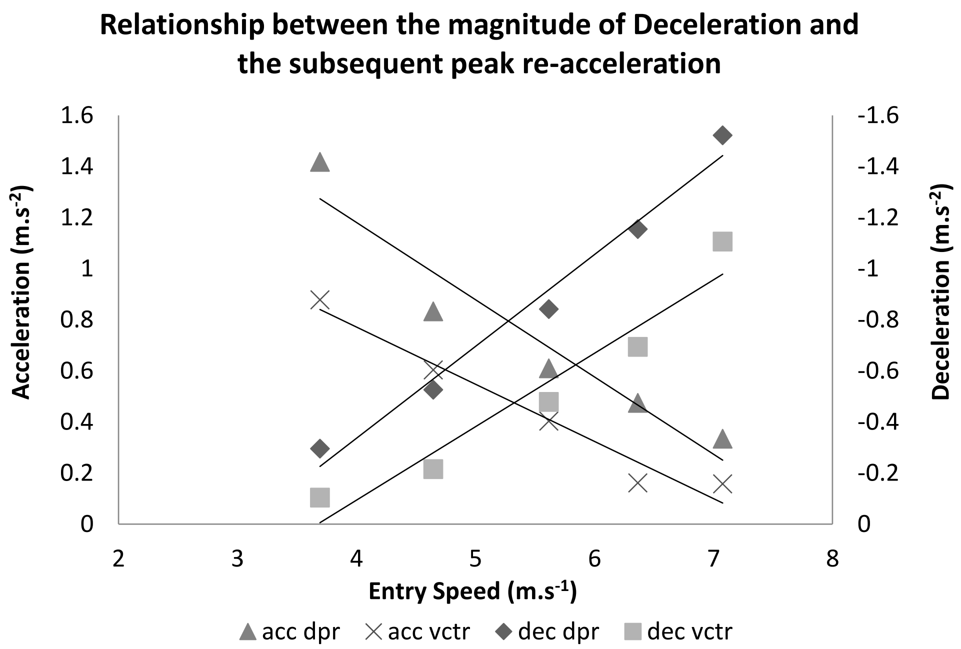

Figure 14: Graph displaying the relationship between the mean recorded entry speed and the corresponding Doppler and vector peak decelerations at the point of deceleration and the subsequent mean peak acceleration at the point of re-acceleration within the hollow test.

Finally, to compare the results from the controlled running speed data and data obtained after a sudden deceleration we can examine how each component impacts the capacity to produce maximal accelerations.

Figure 15 demonstrates that as the starting velocity increases, the capacity to change pace maximally both at constant speed and after a sudden deceleration is reduced. The graph suggests that the capacity to produce maximal accelerations is greater compromised after a rapid deceleration.

The maximal acceleration achieved from the deceleration ‘Hollow’ test was 1.42±0.57 m.s^{-2} recorded by Doppler and 0.88±0.28 m.s^{-2} recorded by vector analysis compared to 2.34±0.35 m.s^{-2} by Doppler and 1.49±0.24 by vector analysis from the controlled speed test.

By examining the peak accelerations achieved at similar run-in speeds – those within the red box zone marked– it is apparent that peak accelerations achieved from a controlled speed are greater than those from a similar speed after a rapid deceleration.

By examining the line of regression from the controlled-run in trial, we could expect to see higher accelerations achieved at the lower entry speeds (2-4 $m.s^{-1}$), indicated by the black arrows from the Hollow Sprint trial data. However, what appears to be the case is that the rapid deceleration of the Hollow test, appears to reduce the capacity to maximally accelerate, despite being initiated from these lower entry speeds. (Figure 15).

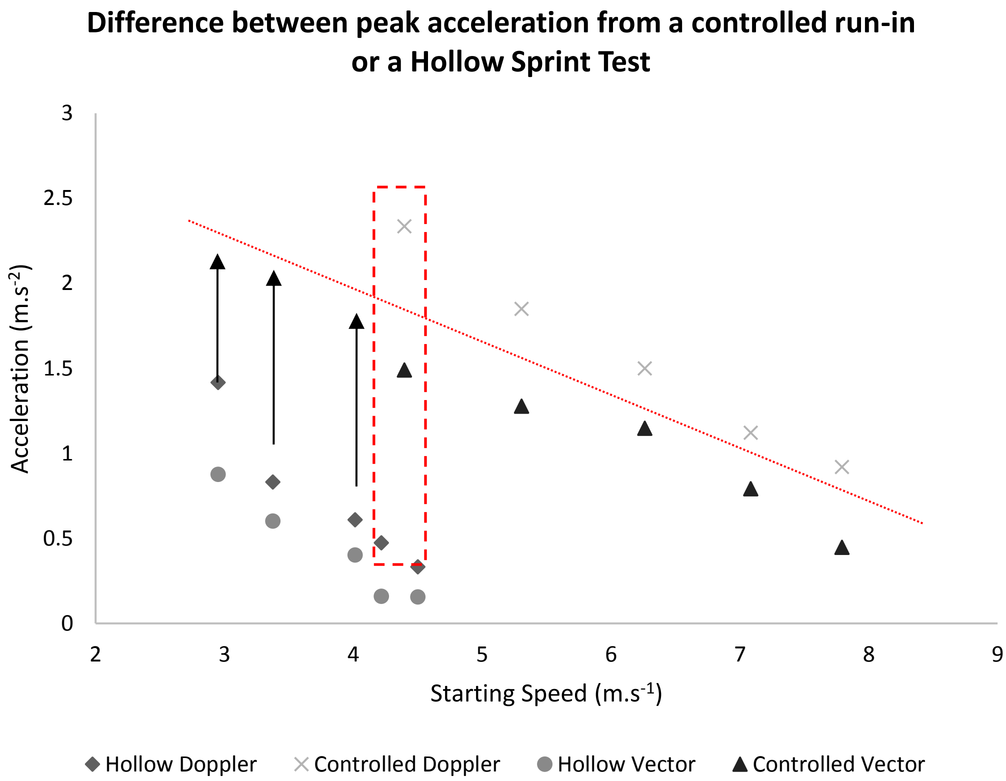

Figure 15: Graph showing the range of different starting speeds recorded from the controlled run-in and after the point of deceleration within the hollow test and the corresponding mean peak acceleration by both Doppler and vector methods. The Red box highlights the similar starting speeds and the peak accelerations achieved at that point in each of the tests.

5. Discussion

5.1 Summary of Findings

The main findings from this study are that maximal acceleration capacity is reduced when the speed at which the acceleration is initiated increases.

In agreement with Sonderegger et. al (2016), our results show a linear decrease in the acceleration capacity when maximum voluntary efforts are initiated from increasing initial running speed. This further highlights the importance of considering the running entry speed prior to acceleration when acceleration measurements are used to evaluate the intensity and load of training stimulus.

By using absolute values, an acceleration of >2.78 $m.s^{-2}$ is often classified as a high acceleration (Varley and Aughey, 2013; Akenhead et al 2013; Akenhead et al 2014).

However, our results show that an acceleration of >2.78 $m.s^{-2}$ would only represent up to 60% of the maximal voluntary acceleration capacity from a standing start position that we observed. In contrast, however, from an entry speed of 4.39

$m.s^{-1}$, very few of our subjects could reach an acceleration of 2.78 $m.s^{-2}$ & this number decreased as the entry speed got quicker. Therefore, accelerations initiated from standing or low-speed running would be overestimated and accelerations from high-speed running underestimated, by using the current absolute acceleration thresholds.

Similar to our findings, Sonderegger et. al (2016) also notes that although the results reported by Varley and Aughey (2013) indicated the issue of having absolute acceleration thresholds, the authors did not explicitly address this problem. They showed that nearly half of all actions with maximal accelerations > 2.78 $m.s^{-2}$ were initiated from speeds of < 3.6 $km.h^{-1}$ and only 8% of these maximal accelerations were then reported when the initial running speed was over 10.8 $km.h^{-1}$ (3$m.s^{-1}$). The authors interpreted this finding by concluding that actions with maximal acceleration very rarely occur with initial running speeds exceeding 10.8 $km.h^{-1}$, rather than suggesting that the initial running speed may have been the limiting factor in the consequent acceleration effort.

However, based on our results, which illustrate a significant decrease in the acceleration capacity with increasing initial entry speed, it seems more likely that even if the players did produce a maximum voluntary acceleration effort, they would not be able to exceed the threshold value of >2.78 $m.s^{-2}$ if the initial running speed was over 10.8 $km.h^{-1}$ (or 3 $m.s^{-1}$ in the case of our study.)

The data also shows that the data generated by Doppler and accelerometer vector outputs can be influenced by the nature of the movements being analysed (i.e a sudden deceleration or change in pace). It appears that Doppler analysis provides a more consistent reflection of acceleration capacity when compared with the time motion analysis observed using traditional timing gates. Furthermore, the ability to harness the elastic contribution to force output (and thereby acceleration) is compromised at higher running speeds where the higher deceleration (and eccentric load) does not result in a higher re-acceleration.

5.2 Maximal Acceleration from a Standing Start

The participants in the present study were young football players at the start of their professional careers. They were all training full-time and at the time of the study had been in full-time training for over 2 years (including time in the performance school partnership programme). As a consequence, their performance in the standardised sprint and jump tests was on a par with senior players within the first team squads (around 1s for 5 m sprint performance and 21.5 inches, or 55 cm, for a counter movement jump). These data are also consistent with performances reported in the literature for professional football players and provide confidence that the results obtained are relevant to monitoring performance within professional sport.

A comparison of these players' capacity to accelerate from a static start allows validation of the current data with that already available in the literature (validating the measurements obtained under the different experimental interventions applied).

When analysing peak acceleration from a static start, the 0-5m distance and 0-1.5s time frame was chosen because they are consistent with the testing protocols applied using traditional light gate technology.

Given a mean sprint effort duration of 1.03 s over (0-5m), the mean acceleration during this phase equates to 4.71 $m.s^{-2}$. Using the standard equation to calculate acceleration A = v-u/t; where u = 0 $m.s^{-1}$, t=1.03 s and v = the average speed covered in 0-5m:

$$v=d/t = 5/1.03 = 4.85 \ m.s^{-1}.$$

$$\text{and therefore, } a = 4.85/1.03 = 4.71 \ m.s^{-2}.$$

This mean “maximal” acceleration observed is consistent with the data described previously in the literature review and supports the notion that accelerations measured in excess of 2.78 $m.s^{-2}$ are a significant effort (Varley and Aughey, 2013; Akenhead et al 2013, Akenhead et al 2014). The data presented here also highlights the difference between using Doppler derived acceleration values and accelerometer derived vectors. The data presented within our findings demonstrates that the vector of the tri-axial accelerometers can under represent the magnitude of the acceleration observed in linear running.

In an aim to establish a true maximal acceleration value from a standing start, the good relationship between the Doppler derived indices and the light gate data previous is logical given that they are both measuring distance and time. However, the tri-axial accelerometers are measuring displacement (accounting for direction and magnitude of the GPS unit's movement) whereas the GPS coordinate and light gates are scalar (measuring distance in relation to time). Therefore, it is important to highlight that the position of the GPS unit could have a big impact on the measured acceleration.

Due to the nature of the experimental protocol for the first trial (the static start), the athletes naturally position themselves into a forward lean position when accelerating from a standing start (and as observed, will still be leaning forward over the short distances we measured). While these data might suggest that the Doppler derived measurements are therefore more valid, it was important to continue analysing both options to determine if there is any need to collect the accelerometer data.

This is important, because during the third trial (the ‘hollow test’), it was observed that a number of the subjects would position their body more upright during the deceleration phase, lifting their trunk and extending their back, becoming more upright as they decelerated and this may be an opportunity to observe how body displacement may affect the measured acceleration by simple Doppler-based analysis.

5.3 Maximal Acceleration from a Moving Start

The data presented here demonstrated the difficulty in accurately controlling the prescribed running speeds during experimental studies, however, in the experimental design these data provide information on a continuum across the usual running speeds (<14 $km.hr^{-1}$ to >24 $km.hr^{-1}$) observed in training and competition in professional football (Bradley et al. 2010).

The results demonstrate clearly that as the velocity at which the athlete runs increases, their capacity to accelerate is reduced.

However, this is perhaps not what we should expect in terms of Newtonian Mechanics where applying a force to an object should result in the same acceleration independent of the speed it is travelling at. On the other hand, in biological systems the capacity to generate force will be influenced by the speed at which the muscle is contracting. Classic physiology textbooks describe the force-velocity relationship where the ability to generate force is inversely related to the velocity of contraction (Vander, Sherman and Lucianno (1994). Therefore, as running speed increases the muscle is shortening progressively quicker to reduce ground contact time (as cadence also increases) and increased angular velocity (as the stride length increases). Thus, as the speed at which the player is travelling increases, the capacity for the muscle to generate force as a result of muscle activation is reduced and the resultant acceleration is compromised. Importantly, however, the metabolic cost of this reduced force output will not change and will therefore still have consequences for the training load concept. Moreover, this ability to change pace during running is an important aspect of team sports and has merit to be monitored individually in providing a sport specific training impulse. Should we therefore consider training change of pace as an independent physical characteristic?

The comparison of Doppler and accelerometer derived acceleration data across the different running velocities presented within the results are of particular interest. The mean Doppler acceleration is consistently higher than the vector of tri-axial accelerations across all of the running speeds measured. However, the magnitude of the difference is much reduced from a standing start and is further reduced at each increase in prescribed running speed. This observation may be important to explain the measurement differences observed. The forward lean position of the subject that is adopted from a standing start may produce an error in the vector of the accelerometer (where the x, y and z planes are disorientated). This error is reduced as the initial running speed increases (and the change in forward lean from running and subsequent acceleration is reduced).

These data may suggest that the positioning of the GPS unit between the scapulae makes a significant contribution to the measurement error observed. The Doppler data is measuring the distance covered by the centre of mass during movement, but the accelerometers are measuring movement in the trunk (during hip flexion and extension) in addition to movements of our centre of mass. The obvious experiment would be to place the unit closer to the centre of mass and compare the resultant outputs (however, in team sports the position between the scapulae is preferred for minimising injury risk from impacts with the GPS units). This could perhaps be scope for further research.

5.4 The Influence of the Stretch Shortening Cycle on Maximal Acceleration

The data observed during the third trial in this study (Hollow Sprint Test) demonstrated that the magnitude of the observed deceleration increased in direct proportion to the running velocity prescribed for (or observed in) the players. This deceleration is often accepted in the literature to provide an eccentric load to the lower limbs. This ground contact and eccentric load should provide a stretch-shortening cycle that may be thought to improve subsequent re-acceleration. However, as the speed of running into the deceleration zone (and the resultant deceleration) increased, there was actually an observed decrease in the resultant re-acceleration. Despite being of initial surprise, this observation could be explained and is consistent with the response in rebound jump height observed with progressive increases in box drop heights for plyometric training (De Villarreal, Kellis, Izquierdo 2009). The increased height of drop leads to an increased ground reaction force but also with increased ground contact time (so that rate of force development and power are compromised) (Makaruk and Sacewicz, 2011). The mechanisms responsible for this observed reduction in performance have been related to the increased requirement for the muscle and connective tissue to absorb energy during the landing.

The data observed in the third trial (Hollow Sprint Test) conducted here is consistent with these observations and adds to the previous observation from trial two (controlled-speed entry) that the acceleration observed may not necessarily reflect the true metabolic or biomechanical load associated with complex movements. During the rapid deceleration, the muscle and connective tissue have an increased requirement to absorb the energy from reduced forward motion (as opposed to landing as described above) and this compromises the ability to recruit the expected stretch-shortening cycle.

5.5 Review of Methods

In previous studies that aimed to control running speed, audio cues and handheld devices have been used to signal when the correct speed was achieved (Akenhead et al 2013) (Varley and Aughey, 2013) (Sonderegger et. al, 2016).

Using such apparatus would certainly improve the ability to control speed more accurately. However, since the speed at the initiation of acceleration and the resultant acceleration were measured simultaneously within our study, the need for precise speed control was less relevant than in other studies.

Therefore, the important observation was that the speed of entry was increasing, which then impacted on the following acceleration or deceleration. The entry speeds observed were still consistent with those reported in the literature to be common speeds within soccer training and match play (Bradley et al, 2010).

This is an important point to note for practitioners. The nature of the ‘Hollow Sprint’ better reflects the movement demands observed within soccer practice, particularly in SSGs with regards to the amount of accelerations. Therefore, rather than being a limitation of our study solely focusing on set, controlled running speeds, our study has in-turn provided a wider range of velocities and situations from which accelerations commenced from. Therefore, the effect size of these results is more relevant to the limitations on using these metrics for monitoring purposes and provides useful information for other practitioners.

5.6 Limitations

While the value of this study is in gaining a better understanding of the monitoring of training and competition load during football, the study protocols restricted the players to running in a linear fashion. This approach does not directly represent the free-movement patterns that need to be observed in soccer training and match play and future studies should focus on the capacity to change speed and direction and to aim to accurately quantify player movement across all directions.

6. Conclusion and Potential Applications

Quantifying training load remains an important consideration for football coaches and sports scientists, but finding the most accurate measure of quantifying training load remains elusive. The current approaches are developments on monitoring only internal load and with advancements in technology we are able to use GPS to perform time motion analysis in training and game play. Although an improvement, this approach is still flawed and its limitations need to be acknowledged and the technology developed.

It is apparent that accelerations make a significant contribution to the overall load experienced by the athlete during sport specific activity (and quantifying load accurately has been a research focus over the past few years). However, it is important to understand that applying technology requires consideration to make sure that what we report reflects the true situation. Firstly, we must understand the different physical demands that occur due to small technical changes made in the training and match environments *e.g*. pitch size, player numbers and tactics around the use of goalkeepers or possession games will require crucially different physical demands.

This study looked at controlled activity in running drills to set a basis for understanding more complex situations within training and match play. The results from this study suggest that thresholds at which we measure acceleration, speed or distance travelled must be relevant to the conditions of the activity (*i.e.* they must be context specific and cannot be set as unconditional end points).

The reduction in observed maximum voluntary acceleration with increased running speed will be important in situations where the context changes player behaviour. For example, increasing the relative playing area during a training game will increase the average speed during the period of play (and this would lead to a reduced number of high level accelerations if the threshold is set to an absolute value). The consequences of this misinformation may be that players initiate an acceleration effort and pay metabolic cost but get further load applied because that effort was not recorded. This could result in potential training overload.

It would seem appropriate that different training prescription has specific speed, distance and acceleration thresholds applied to give appropriate contextual understanding of the measurements being made. Furthermore, in order to interpret data from Accelerometry, we must consider the position of the GPS unit worn and the movements made by the players as these have been shown to impact the final measure of acceleration presented.

This study provides useful information as a practitioner within soccer with regards to monitoring accelerations and understanding better the context of each situation that we are aiming to monitor. Lastly, future study should aim to quantify accelerations within a football specific context with regards to player movements with an aim to analyse these in an individualised approach to each player. This should provide value in adding to the concept of assessing the Training Load.

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