The influence of the frequency of directional change on the physiological responses to intermittent exercise in elite football players

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A thesis submitted in partial fulfilment of the requirements of Liverpool John Moores University for the degree of Master of Philosophy

March 2015

Abstract

Despite the common occurrence of directional change in football, few studies have attempted to investigate the demands of players performing such movement patterns (Stevens et al., 2014; Akenhead et al., 2014; Dellal et al., 2010). The aim of the current thesis was to identify the physiological responses associated with performing directional changes in elite football players.

The aim of the first study was to investigate the occurrence of directional change within an elite football team's typical four-day training week and to determine the external load and subsequent physiological demands associated with performing such movement patterns. Five male elite football players were monitored during each session via global positioning system (GPS), accelerometry (ACC) and heart rate (HR). The data indicated that acceleration and deceleration (movements used to represent the occurrence of directional change) occurred frequently throughout each session of the training week but were found to be significantly higher for one particular training day when compared to all other remaining sessions (+22-43%) ($p < 0.05$). Although the external load as measured through ACC and the rate of perceived exertion (RPE) as measured through the modified Borg scale were greatest for this training day, they were not found to be significantly different when compared to all other training days. The physiological response however as indicated through HR was found to be significantly higher for this training day (+24-40%) ($p < 0.05$). These results would indicate that a higher cardiovascular response may be associated with training sessions that include more frequent changes in direction. Despite these findings the approach used to collect the physiological data within the study may have had several limitations. The biggest limitation was perhaps the influence of training variables other than movements relevant to directional change. There is therefore a need for an investigation which applies greater control of extraneous training variables during data collection. Such an approach would allow for a more precise interpretation regarding the physiological demands associated with performing directional changes.

The aim of the second study was to investigate the external load and subsequent physiological demands of controlled intermittent protocols which included varying frequencies of 180 degree directional changes in elite football players. Thirteen male elite players were monitored via GPS, ACC and HR during protocols which involved one, three or seven change(s) in direction. In this study important extraneous variables such as the total running distance, speed of movement as well as the number and intensity of accelerations and decelerations performed were carefully controlled in an attempt to isolate and manipulate only the movement pattern. The results showed that external load as measured in gravitational force (g-force) was significantly greater for the protocol that involved seven directional changes when compared to the protocol which involved one (+32%) or three (+24%) directional changes ($p < 0.05$). Participants resulting HR as measured through heart rate exertion (HRE) was also significantly higher for the protocol which involved seven directional changes when compared to protocols which involved one (+54%) or three (+53%) directional changes ($p < 0.05$). The increase in the physiological response was further supported by a significant increase in RPE for the protocol which involved seven directional changes (5 ± 1) when compared to the protocols which involved only one (3 ± 0) or three (3 ± 1) directional changes ($p < 0.05$). A positive correlation was found when comparing g-force with both HRE ($r = 0.45$, $p < 0.01$) and RPE ($r = 0.63$, $p < 0.01$). These results show that increasing the frequency of 180 degree directional changes through intermittent exercise protocols, increases the external load and physiological responses in elite football players.

The current research indicates that directional change occurs frequently throughout an elite football team's typical training week. Performing 180 degree directional changes increases the external load which may subsequently elevate the physiological and subjective responses. Careful consideration must therefore be placed on such movement patterns when designing training drills for elite football players throughout various days of the training week.

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Chapter 1

Introduction to thesis

Football is a demanding game when played at an elite level with research showing that elite players expend 6.3 megajoules during a game (Reilly and Thomas, 1979), over a distance of 10.8 kilometers (Di Salvo et al., 2013). Such distances are made up of runs at various speeds with the most notable to performance being high intensity running (HIR) (Di Salvo et al., 2013; Di Salvo et al., 2007; Mohr et al., 2003; Bangsbo et al., 1991). On average players perform 69 HIR efforts during a game (Mohr et al., 2003). These efforts only account for approximately 1 to 10% of the total distance covered (Bangsbo et al., 1991). It seems unlikely that this small percentage of HIR alone would account for the high energy demands observed in elite football. It may be that other factors, such as the specific exercise patterns in which players perform their activity and the type of movements that are used in the sport, are more important contributors to the overall energy demand. An approach which looks at the types of movement patterns that are performed, alongside information on the speed of movement may therefore provide a better model for the examination of the energy demands associated with the game (Osgnach et al., 2010; Reilly, 1997).

Football is a sport which involves a constant change in activity. It is estimated that 1000 to 1500 changes in movement occur during an elite game (Reilly, 2003). Such movements often include movement patterns such as directional change. Directional change consists of deceleration, turning and acceleration movements. These movements have been shown to occur far more frequently than HIR efforts during a game (Akenhead et al., 2013; Bloomfield et al., 2007), suggesting that they could be an important determinant of the overall energy requirements in elite football. Despite these findings only a few studies have specifically investigated the implications that directional change has on football players and attempted to examine the associated physiological demands of such movements in any real detail (Stevens et al., 2014; Akenhead et al. 2014; Dellal et al., 2010). Research has instead focused predominantly on the analysis of the speeds of movement and the implications that this has for the major energy systems that support the activity (Stroyer et al., 2004; Reilly et al., 2000; Rienzi et al., 2000).

Changing direction may alter the external load placed on elite football players (Hewitt et al., 2011; Schot et al., 1995). This load in turn could lead to elevated energy demands. Research investigating directional change has predominantly focused on attempting to measure and interpret only the physiological demands associated with performing such movement patterns (Stevens et al., 2014; Zamparo et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2012; Buchheit et al., 2011; Buchheit et al., 2010; Dellal et al., 2010). Elite players predominantly turn at angles less than 180 degrees during games (Bloomfield et al., 2007), though the existing research would indicate that directional changes performed at such angles have little or no influence on the physiological response associated with the exercise (Zamparo et al., 2014; Buchheit et al., 2012). Irrespective of 180 degree directional changes being infrequently performed by elite players, it would seem pertinent to investigate such movements in these populations as a consequence of their ability to alter the energy demand. Research that has examined 180 degree directional changes has found such movement patterns to cause an increase (Stevens et al., 2014; Akenhead et al., 2014; Zamparo et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Dellal et al., 2010) or no change (Buchheit et al., 2010) in the physiological response when compared to running which involved less frequent 180 degree directional changes or solely linear based constant speed running. The current research is limited however as studies are inconsistent with regard to the protocol design, making it difficult to find a solid basis to enable comparisons between them. An alternative approach which may provide useful evidence regarding the energy demands of directional change would be to examine literature that provides data on the discrete components of changes in direction (deceleration, turning and acceleration) and reviewing each movement independently regarding its contribution to the overall external load and physiological demands of performing such movement patterns. Although such studies are limited it does provide an additional insight in to performing directional change. Research suggests that the deceleration component may potentially contribute to an increase in external load placed on an individual as high braking forces (Schot et al., 1995; Hewitt et al., 2011) have been associated with performing such movements. Other research suggests that the acceleration (Wiemann and Tidow, 1995; Harland and Steele, 1997; Jonhagen et al., 1996; Mero and Komi, 1987; Wiemann and Tidow, 1995; Mero and Peltola, 1989) and turning components (Besier et al., 2003) may contribute to a potential higher energy demand when compared to linear based constant speed running.

Due to the limited nature of the research which looks at directional change or its components (deceleration, turning and acceleration), there remains a need for a more focused approach which investigates the external load and physiological demands associated with elite football players performing such movement patterns. This would add to the understanding of performing directional changes and potentially allow for a more effective planning of the physical stimulus within an elite football players training week.

The aim of this thesis is:

To investigate the influence that frequency of directional change has on the physiological response to intermittent exercise in elite football players.

The hypothesis of this thesis is that:

Performing directional changes during intermittent exercise increases the external load elite football players are exposed to which in turn leads to an elevated physiological response.

Chapter 2

Review of Literature

Football is an intermittent sport which carries a high physical demand when played at an elite level. Players expend an estimated 6.3 megajoules during a 90-minute game (Reilly and Thomas, 1979) covering a total mean distance of 10.8 kilometers (Di Salvo et al., 2013). This distance is made up of runs at various speeds with the most notable to performance being HIR (Di Salvo et al., 2013; Di Salvo et al., 2007; Mohr et al., 2003; Bangsbo et al., 1991). High intensity running refers to movements that occur at a speed of 5.5 meters per second (m/s) or greater (Abt and Lovell, 2009). On average elite players perform 69 HIR efforts during a game which equates to only 2.8% of the total playing duration (Mohr et al., 2003) and 1 to 10% of the total distance covered (Bangsbo et al., 1991). This small percentage of HIR alone would not seem to account for the high total energy demands associated with elite match-play. This discrepancy may be a consequence of other factors such as the specific movement patterns in which players perform their activity and the types of movements that are used in the sport (Osgnach et al., 2010; Bloomfield et al., 2007; Reilly, 1997). Such patterns and movements can also occur at lower speeds, although this fact is often overlooked when analysing the demands of a game. This is especially the case if the focus is on interpreting actions using speed zone categorisation only (Guadino et al., 2014; Bangsbo et al., 2006; Reilly, 1997). Employing an approach that attempts to understand movement patterns alongside the speed at which actions are performed may provide a better reflection of the total energy demands associated with elite game play (Osgnach et al., 2010; Reilly, 1997).

If movement patterns have the potential to influence the energy demand it is important to understand their role in the activity profile completed by the elite player. It has been estimated that players perform 1000 to 1500 changes in movement within an elite game at a rate of one every 5 to 6 seconds (Reilly, 2003). These changes in movement frequently involve movement patterns such as directional change. Directional change involves three components; deceleration, turning and acceleration movements. Research has shown that elite players turn on average 727 times during a game (Bloomfield et al., 2007). Unpublished data, collected over the course of the 2010/ 2011 season, showed that elite players from an English Premier League team completed on average 879 and 844 accelerations and decelerations respectively during a game (Tang, 2012). This data would seem to indicate that changes in movement pattern, such as directional change, occur far more frequently than HIR efforts throughout game play. This may suggest that such movement patterns could be an important determinant of the overall energy requirements in elite football.

The majority of the available research on the demands of the sport has not investigated the implications of such movement patterns in any detail choosing instead to focus predominantly on the analysis of the speeds of movement completed during a game and the implications that these have on the major energy systems that support the activity; for example the aerobic and anaerobic energy pathways (Reilly et al., 2000; Rienzi et al., 2000). This limitation can be highlighted when training models that are relevant to the sport are closely examined. The ergonomics model proposed by Reilly in 2004 is an example of such a framework that attempts to provide a conceptual understanding of football training. This model identifies that both traditional and football specific forms of conditioning exist. Its analysis of specificity does not however seem to extend to the potential importance of movement pattern, particularly directional change, as an important component of the training philosophy (see Figure 2.1). This would seem to represent an important oversight if the fundamental characteristics of the movement have the potential to influence the physical requirements players are exposed to during a training session or game.

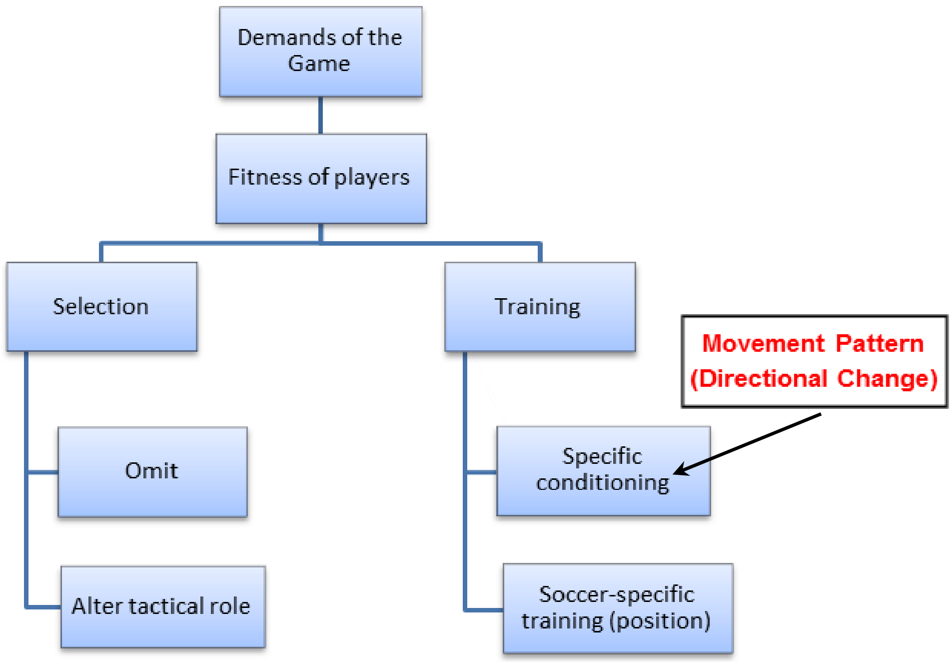

Figure 2.1 - Ergonomics model for the analysis of football (Reilly, 2004). Specific conditioning for elite football players should look beyond just speed of movement and also focus on incorporating movement patterns that are relevant to the sport, such as directional change, when designing training drills to stress various energy systems such as the aerobic and anaerobic pathways.

It is important to consider the movement pattern in elite football as changing direction may alter the external load placed on players (Schot et al., 1995). One potential difference between directional change and more constant speed straight line running are the "forces" acting on participants whilst performing such movements. The literature suggests that this increase in external load may be predominantly due to the deceleration component that is required to fulfil the movement (Hewitt et al., 2011; Schot et al., 1995). Although there is a lack of research on the external load associated with directional change, several studies have looked at the physiological demands associated with performing such movement patterns (Stevens et al., 2014; Akenhead et al., 2014; Zamparo et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2012; Buchheit et al., 2011; Buchheit et al., 2010; Dellal et al., 2010). Despite research showing that elite Premier League players predominantly turn at angles less than 180 degrees during games (Bloomfield et al., 2007), the existing research which has looked at and compared 45, 90 and 135 degree directional change protocols has shown that such smaller turning angles have little or no influence on the physiological response (Zamparo et al., 2014; Buchheit et al., 2012). Although elite players have been shown to perform fewer 180 degree turns during games (Bloomfield et al., 2007), the majority of the research has focused on looking at such turning angles and found such movement patterns to cause an increase (Stevens et al., 2014; Akenhead et al., 2014; Zamparo et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Dellal et al., 2010) or no change (Buchheit et al., 2010) in the physiological response when compared to running which involved less frequent 180 degree directional changes or solely linear based constant speed running. Despite the available studies there remains a difficulty in drawing conclusions regarding the exact physiological demands associated with directional change as the current research provides conflicting data due to its inability to provide a basis to compare between protocols. There is therefore a need for investigations which examine both the external load related to directional change and the physiological responses associated with performing such movement patterns in elite football players. Such data would have the potential to promote better planning and management of the physical stimulus within the training program of elite players.

This review of literature will focus on providing information on the potential influence that directional changes, as performed during exercise, have on the physiological responses. Such information will initially be organised into the individual component parts of directional change namely; acceleration, deceleration and turning. This content will then be followed by an evaluation of the published literature that has attempted to examine the impact of exercise protocols, which have systematically tried to manipulate directional change and analysed the corresponding physiological responses. The review will then be concluded with a summary that provides a detailed rationale for the aim of the thesis.

Acceleration

Acceleration occurs following the turning component of directional change. Understanding how acceleration differs from running at a constant speed provides a basis for suggesting that this component of directional change may alter the physiological response when compared to more continuous running patterns. Research that has looked at acceleration has not always been consistent in its use of terminology. For example within the current literature the term sprinting is often seen to be used interchangeably to describe movements which could be related to either accelerations or more constant speed sprinting actions. Sprinting, when accurately defined, refers to movement at a maximum continuous speed while acceleration can be described as the rate of change in velocity (Brown and Ferrigno, 2005). Little and Williams (2005) demonstrated that acceleration and sprinting were unrelated to each other in tests carried out on 106 professional football players. Their study showed that these two types of movements shared only 39% common variance suggesting that these two concepts are likely to be independent of each other (Little and Williams, 2005). Brown and Ferrigno (2005) suggested that approximately 75% of the maximum running velocity is established over the first 0 to 10 meters. As most of the runs in an elite game of football are performed over such distances (Bangsbo, 1994) it would seem logical to suggest, according to the above definitions, that players spend more time accelerating than running at a constant speed during a game. Such ideas regarding the importance of accelerations to football performance are also supported by the observation that 85% of accelerations during a game do not exceed 4.17 m/s (Varley and Aughey, 2013). Although these accelerations occur at a speed much lower than that associated with HIR, they may still be important components of the overall movement profile.

No studies to date have looked at directly measuring the “forces” associated with acceleration and the subsequent physiological responses that occur as a result of this type of exercise stress. One reason for this lack of research may be the difficultly in evaluating the exact “cost” of such activities in both a laboratory and practical setting. Research has however attempted to indirectly measure the energy demand associated with acceleration. Di Prampero (et al., 2005) proposed that the energy cost of acceleration was higher than constant speed running. The study proposed that acceleration was comparable to uphill running and that therefore an equation previously used to measure the energy cost of uphill running (Minetti et al., 2002) could be applied to determine the energy cost of acceleration (Di Prampero et al., 2005). Buglione and Di Prampero (2013) applied this equation to running protocols which included 180 degree directional changes and found that the results were similar when compared to a direct approach of measuring the energy cost. This finding supports the concept that the acceleration component of directional change is responsible for an increase in energy demand when performing runs that include 180 directional changes. Stevens (et al., 2014) carried out a similar yet more controlled study specifically on football players and found that in contrast to the findings made by Buglione and Di Prampero (et al., 2013) that the equation proposed by Di Prampero (et al., 2005) significantly underestimated the energy cost of intermittent running protocols that involved 180 degree directional changes. Such conflicting findings between the two studies lead to question acceleration as being the sole component of directional change responsible for an increase in energy demand when performing intermittent exercise protocols which involve 180 degree turns. Other studies which have attempted to understand the demands associated with acceleration have investigated the muscular recruitment patterns through electromyographic (EMG) analyses. The data from this research shows that a higher muscular recruitment pattern is associated with periods of acceleration when compared to constant speed running such as sprinting. For example, an increase in the activation of the vastus lateralis (Wiemann and Tidow, 1995), vastus medialis (Harland and Steele, 1997) and hamstrings (Jonhagen et al., 1996; Mero and Komi, 1987; Wiemann and Tidow, 1995) have been observed during the initial phase of acceleration when compared to sprinting. Muscular activity, as evidenced by EMG activity also shows a 4.9% increase in the gastrocnemius, bicep femoris, gluteus maximus, rectis femoris and vastus lateralis musculature at ground contact during acceleration as opposed to sprinting (Mero and Peltola, 1989). These differences in the magnitude of muscle activation between acceleration and constant speed running have also been suggested to be indicative of an increased physiological demand (Bigland-Ritchie and Woods, 1976). Although no studies have directly measured the forces or physiological responses associated with acceleration only, the existing research suggests that a higher energy demand may be associated with performing such movements when compared to constant speed running.

Deceleration

Decelerations are a key component of directional change and frequently occur prior to completing turning actions in elite football (Bloomfield et al., 2009). Deceleration may be described as the ability to decrease speed or come to a stop from a maximal or near-maximal speed (Brown and Ferrigno, 2005). Unlike acceleration which predominantly involves concentric muscle actions, decelerations involve eccentric muscle actions of muscle groups such as the gastrocnemius and knee extensors (Andrews et al., 1977).

Eccentric muscular actions are capable of generating higher amounts of force than concentric muscular actions (Crenshaw et al., 1995; Westing et al., 1991; Westing and Seger, 1989). In contrast to concentric actions, the magnitude of this force during eccentric activity seems to increase linearly as the rate of contraction increases (Westing et al., 1988; Katz, 1939). These findings may explain why elite players have the capacity to perform rapid decelerations during training and games as the nature of the contraction allows for high forces to be generated. Eccentric actions, such as decelerations, are however also associated with a high magnitude of braking forces. Hewitt et al., (2011) proposed that large horizontal (braking) forces are created during deceleration when the feet are positioned ahead of the body's centre of mass. Other research has indicated that by increasing the magnitude of deceleration prior to turning (increasing the turning angle from 45 to 90 degrees) resulted in a 39% increase in braking forces acting on the body (Schot et al., 1995). These braking forces are likely to increase the localised stress placed on the muscle tissue. This may result in muscle damage and lead to a decrement in muscular performance during the days following exposure to the exercise stress (Tee et al., 2007; McHugh and Tetro, 2003).

Although deceleration may cause an increase in external load due to braking forces (Hewitt et al., 2011; Schot et al., 1995) the physiological response associated with performing eccentric contractions seems to be lower than those associated with concentric contractions such as acceleration or constant speed running. Some studies which have looked at the physiological cost of eccentric contractions have shown that cardiovascular responses such as cardiac output and HR are almost twice as low as those seen in activities that require concentric contractions (Navalta, 2004; Robergs et al., 1997; Pivarnik and Sherman, 1990; Knuttgen and Klaussen, 1971). A potential explanation for the reduction in the physiological demand is the suggestion that eccentric muscular actions result in a forced detachment of the myosin head within the muscle (due to the strength of the stretch) (Huxley, 1998). It is suggested that this process leads to a lower energy cost thus reducing the physiological demand when compared to concentric contractions (Huxley, 1998). These studies which have shown a lower cardiovascular demand however are based upon exercise protocols which are predominantly continuous in nature, such as the eccentric activity during cycling on a decline (Knuttgen and Klaussen, 1971) or downhill running (Navalta, 2004; Pivarnik and Sherman, 1990; Robergs et al., 1997). Such contraction patterns are likely to be very different from those associated with an intermittent sport such as football. This may limit the usefulness of this data in increasing our understanding of the physiological demands associated with rapidly decelerating during activities that include multiple changes of direction. Although deceleration is associated with a high external load due to braking forces, the exact physiological responses associated with performing such movement patterns specifically remains to be determined.

Turning

Turning represents the mid component of directional change as it occurs following deceleration and prior to acceleration. There appears to be no studies which have looked at either the "forces" or the associated physiological responses associated with the turning component of directional change in isolation. It may be that such omissions are a result of "turning" being a difficult component of the movement pattern to isolate and control during such exercise protocols. As a consequence of these potential issues the available research seems limited to examining measurements such as EMG activity that have been collected during turning actions that are not completely isolated movements (Besier et al., 2003; Rand and Ohtsuki, 2000; Schot et al. 1995). Besier et al., (2003) showed that by increasing the turning angle from 30 to 60 degrees increased the EMG activity of the bicep femoris muscle and the medial musculature such as the semimembranosus, sartorius, gracilis, vastus medialis and the medial gastrocnemius in football players. This study suggests that larger turning angles increase muscular activity which may potentially be indicative of an increase in energy demand (Bigland-Ritchie and Woods, 1976). Such research would be relevant to elite football as players' complete turns at angles greater than 90 degrees during games (Bloomfield et al., 2009). No research has looked at measuring EMG activity of turns that include angles greater than 90 degrees. The available studies that have included greater turning angles have tended to be more interested in the general movement pattern associated with turning rather than the demands of the turning component alone.

Directional Change

Stevens et al., (2014), Zamparo et al., (2014), Akenhead et al., (2014), Buglione and Di Prampero, (2013), Hatamoto et al., (2013), Buchheit et al., (2012), Buchheit et al., (2011), Buchheit et al., (2010) and Dellal et al., (2010) completed studies that have looked at all components of directional change simultaneously using turning angles greater than 90 degrees (see table 2.1). These studies attempted to compare and measure the physiological demands of running protocols which involved directional changes, with running based protocols which involved less frequent or no directional changes. The outcome of these studies however are inconsistent with some showing directional changes to cause an increase (Stevens et al., 2014; Zamparo et al., 2014; Akenhead et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Dellal et al., 2010), decrease (Buchheit et al., 2012) or no change (Buchheit et al., 2010) in the physiological responses when compared to less frequent directional changes or solely linear based constant speed running. The discrepancies between the outcomes of these studies may be a consequence of differences with regard to the design of the exercise protocols, particularly the rest period, exercise durations, running distance and speeds applied during testing.

AUTHOR	PARTICIPANTS	PROTOCOL	OUTCOME
Stevens et al., 2014	14 male, amateur, football players	Compared continuous running with 10m shuttle runs, 6 × 3-minute reps, running speed: 2.1 – 2.7m/s.	Increased energy cost for shuttle running. Faster running speed further increased energy demand.
Zamparo et al., 2014	9 male, amateur, basketball players	Compared different turning angles (45, 90 & 180 degrees) which were included over 20m shuttle runs. Also compared different shuttle run distances (5, 10 & 25m), 10 × 10-second reps, running speed: 120% of ventilatory threshold.	No difference between turning angles completed over 20m shuttle runs. Increased energy cost and blood lactate for longer distance shuttle run (25m) when compared to shorter shuttle run distances (5m & 10m).
Akenhead et al., 2014	10 male, professional, football players	Compared continuous running with 60, 30 & 20m shuttle runs, 4 sets of 600m (total distance), running speed: 2.5, 3.25 & 4m/s.	Increased physiological demand for shuttle running. More frequent shuttle runs increased blood lactate, RPE and HR. Faster running speed further increased the physiological demand.
Buglione and Di Prampero, 2013	65 male, professional and amateur, various sports	Compared continuous running with 10m & 20m shuttle runs, 4 - 6 minute reps, max running speed: 4.4m/s.	Increased energy cost for shuttle running. More frequent 180 degree directional changes (10m shuttle runs) had greatest energy cost. Faster running speed further increased energy demand.
Hatamoto et al., 2013	10 male, amateur, various sports	Compared different shuttle runs over 3, 3.6, 4.5, 6 & 9m distances, 5 × 5-min reps, running speed: 1.19 & 1.5m/s	Increased energy cost for shortest shuttle run (3m) (most frequent 180 degree directional changes). Faster running speed further increased energy demand.
Buchheit et al., 2012	12 male, regional & national level, team sports	Compared different turning angles (no turn, 45, 90 & 135 degrees), 6 reps over 17.6 - 25m distance with 25s rest in between, running speed: max effort.	Including a turning angle half way did not increase the physiological response. No directional change (no turn, 25m distance) increased HR, blood lactate and RPE response.
Buchheit et al., 2011	10 male, regional level, various sports	Compared continuous running with shuttle runs, 4 × 5-min reps, each protocol included running speeds of: 45, 60, 75 & 90% of VO_{2max}.	Increased energy cost for shuttle running. Team sport players tend to have better running economy during shuttle runs.
Buchheit et al., 2010	13 (unknown), well-trained, team sports	Compared continuous running with runs involving a 180 degree turn, 6 reps covering total distance of 25m with 25s rest in between, running speed: max effort.	No difference in energy cost, blood lactate, HR or RPE response between continuous or directional change running.
Dellal et al., 2010	10 male, amateur, football players	Compared continuous running with shuttle runs at different speeds and durations (10 – 30s reps over 6 – 12 mins), running speed: 100 – 120% VO_{2max}.	Increased physiological demand for shuttle running. Shuttle runs which were completed over the longest duration (30s) at the fastest applied speed (110% VO_{2max}) had the greatest HR, blood lactate and RPE response.

Table 2.1 – Summary table of directional change studies

Studies which found a decrease or no change in physiological demand as a result of directional change utilised extensive rest periods (25 seconds) between successive short duration repetitions of activity (Buchheit et al., 2012; Buchheit et al., 2010). Both studies by Buchheit et al., (2012) and Buchheit et al., (2010) looked at six maximal effort runs over 25 meters, with 25 seconds rest in between and compared it to similar distance runs which included a single directional change half way (45, 90, 135 and 180 degree turn). Such an approach of including only a single directional change half way, whilst only covering such a short distance, may limit the magnitude of accelerations and decelerations performed. It could be that the approach used by these two studies, which involved a combination of short work durations and short running distances alongside extensive rest periods, were not suitable to elicit a notable change in the physiological response when including directional change during intermittent running based protocols (e.g. HR, blood lactate, oxygen consumption and RPE). In contrast studies that have applied longer duration exercise protocols, without extensive rest periods and included more frequent 180 degree directional changes showed an increase in physiological response (e.g. HR, blood lactate, oxygen consumption and RPE) when compared to running protocols involving less frequent or no directional changes (Stevens et al., 2014; Zamparo et al., 2014; Akenhead et al., 2014; Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Dellal et al., 2010). These findings would be more relevant to elite football as these protocols better represent the activity profiles seen during training or game play. Apart from the duration of the exercise and recovery periods being important variables, Stevens et al., (2014), Akenhead et al., (2014), Hatamoto et al., (2013) and Buglione and Di Prampero, (2013) found that faster running speeds, when used as part of a 180 degree directional change protocol, also increased the physiological demand. The speed at which exercise protocols are completed would therefore seem to be another important variable associated with the exercise stimulus that needs to be controlled. These studies would suggest that the energy cost may increase when greater running speeds are applied as a consequence of increases in the intensity and physical effort required for deceleration, turning and acceleration actions. The maximum speeds used within these studies however were still relatively low compared to those performed commonly by football players (2.8m/s (Stevens et al., 2014), 4m/s (Akenhead et al., 2014), 1.5m/s (Hatamoto et al., 2013) and 4.4m/s (Buglione and Di Prampero, 2013)). It would therefore be of interest to know what the physiological responses are when performing directional changes at faster speeds as this may provide a better representation of football performance.

Only one study to date looked at measuring the physiological demands of directional change when completed at faster speeds as observed in football players (Dellal et al., 2010). Three different running speeds were compared for three different protocol durations (10, 20 and 30 seconds). The results of this study showed that directional changes performed at the fastest speed (110% maximal aerobic speed) and over the longest duration (30 seconds) lead to a significant increase in HR response when compared to linear based constant speed running or running that involved directional changes but over a shorter duration (Dellal et al., 2010). This study further supports the concept that the specific nature of the exercise protocol can influence the cardiovascular response associated with the exercise session. Dellal et al., (2010) data may be criticised on the grounds of a failure to adequately control several important aspects of the exercise protocol that may impact the physiological response. Apart from exercise duration, there was no description of whether or how key variables associated with the movement pattern such as running speed or the intensity of acceleration or deceleration were controlled. This study also manipulated protocols through changes in running speeds and exercise durations. As a result of this approach the frequencies of directional change remained the same and were limited to a maximum of only two or three repetitions for all protocols. This approach will potentially limit the application of the data with respect to the broader physiological understanding of the actual movement pattern, directional change. The reason for this is as the study is focused around manipulating the speed and duration at which directional change protocols are performed and not the actual frequency of the movement pattern.

Although completed at a slower running speed Akenhead et al., (2014) applied a more controlled approach when looking at the demands associated with 180 degree directional changes in elite football players. This study is the only investigation to also look at the external load associated with performing such movement patterns. The results showed that external load did not significantly increase alongside an increase in frequency of directional changes. This may have been due to the relatively slow movement speeds (max speed 4m/s) which could have limited the intensity of accelerations and decelerations performed and hence its impact on the overall external load. Further there was no mention as to whether or how deceleration was controlled. Both the low speed of movement and the lack of control with regard to the deceleration component may potentially explain why there was no significant change in external load found within the study. The physiological demands however did increase alongside an increase in frequency of directional change (blood lactate and HR) (Akenhead et al., 2014). Although the authors concluded that this was likely due to an increase in time spent accelerating their interpretation does not consider the possible impact that both the deceleration and turning component of directional change may have had on the overall physiological response. It may therefore be inaccurate to conclude that only the acceleration component was responsible for an increase in the physiological demand. There remains a need for research which applies greater control when investigating the demands associated with directional change. No studies have looked at the relationship between external load and physiological response, during intermittent exercise involving change of direction when completed at faster running speeds relevant to the elite game. Such research would add to the understanding of performing such movement patterns and may potentially allow for a greater planning of the physical stimulus within an elite football players training week.

Summary

Elite football games require a high energy demand. Constant speed movement such as HIR only accounts for a small percentage of the game distance and time, suggesting that other factors may play a key role in contributing to this demand. Changes in a player's movement pattern, more specifically, directional change, typically involve deceleration, turning and acceleration movements. These activities occur far more frequently than HIR efforts during a game. The current literature suggests that an increase in braking forces, EMG activity and the overall physiological demands, could be associated with directional change when compared to linear based constant speed running. This may suggest that such movement patterns are an important aspect of the high energy demands associated with match-play and training. Studies which have examined directional change and compared it to protocols which involved less frequent changes in direction or just linear based constant speed running have provided inconsistent data. This may largely be due to the variation in protocol design and the inability to create a common strategy that allows the movement pattern, directional change, to be isolated, manipulated and compared. There seems a need for the completion of research projects which apply faster running speeds and use greater control during protocols that manipulate the number of changes in direction. Such studies would provide more precise and relevant feedback regarding the demands associated with performing such movement patterns. Knowing the external load and physiological demands associated with directional change when performed at a faster running speed may allow for more effective and optimal planning of the physical stimulus throughout the training week of elite football players.

Chapter 3

The occurrence of directional change during a typical training week and its influence on the physiological responses in elite football players

3.1 Introduction

Football is a sport which involves constant changes in movement during game play (Reilly, 2003). Such changes in movement include movement patterns such as directional change which consist of; deceleration, turning and acceleration movements, all of which have been shown to occur frequently during elite games (Akenhead et al., 2013; Bloomfield et al., 2007; Tang, 2012 unpublished). Performing directional change is different to linear based constant speed running and may contribute to the high overall energy demands associated with football at an elite level. Despite players spending a considerable greater amount of time training, no research has attempted to determine the occurrence of directional change within an elite team's typical training week. There is therefore a need to identify the frequency of such movement patterns during training and to further understand both the external load and physiological demands such movement patterns potentially place on elite football players throughout the training week.

Research has indicated that directional change may alter the external load placed on elite football players (Schot et al., 1995). One potential difference between directional change and more constant speed straight line running is the increase in "forces" acting on players whilst performing such movement patterns. Regardless of this, research which has attempted to measure the external load associated with directional change is limited. Although there is a lack of research on the external load associated with directional change, several studies have looked at the physiological demands associated with performing such movement patterns (Stevens et al., 2014; Zamparo et al., 2014; Akenhead et al., 2014; Buglione and Di Prampero, 2013; Buchheit et al., 2010; Buchheit et al., 2011; Buchheit et al., 2012; Dellal et al., 2010 and Hatamoto et al., 2013). Such studies have showed an increase (Buglione and Di Prampero, 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Dellal et al., 2010), decrease (Buchheit et al., 2012) or no change (Buchheit et al., 2010) in the physiological response, when compared to protocols which involved less frequent directional changes or solely linear based constant speed running (e.g. HR, blood lactate, oxygen consumption and RPE). Despite this research there is a difficulty in drawing conclusions regarding the exact physiological demands associated with directional change as investigations have provided conflicting data, as a consequence of a failure to provide a clear basis with which to compare between the protocols of various studies.

Therefore there remains a need for research which examines the external load and subsequent physiological responses associated with directional change in elite football players. Such investigations may be performed through monitoring players within their specific training environment. The move to the delivery of more specific training stimuli within the preparation programmes of players provides an opportunity to evaluate these activities in terms of their ability to produce an adaptive signal. Football-specific training sessions which involve drills that use smaller playing area and fewer participants tend to be higher in movements relevant to directional change such as accelerations and decelerations when compared to larger playing areas which involve more participants (Gaudino et al., 2014; Hodgson et al., 2014). This manipulation of space to fulfil specific training objectives at various stages of the preparation period may provide an opportunity to investigate the impact of changes in direction on the physiological responses to intermittent exercise. A study which therefore looks to compare sessions with small playing areas and fewer participants compared with larger playing areas and more participants may provide an insight in to the external load and physiological responses associated with movement patterns such as directional change. Such an investigation may not only enhance the understanding of performing directional changes but it may also allow for more effective planning of the physical stimulus within an elite players training week.

The aims of this study are to:

Investigate the occurrence of directional change within an elite football team's typical training week.

Determine the external load and subsequent physiological demands associated with performing directional changes.

3.2 Methodology

General study design

The current study monitored a typical four day training week of an elite academy's youth team. The external load associated with this training was measured to evaluate the relationship between movement pattern (directional change) and the physiological responses. The data collected was used to test the hypothesis that the session which involved the greatest number of directional changes would show the highest external load and as a consequence an increase in the physiological responses to the exercise.

Participants

From the eighteen participants who attended the initial training session, five completed all of the four training days throughout the typical training week. All participants were male, full-time players (age: 17 ± 0 years, weight: 74.4 ± 8.4 kg, height: 1.8 ± 0.3 m) playing at U18 level for an English Premier League football club at the time of testing. Each participant was training full time consistently and did not have a history of cardiovascular disease or any form of injury or medical condition that may have impeded his performance in any way throughout the training week. All participants were training and/ or playing games at least 5 days per week and had at least 6 months experience of being in a full-time training environment at a Premier League club. Participants also had at least 12 months experience of providing post-training subjective feedback through the modified Borg scale and had been familiar with wearing monitoring equipment such as GPS and HR monitors for at least 12 months prior to taking part in this study. Approval by the Liverpool John Moores University Ethical Board was obtained prior to testing.

Experimental procedure

Participants were monitored in-season, during four consecutive training sessions, within a typical training week. Each session took place at the same time of day (between 10:30am and 12 noon). All monitoring was undertaken at the same training facility on one of two grass playing fields located adjacent to each other. Throughout the duration of the study participants were prohibited from undertaking any form of activity other than their typical field and gym sessions which they undertook at the club.

Each days training was ascribed an identity tag that identified the session's location in the match preparation strategy for that week (i.e. the number of days prior to the game it took place). For instance the training session which occurred four days prior to game day was labelled "-4" and so forth. Two of the four training days (-4 and -3) incorporated specific guidelines within the session with regards to area size and the number of participants used in each drill. During the training session on -4 coaches used drills which involved smaller playing areas and fewer participants (four participants or less per team). For the -3 training session coaches used drills which involved larger playing areas and more participants (six participants or more per team). Drills used during the -2 and -1 day sessions did not follow any specific guidelines and involved a mixture of area sizes and participants per team.

GPS with integrated accelerometer, HR monitors and the modified Borg Scale were used on each training day to determine the frequency of accelerations and decelerations (directional changes), external load, physiological demands and the perceived exertion associated with each session.

Experimental Measures

All GPS with integrated accelerometer and HR monitor units were fitted to participants five minutes before the session was due to start on each training day. Each participant wore a 5 hertz (Hz) GPS unit (Statsports, Ireland), which was positioned between the scapulae, using a tightly fitted, secured vest. Before fitting, each unit was placed outside on the training field for 20 minutes prior to warm-up. This helped ensure that all units had found an accurate GPS signal and were recording once training commenced. The variables obtained from GPS included the total number of deceleration and acceleration entries and HIR distance. Accelerations and decelerations were recorded in meters per second squared (m/s/s), where an increase or decrease in speed took place for at least 0.5 seconds (Statsport Technologies, 2012). As GPS is unable to measure directional change or the turning component, acceleration and deceleration were used to signify changes in movement pattern relevant to changing direction. Despite a lower recording frequency (5Hz), GPS was chosen to measure the occurrence of directional change instead of ACC (100Hz). GPS has previously been shown to be a practical tool for monitoring the movement of football players (Domene, 2013; Randers et al., 2010). GPS was selected instead of ACC as changes in body position during play may alter the accelerometers position which can make it difficult to identify g-force entries specifically associated with directional changes. The use of HIR relies on the categorisation of activity using a speed zone approach and is defined as the total distance (in meters) covered at a speed which is equal to or greater than 5.5m/s (Statsport Technologies, 2012). High intensity running is commonly used as a marker of intensity during performance in football (Di Salvo et al., 2013; Di Salvo et al., 2007; Mohr et al., 2003; Bangsbo et al., 1991). In the current study HIR was used as an indicator of intense constant speed running activity.

One hundred Hz three-dimensional (3-D) accelerometers (that were built in to the GPS units) were used to measure the external load acting on participants during each training session. The accelerometers were used to measure the external load acting on participants through gravitational force (g-force) in the vertical, medial-lateral and anterior-posterior planes (Statsport Technologies, 2012). Dynamic stress load (DSL) was the variable used to represent the total magnitude of g-force acting on players, in all planes, throughout each training session. Dynamic stress load is a value which measures accelerations above 2g, to which a fixed weighted score is assigned (Statsport Technologies, 2012). As a consequence of this algorithm greater magnitudes of acceleration are associated with greater values of DSL (Statsport Technologies, 2012). Accelerometers were chosen to determine the external load associated with each training session as they have been shown to be a reliable tool for monitoring physical activity in team sports (Barrett et al., 2014; Cormack et al., 2014; Scott et al., 2013; Boyd et al., 2011).

Heart rate monitors (Polar, Finland), which have previously been used to monitor the physiological responses during football (Randers et al., 2014; Aslan, 2013; Castellano et al., 2013) were also worn. These devices were moistened, placed in direct contact with the skin and secured tightly under the chest using a tight fitting strap. Maximal heart rate (HR_{max}) was obtained prior to the current study for each participant through monitoring participants HR over a minimum duration of 12 months during games, training sessions and maximal endurance tests such as the Yo-Yo intermittent recovery test level 2 (Bangsbo et al., 2008). The HR response to the training sessions was reported using heart rate exertion (HRE). Heart rate exertion is a weighted score which represents the total volume of cardiovascular exertion participants experience during exercise relative to time. A weighting function enables the recorded HRs' to be compared to each participant's individual HR_{max}. The closer the recorded HRs' are to the HR_{max} the greater the associated weighting score applied (Statsport Technologies, 2012). Each of the resulting weighting scores is then multiplied by the duration of exercise (in seconds) for which the HR was elevated to this level. These individual band scores are then totalled to provide an overall HRE score for the entire exercise duration (Statsport Technologies, 2012). In the current study HRE was used as an indication of the physiological demands placed on participants throughout each training session.

Participant's rate of perceived exertion was collected at five minutes after each training session through a modified version of the Borg Scale (Foster et al., 1995) (see appendix A). This data was used to determine participants perceived level of difficulty of each training session. This scale was applied as it has previously been shown to be an effective method for collecting subjective feedback regarding the internal training load in football players post exercise (Impellizzeri et al., 2004).

Statistical Analyses

All data were tested for normality using the Shapiro-Wilk test. All dependent variables, with the exception of RPE, were shown to be normally distributed ($p > 0.05$). A separate one-way repeated measures ANOVA was used to determine the effect that each training day had on the following dependent variables – deceleration entries, acceleration entries, HIR distance, DSL, HRE and RPE. A significance level of $p < 0.05$ was applied throughout. Where a main effect was found a post hoc test was used ($p < 0.05$) to find where the significant differences occurred for each dependent variable. Although RPE was not statistically shown to be normally distributed, upon taking a closer look at the data it was considered suffice to run a parametric test such as a repeated measures ANOVA as suggested by Hopkins (2013). A Pearson's correlation was used to determine a potential relationship between two dependent variables.

3.3 Results

Figure 3.1 shows the mean ± standard deviation (SD) deceleration, acceleration and total deceleration and acceleration entries for each training day. A significant difference in mean scores for deceleration ($F = 19.25$, $p < 0.05$) and acceleration ($F = 16.70$, $p < 0.05$) entries were found. The mean deceleration (515 ± 36) and mean acceleration (556 ± 44) entries for the –4 day training session were found to be significantly higher than any other training day ($p < 0.05$), suggesting that the most directional changes may have been performed during this session. The -1 day training session showed the lowest mean ± SD number of decelerations (290 ± 56) and accelerations (324 ± 64) across the training week.

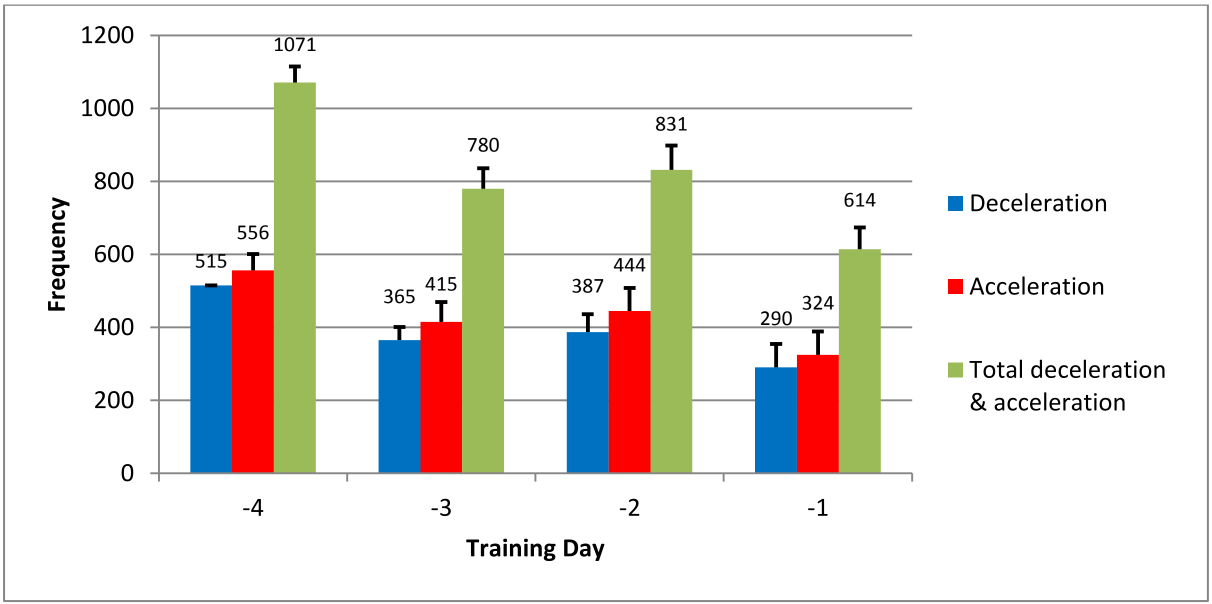

Figure 3.1: Comparison of the mean ± SD frequency of deceleration, acceleration and total deceleration and acceleration for each of the training days included in the sample of training sessions.

Figure 3.2 shows the mean ± SD HIR distance completed during each training day. A significant difference in mean scores for HIR distance ($F = 50.72$, $p < 0.05$) was found. The results collected showed that HIR was significantly greater on training day -3 (515 ± 134m) when compared to all other training days ($p < 0.05$). Mean ± SD HIR was lowest for the session completed on the -4 training day (48 ± 20m).

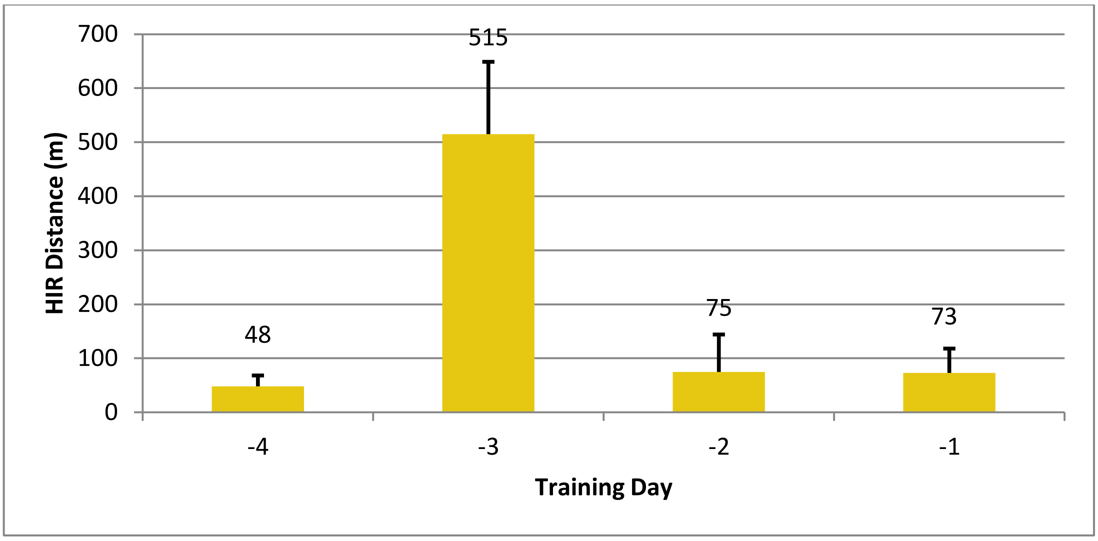

Figure 3.2: Comparison of the mean ± SD HIR distance associated with each of the training days included in the sample of training sessions.

Figure 3.3 shows the mean ± SD DSL score for each training day. A significant difference in mean score for DSL ($F = 9.22$, $p < 0.05$) was found. The -4 training day was associated with a higher mean ± SD DSL (245 ± 79) than all other training days. Dynamic stress load on the -4 training day was significantly higher than the -2 and -1 training days ($p < 0.05$), but not significantly different to the value observed on -3 (159 ± 32) ($p < 0.05$). The -1 day DSL value was the lowest value observed (127 ± 42).

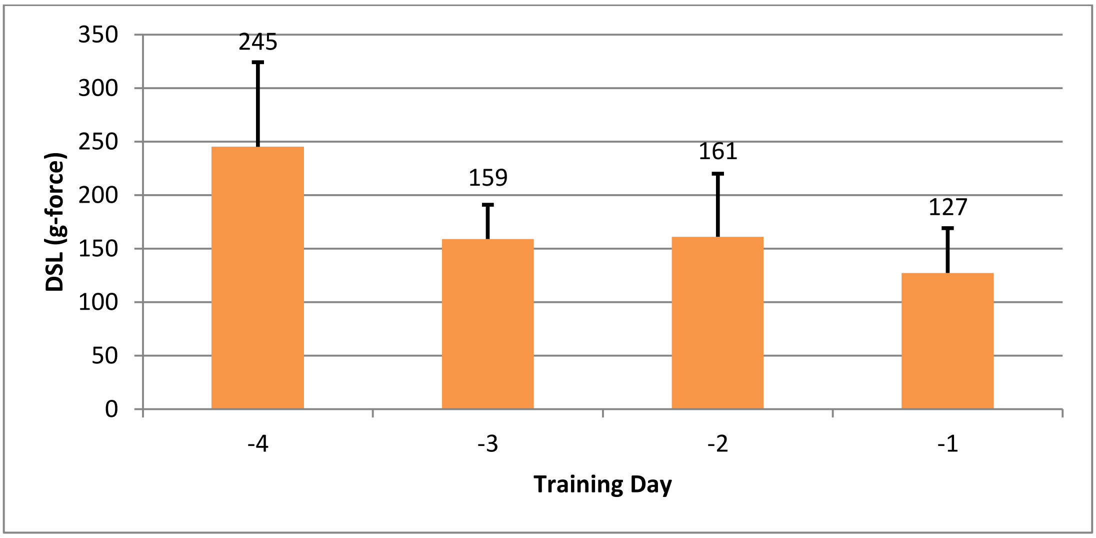

Figure 3.3: Comparison of the mean ± SD DSL associated with each of the training days included in the sample of training sessions.

Figure 3.4 shows the mean ± SD HRE scores for each training day. A significant difference in mean score for HRE ($F = 7.54$, $p < 0.05$) was found. Mean HRE was greatest for the -4 training session (205 ± 55) and was found to be significantly higher when compared to any other training day ($p < 0.05$). In a similar way to most other results associated with this data collection the -1 training day showed the lowest mean ± SD HRE score (122 ± 15). A positive high correlation was found between DSL and HRE ($r = 0.50$, $p < 0.05$).

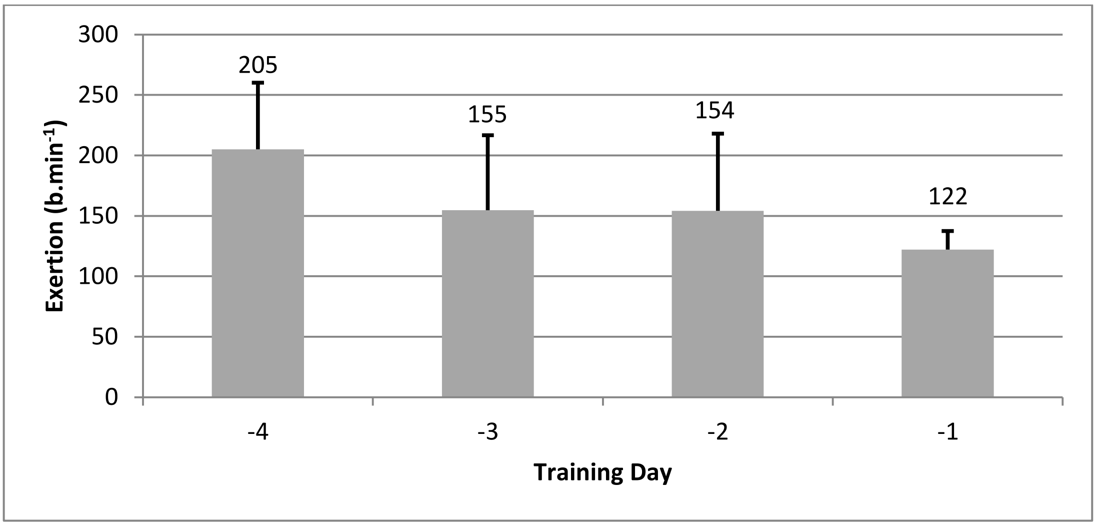

Figure 3.4: Comparison of the mean ± SD HRE associated with each of the training days included in the sample of training sessions.

Figure 3.5 shows the mean ± SD RPE for each training day, as measured through the modified Borg Scale. A significant difference in mean score for RPE ($F = 13.90$, $p < 0.05$) was found. Although the -4 training day had the highest mean RPE score (5 ± 1) it was not significantly different to the -3 and -2 training days ($p < 0.05$). The -1 training day showed the lowest mean RPE score (3 ± 0). This value was significantly lower than that recorded on any other training day ($p < 0.05$). A positive high correlation was found between between DSL and RPE ($r = 0.67$, $p < 0.01$).

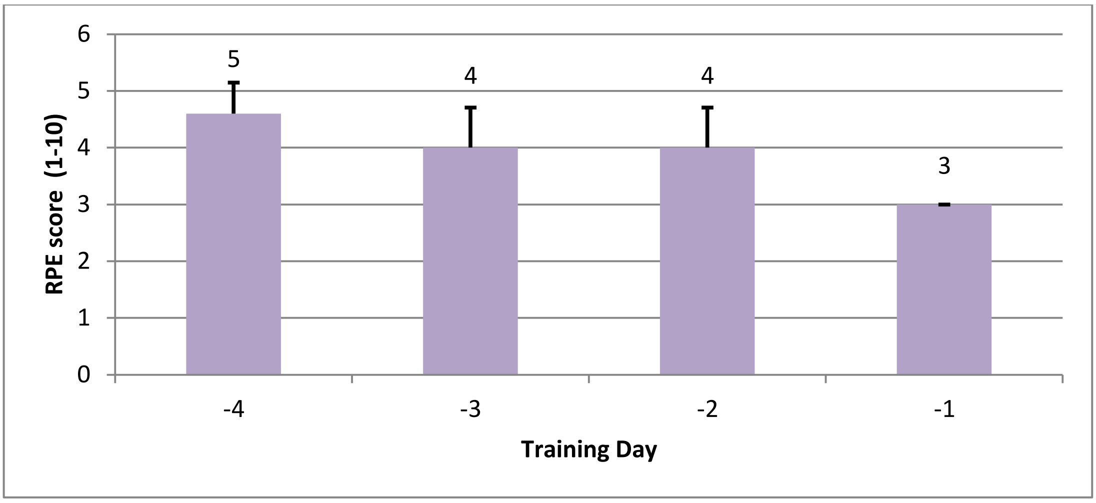

Figure 3.5: Comparison of the mean ± SD RPE associated with each of the training days included in the sample of training sessions.

3.4 Discussion

The objective of this study was to identify the occurrence of accelerations and decelerations (directional change) during an elite football team's typical training week. This data would then be used to compare the physiological responses of sessions that were high in accelerations and decelerations with those that were significantly lower. External load was monitored through ACC and was used to provide an indication of the overall "forces" acting on players throughout each session. The data showed that the session which involved the most frequent accelerations and decelerations resulted in a greater external load being placed on participants when compared to all other training days. Although this increase was not found to be statistically significant it was shown to have a positive high correlation with both HRE and RPE suggesting that an increase in external load may be linked to an increase in physiological response. The physiological response as measured through HRE was found to be significantly greater for the session that involved the highest frequency of accelerations and decelerations. Participant's subjective response also increased for the session which involved the most frequent accelerations and decelerations but similar to the external load this increase was not found to be statistically significant. This data suggests that training sessions which involve more frequent accelerations and decelerations (directional changes) may lead to higher physiological responses than sessions which involve fewer frequencies of directional change.

This study is the first to monitor the occurrence of directional change, through measuring the frequency of accelerations and decelerations performed, during an elite football teams' typical training week. As GPS is unable to measure directional change or turning, both the acceleration and deceleration components of the movement pattern were chosen to represent the incidence of such actions. The results showed that the frequency of accelerations and decelerations were significantly higher for -4, which applied smaller spaces and fewer participants, when compared to any other training day session. This finding lies in accordance with previous research which showed that smaller playing areas, which involve fewer participants, are higher in movements relevant to directional change (accelerations and decelerations), when compared to larger playing areas that involve more participants (Gaudino et al., 2014; Hodgson et al., 2014). This is further supported in the current data which showed that the -3 training session, which used larger spaces and more participants, resulted in significantly less frequent accelerations (-25%) and decelerations (-29%) than the -4 day. Despite including fewer directional changes in the session, -3 involved participants covering a significantly greater constant speed running distance, as indicated through HIR (+85-91%), than any other training day. This finding would also support the concept that training sessions' which utilise larger spaces result in a requirement for players to complete more HIR. The design of the current training week would therefore seem to allow for a comparison of the physiological responses for sessions that include frequent changes in direction and those that include less frequent changes in such movement patterns but involve more constant speed HIR.

In order to show a difference between sessions, external load was monitored through DSL. Although the mean external load as measured through DSL was highest for the -4 session when compared to all other training sessions, it was not found to be significantly greater than the DSL on -3. Despite this failure to illustrate a greater external load, HRE was significantly greater for the -4 training session when compared to all other training days. The RPE also increased alongside HRE for -4 but it was not found to be significantly greater than the -3 or -2 training sessions. The current results suggest that sessions which involve more frequent changes in movement pattern, such as directional change, may have a greater physiological response, as measured through HR, than sessions which involve less frequent directional changes despite having a far greater constant HIR distance.

The conclusions that can be drawn from the data provided in the current investigation must be viewed in the context of several limitations. These limitations include the data collection process and the general study design. One limitation is that the current study does not measure directional change directly. Limitations in technology utilised to measure movements means that the data is limited to making assumptions about the occurrence of directional changes by assessing the frequency of accelerations and decelerations. It is clear that these accelerations and decelerations may not accurately represent changes in direction as such changes in the velocity of movement are possible while moving uni-directionally. The ability of the GPS system to accurately measure accelerations and decelerations may also be questioned. Previous research which has promoted the use of GPS for looking at accelerations and decelerations has looked at units with a recording frequency of 10 Hz (Akenhead et al., 2013). The current study used 5 Hz units which may have limited the level of accuracy regarding the frequency of accelerations and decelerations recorded during each session (Varley et al., 2012). A second limitation is the number of participants used in the study. Due to the rotation of players between different squads, only five participants of an original sample size of eighteen took part in all sessions throughout the training week. A larger sample size may have increased the accuracy of the data and possibly altered the statistical outcome of results, such as DSL, which was almost within significance level when comparing -4 to any other training session day. Perhaps the greatest limitation however is the influence of extraneous variables associated with each training session, due to a lack of control, which may have affected the data collected during training. Dynamic stress load may have been altered during sessions due to actions other than deceleration, turning or acceleration; such as bodily contact between players or players coming in contact with the ground. The cardiovascular and subjective responses may also have been influenced by other variables associated with the training over and above the changes in direction. Such variables include the amount of recovery time and stoppages in play made by coaches throughout the session or the involvement of participants with or without the ball during different drills. Such factors have been shown to influence the cardiovascular response to exercise (e.g. Reilly and Ball, 1984). These limitations all have the potential to impact the validity of the data and as a consequence the conclusions that can be made regarding the influence of directional change on the physiological responses to the exercise. This highlights the need for protocols that apply greater control of extraneous exercise variables when attempting to determine the external load and physiological demands associated with performing movement patterns such as directional change.

The current investigation is the first study to show that movements relevant to directional change (accelerations and decelerations) occur frequently throughout each session of an elite football team's typical training week. The data collected also indicates that the training session which included the highest frequency of accelerations and decelerations elevated the physiological responses associated with the exercise the greatest, when compared to sessions which involve such less frequent movements. This study however includes several important limitations which could potentially influence both the external load and physiological responses investigated in this study. As a result of these limitations there would seem to be a need for a more thorough investigation which attempts to use a more controlled approach when trying to determine the demands specifically associated with directional change. Such a study should focus on comparing carefully controlled protocols where only the frequency of directional change is manipulated. Applying such an approach would allow for a more precise interpretation regarding the external load and physiological demands associated with performing such movement patterns in elite football players.

Chapter 4

The influence of frequency of directional change as performed during controlled intermittent exercise protocols on the physiological responses in elite football players

4.1 Introduction

The first investigation in this thesis attempted to measure the occurrence of directional change by measuring the frequency of accelerations and decelerations throughout each session, during a typical training week. Both the external load and the subsequent physiological responses associated with these training sessions were monitored and compared. While the data from this investigation demonstrated that movements relevant to changing direction (accelerations and decelerations) occur frequently throughout every training session, there were a number of limitations associated with the study. These limitations were related to both means of data collection and a lack of experimental control. This included the inability of GPS to measure directional changes directly, the small sample size and the failure to control variables associated with training that may have impacted both the external load and/or the physiological response. There is therefore a need for a study which produces more precise data regarding directional change through carefully controlled protocols.

Previous studies which have looked at directional change have found such movement patterns to cause an increase (Stevens et al., 2014; Zamparo et al., 2014; Akenhead et al., 2014; Buglione and Di Prampero et al., 2013; Hatamoto et al., 2013, Buchheit et al., 2011; Dellal et al., 2010) decrease (Buchheit et al., 2012) or no change (Buchheit et al., 2010) in the physiological response when compared to running which involved less frequent directional changes or solely linear based running. Most of this research has looked at directional changes which include 180 degree turns (Stevens et al., 2014; Zamparo et al., 2014; Akenhead et al., 2014; Buglione and Di Prampero et al., 2013; Hatamoto et al., 2013; Buchheit et al., 2011; Buchheit et al., 2010; Dellal et al., 2010). Although these turning angles occur less frequently in elite football when compared to smaller turning angles (Bloomfield et al., 2007), they do potentially allow for greater control of all the components of movement (deceleration, turning and acceleration) when investigating directional change from a research perspective. As such they represent the most effective model for investigating research questions associated with changes of direction.

Despite the current research however it remains difficult to conclude with any certainty the exact physiological demands associated with changing direction due to the variation in protocol design and their failure to provide a clear and common methodological basis with which to compare data. Apart from variation in the experimental approach, such studies have also often failed to control extraneous training variables which may carry the potential to influence the training response. These limitations reiterate the need for further research which attempts to compare similar, carefully controlled protocols which look at different frequencies of directional changes. Such a study would ideally be the first to look at a faster running speed that is relevant to elite football performance.

The aim of this study is to:

Investigate the external load and subsequent physiological demands of controlled intermittent protocols of different frequencies of directional change in elite football players.

4.2 Methodology

General study design

The current study compared three testing protocols which involved varying frequencies of directional change. Prior to undertaking any of the three testing protocols participants were required to attend a screening session in order to determine whether they were able to take part in the study. If considered eligible, participants completed a familiarisation session to enable them to become acquainted with the key characteristics of the protocols (e.g. running speed and turning). Testing involved measuring the external load associated with each of the three protocols in order to evaluate the relationship between directional change and the physiological responses. The data collected from this study were used to analyse the hypothesis that an increase in number of directional changes would alter the external load and as a consequence the physiological response associated with the activity.

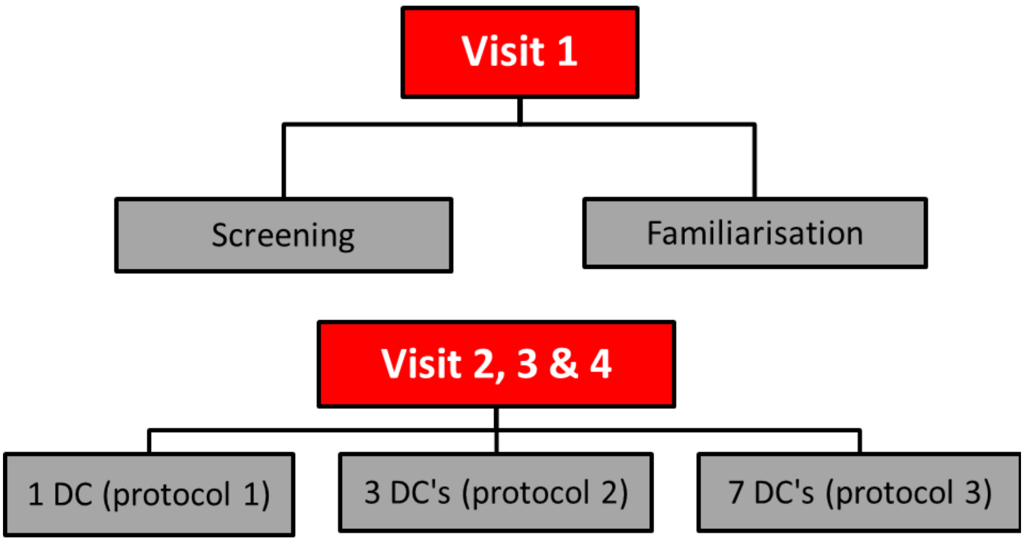

Figure 4.1: General study design. Participants were required to visit the testing centre on four separate occasions. The first visit involved screening and if considered eligible, the completion of a familiarisation session. The three remaining visits involved participants undertaking protocols which involved one, three or seven directional change(s) (DC).

Participants

Thirteen male, elite full-time football players took part in the study. All participants (age: 18 ±1 years, weight: 79.5 ± 7.0 kg, height: 1.8 ± 0.5 m) were playing at U18 or U21 level for an English Premier League football club at the time of testing. Participants were excluded if they were not training full time consistently, had a history of cardiovascular disease or any form of injury or medical condition that may have impeded their performance in any way throughout the duration of the study. All players were training and/ or playing games at least 5 days per week and had at least 12 months experience of being in a full-time training environment at a Premier League football club. Participants also had at least 12 months experience of providing post-training subjective feedback through the modified Borg scale and had been familiar with wearing GPS and HR monitors for at least 12 months prior to taking part in this study. All participants completed informed consent prior to taking part in the study (see appendix D). Approval by the Liverpool John Moores University Ethical Board was obtained prior to testing.

Pre-Testing procedure

During the first visit all participants were screened using a Physical Activity Readiness Questionnaire (PAR-Q) (See appendix B). Once players were considered fit to participate they were familiarised using a modified version of the testing protocol. All participants (n = 13) completed at least one familiarisation session. The familiarisation protocol required participants to accelerate in a straight line to a speed of 6 meters per second (m/s) over a distance of 36 meters. Speed was controlled using a high pitch audio signal that played every second from an MP3 player (JVC model no: CA-UXLP5). This feedback provided participants an indication of where they were required to be at a given time throughout the shuttle run. Cones were placed precisely six meters apart along the track to enable participants to evaluate their position. Upon reaching the 36 meter mark a red cone and a double audio signal acted as an indicator for participants to decelerate (over a distance of 2 meters) before coming to a stop and turning with both feet behind a marked line (also marked using a second red cone) (see figure 4.2). The double audio signal was followed by a single audio signal after a 1.5 second delay, which acted as an indicator for participants to re-accelerate to a speed of 6m/s and return to the starting point. The 1.5 second delay was applied as pilot work using speed gates (Brower, USA) indicated that this was the mean time it took for participants to decelerate, turn and get to the starting point for the second shuttle run. All familiarisation and testing protocols were carried out on an outdoor synthetic all-weather surface (Ligaturf 240 RS+, Germany).

Figure 4.2: Familiarisation and testing area

Experimental procedure

All testing was completed in-season, on three separate occasions, between 9:30am and 10:30am, prior to training. Each of the three testing sessions was at least one week apart. During the duration of the study participants were prohibited from playing games, training or gym activity within the 48 hours preceding testing. They were also prohibited from participating in any form of physical activity prior to undertaking one of the protocols on any of the testing days. Participants were permitted to take part in club organised gym activity, training and games at any stage outside of the mentioned time periods. On each day of testing participants were separated in to three groups and assigned to one of the three testing protocols using a randomised order.

Common to all three testing visits was a standardised dynamic warm-up which was designed to prepare all participants for any of the three testing protocols. The 6-minute warm-up involved multi-directional movement, dynamic movements and accelerations over a 20 × 8 meter area (see Appendix D). A standard rest period of at least four minutes between warm-up and data collection was consistently applied for all testing sessions. All three testing protocols followed the same procedure as the familiarisation protocol. The testing protocols included one, three or seven change(s) of direction (see figure 4.3) over a total distance of 144 meters (not including deceleration zone). The time taken to complete the one, three and seven directional change protocols was 25.5, 28.5 and 34.5 seconds respectively. Once participants had completed the testing protocol they were immediately seated on a bench next to the testing area for five minutes after which their RPE was recorded.

GPS with integrated accelerometer, HR monitors and subjective feedback were used on each testing day to determine the external load, physiological demands and the perceived exertion associated with each directional change protocol.

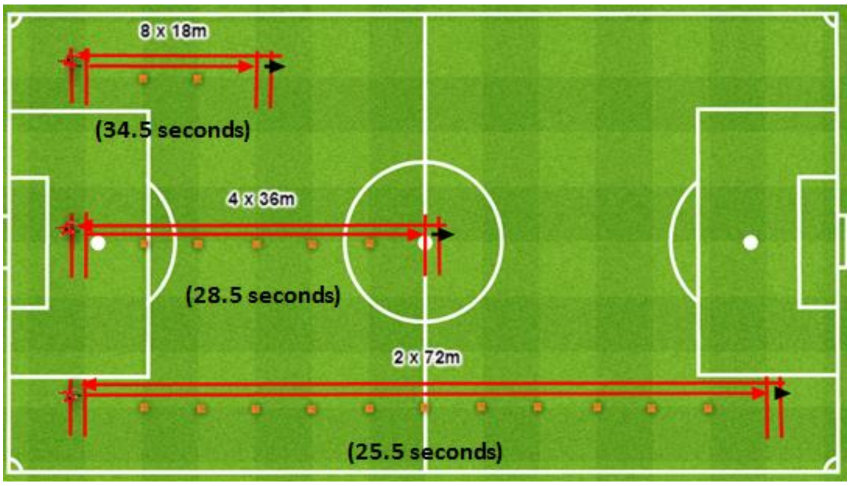

Figure 4.3: Diagrammatic representation of the three testing protocols. Each protocol included one (2 × 72m), three (4 × 36m) or seven (8 × 18m) 180 degree directional changes. The distance of each of the specific shuttle runs decreased as the number of directional changes increased. The duration of each protocol also differed due to the 1.5 second delay allocated for each turn. All testing protocols had a total running distance of 144 meters (excluding the 2 meter deceleration zones).

Experimental Measures

All GPS and HR monitor units were fitted to participants five minutes before the warm-up on all testing days. Each participant wore a 5Hz GPS units (Statsports, Ireland), which was positioned between the scapulae, using a tightly fitted, secured vest. Before fitting, each unit was placed outside on the testing area for 20 minutes prior to warm-up. This helped ensure that all units had found an accurate GPS signal and were recording once testing commenced.

The external load acting on participants throughout each protocol was measured in gravitational force (g-force) using a 100Hz 3-D accelerometer built in to each GPS unit (see chapter 3, section 3.2). Each impact in the vertical, medial-lateral and anterior-posterior plane was measured through accessing the raw data of the accelerometer. The total sum of negative and positive impacts in all three planes, was then calculated and used to represent the total magnitude of external load acting on participants throughout each protocol. Analysing the accelerometer data in such a way ruled out the use of algorithm, which in turn provided a more direct representation of the data regarding the g-forces acting on participants throughout each testing protocol.

The variable obtained from GPS was HIR distance (m) (see chapter 3, section 3.2). HIR was measured in the current study to determine the linear based constant speed running distance completed throughout each testing protocol.

Heart rate exertion and peak heart rate (HR_{peak}) were used to measure the cardiovascular demands placed on participants throughout each testing protocol. Heart rate exertion was calculated as previously outlined (see chapter 3, section 3.2) in order to determine the total magnitude of cardiovascular stress experienced by participants throughout the duration of each testing protocol. To measure HRE participants HR_{max} needed to be identified. As previously outlined this was taken based on data collected prior to this study over a minimum period of 12 months (see chapter 3, section 3.2).

Subjective feedback was collected through the modified version of the Borg Scale (Foster et al., 1995) for reasons previously outlined (see chapter 3, section 3.2). Participant's scores were recorded at five minutes post testing having rested in a seated position at the testing location.

Statistical Analyses

All data were tested for normality using the Shapiro-Wilk test. All dependent variables, with the exception of HRE and RPE, were shown to be normally distributed ($p > 0.05$). A one-way repeated measures ANOVA was used to determine the effect that each testing protocol had on the following dependent variables – total g-force, HIR distance, HRE and RPE. A significance level of $p < 0.05$ was applied throughout. Where a main effect was found a post hoc test was used ($p < 0.05$) to find where the significant differences occurred for each dependent variable. Although HRE and RPE were not statistically shown to be normally distributed, upon taking a closer look at the data it was considered suffice to run a parametric test such as a repeated measures ANOVA as suggested by Hopkins (2013). A Pearson's correlation was used to determine a potential relationship between two dependent variables.

4.3 Results

Figure 4.4 shows the mean ± SD g-force recorded for each protocol using the raw data from the accelerometer. A significant difference in mean score for g-force ($F = 496.50$, $p < 0.05$) was found. The protocol which involved seven directional changes showed the highest mean ± SD g-force (8628 ± 1630g) which was significantly higher than both protocols which involved either three or one directional change(s) ($p < 0.05$). The protocol which involved three directional changes was significantly higher in terms of g-force than the protocol which involved one directional change (5888 ± 1159g) ($p < 0.05$).

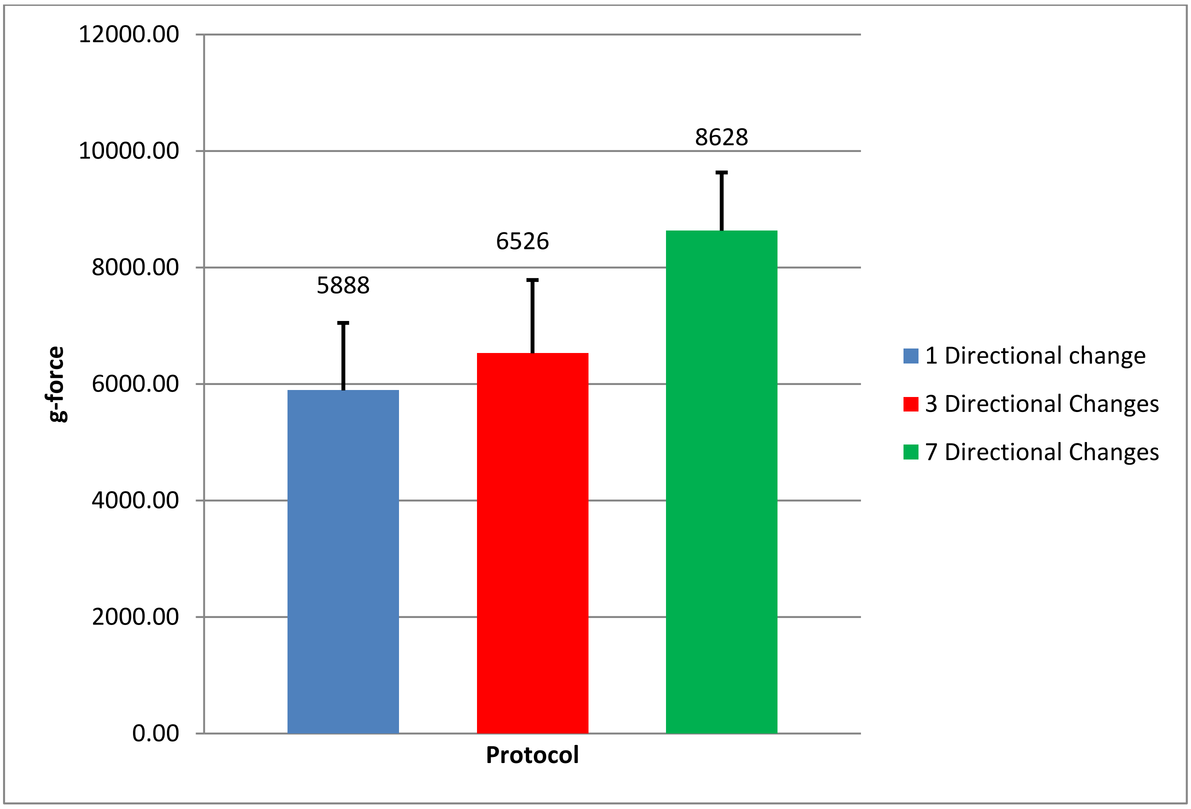

Figure 4.4: Comparison of the mean ± SD g-force associated with each of the protocols included in the sample of testing sessions.

Figure 4.5 illustrates the total mean ± SD HIR distance covered in each protocol. A significant difference in mean score for HIR distance ($F = 88.49$, $p < 0.05$) was found. The protocol which involved one directional change had the highest mean HIR distance (104 ± 11m). This equated to around 72% of the total distance covered. The protocol which involved three directional changes had a mean HIR distance of 101 ± 9m (70% of the total distance covered). The protocols which involved one or three directional changes did not differ significantly in terms of HIR distance ($p > 0.05$). Both of these protocols did, however, produce a significantly higher mean HIR distance than the protocol which involved seven directional changes ($p < 0.05$). This protocol produced a mean HIR distance of 56 ± 15m which equated to only 39% of the total distance covered. There was a negative high correlation between g-force and HIR ($r = -0.69$, $p < 0.01$).

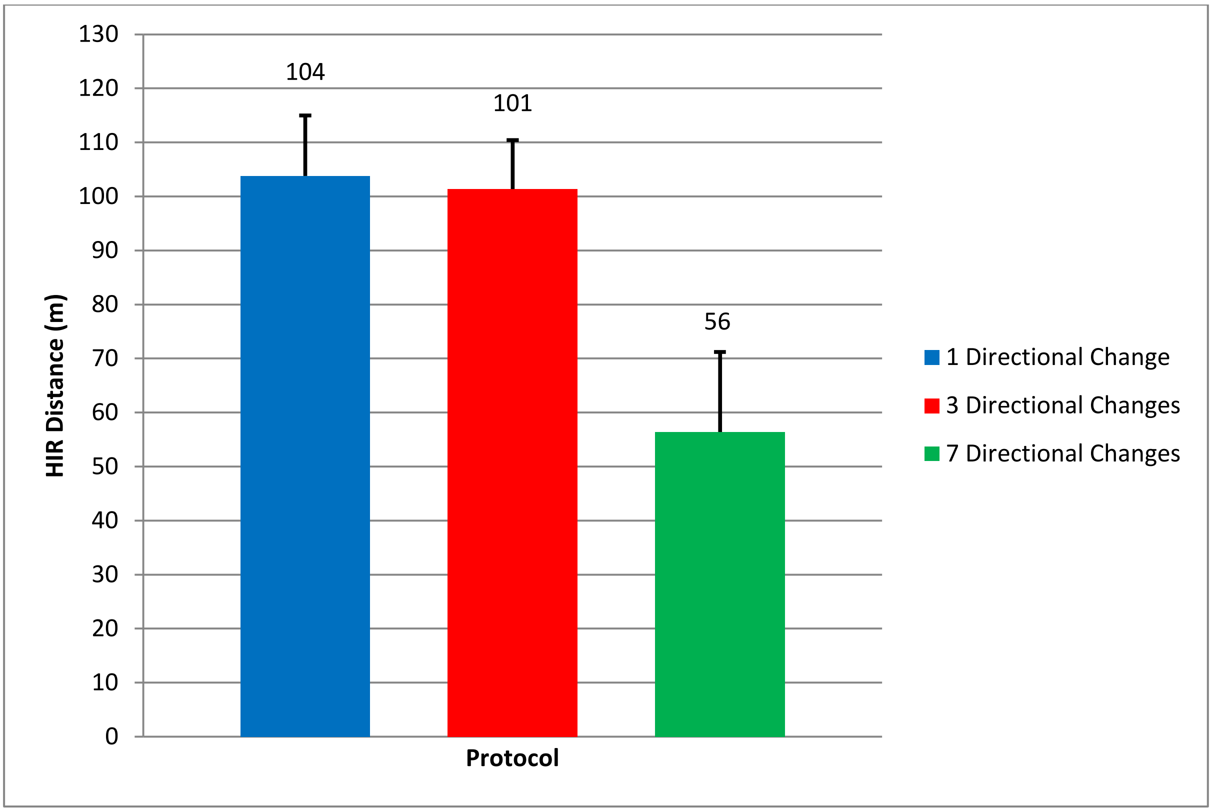

Figure 4.5: Comparison of the mean ± SD HIR distance associated with each of the protocols included in the sample of testing sessions.

Figure 4.6 illustrates the mean ± SD HRE for each protocol. A significant difference in mean score for HRE ($F = 11.47$, $p < 0.05$) was found. Participants obtained the highest mean HRE during the protocol which involved seven directional changes (1.10 ± 0.7). This was found to be significantly higher than the protocols which involved either three or one directional change(s) ($p < 0.05$). The protocol which involved three directional changes had a higher mean value (0.52 ± 0.24) than the protocol which involved one directional change (0.51 ± 0.25) but this difference was not found to be significantly different ($p > 0.05$). There was a positive medium correlation between g-force and HRE (r = 0.45, p < 0.01). A negative high correlation was also found between HIR and HRE (r = -0.52, p < 0.01).

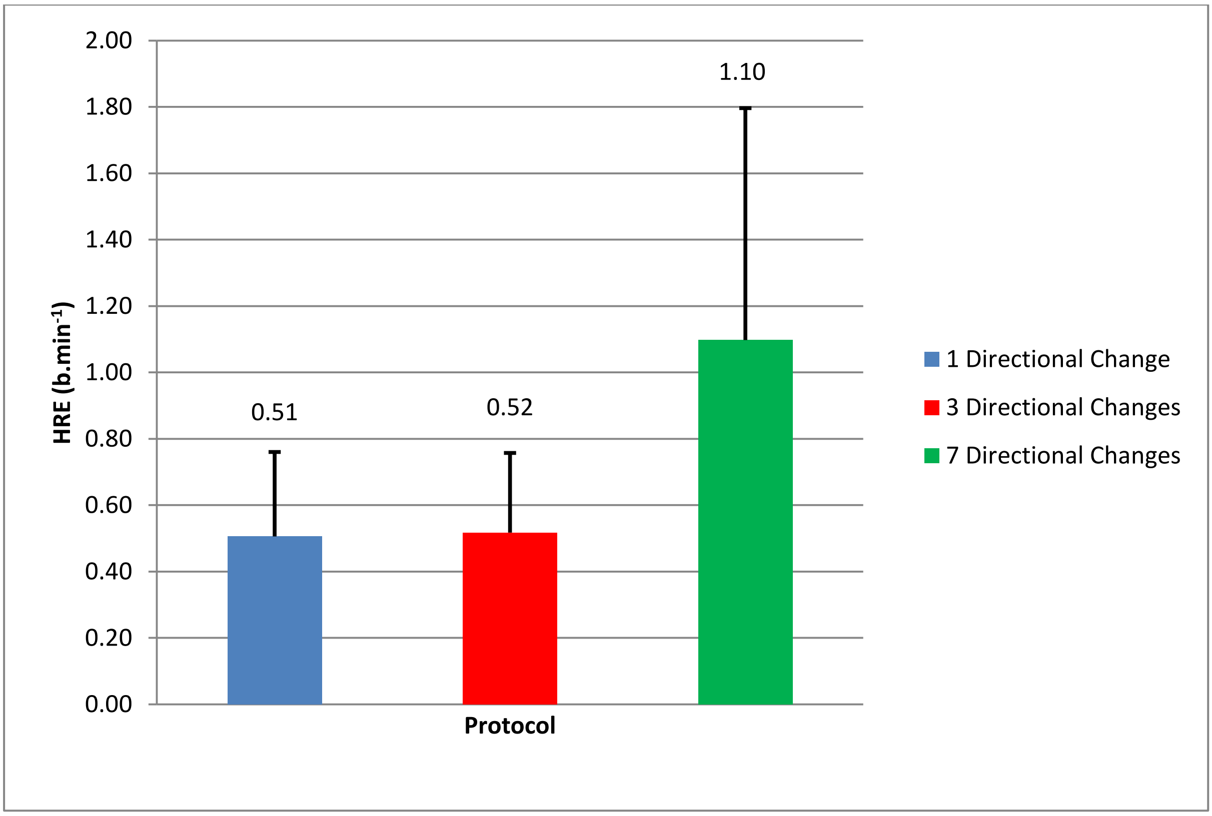

Figure 4.6: Comparison of the mean ± SD HRE associated with each of the protocols included in the sample of testing sessions.

Figure 4.7 illustrates the mean ± SD RPE scores for each protocol. A significant difference in mean score for RPE (F = 26.01, p < 0.05) was found. The protocol which involved seven directional changes led to the highest mean RPE score collected from participants (5 ± 1). This score was significantly higher than both protocols which involved either three (3 ± 1) or one (3 ± 0) directional changes (p < 0.05). The subjective evaluation of the protocols which involved either three or one directional change(s) was not found to be significantly different (p > 0.05). There was a positive high correlation between g-force and RPE (r = 0.63, p < 0.01). A negative high correlation was also found between HIR and RPE (r = -0.69, p < 0.01).

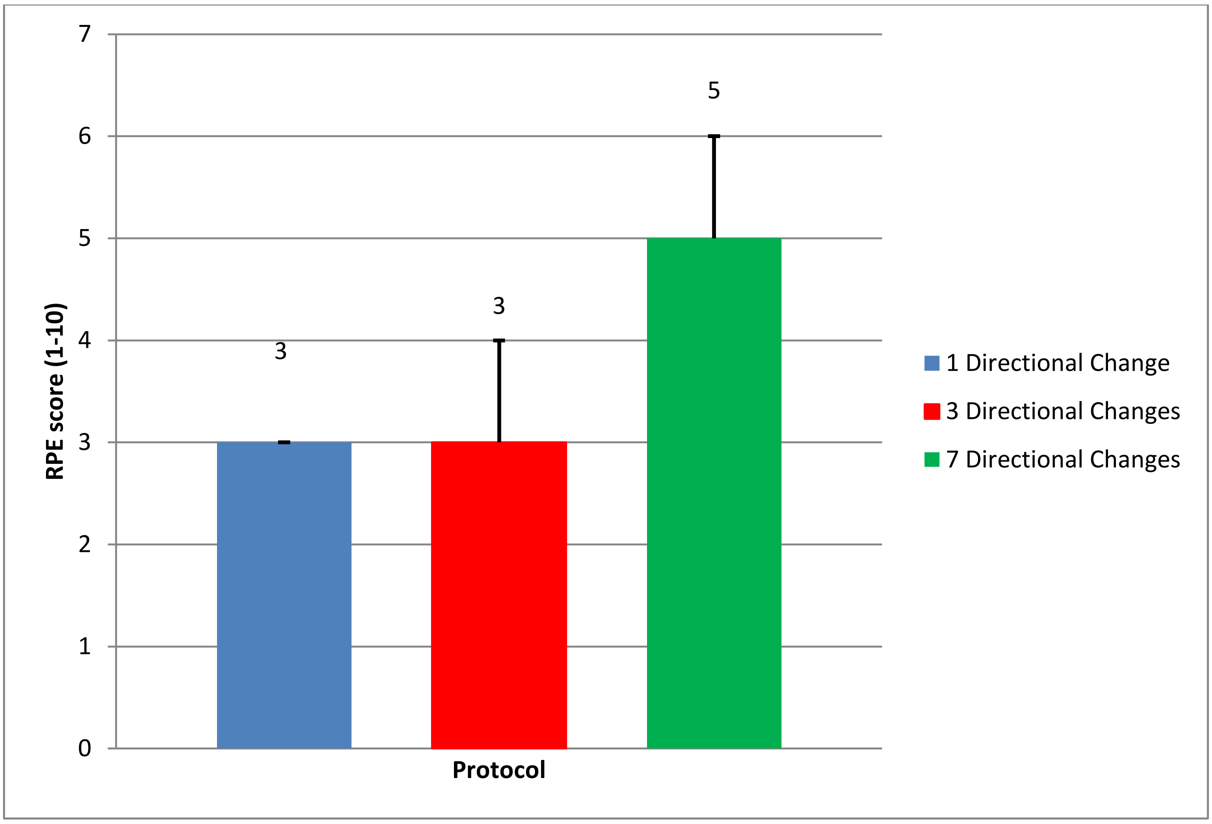

Figure 4.7: Comparison of the mean ± SD RPE associated with each of the protocols included in the sample of testing sessions.

4.4 Discussion

The primary objective of this study was to determine whether an increase in the number of 180 degree directional changes completed altered the physiological responses observed in elite football players during simulated running drills. External load was monitored via ACC and was used as an indicator of the "forces" acting on participants throughout each protocol. The data associated with this variable showed significant increases as the number of changes in direction increased. The physiological responses, as measured through HR, and the subjective responses to exercise, as recorded through RPE, were also significantly elevated when participants performed protocols that involved seven directional changes as opposed to protocols that involved less frequent directional changes. The outcome of this study would seem to demonstrate that running patterns which involve frequent directional changes may be more physiologically demanding than patterns of activity that involve less frequent changes in direction. This data has implications for the design of training drills and preparation strategies for the elite football player.

The current study is the first controlled attempt to look at three protocols which involve varying frequencies of directional changes completed at a faster HIR speed relevant to elite football players. In order to do this, important extraneous variables which could influence the exercise stress had to be carefully controlled across each of the three testing protocols. These variables included; the total running distance, the speed of movement as well as the number and intensity of accelerations and decelerations performed. Such control allowed for the independent variable in this study, directional change, to be isolated and manipulated accordingly. High intensity running, a common marker used to gauge players physical performance during games and training, was also manipulated in this study by reducing its distance during protocols where the frequency of directional changes were increased. The current research is only the second study which attempts to monitor and measure the external load acting on elite football players whilst performing directional change protocols which included 180 degree turns. Only one previous study has attempted to measure the external load acting on elite football players when performing directional changes, although this lacked control and looked at slower running speeds (max speed: 4 m/s) (Akenhead et al., 2014). In the current study external load was also measured through g-force but in contrast to Akenhead et al., (2014) it was shown to significantly increase for protocols that involved more frequent directional changes.

The mean sum of g-force (which represented the total magnitude of "forces" acting on participants) was significantly higher when the number of directional changes was elevated from one to three (+11%) or from one to seven (+47%). In contrast to Akenhead et al., (2014) the current study applied a faster running speed (6 m/s) which in turn would have increased the intensity of accelerations and decelerations performed. This may explain why there was a significant increase in g-force found within the current study. The results suggest that performing higher threshold decelerations, turns and/ or accelerations increases the external load placed on elite football players. In this study the sum of g-force was selected instead of DSL in order to rule out the use of an algorithm directly calculated by the GPS manufacturer’s software. Although DSL is easier to obtain, the sensitivity of this variable and its accuracy regarding the representation of the data has not been reported. Considering the short duration of the protocols and the need to maximise the use of the data, a direct approach was considered to be more appropriate for this investigation. Although monitoring g-force through the use of accelerometers such as those used in the current study have shown to be reliable (Barrett et al., 2014), it is acknowledged that in this investigation it would be difficult to conclude or evaluate the contribution of each component of directional change (deceleration, turning and acceleration) to the overall external load. The available research suggests that the deceleration component of directional change may contribute to an increase in g-force, as performing such movements has previously been associated with the production of high braking forces (Hewitt et al., 2011; Schot et al., 1995). Similar to Akenhead et al., (2014) testing was completed on an artificial surface. Although elite player's perception of difficulty has been shown to be greater when exercising on artificial surfaces instead of grass, research has indicated that measurements of external load or physiological demands are unaffected by such changes (Ndelec et al., 2013). The results of the current study may therefore be applicable to training surfaces regardless if they are artificial or natural. Despite the outcome of the current research there is a need for further investigations which look at the external load associated with performing each component of directional change in isolation and its contribution to the overall movement pattern. Such an approach will provide a greater insight and facilitate understanding of the movement demands associated with performing directional changes.

An increase in external load was accompanied by an elevated cardiovascular and subjective response in the current study with results showing medium to high positive correlations. The cardiovascular response as measured through HRE was significantly higher for the protocol that involved seven directional changes when compared to the protocols which involved either one (+54%) or three (+53%) directional changes. The subjective response as measured through RPE was also significantly higher for the protocol that involved seven directional changes (5 ±1) when compared to the protocols that involved either one (3 ±0) or three (3 ±1) directional change(s). These observations are in accordance with previous research which have found a significant increase in HR (Buchheit et al., 2011; Dellal et al., 2010) and subjective responses (Dellal et al., 2010) for protocols that involved directional changes when compared to linear based constant speed running, albeit using investigations that lacked control. The results of the current study show that increasing the frequency of directional changes elevates the external load and subsequent HR and subjective responses.

Research which may help explain the increase in cardiovascular response as a result of undertaking frequent directional changes is scarce within the literature. Although it has been suggested that the acceleration component of directional change is responsible for an increase in physiological response (Akenhead et al., 2014), it would be difficult to conclude this with any certainty as such studies have not considered the potential contribution of deceleration or turning to the overall energy demand. Other studies which have examined EMG activity suggest that acceleration has a higher activity pattern than constant speed running (Wiemann and Tidow, 1995; Harland and Steele, 1997; Jonhagen et al., 1996; Mero and Komi, 1987; Wiemann and Tidow, 1995; Mero and Peltola, 1989) and that larger turning angles, such as those used in the current study, have a greater EMG activity than smaller turning angles (Besier et al., 2003). It has been suggested that such increases in EMG activity may be indicative of an elevated energy demand which could potentially explain the higher HR responses observed in the current study (Bigland-Ritchie and Woods, 1976). Research which has attempted to indirectly measure the energy expenditure associated with acceleration suggests that a higher energy demand is associated with this component of directional change when compared to linear based constant speed running (Di Prampero et al., 2005). A third possible explanation is that acceleration may be more energy demanding than constant speed movement such as HIR. The research suggests that efficient mechanical energy stored in the series elastic component becomes available at speeds greater than 5m/s (Cavagna et al., 1971). This may possibly suggest why the protocol with the greatest number of accelerations and lowest HIR distance had the greatest HR response as less time was spent moving in a more energy efficient state. This limited research and the design of the current investigation make it difficult to conclude, with any certainty, which specific components of directional change may be responsible for the increase in cardiovascular response observed in this investigation. Similar to understanding the increases in external load, future research projects would ideally attempt to separate and isolate directional change in to its individual components (deceleration, turning and acceleration) and systematically investigate the cardiovascular demand of each within a controlled environment.

Although increases in RPE scores within the current study may be explained by elevated HR responses, such subjective feedback may perhaps also be due to an increase in the external load associated with the exercise. Although RPE, as collected through a modified version of the Borg Scale (Foster et al., 1995), is a valid means for collecting subjective feedback regarding the internal training load in football players post exercise (Impellizzeri et al., 2004), it has not previously been validated to describe the movement demands associated with exercise. It may be that RPE scores recorded in the current study were reflective of a more global demand associated with performing running protocols that involved frequent directional changes. This global demand may be reflective of increased requirements from other physiological systems. This may include fatigue of the nervous system and increase trauma to the muscular system.

This study highlights the importance of recognising the movement pattern in football. The results of this investigation showed a high negative correlation between HIR and physiological response, suggesting that the movement pattern, directional change, was responsible for the elevated physiological response. Although HIR has commonly been used as an intensity marker in football, the results of the current study would raise questions regarding its sole use during elite football performance. Training drills which involve constant changes in direction increase the movement demands and cardiovascular responses in elite football players. Special consideration must therefore be placed on directional change when designing training drills throughout various days of the training week as such movement patterns may influence the physiological demands players are exposed to.

Chapter 5

Conclusion of thesis

The aim of the current thesis was to investigate the influence of directional change on the physiological response to intermittent exercise in elite football players. The first investigation looked to monitor players within their training environment. This approach was taken to determine the occurrence of directional change during an elite teams typical four day training week. The design of the training week allowed for the comparison of a session which involved a high frequency of accelerations and decelerations (which was used to represent directional changes) and a session with a lower number of accelerations and decelerations but a high volume of constant speed HIR. Although the results of this study suggest that the physiological response may have been greatest for the training session which involved the most frequent directional changes, there were several limitations which may have affected the data collected throughout the study. This included the inability to control extraneous training variables that could have influenced the physiological demands participants were exposed to throughout each session. As a consequence of these limitations there was a need for a second more controlled study which allowed for the comparison of intermittent protocols that involved varying frequencies of directional changes, whilst carefully controlling extraneous exercise variables. High intensity running was also manipulated in this study by reducing its distance during protocols where the frequency of directional changes was increased. The results of this study showed that the external load was greatest for the protocol which involved the highest number of directional changes and the lowest volume of HIR distance. The increase in external load was accompanied by an increase in the physiological response as measured through HR and RPE. Despite showing that movement patterns such as directional change increase the external load and physiological response in elite football players, the results of the study also lead to question the use of HIR as a marker of intensity in football. The design of this investigation however did not allow for an interpretation regarding the contribution that the various individual components of directional change (deceleration, turning and acceleration movements) made to the overall external load or physiological demands. Future research should therefore focus on looking at the external demands and physiological responses of performing such movements individually and in isolation. The current thesis indicates that elite football players frequently perform directional changes during sessions that are undertaken as part of a typical training week. Performing such movement patterns, as demonstrated by looking at 180 degree turns, increases the external load and physiological demands elite football players are exposed to. These findings highlight the importance of considering movement pattern when designing and implementing training drills for elite football players.

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Appendix

Appendix A

Modified Borg Scale

(Foster et al., 1995)

0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal

Appendix B

Participant Information Sheet

PARTICIPANT INFORMATION SHEET

Research Institute for Sport and Exercise Sciences
Liverpool John Moores University, Tom Reilly Building, Liverpool, L3 5AF

Researcher: Remy Tang

Supervisory Team: Professor Barry Drust, Professor Tim Cable and Dr. Giles Warrington

Study Title: The influence of varying frequencies of directional change on the external load and subsequent physiological responses in elite soccer players

You are being invited to take part in a research study that is sponsored by Liverpool Football Club. The study will look at the effects of acceleration, deceleration and turning and the demands it places on elite football players. Before you decide whether to participate it is important that you understand why the research is being done and what it involves. Please take time to read the following information. Ask us if there is anything that is not clear or if you would like more information. Please take the time to decide if you want to take part or not.

If you choose to participate in the study you will be required to visit the Liverpool FC Academy on four separate occasions. On your first visit you will be asked to complete a physical activity readiness questionnaire (PAR-Q) in order to determine your level of activity. Following this your age, height and weight will be recorded. If considered eligible to participate you will be requested to familiarise yourself with the turning area and running speed which will be dictated using audio sounds projected by an audio player. This speed will be approximately three quarter pace. This session will involve minimal to no discomfort.

On the second, third and fourth visit you will be requested to complete one of three testing protocols. All testing protocols are the same in distance and will require you to run at the same speed as in your previous visit. The only difference between each session is the number of turns you will be required to make. The total number of turns will be one, three or seven per session. Each of the three testing protocols will take between 26 and 35 seconds to complete. Five minutes after the exercise has been completed you will be asked to score how the session felt on a scale of 1 to 10.

All testing will be completed within a 4 to 6 week period. Throughout all four visits you will be required to wear both a global positioning system (GPS) and heart rate monitor unit. Both of these units are worn to provide the tester with feedback regarding the demands of each testing protocol. This feedback will include measurements of force, high intensity running and heart rate. Both of these units will be secured to your body and will not give you any discomfort.

This study will entail no side effects, and poses no additional risks other than your normal training. All information collected during each trial is stored in participant data files and will remain strictly confidential. The data will not be disclosed or accessed by anyone except the

researcher and the supervisory team. All data will be stored on a password protected computer. The tester only will have access to this computer. All information collected will be used to determine whether there is a difference in demand placed on participants as a result of undertaking each exercise protocol. Your involvement is completely voluntary. If for any reason at any time during the study you wish to withdraw you are free to do so. A decision to withdraw or a decision to not take part will receive the same standard of care. If you do decide to take part you will be asked to sign an informed consent form which you may keep a copy of.

If you have any problems or concerns, do not hesitate to contact me. My contact details are listed at the bottom of the page.

Thank you

Remy

Remy Tang

Address: The Liverpool Way, Kirkby, Knowsley, Merseyside, L33 7ED

Phone: 0151 477 1216

Email: Remy.Tang@liverpoolfc.com

Appendix C

Physical Activity Readiness Questionnaire

<u>Physical Activity Readiness Questionnaire (PAR-Q)</u>

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: Check YES or NO.

YES	NO	
		Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?
		Do you feel pain in your chest when you do physical activity?
		In the past month, have you ever had chest pain when you were not doing physical activity?
		Do you lose your balance because of dizziness or do you ever lose consciousness?
		Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
		Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or a heart condition?
		Do you know of <u>any other reason</u> why you should not do physical activity?

If you answered yes to one or more questions:
Talk with your doctor by phone or in person BEFORE you participate in any part of this study. Tell your doctor about the PAR-Q and which questions you answered YES to.

No to all questions:

If you answered no honestly to all PAR-Q questions, you can be reasonably sure that you can participate in the study.

Delay participation:

- If you are not feeling well because of a temporary illness such as a cold or fever – wait until you feel better before taking part in any part of the study.

Please Note: *If your health changes so that you then answer "YES" to any of the above questions, inform the principal investigator (Remy Tang) immediately.*

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

Name: ________________________ Date: ________________________

Signature: _____________________ Witness: ____________________

Appendix D

Informed Consent Form

CONSENT FORM

Research Institute for Sport and Exercise Sciences
Liverpool John Moores University, Tom Reilly Building, Liverpool, L3 5AF

Project Title: The influence of varying frequencies of directional changes on the external load and subsequent physiological responses in elite football players

Name of Volunteer (Please Print):..

Principle Investigator (PI): Remy Tang

I confirm that I have read and understand the information provided for the above study. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily ☐

I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and that this will not affect my legal rights. ☐

I understand that any personal information collected during the study will be anonymised and remain confidential ☐

I agree for the removal and use of blood samples for this investigation ☐

I agree for any photographs taken during the investigation to be used ☐

I agree to take part in the above study ☐

Name of Participant	Date	Signature
Name of Researcher	Date	Signature
Name of Person taking consent (if different from researcher)	Date	Signature

Appendix E

Standard Testing Warm-Up

Standard Testing Warm-Up Protocol

Multi-directional movement	Jog, back-pedal, side-step, heals under glutes, Russian march, open groins, open groins backwards, side-steps with high knees, carioca, linear stride		
Dynamic movements	1	Deep squat	6 reps
	2	Split squat	4 reps left & right
	3	Lateral squat	4 reps (2 second holds) left & right
	4	Inch worms	4 reps
	5	Calf pumps	8 reps left & right
	6	Spiderman	6 reps left & right
	7	Linear leg swings	6 reps left & right
	8	Lateral leg swings	6 reps left & right
	9	Straight leg kicks	6 reps left & right
	10	Leg kicks across body	6 reps left & right
	11	Skipping	20 meters
Accelerations	50% of max acceleration, 75% of max acceleration, 100% of max acceleration (20 meters)		