Effects of High-Intensity Intermittent Exercise on Decision-Making in Soccer

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Abstract

The aim of this thesis was to identify physiological factors associated with decision-making performance of soccer players. If a decrement in decision-making performance was observed, a second aim would be to assess the extent to which soccer players' decision-making capability could be improved and trained. To achieve these aims there were four specific objectives: 1) To measure decision-making in soccer players using a soccer-specific protocol to assess decision-making and determine the reproducibility of the protocol's measures; 2) determine the effect of soccer-specific intermittent exercise on decision-making capability of soccer players; 3) assess the influence of repeated sprints and sprint-recovery duration on decision-making performance of soccer players and 4) assess the extent to which decision-making can be trained, by comparing perceptual video training with a soccer-specific field-based perceptual training programme.

Reproducibility of decision-making measures was determined by test-retest method. Ten male participants performed 10 decision-making test trials, rested for one hour then completed a further 10 trials on two occasions. Analysis revealed response time Intraclass Correlation Coefficient (ICC) = 0.91 and response accuracy ICC = 0.80. Coefficient of variation for response time was 3.4% and for response accuracy 4.6% indicated measures were reproducible. Using this protocol, 15 participants performed an experimental trial (decision-making task, before and after an intermittent treadmill protocol) and a control trial (before and after decision-making task) on separate occasions. Means were compared using a fully repeated measures factorial analysis of variance. There was an interaction for response time ($p < 0.01$), $d = 0.64$ (large) and an interaction in response accuracy ($p < 0.01$), $d = 0.84$ (large) which indicated that players' decision-making performance was impaired probably because of the physiological strain imposed.

Investigating these findings, 10 male participants performed, the decision-making task separated by 10 x 10-s repeated sprints with either a 15-s or a 30-s recovery period on different occasions. Means were compared using a fully repeated-measures factorial analysis of variance. There was an interaction for response time ($p < 0.01$), $d = 0.42$ (moderate). There was also an interaction for response accuracy ($p < 0.01$), $d = 0.85$ (large) highlighting, response time and accuracy were adversely affected as a consequence of the repeated sprints.

As a decrement in decision-making was observed, 24 male participants were divided randomly into one of four groups (control, placebo, perceptual training and a field-based decision-making training group) of six participants. Repeated sprints and decision-making performance was assessed before and after a six-week perceptual training intervention and during a retention test after a further seven days. Groups were compared using a two-way multivariate analysis of variance, by groups and occasion. Players who underwent field-based training improved their response time ($p < 0.01$), $d = 0.34$ (small) and response accuracy ($p < 0.01$), $d = 0.88$ (large) after the six-week training intervention. This illustrated that field-based decision-making training facilitated the acquisition of perceptual skill in soccer and could be used as part of players' overall training programme.

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Contents

List of Symbols and Abbreviations

$(a-\bar{v})$	arterial-venous
~	approximately
μl	microlitre
AMP	adenosine monophosphate
ADP	adenosine diphosphate
ANOVA	analysis of variance
ATP	adenosine triphosphate
ATPase	adenosine triphosphatase
BASES	British Association of Sport and Exercise Sciences
BERA	Business and Economics Research Advisor
BTPS	body temperature and pressure saturated
Ca^{++}	calcium ion
CO_2	carbon dioxide
$\dot{Q}$	cardiac output
cm	centimetre: unit of length
CNS	central nervous system
CV	coefficient of variation
Cr	creatine
DV	dependent variable
ECG	electrocardiograms
ETC	electron transport chain
F.A.	Football Association
FIFA	Federation Internationale de Football Association
$FADH_2$	flavin adenine dinucleotide

H^+	hydrogen ion
H_2O	water
HR	heart rate
IV	independent variable
IMP	inosine monophosphate
ICC	intraclass correlation
K	kelvin
K	potassium
K^+	potassium ion
kg	kilogram
km	kilometer
l	litre
LPR	least product regression
LOA	limits of agreement
m	million: unit of currency
m	meter: unit of length
$m \cdot s^{-1}$	meter per second
min	minute: unit of time
ml	millilitre
$ml \cdot kg^{-1} \cdot min^{-1}$	millilitres per kilogram of bodyweight per minute
mmHg	millimetre of mercury
$mmol \cdot l^{-1}$	millimole
MPO	maximum power output
MANOVA	multivariate analysis of variance
n	sample size.
Na^+	sodium ion

NH_3	ammonia
NADH	nicotinamide adenine dinucleotide
O_2	oxygen
$\dot{V}O_2$	rate of oxygen uptake
$\dot{V}O_2$ max	maximal oxygen uptake
PCr	phosphocreatine
pH	measure of acidity of a solution
Pi	inorganic phosphate
PSI	pound-force per square inch
RER	respiratory exchange ratio
RPE	rate of perceived exertion
s	second: unit of time
SD_{diff}	standard deviation of the difference
SE_M	standard error of the mean
STPD	standard temperature and pressure dry
TEM	technical error of measurement
TCA	tricarboxylic acid
UEFA 'A'	Union of European Football Association 'Advanced'
yd	yard: unit of length

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CHAPTER 1

Introduction

1.1 Introduction

Sport and Exercise Science is the scientific study of factors that influence the ability to perform exercise (Winter and Fowler, 2009) and an interesting area of study is the often multifactorial nature of soccer. Performance in soccer is determined by players' physiological (ability to repeatedly perform high-intensity intermittent exercise), technical (kicking and heading), tactical (positional awareness and style of play) and psychological (decision-making) characteristics (Bangsbo, 1994). These areas overlap and influence each other, as the decision-making capability of a player could be impaired if a player's physiological state is not sufficiently high to meet the needs of matches. Good decision-making is thought to be at least as important as good technique (Smith, 1976). Decisions are constantly made while a player is engaged in match play and a player's decision-making capability could be the difference between a team winning or losing a match.

Researchers have attempted to assess decision-making in soccer by tachistoscopically measuring voice reactions to a selection of soccer slides that depicted actual attacking situations. These slides were projected onto a screen (McMorris and Graydon, 1996) but no studies have effectively used a soccer-specific protocol to quantify decision-making capability, which could be useful. Therefore, a reproducible protocol should be devised to provide an ecologically valid form of assessment that will in turn provide beneficial information for managers and coaches. In doing so, suitable training sessions to improve player performance could be designed, implemented and evaluated.

improved physical training is the foundation upon which other [psychological, technical, and tactical] factors could be based (Bangsbo, 1993). The use of physiological and psychological assessments to enhance performance in intermittent sports like soccer is challenging. Intermittency involves a complex interaction of several physiological processes as soccer is characterised by periods of high-intensity exercise (sprinting) that are interspersed with low-intensity passive and active recovery periods, for example walking, jogging and standing still (Bangsbo, 1994). While energy is produced primarily via anaerobic pathways during the short maximal-intensity bouts of exercise (Bangsbo, 1994), measures of heart rate and oxygen consumption ($\dot{V}O_2$) indicate the predominant energy pathway throughout a match is aerobic (Mohr, 2003).

Because of the intermittent and acyclical nature of activity during a match, many actions that affect outcomes are performed at a high-intensity (Bangsbo, 1994) and a player's physiological, psychological and technical performance has been shown to decline in the latter stages of the first half and towards the end of the match (Reilly, 1996). The effect of high-intensity intermittent exercise on decision-making performance in soccer has not been formally studied so further investigation is needed in an attempt to improve understanding of the decision-making process during and after high-intensity intermittent exercise.

The importance of high-intensity exercise can be illustrated by the activity profile of soccer players to match play. In a comparison of halves, the volume of high-intensity running in the second half of a match, for example, sprinting (> 21 $km \cdot h^{-1}$) represents only 28% of total playing time (Bangsbo, 1994). Furthermore, distance covered during high-intensity running in the second half can be 35 - 45% less than that of first half without a reduction in low-intensity running (Mohr *et al.*, 2003). The ability to repeatedly sprint are decisive and the most obvious difference between teams of varying skill is the intensity of matches (Ekblom, 1986). Consequently, the ability to perform repeated sprints would be a determinant quality to play at higher standard. For high-standard players, this means they must be able to perform multiple sprints and high-intensity runs and recover quickly. Several authors (Balsom *et al.*, 1992, 1994; Aziz *et al.*, 2000; Bishop *et al.*, 2001) have studied the performance of repeated-sprint exercise alternated with short recovery periods. The ability to perform these sprints depends on several variables such as aerobic fitness (McMahon and Wenger, 1998), the ability to buffer hydrogen ions (Bishop *et al.*, 2004), sprint and sprint recovery duration (Balsom *et al.*, 1992) and muscle glycogen concentration (Balsom *et al.*, 1999).

No current studies have been undertaken to assess the association between players' repeated-sprint performance and decision-making capability. Therefore, further investigation would identify processes that could influence performance and ascertain the extent to which decrements in players' decision-making capabilities are attributed to fatigue or any other factors.

Fatigue can be described as the inability to continue functioning at prescribed exercise intensity (Hagberg, 1981; Gandevia *et al.*, 1995; Hawley and Reilly, 1997) in the presence of an increased perception of effort (Enoka and Stuart, 1992). Mechanisms of fatigue can be separated into peripheral and central components (Gandevia, 1992; Kent–Braun, 1999). Peripheral mechanisms have been well-studied and include specific impairments in neuromuscular transmission and impulse propagation in the sarcoplasmic reticulum involving calcium release and uptake, substrate depletion and various other metabolic factors that disrupt energy provision and contraction (Davis, 1995).

Central mechanisms of fatigue are described as a reduction in the neural drive or motor command to the muscles that results in a decline in the force output (Gandevia, 2001; Kay *et al.*, 2001). For example, in soccer, metabolic and central fatigue can be expressed as lapses in concentration, delayed responses and errors in decision-making (Reilly, 2002). Soccer players must also possess appropriate perceptual skills (decision-making, concentration, anticipation and awareness) to perform to the best of their ability. However, precise mechanisms of central fatigue and its influence on perceptual skills like decision-making are unknown.

Researchers have used several techniques to examine the extent to which perceptual skills can be trained. The progression of these methods is largely attributable to technological advances as opposed to developments in underlying theory (Williams and Ward, 2003). Methods employed have ranged from simple slide presentations to video simulations and field-based interventions. The majority of this work has attempted to train players to identify postural cues more effectively as opposed to other potentially trainable skills, such as the recognition of patterns of play.

1.2 Aims and objectives

The aim of this thesis is to identify physiological factors associated with decision-making performance of soccer players. If a decrement in decision-making performance is observed, a second aim will be to assess the extent to which soccer players' decision-making capability can be improved and trained.

To achieve these aims there are four specific objectives:

1 To measure decision-making in soccer players using a soccer-specific protocol to assess decision-making and determine the reproducibility of the protocol's measures.

2 Determine the effect of soccer-specific intermittent exercise on decision-making capability of soccer players.

3 Assess the influence of repeated sprints and sprint-recovery duration on decision-making capability of soccer players.

4 Assess the extent to which decision-making can be trained and retained, by comparing perceptual video training with a soccer-specific field-based perceptual training programme.

CHAPTER 2

Review of Literature

2.1 Association football

2.1.1 Historical background

The physiology of exercise is the study of how the body responds and adapts to exercise was probably first studied in early Greece and Asia in the fourth and fifth centuries BC. The ancient civilizations of Syria, Egypt, Persia, India and China also recorded references to sports games and health practices (Robergs and Roberts, 1996). The greatest influence on Western civilization came from the Greek physicians of antiquity Herodicus in 480 BC; Hippocrates (460 – 377 BC) and Claudius Galenus or Galen (AD 131 – 201) (Porter, 1999). Herodicus, a physician and athlete, was the first person to advocate proper diet in physical training. However, it was Archibald V. Hill and colleagues (1924) who were pioneers in the measurement of human physiological responses to the onset of exercise. Considerable advances in physiological assessments have been since then making it possible to identify physiological processes that could influence the ability to perform exercise, particularly in football.

Attempts to explain the origins of football vary and depend on national perceptions (Ekblom, 1994). Early evidence of participation in activity resembling soccer dates back to the 2nd and 3rd centuries BC, when Chinese military personnel kicked a ball into a net as part of a game or skill-building exercise (Hill, 2003). In Kingston upon Thames, Surrey, the local game traditionally played there each Shrove Tuesday originated from a Saxon defeat of Danish invaders, where the head of a defeated Danish chieftain was kicked in celebration around the streets and the game grew out of that. It is widely accepted that the modern game of soccer was developed in Britain, where it is commonly known as football (Ekblom, 1994).

The developing game involved people from rival towns and villages attempting to move a ball to a predetermined spot. A game could last all day and was notoriously violent, with kicking, gouging, biting and punching allowed (Ekblom, 1994). It was not until 1815 that Eton College established a set of rules that resembled those of the modern game. The rules were standardised and adopted by most of England's universities becoming known as Cambridge rules. In 1863, the formation of the Football Association (F.A.) and further rule changes followed, notably, handling of the ball was banned, thus making the split between Association and Rugby Football. The F.A. introduced a Challenge Cup (F.A. Cup) in 1873, for which all clubs belonging to the Association were invited to compete. Professionalism was legalised in 1885 and a league was introduced in 1888 in which 12 clubs participated. From these modest beginnings, football is the one sport that has overwhelming global appeal, transcending national, cultural, religious and gender boundaries, as well as socio-economic class (Business and Economics Research Advisor (BERA), 2005).

Referred to as soccer in the rest of the world, professional football is truly an international sport, with 300,000 soccer clubs and 240 million registered players worldwide 30 million of which are women (BERA, 2005). Some players have annual salaries of millions of pounds, while others are paid very little. European players are the most highly paid, however, salary distribution and management varies from club to club and from association to association (BERA, 2005). Total wage costs for the 'big five' European leagues [English Premiership, Germany's Bundesliga, Spain's La Liga, Italy's Serie A and France's Ligue 1] increased by €260 m (7%) in 2006/7, primarily driven by a €171 m (13%) increase in English Premier League clubs' wages over to €1.4 billion. Premier League clubs' wages were more than €0.6 billion (75%) higher than in Spain's La Liga (€0.8 billion) and double the wage costs paid by the other 'big five' leagues (Deloitte, 2008).

The largest increases in wages in 2006/7 were reported by Chelsea (19m), West Ham United (13m), Portsmouth (12m), Newcastle United (10m) and Liverpool (9m), with West Ham United and Portsmouth investing in their playing squads following the arrival of new owners (Deloitte, 2008). Manchester United wages remained constant, but they shattered their own record for operating profits set in 2003/4 (£52m), with operating profits of £66m in 2006/7, which exemplifies the game's economic strength in this country and the need to have highly skilled players.

2.1.2 Rules

A game of soccer is played between two teams of eleven players (excluding substitutes), consisting of one goalkeeper and 10 outfield players. It is played on a rectangular grass field 90-100 m in length by 45-90 m in width with a net at each end. The distance between the goal posts is 7.32 m and the distance from the lower edge of the crossbar to the ground is 2.44 m. The objective of the game is to score by manoeuvring the ball into the opposing goal. Only the goalkeepers, whose role is to prevent the opposition from scoring, are permitted to handle the ball, although this is restricted to a designated area that encompasses their team's net. Outfield players must not intentionally use their hands or arms to propel the ball in general play. Outfield players can typically be separated into: 1) defenders, whose primary role is to defend their goal by limiting the opposition scoring opportunities, 2) midfielders, who link defence with attack and 3) forwards, whose major responsibility is to score in the opposition's goal. A soccer match consists of 45-minute halves, separated by a 15 min break. The winner is the team that has scored most goals at the end of the match; if both teams have an equal number of goals then the game is a draw (Federation Internationale de Football Association (FIFA), 2008).

2.2 Theoretical perspectives on soccer

To the Information Processing Theorists (Cognitivists) of motor control (how movement skills are controlled, developed and acquired), decision-making in soccer follows perception and proceeds action, however, Dynamical Systems Theorists try to avoid the term decision-making and consider it as being part of perception-action coupling, which allows players to achieve their goal. This theory will be covered later.

Information processing theorists have historically relied on a computer metaphor to explain motor control. This metaphor likens the operations of the brain and central nervous to those of a sophisticated computer. The brain and nervous system, like the computer, transform an array of (sensory) input information through computation to produce a particular desired (motor) output. Traditional information processing models of motor skill performance emphasize three purportedly sequential processes as underpinning the production of skilled movement: 1) perception, 2) decision-making and 3) movement execution (McMorris, 2004). Perception is the process through which a player determines what is occurring (and is about to occur) within their surrounding external environment and within the internal environment of their own bodies and extrapolates the current and prospective relationship between these two. Decision-making is the process by which an appropriate movement response is selected (from a range of possible options). Movement execution is the process by which the selected response is organised, initiated and controlled (McMorris, 2004).

According to information processing theory, the ability to make accurate decisions is complex. The information processing model (Figure 2.1) illustrates that input is interpreted at the perception stage and the chosen cues are passed to the short term memory (STM), where they are compared to past experience recalled from the long term memory (LTM). Based on this comparison a decision as to what to do is made, this process is called working memory (Baddeley, 1986). Perception must be accurate if good decisions are to be made. If the wrong information is passed to the STM, a wrong decision is inevitable. Selective attention allows a player to ensure that they perceive the correct information and pass it on to the STM. Comparing the information passed to the STM with past experience held in the LTM is also complex, because no two situations are the same.

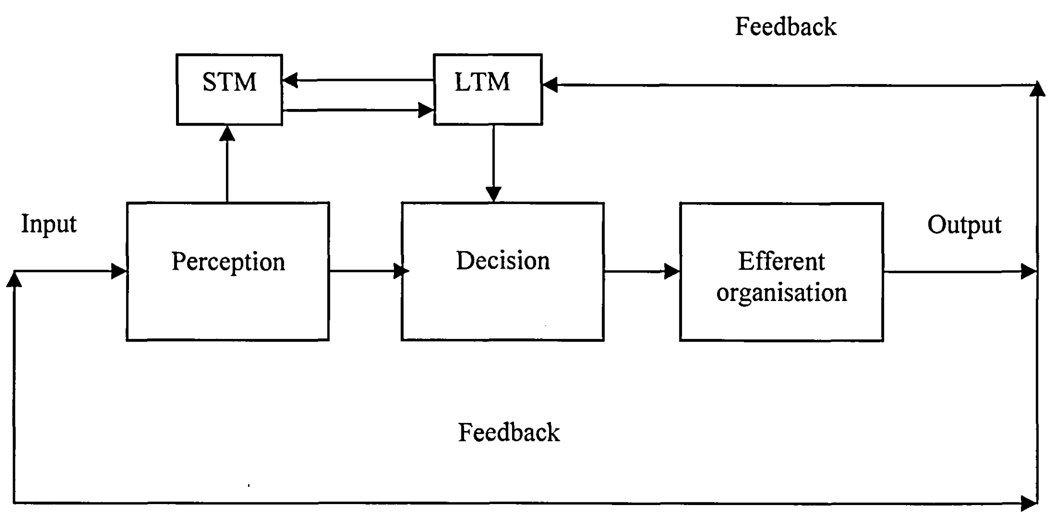

Figure 2.1 Model of information processing (adapted from Welford, 1968)

A limitation with the information processing theorists' explanation of how players make decisions is that the amount of information that must be held in the STM and recalled from the LTM in order to make good decisions is important (McMorris, 2004). Comparing the information must be time consuming, yet it is known that skilled players make quick decisions in complex environments. Information processing theory does not explain how players are able to make quick decisions as quickly as they do (McMorris, 2004). Anderson's (1982) Adaptive Control of Thought (ACT) theory attempted to explain this, it states that players predetermine what they will do in any given situation and claims that players go through a series of 'if this happens, then I'll do that' decisions. The decision is still based on past experience but deciding beforehand, what they will do allows players to respond quickly, which is often necessary in soccer (McMorris, 2004).

Furthermore, the period of time when players learn what to do in any given situation is said to be the time taken to develop declarative knowledge. Declarative knowledge is knowing what to do. Anderson states that players acquire declarative knowledge prior to what he terms procedural knowledge. Procedural knowledge is not merely making the correct decision but knowing how to ensure that the goal of their action is met (McMorris, 2004). However, there is no proof that declarative knowledge precedes procedural knowledge in soccer.

From a Dynamical Systems Theory viewpoint, dynamics refers to the way a system (a collection of related parts that we perceive as a single entity, for example, the nervous system) changes over time. Moreover, a dynamical-system is one that changes in time; what changes is the state of the system (Norton, 1995). For example, the human body could be seen as a dynamical system. Soccer players' physiological state can change toward the end of a match because of the onset of fatigue, leading to a decline in performance. However, Kelso (1995) suggested that co-ordinated movements evolve over time as a function of the interaction between the player and the environment, which is fundamental to the dynamical systems approach of analysis.

The environment dictates what players are allowed to do at any given time in any specific situation (decision-making); these opportunities for action from a dynamical perspective are called affordances and were previously considered to be an optical variable. Affordances evolve over time and could be unique in each situation, as no two situations in soccer are the same. While affordances are present, they will not be acted upon if a player is unaware of their existence and doesn't perceive them. Players must actively search the environment, using afferent (sensory) nerves to identify the presence of affordances and efferent (motor) nerves to act accordingly, therefore, linking perception and action (perception-action coupling). Furthermore, perception of the affordance is dependent on movement, as much as receiving sensory information, so, once a player begins to act, it is both perception and action that controls movement (McMorris, 2004).

Dynamical-systems theorists believe that the central nervous system plays an important role in explaining actions players make. This system provides a broad set of commands that are said to be functionally specific (Davids *et al.*, 2008). They are as simple as 'kick or catch the ball'. It is the role of perception-action coupling to determine exactly how the command is carried out, for example, the way in which the ball is kicked, whether it's with the instep, inside or outside of the foot. The perception-action coupling found in any given situation in soccer is unique to that situation and will depend on what is required to achieve the correct decision (Davids *et al.*, 2008). The major elements involved in these two theories overlap and could apply equally.

2.2.1 Characteristics of decision-making in soccer from a theoretical perspective

In discussing the complexity of decision-making in soccer, McMorris and Graydon (1997) reported that knowing which cues to process did not guarantee successful decision-making. The cues must be perceived accurately. The inter-relationship between attackers and defenders and in particular, the space behind, between and in front of them must be determined. This information will tell players what options are open to them in that particular situation. This can be compared with past experience of similar situations and based on that comparison, a decision of what action to take can be made.

In making a decision, however, the players should also take into account their own abilities and that of the opposition, the physical conditions in which the game is being played, the score at that particular moment and the area of the field in which the action is taking place (McMorris and MacGillivary, 1988). Furthermore, the situation is exacerbated by the fact that players often have to make decisions quickly, if the initiative is not to be lost.

In Figure 2.2, selected elements that are likely to influence each player's successive decisions during sequences of action are identified. As illustrated in this model, decision-making can be seen as triggered by a soccer action that offers a given system of play. Furthermore, the importance placed on players' physiological capabilities is crucial to the process, as poor physical fitness would not delay the onset of fatigue and thus a decrement in decision-making performance. As discussed earlier, this system of play will likely be perceived and interpreted differently by various players involved in the action and by outside observers as well, which could lead to differentiated decision-making.

Perception, related to selective attention and subsequent decision-making, could be influenced by a series of elements. The elements listed depend on what each player must take into account. From a dynamic systems perspective, the activities of the player's are regarded as fundamental in the collection of information for perception and likewise, perception is thought of as instrumental for the initiating and control of action whenever decisions have to be made.

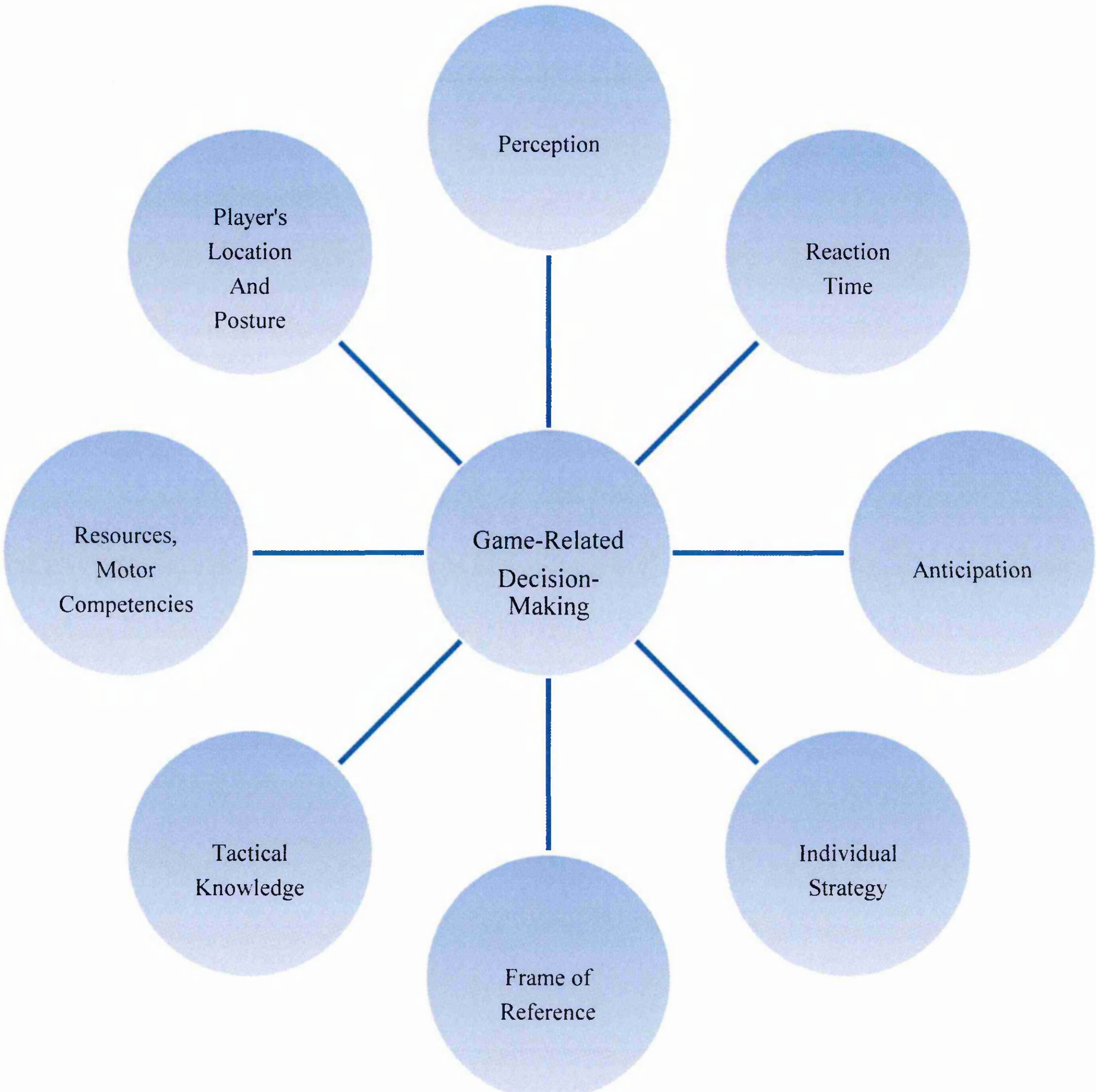

Figure 2.2. Some elements of the individual decision-making process in soccer (translated and adapted from Gréhaigne & Godbout, 1999).

While soccer implies the presence of team-mates, choices of action rest ultimately on each player. Decision-making elements related to each individual player shown in Figure 2.2 are as follows:

2.2.1.1 Perception

Perception is an important determinant of sports expertise (Williams *et al.*, 1999). This applies to soccer, where players are confronted with a complex and rapidly changing environment (Williams, 2000). Players must assimilate information from the ball, team-mates and opponents before deciding on an appropriate response based on current objectives e.g. strategy and tactics and action constraints e.g. technical ability and physical capability (Williams, 2000). Such decisions are often made under challenging circumstances, with opponents trying to restrict the 'time' and 'space' available to perform. This 'temporal pressure' suggests that a player's ability to anticipate future events, from early components of an action sequence, is an integral part of skilled soccer performance (Williams, 2000).

Studies comparing the perceptual and decision-making skills of expert and novice soccer players are systematic in their findings to support general conclusions that expertise is very task and context-specific and expert-novice differences arise infrequently on tasks using general stimuli (Abernethy, 1996). Systematic expert-novice differences do emerge when tasks are used that require the processing of sport-specific visual information. The most consistent finding is that, like their counterparts in cognitive activities such as chess (Chase and Simon, 1973) expert soccer players are both faster and more accurate than novices in recognising and recalling patterns from their domain of expertise.

In studies of expert basketball and hockey players who were presented briefly with slides showing developing offensive patterns highlighted that experts were superior to novices in recalling the position of both team mates and opponents in the particular play (Starkes and Deakin, 1984). If however, a slide is presented lacking the normal display structure, the recall performance of the expert regresses to that of a novice, demonstrating that the expert advantage lies with domain-specific pattern recognition and is not a consequence of a more generalised superiority for rapid information acquisition and encoding of patterns. The experts' perceptual advantage in these tasks could be linked directly to knowledge development, it having been posited that experts have both a larger store of domain-specific patterns and a superior discrimination process for comparing observed patterns with stored ones (Thomas *et al*., 1986).

Examining the extent to which experts pick up more information than novices from events before ball flight, Abernethy and Russell (1987) concluded that there are early periods in the development of the opponents shot during which only experts are able to extract useful information. These differences in time course information pick-up between experts and novices occur because experts are able to pick up information from different (and additional) sources than those by novices and that expert perception in soccer is characterised by a superior ability to pick up and interpret the essential kinematic detail in an opponent's action, for example more proximal segments of the kicking action (Abernethy and Russell, 1987).

Expert-novice differences are often shown in advanced cue use and this difference in perception need not necessarily be matched by concomitant differences in visual search patterns, as revealed through eye movement recordings or by any conscious awareness by the player of their sources of information (Abernethy, 1996). Furthermore, differences in anticipatory performance between expert and novice racquet sport players to occur in the absence of any differences in either visual search patterns or self-reported cue use (Abernethy and Russell, 1987). Expert-novice differences in visual search patterns exist on some tasks (Williams *et al.*, 1994), but they are not necessary for perceptual differences to occur nor do they reliably indicate such differences (Helsen and Pauwels, 1993).

It has been suggested that experts have superior advance expectancies of possible events based on their knowledge of situational probabilities (Abernethy, 1996). Experts could reduce their decision-making time and error by developing a set of subjective probabilities for each event that comes to replicate the actual event probabilities. Such effects are difficult to examine because even though the actual probabilities of match events can be manipulated, the manipulation of the implicit subjective probabilities assigned to these events by the individual player can be problematic (Alain and Proteau, 1980).

2.2.1.2 Reaction time

In cognitive psychology, response time improves with exercise probably as a result of arousal of the central nervous system (Adam *et al.*, 1997; Arcelin *et al.*, 1997; Chmura *et al.*, 1998). This exercise-induced arousal leads to a narrowing of attentional focus and hence improves reaction time (Gould and Krane, 1992). However, high-intensity exercise and prolonged exercise seem adversely to affect reaction time, probably because of the resulting CNS fatigue (Lemmink and Visscher, 2005) and therefore, decision-making ability could be impaired.

in soccer, Kelly (1979) measured reaction times of English Football league players to a visual stimulus and found that the players had faster reaction times than normal values and were similar to reaction times of track and field athletes. He concluded that athletes were superior to non-athletes in this measure. Fast reaction denotes a general athletic ability, while fast reactions in a complex decision-making task specific to soccer characterises match-related anticipation, assesses players' perceptual capabilities (Ekblom, 1986).

A major limitation of most studies is the focus mainly on continuous exercise as opposed to the intermittent nature of soccer. The experimental design and protocol used by Fleury *et al.* (1981) failed to replicate soccer actions and the combination of high and low exercise-intensity periods did not correspond to the intermittent nature of soccer matches (Mohr *et al.*, 2003). A second limitation of most studies has been the use only of reaction time (Kroll, 1973; Bender and McGlynn 1976; Collardeau *et al.*, 2001) and disregards other aspects such as response accuracy. Those few studies in which accuracy has been addressed usually report no change or increased accuracy (Paas and Adam, 1991; Yagi *et al.*, 1999).

2.2.1.3 Anticipation

Perceptual skills play a crucial role in sport performance and participation (Williams *et al.*, 1999). Anticipation facilitates performance in several ways: it permits response integration and thereby effectively reduces the number of discrete choices and decisions that must be made. It also permits a smooth adjustment of effort to the difficulty of each choice and each response (Kahneman, 1973). The ability to anticipate a future event based on information arising early in the display is often regarded as one of the most important perceptual skills underlying motor performance (Williams *et al.*, 2002).

Soccer players have to process information about the positions of team-mates and other players during a match, the speed and direction of the oncoming ball and position in space of their own body and limbs (Abernethy, 1987). Moreover, because of the speed of the game, anticipation must occur in advance of critical events such as the onset of ball flight and for this reason good anticipatory skills have been frequently advanced as an important pre-requisite for success in soccer (Abernethy, 1987).

Furthermore, although research on perceptual skill is rapidly expanding, knowledge about mechanisms that underpin anticipation skill is limited and there have been few attempts to determine the extent to which its acquisition can be facilitated through training and instruction (Williams *et al.*, 2002).

2.2.1.4 Individual strategy

This is a type of planning based on the hypothesis of likely actions undertaken by team-mates and the opposition (Gréhaigne *et al.*, 1999); this prior planning could influence the player's selective attention and it gives a particular orientation to decisions that will be taken during the game before play has started.

2.2.1.5 Frame of reference

The declarative and procedural knowledge accumulated through passed experience influences the player's interpretation of a system of play perceived in connection with efficient action rules and this constraints led approach is fundamental in viewing soccer from a dynamical systems approach.

2.2.1.6 Tactical knowledge

This type of knowledge could contain some theoretical concepts but remains mostly experiential, based on notions extracted from practice during training or match-play. Once a system of play has been perceived, the player must make sense of it. The recall of successful and unsuccessful solutions helps players assess the relevance of such responses. Thus, strategic and tactical knowledge orients decision-making (Gréhaigne *et al.*, 1999).

2.2.1.7 Players' resources

Knowledge about the consciousness of one's present resources serves as a filter, allowing the player to consider or reject certain hypotheses. Such resources could relate to the player's level and range of motor skills, motor competencies and soccer-specific motor skills. Other variable characteristics of a player, such as the physiological state, concentration level and motivation, could also enhance or hinder perception and decision-making.

2.2.1.8 Player's location and posture

A player's location and posture determine the possibilities of the player's response given their resources; a wrong perception of the player's position and posture could negatively affect decision-making. Furthermore, various inhibiting factors such as fatigue could be attributed to a player inaccurately perceiving his current position on the field of play. As well as a players' posture, fatigue can also affect player's co-ordination and ability to concentrate for long periods, resulting in being out of position, mistiming tackles and slow response to movements of team-mates and opposition.

From a dynamical systems perspective, soccer can be considered as a dynamical system that comprises several interactive parts, for example, players, ball, referees and pitch size (McGarry *et al.*, 2002; Araújo *et al.*, 2003). These parts influence the rhythm and tempo of match play that is characterised by quick turn-over of possession. The match is also characterised by an opposed relationship, where each team must co-ordinate its actions to regain possession, keep and move the ball to provide scoring opportunities.

The self-organising dynamical pattern of soccer, allows between-person dynamics (interpersonal duel of a winger against a full back or a striker against a defender) that are derived from the pattern and or formation of the team. The quality and movement of a player who possesses several aspects of skill that disrupts the rhythm or tempo could be the decisive factor for a team's success. Changes in match rhythm or tempo as a result of quality play are called perturbations (McGarry *et al.*, 2002).

Therefore, the match can be characterised by what is known as order-order transitions where, player actions could de-stabilize or re-stabilize the system accordingly (Davids *et al.*, 2005). These ideas fit well with tactical considerations in soccer, since, at one level of analysis, the match can be described as a series of sub-phases, such as attacking and defending, which could constrain the coordination of movements between attackers and defenders. Sub-phase simulations (for example, 1 v 1, 2 v 2 and 3 v 3) typify practice sessions in soccer (Davids *et al.*, 2005). Instances where perturbations occur are usually during sub-phases, where attackers and defenders are involved in an interpersonal duel and constant adjustment by the defender. Any movement by the attacker to outwit the defender is a characteristic of dribbling and can be understood as a type of interpersonal coordination.

In soccer, the aim of attackers is to disrupt the symmetry of the system by getting past the defender to score directly or create scoring opportunities, while defenders seek to remain between the attacker and the goal to stop the attacker from scoring and regain possession of the ball (Davids *et al.*, 2005). Therefore, when the defender matches the movements of the attacker and remains in position between the attacker and the goal, the symmetry of the system remains stable. But when the attacker dribbles passed the defender, near the goal, the attacker destroys the system's stability.

At this level of analysis, sub-phases can be described as the creation, maintenance and dissolution of an interpersonal duel, which relies on information about its ongoing coordinative (kinematics and kinetic) state (Davids *et al.*, 2005). According to Araújo *et al.*, (2003), because of the dynamics of competitive nature of soccer, there is not enough information to specify a goal path completely in advance for attackers. Consequently, goal path selection (decision-making) for an attacker in de-stabilising the system and the decision-making of a defender in stabilising the system during an interpersonal duel can be viewed as an emergent process.

The term soft-assembly can be used to describe the decision-making that emerges in sub-phases and is tailored to the immediate context of a match. Of particular interest is the intrinsic metric or specific measurement system that attackers or defenders use for making decisions in relation to their position and the position of the opposition on the pitch. Dynamical systems theory predicts that this decision would not occur at an absolute critical distance every time, but would emerge from the intrinsic metric of the specific system formed by each interpersonal dual (Davids *et al.*, 2005).

Authors have attempted to study this distance, which led to Bain *et al.* (1978) describing it as the 'interpersonal distance' between the attacker and the defender. Literature on team ball games reveals that a potential order parameter could be the median point of the distance of both players to the goal. However, the distance between an attacker and defender in soccer has not been studied and it is difficult to quantify as every situation is different, although soccer coaching manuals suggest that for defenders, a distance arms-length away from your opponent is sufficient to make a challenge. Furthermore, these studies did not take into account the skill of attackers and defenders, fatigue, fitness, injuries or the state of the match (whether or not one team is losing/winning or if one team has numerical advantage), all these constraints could impact on interpersonal distances.

2.3 Research on decision-making in soccer

Successful performance in soccer requires not only sound technique but also quick and accurate decision-making (Hughes, 1980). Players must make these decisions while they engage in high-intensity exercise. Various authors have attempted to investigate the effects of exercise on decision-making as a link with a change in players' physiological state with a decrement in soccer performance.

Marriott *et al.* (1993) examined the effect of exercise on decision-making in soccer. They tested experienced college soccer players and non-soccer players at rest and following two 45-min bouts of running on a treadmill. The players conducted moderate exercise, which was equivalent to a heart rate of 157 beats·min^{-1}, approximately 80% of their estimated maximum. Participants were shown slides of soccer situations for 20-s and then answered multiple-choice questions concerning passing situations, only decision-making accuracy was reported.

The same slides were used in each exercise condition and participants were tested first at rest and then during exercise, which could be considered limitation of the study. Furthermore, an habituation or learning effect cannot be discounted, as the ability to process information could also be a factor.

Marriott *et al.* (1993) did not examine the reproducibility of test measures or examine the possibility of learning or habituation effects. Furthermore, the methods of determining decision-making in this study did not assess the speed at which decisions were made in soccer. Although previous research has examined accuracy of decision-making, speed of decision-making has been overlooked mainly because of technical challenges involved despite the fact that both are important in soccer (Hughes, 1980). Decisions must be made not only accurately but also quickly. Marriott *et al.*, (1993) reported that accuracy following the first bout of exercise resulted in improvement in performance for the non soccer players. Therefore, because of these limitations, the study could not be considered an accurate and valid measure of decision-making in soccer.

Studies by McMorris and Graydon, (1996a,b;1997a,b) and McMorris *et al.*, (1999) have advanced knowledge in decision-making in soccer. The decision-making tests used by McMorris and Graydon, (1996a,b; 1997a) consisted of attacking decision-making situations simulated on a half-sized table tennis table top using model soccer players. The attacks were photographed, converted into slides and presented to the players via a projector onto a screen fitted with a tachistoscopic timing device. The slides were displayed for 2 s and the players were asked to decide as quickly as possible if the player in possession of the ball should pass, shoot, dribble or run. Participants' speed of vocal response (decision) was recorded. The players conducted the decision-making test at rest, after cycling at 70% maximal power output (MPO) and again at 100% MPO. There was an improvement in decision-making speed for both experienced and inexperienced soccer players. Furthermore, it was reported that the exercise condition did not affect the players' decision-making accuracy.

McMorris and Graydon (1996b) conducted another study in decision-making, this time manipulating task complexity. The decision-making tests were in two parts, part one, consisted the same decision-making test as in their previous study (McMorris and Graydon, 1996a) and in the second part of the study, players were required to make their decision from the perspective of one of the players shown in the slide. The exercise protocol was exactly the same as in the previous study. The results showed that there was a significant decrease in the players' decision-making speed and no effect on decision-making accuracy for both parts of the experiment, which contradicted their previous study..

Further investigation into the effects of exercise on decision-making of soccer players and in particular, visual search by McMorris and Graydon (1997a) led them to conduct two experiments. The first, evaluated players' speed of detecting familiar and unfamiliar soccer situations. Players were instructed to determine the presence or absence of a ball from the slides as quickly as possible. Again, the exercise protocol was the same as in previous studies, response time was longer at 100% MPO and the speed of visual search improved to the unfamiliar situations as a result of the exercise. The second experiment, investigated visual search time, decision-making speed and decision-making accuracy in a button-pressing model. The results indicated that decision-making speed and accuracy were improved as a consequence of exercise.

investigations into the decision-making of soccer players by McMorris and Graydon, (1996a,b; 1997a,b); McMorris *et al.*, (1999) have limitations, noticeably concerning ecological validity. The type of exercise used to facilitate physiological strain on the players, for example, cycling at 70% or 100% MPO is not soccer-specific and high-intensity intermittent exercise protocol specific to soccer could have produced different results in speed and accuracy of decision-making especially if the players were fatigued, which was not investigated in any of the studies. The decision-making tests (slide presentations, presentations of familiar and unfamiliar situations, voice recognition, use of a table tennis top and button pressing) are cognitive-based not dynamic in nature or soccer-specific and learning; habituation and ceiling effects have been reported as a probable cause of discrepancies in the results of the decision-making tests prompting the authors to address these issues in a series of studies.

Despite the assumed importance of soccer-related decision-making, little empirical research has attempted to examine this aspect. This is probably because of difficulties in controlling such an experiment and in particular, developing a valid, reliable and objective method that tests decision-making performance. Previous research into decision-making of soccer players has suggested that moderate exercise induces better decision-making performance than at rest and during fatigue. However, no studies to date have attempted to determine the extent to which high-intensity intermittent exercise has a detrimental effect on decision-making performance in soccer during the onset of fatigue, using reliable soccer-specific experimental protocols.

2.4 Factors that could inhibit decision-making in soccer

In soccer, players must repeatedly perform high-intensity exercise along with a decisional or perceptual task (Brisswalter *et al.*, 2002). The intermittent nature of soccer places extensive demands on aerobic and anaerobic energy systems; both being needed to enable players to perform to the best of their ability and to make quick and accurate decisions. Fatigue during the latter stages of the first and second halves of a match can be crucial to the outcome, as players' perceptual skills and performance could be impaired, which could lead to errors in decision-making, anticipation and longer response times. The following sections will attempt to investigate the possible causes in the decrement of decision-making performance of soccer players during a match.

2.4.1 Activity profile of outfield soccer players

Invasive field games, such as soccer, are characterised by intermittent activity profiles and results in the physiological demands of soccer being more complex than continuous exercise (Drust *et al.*, 2000). Many time-motion analyses of competitive matches have centered on distances covered (Reilly and Thomas, 1979; Mohr *et al.*, 2003; Krustrup *et al.*, 2005), however, the link between distance covered and the decision-making capabilities of soccer players has not been studied. Researchers, therefore, could only assume that a reduction in distance covered possibly because of fatigue and a decline in the ability of the players to repeat high-intensity exercise would have a detrimental effect on a player's decision-making performance. If a player demonstrates inadequate fitness, they would not be able to delay the onset of fatigue, thus concentration and co-ordination could be affected, making the ability to perceive affordances, deal with perturbations and defend sub-phases effectively, difficult.

The distance covered by a top-class outfield player during a match ranges from 10-13 km and is a function of positional role. In a study of top-class players, Mohr *et al.* (2003) found that central defenders covered less overall distance (9.74 ± 0.22 km) and performed less high-intensity running than midfield players (11.00 ± 0.21 km), fullbacks (10.98 ± 0.23 km) and forwards (10.48 ± 0.30 km), which is probably linked to the tactical roles of the central defenders and their lower physical capacity (Bangsbo, 1994; Mohr *et al.*, 2003). Midfielders, fullbacks and forwards covered a considerable ($p < 0.05$) distance at a high-intensity than the defenders (2.23 ± 0.15 km, 2.46 ± 0.13 km, 2.28 ± 0.14 km vs 1.69 ± 0.10 km, respectively). The forwards and the fullbacks covered a greater ($p < 0.05$) distance when sprinting than the midfield players and defenders (0.69 ± 0.08 km and 0.64 ± 0.06 km vs 0.44 ± 0.04 km and 0.44 ± 0.03 km, respectively).

All players in both groups showed a reduction ($p < 0.05$) in high-intensity running in the second compared with the first half. The forwards showed a greater ($p < 0.05$) decline in sprinting distance from the first to the second half than the defenders and the midfield players (19 ± 5%, vs 11 ± 6% and 8 ± 4% respectively).

It has been widely reported that 85 to 90% of many of the activities a player performs during a game are at low or sub-maximal intensities (Thomas and Reilly, 1976; Drust *et al.*, 1998; Mohr *et al.*, 2003). Consequently, soccer has been reported to involve a large ratio of low to high-intensity running (sprinting), in terms of time on the pitch (7:1 Thomas and Reilly, 1976; Bangsbo, 1993) and distance run (22:1, Thomas and Reilly, 1976).

During soccer, players have been shown to sprint approximately every 90 s, each sprint lasting 2 - 4 s (Bangsbo *et al.,* 1991). Using a high-time-resolution computer analysis system, Bangsbo and Mohr (2005) examined fluctuations in high-intensity exercise, running speeds and recovery time from sprints during several top-class soccer matches. They reported that sprinting speed in games reached peak values of approximately 32 $km \cdot h^{-1}$ and that sprints over more than 30 m demanded longer recovery than the usual sprints (between 10 m and 15 m) during a game. Therefore, the ability to perform high-intensity exercise (which would impinge on the energy systems of the player) and make quick and accurate decisions could be a necessity for successful soccer performance.

2.4.1.2 Energy requirements for soccer

It has been demonstrated that both anaerobic (Bangsbo *et al.*, 1991; Florida-James and Reilly, 1995) and aerobic (Reilly and Holmes, 1983; Florida-James and Reilly, 1995) energy systems are heavily taxed during the course of a soccer match. Rather than acting separately, the energy systems interact in an attempt to maintain ATP provision for muscle contraction.

2.4.1.3 Anaerobic energy metabolism

At the start of intermittent exercise, oxygen (O_2) bound to myoglobin in the muscle and haemoglobin in the blood, as well as O_2 already in the muscle provide a direct source of O_2 than can be used for energy provision (Saltin *et al.*, 1976). However, this aerobic contribution is not sufficient to provide all the energy required at the onset of high-intensity exercise (Spriet, 1995). To ensure muscle force development can continue, anaerobic energy systems must contribute. Furthermore, the ability to generate energy rapidly for a sprint is as necessary as the ability to generate sustained energy over 90 min of a match (Maclaren, 1996).

$$ATP \xrightarrow{ATPase} ADP + P_i + H^+ + energy \qquad (1)$$

where ADP is adenosine 5'-diphosphate, Pi is inorganic phosphate and H^+ is a hydrogen ion. Adenosine triphosphate is the only usable form of energy in muscle contractions, where ATP is broken down to adenosine diphosphate (ADP) by the action of enzymes (ATPase) at the cross-bridge heads of the muscle filaments. Adenosine triphosphate is a high-energy compound, which is used as an immediate source of energy for muscle activity. ATP stores will become depleted after 1-2 seconds of maximal exercise, ATP for continued muscular exercise is resynthesised by the integration of various metabolic processes (Gaitanos *et al.*, 1993). The two main anaerobic producing pathways that interact to maintain the supply of ATP for muscular force development are ATP-PCr and anaerobic glycolysis.

As phosphocreatine (PCr) is resynthesised during the periods of rest and low-intensity exercise, PCr concentration will rise and fall because of the intermittent demands for high rates of energy production during match play (Bangsbo, 1994). The reaction is catalysed by the enzyme creatine kinase and results in the formation of ATP and free creatine (Cr).

$$PCr + ADP + H^+ \longleftrightarrow ATP + Cr \qquad (2)$$

Intramuscular PCr stores play an important role as an energy buffer, providing phosphate for ADP in the resynthesis of ATP and immediate energy for muscular contraction at the onset of exercise and during short term high-intensity exercise. Anaerobic glycolysis involves the breakdown of glucose, mainly in the form of muscle glycogen to ATP and lactate. ATP production from anaerobic glycolysis is activated rapidly at the onset of maximal exercise reaching peak values of approximately 6-9 $mmol \cdot l^{-1}$, after approximately 5 seconds (Gastin, 2001), therefore to maintain ATP provision, contributions are required from simultaneously operating metabolic pathways. At the onset of exercise or during heavy-intensity exercise, pyruvate is subsequently converted to lactate, where:

$$\text{Glucose} + 2\ \text{ADP} + 2\ \text{Pi} \longrightarrow 2\ \text{Lactate} + 2\ H^+ + 2\ \text{ATP} \qquad (3)$$

2.4.1.4 Anaerobic energy production in soccer

Elite-standard soccer players perform 150 – 250 brief intense actions during a game (Mohr *et al.*, 2003), which could indicate that the rate of anaerobic energy turnover is high at certain times of a game. Even though not studied directly, the intense exercise during a game can lead to a high rate of creatine phosphate breakdown, which to some extent is resynthesised in the following low-intensity exercise periods (Bangsbo, 1994).

The recovery kinetics of PCr have been examined and the consensus of opinion appears to be that PCr recovery kinetics are complex, as reflected by large individual and between-protocol differences (Glaister, 2005). Analysis of PCr recovery kinetics under chaemic conditions have demonstrated that PCr resynthesis is achieved via aerobic ATP resynthesis (Quistorff, *et al.*, 1992). Information on the influence of recovery duration on PCr resynthesis during repeated sprints in a match is sparse due to the invasive nature of muscle biopsy procedures. However, using 10 x 6 s maximal sprints, Gaitanos, *et al.* (1993) reported that 30 s recovery periods enabled PCr to make a substantial contribution (≥50% of the total anaerobic ATP provision) to ATP resynthesis throughout each sprint. Furthermore, despite a progressive decline in the pre-sprint concentration of PCr throughout each trial, it is likely that with resynthesis rates of approximately 1.3 mmol/kg dm s, 30 s recovery periods would have enabled PCr to continue to make a contribution to total ATP resynthesis beyond the final sprint (Glaister, 2005).

During a sprint, the rapid drop in PCr concentration is offset by the increased activation of glycolysis with the two processes combining to maintain ATP turnover at a rate of 11-14 $mmol \cdot l^{-1}$ ATP/kg dm/s (Gaitanos, *et al.*, 1993). At high glycolytic rates, the concentration of muscle lactate increases and the associated increase in hydrogen ion (H^+) concentration has often been implicated as a possible cause of fatigue (Bergström and Hultman (1991).

The rate of glycolytic ATP provision is regulated by the intricate interplay between metabolic factors. During a match, progressive changes in the metabolic environment lead to a gradual inhibition of glycolysis with repeated sprints (Gaitanos *et al.* 1993). For example, in a study by Gaitanos *et al.* (1993) glycolysis accounted for 44% of the total anaerobic ATP provision during the first sprint, while the corresponding value for the tenth sprint was 16%. Moreover, in four of the participants (n = 7), the glycolitic contribution to total anaerobic ATP production during the tenth sprint was estimated to be zero. Various mechanisms have been postulated to account for the inhibition of glycolysis with repeated sprints (Bangsbo, 1996). One suggestion is that glycolysis is impaired by the progressive depletion of muscle glycogen stores that accompanies this exercise (Gaitanos *et al.* 1993).

As well as the decline in creatine phosphate, mean blood lactate concentrations of 2 – 10 $\text{mmol}\cdot\text{l}^{-1}$ have been observed during soccer matches, with individual values above 12 $\text{mmol}\cdot\text{l}^{-1}$ (Bangsbo, 1994; Krustrup *et al.*, 2006). These findings indicate that the rate of muscle lactate production is high during match play, but muscle lactate has been measured in only a single study. In a friendly match between non-professional teams, it was observed that muscle lactate rose four-fold (to approximately 15 $\text{mmol} \cdot \text{kg dry mass}^{-1}$) compared with resting values after intense periods in both halves, with the highest value being 35 $\text{mmol} \cdot \text{kg dry mass}^{-1}$ (Krustrup *et al.*, 2006). The decrement in soccer performance during the match was related to increased muscle lactate concentration.

Based on several studies using short-term maximal exercise performed in the laboratory (Gaitanos *et al.*, 1993; Nevill *et al.*, 1989) and the findings of high blood lactate and moderate lactate concentrations during match play, it is suggested that the rate of glycolysis is high for short periods during a match and the implications of this process as a possible mechanism for the decline in soccer performance is still inconclusive. Therefore, no assumptions can be made as to the extent to which the anaerobic energy system is responsible in the decrement in decision-making performance without investigating the role played by the aerobic energy system.

2.4.1.3 Aerobic energy metabolism

Regeneration of ATP from aerobic glycolysis involves the conversion of glucose or glycogen to pyruvate. However, if glycolytic flux does not exceed mitochondrial activity, lactate is not formed and oxidative phosphorylation occurs in the mitochondria. The beta-oxidation of fatty acids inside the mitochondria will also take place. The final reaction of oxidative phosphorylation is:

$$\text{NADH} + \tfrac{1}{2}\,O_2 + H^+ + 3\ \text{ADP} + 3\ \text{Pi} \longrightarrow 3\ \text{ATP} + \text{NAD}^+ + H_2O \qquad (4)$$

There are two metabolic pathways involved in oxidative phosphorylation: tricarboxylic acid cycle (TCA), which breaks down acetyl units derived from fuel molecules and generates the reduced coenzymes nicotinamide adenine dinucleotide (NADH) and flavin adenine dinucleotide ($FADH_2$) as well as carbon dioxide (CO_2) and the electron transport chain (ETC) where free energy, released when electrons are transferred from NADH and $FADH_2$ to O_2, gets channelled into phosphorylation of ADP to make ATP, that is, it drives the reaction:

$$\text{ADP} + \text{Pi} \longrightarrow \text{ATP} + H_2O \qquad (5)$$

During electron transfer from NADH and $FADH_2$ to O_2, free energy released pumps protons (H^+) from the matrix side of the inner membrane of the mitochondria to the outer side thus creating an electrochemical gradient. When protons return down the gradient, the free energy released is used to resynthesise ATP from ADP and Pi.

2.4.1.6 Aerobic energy metabolism in soccer

A player's mean $\dot{V}O_2$ during a 90 min soccer match is equivalent to 35.2 ± 1.1 $ml \cdot kg^{-1} \cdot min^{-1}$ or approximately 60% of the mean maximum oxygen uptake ($\dot{V}O_2$ max) (Tumilty, 1993). However, Bangsbo (1994) reported that the oxygen cost was closer to 60.6 ± 1.0 $ml \cdot kg^{-1} \cdot min^{-1}$ or approximately 80% of $\dot{V}O_2$ max. Higher energy-requiring activities, such as dribbling, running sideways and backwards have been suggested to be the cause (Reilly and Ball, 1984; Reilly and Bowen, 1984). Most of the distance covered in a soccer match is a combination of walking and low-intensity running which require a limited energy turnover (Bangsbo *et al.*, 2006). In terms of energy production, it has been shown that high-intensity exercise periods are important.

The large aerobic energy production in soccer and the pronounced anaerobic energy turnover during periods of a match are associated with a large consumption of substrates (Bangsbo, 1994). As soccer involves periods of high-intensity exercise, carbohydrate, in particular muscle glycogen is used (Hargreaves, 1994). Saltin (1973) observed that muscle glycogen stores were almost depleted at half time when the pre-match values were low (~ 200 mmol · kg dry mass $^{-1}$) which could cause fatigue, since the development of fatigue during prolonged intermittent exercise has been associated with the lack of muscle glycogen (Bangsbo *et al.*, 2006).

Moreover, elevating muscle glycogen before high-intensity intermittent exercise using a carbohydrate diet improves performance during such exercise (Balsom *et al.*, 1999), but Jacobs *et al.*, 1982; Krustrup *et al.*, 2006 have contradicted these findings and observed that muscle glycogen during a match decreases to values below that required to maintain maximal glycolyic rate (200 mmol · kg dry mass^{-1}). In a study by Krustrup *et al.* (2006), the muscle glycogen concentration at the end of a match was reduced to 150

- 350 mmol · kg dry mass^{-1}, therefore, suggesting there was still glycogen available. However, histochemical analysis revealed that approximately half of the individual muscle fibres of both types were almost depleted or depleted of glycogen (Bangsbo *et al.*, 2006). Nevertheless, it is unclear what the mechanisms are behind the possible causal relationship between muscle glycogen concentration and fatigue during high-intensity intermittent exercise.

If the duration of the exercise period is limited to a few seconds, oxygen bound to myoglobin (MbO_2) could buffer the initial oxygen demand of the exercise (Conley, *et al.*, 2000). During recovery, MbO_2 stores are fully replenished within 20 seconds of the cessation of exercise (Richardson *et al.*, 1995). With such rapid rate of resaturation, it is unlikely that the availability of oxygen from myoglobin would be a limiting factor during repeated sprints; however more research is required to fully establish the role of myoglobin during single and repeated sprints.

Based on the above findings, Bangsbo *et al.* (2001) estimated the mean rate of aerobic ATP turnover during the first 5 seconds of a 3 minute bout of intense (~120% $\dot{V}O_2$ max) exercise to be 0.7 mmol·l^{-1} ATP/kg dm/s. This value compares well with the value of 1.3 mmol·l^{-1} ATP/kg dm/s calculated by Parolin *et al.* (1999) during the first 6 seconds of a 30 second sprint and substantiates the small (<10%) aerobic contribution to overall ATP resynthesis during a single short sprint. However, as sprints are repeated, the level of aerobic ATP provision is reported to increase progressively due to elevated and possibly accelerated $\dot{V}O_2$ kinetics (Gaitanos *et al.* 1993).

2.4.1.7 Fatigue during repeated sprints

During repeated sprints, fatigue can be associated with changes in the intramuscular environment (MacIntosh and Rassier, 2002). Although the precise aetiology of muscular fatigue remains an issue of conjecture, causative factors include: a lack of available ATP for actin-myosin coupling, Na^+/K^+ pumping and Ca^{2+} uptake by the sarcoplasmic reticulum (SR), an inhibition of any of these by various metabolic by-products or alterations of excitation-contraction coupling from the action potential to Ca^{2+} release from the SR (Hultman *et al.*, 1990).

The notion that muscular fatigue could be because of a failure of the metabolic processes to resynthesise ATP at the required rate is supported by the fact that fatigue during repeated sprints is associated with signs of energy deficiency, for example, increased concentrations of IMP and hypoxanthine (Hellsten-Westing, *et al.*, 1993). Since energy provision during repeated sprints is maintained predominantly by anaerobic sources (PCr degradation and glycolysis) deficiencies in energy provision are likely to be associated with limitations in anaerobic metabolism (Glaister, 2005).

2.5 Electrical and metabolic mechanisms of fatigue

Fatigue could involve different processes associated with CNS command or peripheral mechanisms related to decision-making. CNS fatigue causes a drop in motivation, impaired transmission down the spinal cord and impaired recruitment of motor neurons could make quick and accurate decisions difficult when this occurs. Peripheral fatigue could involve impairment in the function of the peripheral nerves, neuromuscular junction, electrical activity of the muscle fibres, or the process of activation within the muscle fibres (Gibson and Edwards 1985; Lehmann *et al.*, 1993), but the details of this process and the effect it has on decision-making warrants further investigation.

Peripheral fatigue can be divided into two types: high-frequency fatigue (electromechanical fatigue) and low-frequency fatigue (mechanico-metabolic fatigue) (Gibson and Edwards 1985). During high-frequency fatigue, force output drops as a result of action potential failure along the sarcolemma of the muscle cell. The sarcolemma helps transmit electrical signals into the porous openings on the muscle cell's surface (T-tubules) and on the individual actin and myosin filaments within the contractile mechanisms. The failure of electrical signals (action potentials) to propagate is due to potassium (K^+) build-up in the T-tubules and the spaces between the actin and myosin filaments. Low-frequency fatigue is caused primarily by cellular damage, especially associated with eccentric contractions. Cellular damage leaves the muscle cell in a state of disarray; as a consequence, the electrical signals are weak (Bompa, 1999) and the resultant impulse and response to decisions could be impaired.

The CNS has two basic processes, excitation and inhibition. Excitation is a stimulating process for exercise; inhibition is a restraining process. Training alternates between the two processes (Bompa, 1999). For any stimulation, the CNS sends a nerve impulse to the muscle in preparation for exercise. The speed, power and frequency of the nerve impulse depend on the state of the CNS. When (controlled) excitation prevails the nerve impulses are the most effective, evidenced by a good performance. When, as a result of fatigue, the nervous cell is in a state of inhibition, the muscle contraction is slower and weaker (Bompa, 1999). Thus, the force of contraction and the number of motor units (muscle fibres) recruited directly relates to the electrical activation the CNS sends. Nerve cell working capacity cannot be maintained for long. Under the physiological strain of training and matches, working capacity decreases. If the player maintains high-intensity exercise, the nerve cell assumes a state of inhibition to protect itself from external stimuli. Once in this state, the nerve cell does not respond with the same activation. The force generated by the working muscle diminishes because some nerve cells lower their firing rate below threshold level. This decreases the number of motor units recruited (Bompa, 1999).

Should the coach disregard the needs of alternating high with low intensity training days, the new intensive stimuli will result in exhaustion, when the nerve cell is in a state of inhibition of protection. While in this state, performance is below normal (Bompa, 1999). Fast-twitch fibres, fast glycolitic (FG) and fast oxidative glycolitic (FOG) are more susceptible to fatigue than slow-twitch fibres (ST). Fast twitch fibres have a high potential for fast turnover of Ca^{2+} ions and ATP-CP in connection with muscular contraction and for ATP-CP production via anaerobic processes. However, ST fibres have a higher aerobic potential evidenced by a higher myoglobin and mitochondrial enzymatic activity level (Edgerton, 1976; Ruff, 1989).

Skeletal muscle produces force by progressively activating its motor units and regulating their firing frequency, which is increased to enhance force output. Slow-twitch muscle fibres are recruited for the size of their motor-neuron cell body and their predominant aerobic metabolism. As the demand for force increases, FOG fibres are recruited, followed by FG, which can generate the most force (Edgerton, 1976; Rose and Rothstein, 1982).

Players can neutralise fatigue, which inhibits muscle activity, some by a modulating strategy, responding to it through the ability of the motor units to alter firing frequency.

The muscle can maintain force more effectively under a state of fatigue. However, if the duration of sustained maximum contraction increases, the frequency of motor units firing decreases signalling that inhibition will become more prominent (Bigland-Ritchie *et al.*, 1983).

When analysing the functional capacity of the CNS during fatigue, consideration of how the player perceives fatigue and past physical capacity in training and matches is needed. When physical capacity is higher than the level of fatigue experienced in testing or matches, the player's motivation and capacity to overcome fatigue are enhanced. Motivation relates to past experience and conditioning (Bompa, 1999).

Maximal high-intensity exercise at the muscular level can result in muscle fibre damage or metabolic fatigue, such as the depletion of fuel, the accumulation of Ca^{2+} flux in the muscle, or the build-up of intramuscular hydrogen ions (pH) (Allen *et al.*, 1992; Sahlin 1992). Metabolic mechanisms of fatigue can occur during prolonged continuous exercise or during repeated sprints (Bompa, 1999).

The events leading to voluntary muscular contractions involve a controlling chain of command from the brain to actomyosin cross bridges (Figure 2.3). Fatigue could be due to impairment at any one or more links in the chain (Gibson and Edwards, 1985), thus causing a decrease in decision-making performance.

		Possible fatigue mechanism
Psyche		
Brain		
↓	←	Impaired motivation i.e. neural motor drive and motor unit recruitment
Spinal Column		
↓	←	Impaired reflex drive
Peripheral nerve		
↓	←	Impaired neuromuscular transmission
Muscle sarcolemma		
↓	←	Impaired action potential
Transverse tubular system	←	K^+, Na^+, H_2O imbalance
↓	←	Impaired excitation
Ca^{++}		
↓	←	Impaired activation and energy supply
Actin-myosin interaction		
↓		
Cross bridge tension + heat	←	Thermal damage
↓	←	Sarcomere damage
Force/Power output		

Figure 2.3.Chain of command for muscular contraction and possible mechanisms underlying fatigue (Gibson and Edwards, 1985).

2.5.1 Fatigue and soccer performance

There is increasing evidence that fatigue can lead to a deterioration of soccer performance in the form of lapses in concentration, delayed responses and errors in decision-making (Reilly, 2002). The likely time during a match for these occurrences has been shown to be toward the end of each half and at the beginning of the second half (Reilly and Lewis, 1985).

Factors such as a reduction in distance covered, and the ability to perform high-intensity exercise in soccer, has already been identified as manifestations of fatigue in soccer players, however, factors such as dehydration and hyperthermia have not been taken into account and could also contribute to the development of fatigue (Magnal *et al.*, 2003) furthermore, their role in delayed responses and errors in decision-making in soccer is not known. Soccer players have been reported to lose up to 3 l of fluid during games in temperate thermal environments and as much as 4 - 5 l in hot and humid environment (Bangsbo, 1994; Reilly, 1997) and it has been observed that 5 and 10 m sprint times are slowed by hypohydration amounting to 2.7% of body mass (Magal *et al.*, 2003).

However, in a study by Krustrup *et al.* (2006) there was a reduction in sprint performance, although the fluid loss of the players was approximately only 1% of body mass and no effect on core or muscle temperature was observed in a study with a similar loss of fluid (Mohr *et al.*, 2004). This finding suggests that fluid loss is not always an important component in the impaired performance seen towards the end of a match.

2.5.1.2 Transient fatigue in soccer

The activity profile of soccer players comprises cycles of exercise and recovery that recur in an unpredictable way (Reilly, 2002). These exercise bouts and recovery periods can vary in frequency, intensity and duration. An individual player can have successive periods of repetitive high-intensity activity with inadequate time to recover in-between the exercise bouts. If pressurised, this player could lose performance capability, but only on a temporary basis (Reilly, 2002).

Soccer players can experience temporary fatigue during a match. In a time-motion video analysis study Mohr *et al.* (2003) reported that the amount of high-intensity running in the 5-min period immediately after the most intense 5-min interval recorded during a match was less than the mean of the entire match. This finding indicates that performance was reduced after a period of intense exercise, which could have been a result of the natural variation in the intensity in matches attributable to tactical or psychological factors.

However, in another study, players performed a repeated sprint test immediately after a short-term intense period during a match and at the end of each half (Krustrup *et al.*, 2003). It was shown that after intense periods in the first half, player's sprint performance was reduced, whereas at the end of the first half the ability to perform repeated sprints was recovered. These results suggest that soccer players experience fatigue temporarily during a match, although, further studies will be needed to substantiate these claims.

In matches studied by Krustrup *et al.* (2006), muscle inosine monophosphate (IMP) concentrations were higher at the end than before the match and raised NH_3 concentrations also indicate that the adenosine monophosphate (AMP) deaminase reaction was stimulated. Moreover, the muscle IMP concentrations were lower than observed during exhaustive exercise (Hellsten, 1999) ATP was only moderately reduced. Therefore, it is unlikely that fatigue occurred as a result of a low energy status of the contracting muscles (Bangsbo *et al.*, 2006).

To provide further explanations of the occurrence of fatigue during soccer, suggestions that the development of fatigue during high-intensity exercise is related to an accumulation of potassium in the muscle interstitium and the concomitant electrical disturbances in the muscle cell have been made (Bangsbo *et al.*, 1996; Nordsborg *et al.*, 2003). At the point of exhaustion after short-term exercise (~ 5 min), the interstitial potassium concentration is elevated to approximately 12 $mmol \cdot l^{-1}$ (Mohr *et al.*, 2004), which according to in vitro studies is high enough to depolarize the muscle membrane potential and reduce force development (Cairns and Dulhunty, 1995).

Potassium loss could also occur through the K_{ATP} channels located in the sarcolemma, which tend to open when intramuscular pH declines (Davis, 1990). Hence the accumulation of interstitial potassium could be indicative of anaerobic metabolism (Mohr *et al.*, 2005). Furthermore, soccer players could experience temporary fatigue as a consequence of accumulation of extracellular potassium and concomitant electrical disturbances in the muscle cell. However, at present little is known about potassium turnover in the muscle during a soccer match (Mohr *et al.*, 2005).

The role central mechanisms of fatigue play in a possible decrement in performance and impaired decision-making in soccer has received little or no attention. Central fatigue can be defined as a subset of fatigue associated with specific alterations in CNS function that cannot reasonably be explained by dysfunction in muscle (Davis and Bailey, 1997). This definition allows for the inclusion of 'psychological' factors like perception and in particular, decision-making as an important factor in the explanation of this phenomenon.

The central fatigue hypothesis is based on the assumption that during prolonged exercise the synthesis and metabolism of central monoamines, in particular the neurotransmitters serotonin, dopamine and noradrenaline (5-hydroxytryptamine) or (5-HT) are influenced (Meeusen *et al.*, 2006). Newsholm *et al.* (1987) were the first to provide a possible explanation for 5-HT as a mediator for central fatigue and suggested that prolonged high-intensity exercise results in an increase in brain serotonergic activity that could augment lethargy, cause an altered sensation of effort, a possible differing tolerance of pain/discomfort and a loss of drive and motivation and the realisation that exercise could affect important factors controlling brain 5-HT synthesis and turnover. Moreover, in theory, the rate of serotonin synthesis is largely dependent on the peripheral availability of the essential amino acid tryptophan (TRP) and an increase in the delivery of tryptophan to the CNS could increase serotonergic activity because the rate-limiting enzyme, tryptophan hydroxylase, is not saturated under physiological conditions. Furthermore, free tryptophan (f-TRP) and the branched-chained amino acids (BCAA) share the same carrier in order to pass across the blood-brain barrier, meaning that the plasma concentration ratio of (f-TRP/BCAA) is considered to be an important determinant of serotonin synthesis and its relationship with a player's mental state (Davis, 1995).

However, as central fatigue is a multifaceted phenomenon, there are peripheral factors and other cerebral factors that could limit exercise and decision-making performance, all of which influence signal transduction, since the brain cells communicate through chemical substances (Meeusen *et al.*, 2006). Peripheral fatigue has been well studied and fatigue during both high-intensity short-term exercise and moderate to low-intensity prolonged exercise is accompanied by a decreased capacity to resynthesise ATP within the active muscle. Cellular ADP concentration rises and the total adenine nucleotide pool is reduced (Sahlin, 1992).

One area of the CNS that has received little attention in relation to exercise is the blood-brain barrier and the possibility that changes in its integrity could be involved in the fatigue process (Meeusen *et al.*, 2006). The relatively impermeability of the blood-brain barrier helps to maintain a stable environment for the brain by regulating exchange between the CNS and the extra-cerebral environment (Meeusen *et al.*, 2006). While the blood-brain barrier is largely resistant to changes in permeability, there are circumstances in which the function of the blood-brain barrier can be either acutely or chronically compromised, with changes potentially resulting in a disturbance of a wide range of homeostatic mechanisms (Meeusen *et al.*, 2006).

There is some evidence that prolonged high-intensity exercise could lead to increased blood-brain barrier permeability thus causing fatigue and a decrement in performance. In a study by Watson *et al.* (2005), they reported an increase in circulating serum S 100β, a proposed peripheral marker of blood-brain barrier permeability, following prolonged exercise in a warm environment. This response was not apparent following exercise in temperate conditions (Watson *et al.*, 2005). A similar increase in serum S 100β was reported following soccer drills involving the repeated heading of soccer ball

(Stalnacke *et al.*, 2004) although the authors of these studies incorrectly interpreted this change as an indication of neural damage. Serum S 100β is now being employed as an index of brain trauma in players who suffer injuries in sport (Meeusen *et al.*, 2006). However, at present, the functional consequences of changes in blood-brain barrier permeability during high-intensity exercise are not clear.

Other cerebral metabolic, thermodynamic, circulatory and humoral responses could all lead to a disturbance of cerebral homeostasis and eventually central fatigue (Meeusen *et al.*, 2006). There is evidence that because of the extreme disturbance of homeostasis that occurs during prolonged exercise, peripheral and central regulatory mechanisms will be stressed, but it is not possible to determine the exact regulation and the importance of each factor (Meeusen *et al.*, 2006). There is evidence that provision of energy drinks reduces the effects of central fatigue, water providing a lesser benefit (Reilly, 2002). The use of branched-chain amino acids has also been advocated, although the evidence of a positive effect has been contested.

The role of central mechanisms of fatigue during high-intensity exercise and its effect on decision-making in soccer, however, has not been well studied and researchers have found it difficult to explain the possible causes. It has been known that psychological factors (perceptual) can affect exercise performance (Asmussen, 1979; Secher, 1992) and that under most circumstances fatigue results from the player's unwillingness to generate adequate central drive to maintain the force or power output.

Therefore, the need to investigate the possible detrimental effect fatigue has on decision-making in soccer could prove beneficial to a player and coaching staff, in order to implement realistic and practical coaching interventions to maintain a high level of soccer performance.

2.5.1.3 Physiological fatigue and decision-making

The physiological effects of exercise on cognitive/perceptual motor performance have been studied, but outcomes have been contradictory. Possible reasons can be the diversity of methods chosen with regard to the physical exercise mode and protocol, physical fitness or sport experience of the players, nature and complexity of the task and time of administering the task (Etnier *et al.*, 1997; McMorris and Graydon, 2000; Brisswalter *et al.*, 2002). Etnier *et al.* (1997) concluded that the overall effect of exercise on cognitive/perceptual performance was small and positive. McMorris and Graydon (2000) reported that incremental exercise had no effect on the accuracy of cognitive/perceptual motor performance and Tomporowski (2003) concluded that aerobic exercise had selective effects on specific aspects of information processing.

Reaction time is often used to study the elementary aspects of cognitive/perceptual motor performance during exercise. Most studies have indicated that cognition improves with moderate exercise probably as a result of arousal of the central nervous system (Arcelin *et al.*, 1997). This exercise-induced arousal leads to a narrowing of attentional focus and hence improves reaction time (Gould and Krane, 1992). McMorris and Graydon (1996a) have reported that exercise-induced arousal leads to more allocatable resources available in the central nervous system which in turn would lead to improved reaction time. These conflicting results highlight the difficulty in assessing cognitive/perceptual motor performance, but what is common to these studies is the conclusion that if a player is involved in prolonged high-intensity exercise, then fatigue is unavoidable, furthermore, fatigue could also lead to decrement in cognitive/perceptual motor performance (McMorris and Keen, 1994), through mechanisms including dehydration, depletion of muscle glycogen or central nervous system mechanisms (Cian *et al.*, 2000).

A limitation of most studies from a sport perspective is the focus on continuous exercise. Soccer can be described as intermittent activity, as during a match, bouts of high-intensity exercise (repeated sprints) are interspersed with periods of low-intensity exercise (jogging and walking) (Bangsbo, 1994). It is hypothesised that during soccer, the aforementioned effects of exercise on reaction time interact: during periods of high-intensity exercise, negative effects from fatigue could dominate, while during periods of low-intensity exercise positive effects from exercise-induced arousal could play the more important role.

A second limitation has been the lack of soccer-specific protocols to assess cognitive/perceptual responses and movements of soccer players. A third limitation has been the use of reaction time only and disregarded other aspects such as response accuracy. Studies in which accuracy has been addressed usually report no change or increased accuracy (Paas and Adam, 1991). Changes in response accuracy during exercise could point to changes in speed-accuracy strategies, so therefore, the number of incorrect responses to specify response accuracy should be included in any protocol. A fourth limitation is that most studies do not take into account individual differences in fitness or sport experience. A fifth limitation is that reaction time measurements are often limited to manual processes. In soccer, whole body and particular lower limb movement reactions are important for performance (Lemmink and Visscher, 2005).

To clarify the relationship between high-intensity intermittent exercise and cognitive/perceptual motor performance, it would be necessary to study the specific influence of mode, intensity, work-rest ratio and duration of intermittent exercise and the sensitivity of reaction time and other cognitive/perceptual tasks. An important area that would also need to be addressed would be trying to control learning effects and familiarisation of the task, although this can be difficult, it could be minimised by implementing pre-test trials of the task to be undertaken.

2.6 Measures of physiological function and soccer performance

Extensive physiological assessments of soccer players have been undertaken in an attempt to quantify the importance of aerobic and anaerobic energy provision for the performance of high-intensity soccer-specific exercise.

2.6.1 Maximal oxygen uptake ($\dot{V}O_2$ max)

Maximal oxygen uptake is defined as the maximum rate at which an individual can extract, transport and use O_2 at sea level (Åstrand and Rodahl, 1986). The $\dot{V}O_2$ max of an individual is achieved when both cardiac output ($\dot{Q}$) and the arterial-venous O_2 content difference (C (a-$\bar{v}$) O_2) are maximal, which is expressed in an arrangement of the Fick equation:

$$\dot{V}O_2 \text{ max} = \dot{Q} \text{ max} \cdot (C\ (a\text{-}\bar{v})\ O_2) \text{ max} \qquad (6)$$

During soccer where a player is required to support their body, $\dot{V}O_2$ max is expressed relative to body mass (ml·kg^{-1}·min^{-1}). An accurate measure of a soccer player's $\dot{V}O_2$

max can be obtained through direct determination $\dot{V}O_2$ max (Armstrong and Costill, 1985), where pulmonary gas exchange is typically measured during an incremental treadmill test to volitional exhaustion. Manipulating the speed or gradient of the treadmill progressively increases the intensity of the exercise. Importantly, $\dot{V}O_2$ max has been reported to be ~ 4% lower during a speed compared to a gradient protocol. This could be explained by the fact that if players are not accustomed to running at high speeds, it is their inability to run quickly that stops them prematurely, rather than the attainment of volitional exhaustion.

2.6.1.2 Relationship between $\dot{V}O_2$ max and soccer performance

The $\dot{V}O_2$ max of soccer players has been observed to range from 56 to 69 $ml \cdot kg^{-1} \cdot min^{-1}$ (Puga *et al.*, 1990; Davis & Brewer, 1992; Bangsbo, 1993), which is higher than sedentary individuals and similar to that reported for athletes from other team sports (Bangsbo, 1998). Such a range in $\dot{V}O_2$ max values appears to be the result of positional differences in aerobic fitness, with midfielders and fullbacks typically possessing the greatest aerobic capacity, followed by forwards and then central defenders (Puga *et al.*, 1990; Rahkila and Luhtanen, 1991). Such differences in aerobic fitness among players could be attributed to position-specific physiological loads, as $\dot{V}O_2$ max has been found to be associated with the total-distance-run during a match ($r = 0.98$, Smaros, 1980; $r = 0.68$, Reilly, 1996). A large $\dot{V}O_2$ max could be beneficial for soccer performance as a high level of aerobic fitness has been associated with enhanced recovery capabilities following high-intensity exercise (Tomlin and Wenger, 2001).

Direct support for the importance of $\dot{V}O_2$ max for soccer performance was provided by Helgerud *et al.* (2001), who reported that, an increase in the $\dot{V}O_2$ max of well trained soccer players from 58.1 ± 4.5 $ml.kg^{-1}.min^{-1}$ to 64.3 ± 3.9 $ml.kg^{-1}.min^{-1}$ was associated with an increase in the number of sprints performed during a match. Furthermore, the distance run in a test of soccer-specific high-intensity running capacity has been found to be positively correlated with $\dot{V}O_2$ max ($r = 0.79$, Krustrup *et al.*, 2003). However, several studies have reported that $\dot{V}O_2$ max is not associated with the amount of high-intensity running performed during match play (Krustrup *et al.*, 2003; Mohr *et al.*, 2003).

2.7 Soccer-specific performance measure

Soccer-specific performance tests can provide a direct means of investigating the physiological processes involved in the performance of high-intensity soccer-specific exercise. The methods that can be used in competition to determine the physiological stresses associated with match play are limited, therefore, for the purpose of this thesis, attention shall be focused on measures of intermittent high-intensity exercise capability using a laboratory-based protocol.

2.7.1 Soccer-specific intermittent protocol

Physiological responses to intermittent exercise have been compared with continuous exercise at the same intensity in an attempt to evaluate differences between exercise patterns and hence the physiological stress associated with discrete bouts of each type of activity (Åstrand *et al.*, 1960; Edwards *et al.*, 1973). Comparisons of these two exercise patterns are important, as both intermittent and continuous exercise are used in soccer training to facilitate physiological adaptations to improve performance (Drust *et al.*, 2000). Intermittent exercise performed at the same intensity as continuous exercise has been associated with increased physiological strain (Edwards *et al.*, 1973).

Several researchers have devised laboratory-based exercise protocols to assess the physiological and metabolic responses to intermittent exercise (Balson *et al.*, 1992b). The intermittent activity patterns used in these investigations have primarily been repeated bouts of high-intensity efforts of short duration separated by static recovery. Attempts have been made to develop protocols that replicate the activity patterns observed in multiple-sprint sports using a non-motorised treadmill (Nevill *et al.*, 1995) and field-based protocols (Nicholas, *et al.*, 1995). These studies, despite eliciting physiological responses similar to those observed during match play (Nicholas, *et al.*, 2000) have concentrated on examining the physiological stresses associated with multiple sprint performance or the influence of carbohydrate-electrolyte solutions on intermittent endurance capacity.

A soccer-specific protocol (Drust *et al.*, 2000) replicates soccer in several ways. The total duration of the protocol is 46:11 min when the two sections are combined with static rest. Such a time closely replicates one half of a soccer match with some additional time attributable for stoppages. Exercise patterns observed in match play (jogging, walking, and sprinting) are incorporated at speeds close to those observed during matches (Van Gool *et al.*, 1988). The physiological responses (oxygen consumption, heart rate and min ventilation) to the protocol were similar to those observed during soccer match play.

Such similarities indicate the relevance of this intermittent protocol as a model of match play intensities. Nevertheless, there are limitations to the activity profiles observed between the soccer-specific intermittent protocol and match play. These include a lower frequency of activity changes, the omission of utility movements, such as backwards and sideways walking and jogging and the lack of game skills (kicking, heading and tackling). The exclusion of these components probably results in reduced energy demands in the protocol compared with match play (Bangsbo, 1994).

However, their inclusion would make it more difficult to assess the physiological responses to soccer-specific intermittent exercise under controlled conditions. Despite these problems, the locomotive patterns used in the protocol provide a good representation of match play intensities and can be achieved on a motorized treadmill.

2.7.1.2 Repeated sprint performance

The term repeated sprint ability was first introduced by Fitzsimons *et al.* (1993) and refers to the ability to perform maximal sprint efforts (Dawson *et al.*, 1993). Although there are a variety of repeated sprint tests very few have actually been based on match analysis data. In trying to understand the physiological mechanisms involved in repeated sprint ability, various field tests have been developed (Fitzsimons *et al.* 1993; Bangsbo, 1994; Wadley and Rossignol, 1998). These protocols have taken similar formats, the sprint durations for each test varying between 20-40 m, the number of repetitions being 16-18, with recoveries of between 15-25-s.

All previous studies involving repeated sprint protocols have made some attempt to establish the logical validity of the protocol, claiming that a test of repeated sprints will challenge the energy systems in a manner that closely replicates match play (Bangsbo, 1994).

An active recovery (ie, 30-40% of $\dot{V}O_2$ max) has been shown to promote faster clearance of blood lactate when undertaken after high-intensity exercise (Thiriet, *et al.*, 1993). Furthermore, an active recovery has also been reported to improve power output recovery during subsequent exercise bouts in most studies (Thiriet, *et al.*, 1993). However, these aforementioned studies have used exercise protocols that are not soccer specific (ie, exercise durations of 15 – 2 min and recovery durations of 3-20 min). One study that has used a protocol more specific to soccer (i.e., eight 6-s cycling sprints with 30s of recovery between sprints) reported an increase in peak power output and total work when an active recovery (cycling at 60 W; approximately 30-40% $\dot{V}O_2$ max) was undertaken, compared with a passive recovery (Signorile, *et al.*, 1993). The authors concluded that an active recovery results in superior performance compared with passive recovery, during short duration, repeated-sprint activity. Unfortunately, Signorile *et al.* (1993) did not measure any blood or muscle metabolites to gain an insight into the mechanisms underlying this performance difference.

In contrast, an active recovery (15s at 40% of $\dot{V}O_2$ max) has also been reported to decrease performance during high-intensity intermittent exercise (15s at 120% of $\dot{V}O_2$ max) compared with passive recovery, with the time to exhaustion being different (427 ± 118 and 962 ± 314 s, respectively, p □ 0.001) (Dupont, *et al.*, 2004). This performance decrement was correlated with a greater decline in oxyhemoglobin, measured via near infrared spectroscopy and the authors speculated that active recovery could restrict reoxygenation of myoglobin and phosphocreatine (PCr) resynthesis (Dupont, *et al.*, 2004).

For the purpose of this thesis, the repeated sprint test consisted of players being harnessed and sprinting on a motorised treadmill at approximately 21- 25 $km \cdot h^{-1}$ (120% of $\dot{V}O_2$ max denotes high-intensity exercise during competitive match play, Mohr *et al.*, 2003) for 10 x 10 s sprints, with either a 15-s or a 30-s recovery period in between, straddling the treadmill belt after every bout. The test was used to gain information regarding the physiological mechanisms that influence high-intensity soccer specific exercise capabilities seen in soccer. Furthermore, no studies have attempted to investigate a possible association with repeated sprint and decision-making performance in soccer.

2.7.1.2.2 Information Processing and Learning

To the information processing theorists, motor learning is about increasing the players' LTM store – in particular, developing motor programs (McMorris, 2004). Learning movements is primarily a CNS task. It is thought that the pathway from the CNS to the muscles become more streamlined as we learn. Basically, the neural interconnections in the Peripheral Nervous System (PNS) become stronger. This is shown by an improvement in co-ordination and can be observed by the fact that the expert appear to be performing more easily and in a smoother manner than the novice (McMorris, 2004).

This cognitive, CNS dominated idea of learning led Anderson to develop his ACT theory. He believes that the first stage of learning is to acquire declarative knowledge, which is knowing 'what to do'. As players practice, they move from possessing declarative knowledge to possessing procedural knowledge, which is 'being able to do the skill'. Although this theory was developed for verbal skills, it has been widely received in the cognitive motor learning field (McMorris, 2004). However, research examining implicit learning has suggested that players obtain procedural knowledge without having declarative knowledge of the skill (Masters, 2000).

While implicit learning could be difficult to explain from an information processing standpoint, another phenomenon – the effect of mental rehearsal supports the notion of CNS control of movement, particularly working in conjunction with physical rehearsal

(McMorris, 2004). It has been shown that players, who use mental rehearsal as well as physical rehearsal, learn more quickly than those using physical rehearsal (McMorris, 2004). An advantage of using mental rehearsal is that by thinking about the skill, the player builds up a picture or model in the CNS of how the skill should be performed. The second advantage concerns how mental rehearsal works is based on the idea that the CNS cannot differentiate between mental activity, in its own right and mental activity that leads to motor performance (McMorris, 2004). Therefore, if a player thinks about doing something the CNS learns the same, or almost the same, as actually doing the task. There are different kinds of mental rehearsal, the most common form being mental imagery. In mental imagery, the player sees themselves as doing the skill. It is believed that in this way, they experience the task almost as well as if they were actually doing it (McMorris, 2004).

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2.7.1.2.3 Demonstration

The quality of demonstration is an important factor in cognitive learning in soccer. For players to learn by observation, the demonstration needs to be correct. If the demonstration is incorrect, there is a possibility of the player copying the incorrect movement. The coach needs to decide the extent to which their standard of performance is satisfactory to demonstrate the skill. The demonstration needs to be adequate, not perfect (McMorris, 2004). Some coaches overcome limitations by demonstrating in slow motion, however, this technique should only be used when speed is not an essential in the performance of the skill.

Slow motion demonstrations could, however, be necessary in some cases even when the coach can demonstrate at normal speed. Some skills can be performed too quickly for the player to see exactly what is happening; in such cases the coach will have to give a slow motion demonstration, but only after a real-time demonstration has been previously carried out (McMorris, 2004).

2.7.1.2.4 Advance cue utilisation

Advance cue utilisation refers to a player's ability to make accurate predictions based on contextual information available early in an action sequence (Abernethy, 1987). The ability to make predictions upon partial or advance sources of information is what Poulton (1957) referred to as perceptual anticipation. Perceptual anticipation is essential in soccer because inherent limitations in the player's reaction time and movement time would result in decision-making being made too late to provide an effective counter (Glencross and Cibich, 1977).

Several techniques have been used to examine advanced cue utilisation in soccer. These are logically divided into laboratory and field-based approaches (Abernethy, 1987). The lab-based tests involve mainly using film occlusion and a reaction time paradigm. In the film occlusion approach, the duration and nature of the display is externally controlled and constrained by the experimenter, whereas, in the reaction time paradigm, response time or viewing time is under participant control and is allowed to covey with response accuracy. In contrast, field-based approaches have embraced a more ecological emphasis by measuring performance directly using techniques such as high-speed film analysis and liquid crystal occlusion glasses (Williams *et al.*, 2004).

2.7.1.2.5 Practice

Shea and Morgan (1979) were among the first to show that block practice facilitates early performance, but is not as effective as random practice during later retention and transfer. During random practice, tasks from several classes are experienced in random order, whereas in blocked practice, a given skill is practiced on many occasions (Schmidt, 1991).

In a study of learning four different arm movements, Shea and Morgan (1979) reported that during acquisition, the blocked group performed better over the trials; however, during the retention and transfer, their performance fell to levels similar to those found in early training. Although the random group never achieved the levels of the blocked group during acquisition, they reached their best performance during retention and transfer.

Since this study, variable practice has also emerged as an effective mode of practice. During variable practice, many variations of a single class of actions are practiced instead of the simple repetition of the same skill (Schmidt, 1991). The efficacy of random or variable practice has been established in a wide range of laboratory and field tasks; however, none of these studies have attempted to implement these practice interventions in soccer, as the benefits of various forms of practice could be beneficial to the player in their learning of complex skills.

2.7.1.2.6 Feedback

Research into providing abundant feedback to athletes of all ages and level of competition was universally encouraged (Vickers *et al.*, 1999). However, research advocates reducing feedback as skill improves (Lee and Carnahan, 1990; Schmidt, 1991). To achieve good long-term performance, it is now recommended that feedback is gradually reduced or faded, requiring players to function more independently of external guidance and correction (Vickers *et al.*, 1999).

There is growing evidence that visual feedback remains important for movement control after extensive levels of practice (Proteau and Cournoyer, 1990; Proteau and Marteniuk, 1993). Furthermore, it has been shown that part of the learning process involves the discovery of specific control strategies that enable players in particular to optimise the utilisation of visual feedback (Elliot *et al.*, 1995; Khan and Franks, 2000).

Augmented feedback augments task-intrinsic feedback in two distinct ways. In some situations, augmented feedback enhances the task-intrinsic feedback the player's sensory system can readily detect on its own (Magill, 1998). For example, a soccer coach could tell a goalkeeper where his hands were positioned in an attempt to catch a soccer ball whilst making a difficult save, even though the goalkeeper could feel for himself where they were. Or, it could add information that the player cannot detect using their sensory system. For example, the soccer coach could tell a defender where the player and the ball went after the player made a miss-timed tackle because the player did not see what happened after the attempted tackle. In each of these situations, augment feedback provides performance information that otherwise would not be available to the player (Magill, 1998).

2.8 Dynamical systems and learning

Information processing theorists believe learning is about developing memory and is primarily a function of the CNS. To the dynamical systems theorists, memory is of little use in the learning of motor skills (McMorris, 2006). There is no need for a specific motor programme or the CNS to perform movement. This is taken care of by the interaction between the environment and the player. So, the key to learning is for the player to become attuned to affordances and control co-ordination changes. As perception and action are coupled, once the player has decided what goal they want to achieve, they explore the environment to find the affordance - this will occur naturally by trial and error. The major role of the coach is to help the player to perceive the affordances. The coach must also be aware that what could be deemed as an affordance to them may not be to the player. The coach could therefore guide the player towards perceiving the affordances themselves, known as guided discovery learning.

However, viewing the role of memory in this way can be misleading as many soccer actions are based and formulated through the ability to recall actions from memory and it is the quality of the player that determines if this knowledge is used effectively. Therefore, the two theories centred on the role of memory in perception and action should be used in conjunction with each other to enhance player performance and ultimately improve decision-making (McMorris, 2006).

Whatever learning techniques are used (trial and error or guided discovery), the factors that affect learning are task (e.g. rule changes, relating to severe punishment of miss-timed tackles, which could result in a player being sent off), environmental (better quality soccer pitch surfaces allows for a high standard of passing and movement by the attacking team, making it difficult for defenders to anticipate quickly to dangerous situations) and organismic constraints (e.g. changes in physique results in a change the way a player moves). Newell (1986) stated, when planning a practice, the coach should take into account all three constraints, as they have a triangular effect on learning (Figure 2.4). Practice should take into account this interaction. Another factor is motivation or 'bootstrapping'. Bootstrapping means stretching the player beyond what they can already do. In other words, the coach manipulates the constraints so that the player must acquire a new skill or a new dimension of an old skill to achieve their goal (McMorris, 2004).

One of the effects of bootstrapping is 'freezing' and 'unfreezing' the degrees of freedom Turvey (1992). Turvey suggested that when a skill is learned for the first time, it is difficult to control the muscles and joints that are used. As a result, players will naturally overcome this by freezing many of the degrees of freedom, for example, they will ensure that some joints are kept locked. Watching a player learning to defend a 1 v 1 or a 2 v 1 situation, it is clear to see that they become tentative and unsure as to the correct decision to be made and often their body position is rigid, upright and forward facing in their stance. At this stage the player must free the degrees of freedom in order to perform the task efficiently. For example, they must get side-on, with knees slightly bent in their stance and get arms length in distance away from the attacker. As the player develops and improves, the coach will then demonstrate the principles of tackling in these situations. So the quality of instruction and feedback by the coach is paramount for effective learning to take place.

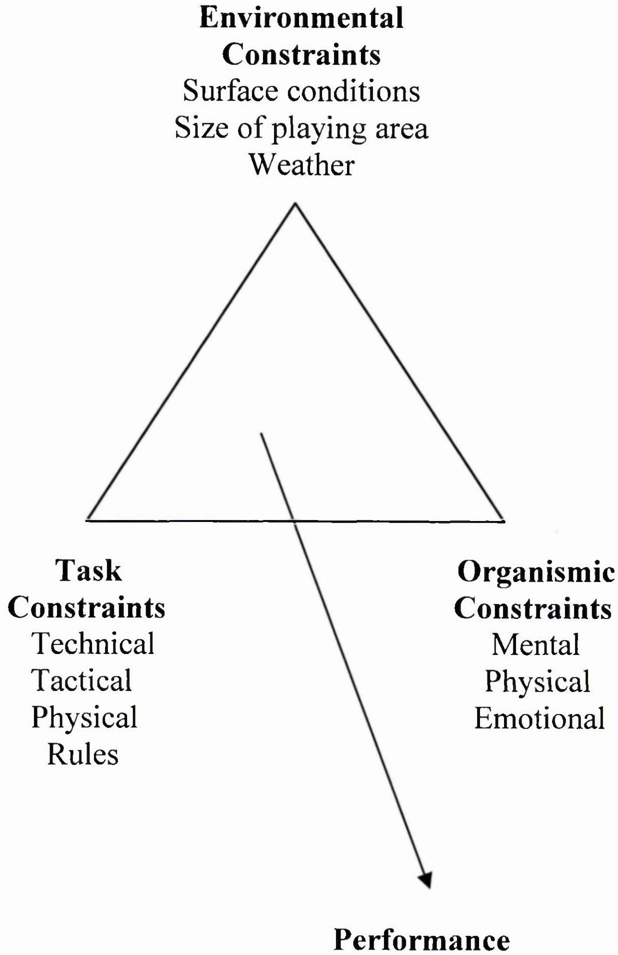


Figure 2.4 How constraints affect learning (adapted from Newell, 1986).

2.8.1 Feedback and Instruction

Few studies have attempted to identify factors that underpin effective practice or how the acquisition of skills can be facilitated through the instruction process. The coaching process necessitates that information is conveyed to the player as to the behaviour required, the session is then structured to provide an opportunity for practice and feedback is provided to guide the player's attempts to acquire the skill (Figure 2.5). The specific nature of the process is determined by the mode of instruction and coaching philosophy adopted by the coach (Williams, 2003).

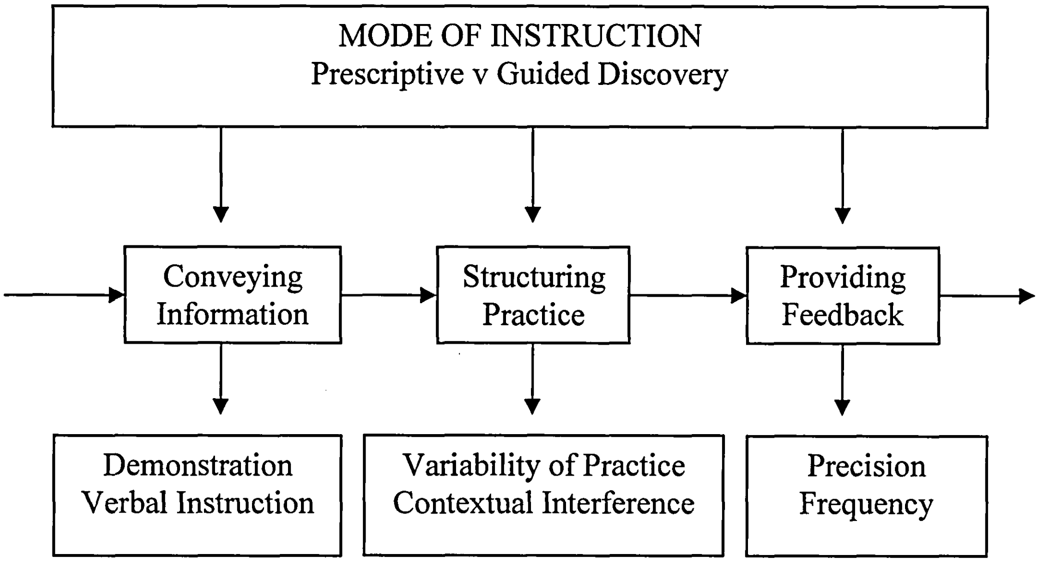


Figure 2.5 Important factors underlying effective instruction (Williams, 2003).

Demonstrations are no more effective than verbal instruction or practice alone when the information conveyed is low and / or when the task requires that the player develop a 'feel' for the movement or to 'scale' an existing movement pattern. An implication is that demonstrations are likely to be most effective early rather than later in learning as the player is trying to develop a new pattern of coordination (Williams, 2003). However, a potential disadvantage when demonstrating a skill early in learning is that the coach can impose a movement pattern on the player that is not ideal for him and should allow the player opportunity to try out the skill prior to viewing the demonstration, this could be a better option for the coach. Verbal instruction as to the goal of the task could be sufficient to enable the player to engage in trial and error or discovery learning and could, in the long-term, produce more flexible and adaptable skills.

A common misconception is that repetitive practise of a skill under constant practice conditions is essential for effective skill acquisition. Although such practice is successful in producing effective performance within a particular training session, variable practice conditions are essential for long-term retention of soccer skills like decision-making. It is therefore, imperative that coaches introduce variety into their training sessions early in learning (Williams, 2003).

Coaches should try and progress from using structured drill-type practices to more realistic games and vary the skill practises in a random manner (contextual interference), rather than practice one skill per training session in a blocked manner (low contextual interference). A radical view would be to introduce random and variable practice sessions from the outset through small sided and conditioned games, (for example, 2 v 2, 3 v 3 or 2 v 1 and 3 v 2).

The tendency is for coaches to provide detailed feedback on a frequent basis. Although feedback is essential for skill acquisition, it is suggested that players should be encouraged to rely on their own intrinsic feedback processes rather than on augmented feedback from the coach (Williams, 2003). It is likely that when coaches reduce the frequency and precision of feedback, performance during training sessions would not be as efficient as was previously the case when feedback was provided in abundance. In contrast, the process of 'fading out' feedback over time is likely to facilitate learning and long-term soccer performance.

In essence, the presumption is that skills learnt through guided discovery are more adaptable, flexible, more resistant to forgetting and less likely to break down under pressure than those developed through more prescriptive approaches.

2.8.1.2 Can decision-making be trained?

Historically, it has been suggested that players' abilities to acquire such skills is genetically determined and that it is too difficult to enhance the acquisition of these skills via structured training programmes. However, these studies have been contradicted by Williams *et al.* (2004) and studies have shown improvements in anticipatory and decision-making performance following the implementation of training programmes designed to enhance perceptual skill, for example (Williams and Grant, 1999; Williams and Ward, 2003).

The majority of studies have employed video-based simulations techniques with varying degrees of instruction and feedback to try to enhance perceptual skill in sport (Williams and Ward, 2003). The typical approach has been to produce video simulations that re-create the performer's customary view of the action and has proved more effective than slide presentations (Williams *et al.*, 2004). The advantages of using video simulation for perceptual training is that learning can occur at a self-regulatory pace, in and outside of regular practice time, or when the player is injured or fatigued (Williams *et al.*, 2004).

Virtual reality environments have been proposed, where the player is placed into a situation that looks, feels, smells and sounds to some degree like the real setting. The player can move their head, eyes and limbs to explore the multisensory, three-dimensional environment and they can interact with objects and people (Psokta, 1995). Some systems involve head-mounted displays, whereas others employ desktop computers or projected images that involve one or more screens (Loomis *et al.*, 1999).

Although there are problems to be resolved, such as the cost of the system, slow graphics updates and difficulty in creating realistic tactile stimuli and three-dimensional sound production (Abernethy *et al.*, 1998), such technology is likely to play an increasing role in performance enhancement in sport.

A potential advantage with simulators and virtual training environments over video is that they allow the player to move in response to the evolving display. Michaels and Carello (1981) suggested that close functional links between perceptual and physical (action) variables should be maintained during practice and performance. The suggestion is that during training the performance environment should be preserved by presenting performers with visual, tactile and auditory information and by requiring them to move in response to the action. However, for the purpose of this thesis, video simulated training will be used in an attempt to measure the extent to which soccer players can be trained to improve decision-making performance.

Williams and Grant (1999) provided a detailed critical review of early research on perceptual training. They supported the notion that perceptual skill in sport (certain aspects of soccer) can be trained using video simulation with appropriate instruction and feedback. They also highlighted potential shortcomings of these studies and proposed suggestions for future study. Most of the studies reviewed failed to employ a placebo (e.g. a group that reads or views other instructional material) and/or control groups (e.g. a group who receives no training or one that merely observes training film without receiving formal instruction) (Christina *et al.*, 1990; Adolphe *et al.*, 1997; Scott *et al.*, 1998) in addition to the conventional training group.

To assess the extent to which training did facilitate performance, or if improvements in performance were due to conformational bias or increased familiarity with the test as opposed to any meaningful treatment effect, various studies (Farrow *et al.*, 1998; Franks and Hanvey, 1997; McMorris and Hauxwell, 1997; Williams and Burwitz, 1993) failed to employ suitable transfer tests to determine whether the improvements observed in the laboratory setting actually transfer back to match situation. However, Williams *et al.* (2003) addressed these issues in a study involving the penalty flick in field hockey. They showed improvements in performance for the training group, providing strong evidence to support the use of video-based training programs as a method of enhancing perceptual skill in sport.

Further investigation is required to determine circumstances in which perception-only training can be more effective than perception-action training and visa versa (Williams *et al.*, 2004). No studies have been published as to the extent to which soccer players' perceptual skill can be enhanced through video or field-based training interventions. Furthermore, it is commonly believed that practice when fatigued is detrimental to skill learning. However, whilst practice under such conditions could have a negative effect on soccer performance (in particular, decision-making) during the session, it is likely that learning is not affected (Williams *et al.*, 2004). Players have to perform skills under a variety of circumstances for instance, when they are anxious and / or fatigued and consequently, it is important to mimic such conditions during training sessions (Williams, 2003). By doing so, factors that inhibit successful decision-making in soccer must be taken into account.

A player's ability to make correct split-seconds decisions is particularly critical at higher standards of competition where time and space are limited. The individual who can consistently decide on the best course of action from a variety of possible actions under conditions of limited time, restricted space, fatigue and challenging opponents will have a decided edge on players who lack that ability (Luxbacher, 1995).

A player who has been repeatedly exposed to similar match situations will, in theory, improve his decision-making speed over time. A player's ability to process information from the environment is also important. The quicker a player can assimilate and analyze information, the quicker they'll make the correct decision (Luxbacher, 1995). This can be achieved by involving players in game-simulated drills that require quick and accurate decisions to a variety of constantly changing variables seen in soccer. The field-based soccer drills which aim to improve perceptual skill (decision-making) during this thesis will aim to place players in situations that attempt to replicate the conditions faced in actual matches.

2.9 Summary

In conclusion, both information processing and dynamical systems theories assert the importance of good selective attention, the need to search the relevant parts of the display. To the information processing theorists, this allows the player to perceive the present display and to extract similar past experiences from LTM. To the dynamical systems theorists, it allows the player to achieve their goal. Both theories accept that experience plays a major role in the choice of areas of the display to which they should attend (McMorris, 2004).

While dynamical systems theory emphasises the importance of task, organismic and environmental constraints on the making of decisions, this is not neglected by the information processing theorists. It is implicit within the comparison of present and past experience taking place in working memory. From an information processing approach, making decisions in soccer, players would have to account for their own strengths and weaknesses of team-mates and opponents, the condition of the pitch, the weather and the score at that particular moment (McMorris and MacGillivary, 1988). These factors are no different from organismic (own strengths and weaknesses of team-mates and opponents), environmental (the condition of the pitch, the weather) and task (the score at that particular moment) constraints.

Another factor that could impinge on the soccer players' decision-making performance is the effects of exercise, in particular, fatigue. The physiological effects of exercise on decision-making in soccer have been studied by McMorris and Graydon (1996a) who concluded that arousal is concerned with speed of response regardless of the nature of the response, physical or mental. However, the issue of fatigue during intermittent exercise is complex and is difficult to identify a single factor in the muscle responsible for the reduction in co-ordinated movements associated with decision-making performance in soccer.

Based on measurements of ATP and CP muscle biopsies at the end of high-intensity exercise, it appears that muscle fatigue is not caused by a lack of energy, or muscle glycogen depletion which represents only one important fatigue agent during a match. Furthermore, accumulation of lactate and a disturbance of the acid/base balance of skeletal muscle do not appear to be crucial for fatigue. Instead, fatigue during intense periods of a match could be associated with an excitation-coupling failure, a reduced nervous drive due to reflex inhibition at the spinal level or an accumulation of interstitial potassium in the muscle (Bangsbo, 2000). The precise mechanisms of fatigue or the physiological stresses associated with co-ordinated movements involved in decision-making in soccer players requires further investigation.

When co-ordinated movements are impaired (shown by a decrement in players' decision-making performance) on a regular basis during a match as a consequence of physiological stresses or fatigue, it's the coaches responsibility to identify when these occurrences were happening and devise suitable training strategies during the week in an attempt to minimise the decrement in players' decision-making performance during a match. The fact that coaches can aid learning is accepted by both information processing and dynamical systems theorists and that some form of feedback is necessary for learning to take place, but this could take place at a sub-conscious level. As a result, it is believed that learning can be implicit (McMorris, 2004).

Little is agreed regarding memory, except that it is used to determine goals for action and that being 'attuned to affordances' is another way of saying 'memory' then it could be argued that there is an agreement that some form of rehearsal is necessary for memory to be developed. It would also appear that there are limitations to the capacity of short-term memory and to the time it takes to develop a representation in the CNS (McMorris, 2004). Furthermore, no studies have used these field-based soccer drills to improve decision-making of players in comparison to other perceptual training aids and the results and conclusion would provide valuable information to soccer coaches and managers in the formation of suitable training methods to improve decision-making in soccer.

CHAPTER 3

General Methods

The following methods relate to the individual studies completed as part of this thesis. This chapter provides a detailed description of: 1) the equipment used and it's calibration; 2) the protocols used for the acquisition of anthropometric, physiological and psychological data; 3) data preparation and analysis techniques and 4) statistical analyses.

3.1 Equipment and calibration

The equipment used in this thesis can be separated into six categories: 1) ergometry; 2) pulmonary gas analysis; 3) HR monitoring; 4) lactate analysis; 5) glucose analysis and 6) response pads and timing equipment.

3.1.1 Ergometry

A motorised treadmill (Saturn, HP Cosmos, Nussdorf - Traunstein, Germany) was used to measure physiological responses to sub-maximal and maximal running speeds. The treadmill had a top speed of 40 $km \cdot h^{-1}$ (11.11 $m \cdot s^{-1}$), with 7 acceleration/deceleration steps (from 0 to 40 $km \cdot h^{-1}$ in 3 to 131 s). The treadmill belt could be elevated between 0 and 25% (0 - 14°) by increments of 0.1%.

3.1.1.2 Calibration of treadmill speed and inclination

Speed of the treadmill belt was verified over the range of speeds applicable to investigations in this thesis. The following formula was used:

Speed = d/t

Where d is the distance (m) that would be travelled in 20 revolutions of the treadmill belt and t is the mean of three measures of the time (s) taken for 20 revolutions. A marker was placed on the treadmill belt to allow identification of one full revolution of the belt. Time taken for 20 revolutions of the belt at each pre-determined speed was recorded with a stop watch (C200 sport, Casio, UK) to the nearest 0.1 s.

To verify zero incline, the elevation meter of the treadmill was set to zero and a spirit level was used to ensure the treadmill belt was level in the horizontal plane. Vertical incline of the treadmill belt was expressed as the sine of the angle, in which sine equals the vertical rise over the hypotenuse:

Treadmill incline (sine) = (rise/hypotenuse) x 100

3.1.2 Pulmonary gas analysis

Pulmonary gas concentrations were measured by mass spectrometry (CPX/D, Medgraphics, St Paul, MN, USA). Expiratory and inspiratory gas volumes were determined from the breathing of room air through dead space (20 ml) bi-directional differential pressure pneumotach (Medgraghics Corporation, St Paul, MN, USA). Expiratory gas concentrations were sampled by a capillary tube inserted into the pneumotach. The sample line was connected to the zirconian O_2 and infrared CO_2 analysers and the pneumatach to a flow module. The flow volume and gas concentration signals were sent to a computer (Elonex PC 466/1, UK) via an analogue-to-digital converter for integration by Breeze3 software *v* 1.0 (Medgraghics Corporation, St Paul, MN, USA).

3.1.2.1 Calibration of pulmonary gas analysis equipment

The CPX/D Medgraphics were calibrated immediately before and verified immediately after each exercise test in the same systematic order: 1) gas calibration, 2) volume calibration and 3) lag time calibration.

3.1.2.1.1 Gas Calibration

Calibration of the CPX/D Medgraphics was performed using high tolerance (± 0.03%) gasses (Medgraghics Corporation, St Paul, MN, USA) of fixed concentration (Reference gas, 21% O_2, 0% CO_2, Bal N_2 and calibration gas, 12% O_2, 5% CO_2, Bal N_2). A two-point calibration was performed, 21% and 12% for O_2 and 5% and 0% for CO_2. Gas was delivered to the analysers at a pressure of 15 PSI along the capillary sample line. A successful calibration resulted in measurement of the reference gas to within ± 0.03%.

3.1.2.1.2 Volume Calibration

It was necessary to apply a correction factor to account for the effects of differences in ambient temperature, pressure and water vapour on measures of volume. Standard temperature and pressure dry (STPD) was calculated for a dry gas at a temperature of 273 K and a pressure of 760 mmHg. With all other physiological gas-related measures, body temperature and pressure saturated (BTPS) were used, where temperature was 310 K and pressure was ambient and saturated with water vapour.

Gas volume was calibrated using a precision 3 l syringe (Hans Rudolph Inc, Kansas City, MO, USA) to pump room air at a rate representative of human ventilation during exercise (- 2 l·s^{-1}) through a turbine. The accuracy of the turbine volume determination was deemed suitable if the mean of five inspiratory and expiratory volumes was within ± 1% (30 ml) of 3 l.

The bi-directional differential pressure pneumotach (Medgraghics Corporation, St Paul, MN, USA) of the CPX/D was calibrated using the precision 3 l syringe (Hans Rudolph Inc, Kansas City, MO, USA). Following the manufacturer's guidelines, room air was pumped through the pneumotach at five inspiration and expiration flow rates ranging from 0.5 to 6.$l \cdot s^{-1}$. The calibration was successful if the inspiration and expiration volumes for each flow rate were within ± 1% of 3.l.

3.1.2.1.3 Lag-Time Calibration

Measures of gas volume are provided almost instantaneously, whereas the measurement of fractional gas concentrations is delayed by the transport of expired gasses from the mouthpiece to the gas analysis system and the response of the gas analysis system to a change in gas concentration. Integration of these two signals via a lag-time calibration is necessary for the accurate determination of $\dot{V}O_2$.

Lag-time calibration for the CPX/D was performed by the Breeze3 software *v*1.0 (Medgraghics Corporation, St Paul, MN, USA). Using the reference and calibration gases described in section 3.1.2.1.1, the software recorded the time for the rapid-response analysers to measure near square-wave changes in O_2 (21% to 12%) and CO_2 (0% to 5%) concentrations. The calibration was successful if the time taken for the analysers to measure these changes in O_2 and CO_2 concentrations was within 0.1 to 0.6 s. The Breeze3 software then aligned the response time of the analysers with that of the pneumotach.

3.1.3 Heart rate monitoring

During all exercise tests, HR was continuously recorded every 5 s using a short-range telemetric HR monitor (Accurex Plus, Polar Electro Oy, Kempele, Finland). An electrode belt worn around the chest measured the time between each R-R interval of the heart's sinus rhythm. This information was telemetrically transmitted to a receiver and displayed in beats·min^{-1}. Previous research (Leger and Thivierge, 1988) has demonstrated that the accuracy of Polar HR monitors is comparable to that of electrocardiograms (ECG).

3.1.4 Blood lactate analysis

Blood lactate was determined from duplicate samples of whole capillary blood taken at the fingertip. The skin of the fingertip was punctured using a lancet (Soft Clix Pro, Roche, Sussex, UK). Whole capillary blood was then drawn into a 25 µl sample tube (YSI Inc, Yellow Springs, OH, USA) via capillary action. The sample was immediately analysed using an automated lactate analyser (1500 Sport, YSI Inc, Yellow Springs, OH, USA) that uses immobilised enzyme electrode technology. A thin film of lactate enzyme is immobilised within the membrane. Hydrogen peroxide is produced when the lactate in the injected blood sample diffuses through the membrane. The hydrogen peroxide measured at a platinum electrode, is proportional to the lactate in the sample. The measurement range of the YSI 1500 sport is 0 to 30 mmol·l^{-1}, with a precision of 2% of the reading or 0.1 mmol·l^{-1}, which ever is larger.

3.1.4.1 Calibration of the lactate analyser

The lactate analyser was calibrated before each exercise test and every 10 samples thereafter using 25 µl of a 5 mmol·l^{-1} lactate standard (YSI Inc, Yellow Springs, OH, USA). Calibration was deemed acceptable if values were within ± 0.25 $mmol \cdot l^{-1}$ (5%) of the 5 $mmol \cdot l^{-1}$ standard. If the value for the calibration check was outside this range then the calibration procedure was repeated. Calibration was verified by injecting 25 μl of a lactate standard that would have a similar concentration to that of subsequent blood samples (Table 3.1).

Table 3.1 Lactate standard concentrations used to verify the calibration of the lactate analyser.

Physical activity	Lactate standard concentration ($mmol \cdot l^{-1}$)
Rest / moderate	2.5
Heavy exercise	5.0
Maximal exercise	10.0

3.1.4.2 Blood glucose analysis

Blood glucose was determined from duplicate samples of whole capillary blood taken at the fingertip. The skin of the fingertip was punctured using a lancet (Soft Clix Pro, Roche, Sussex, UK). Whole capillary blood (5 μl) was then applied to a cuvette by capillary action. The sample was immediately analysed using a HemoCue B-Glucose Analyser (Hemocue AB, Angelholm, Sweden). The analyser displayed the results within 40-240 s depending on the blood glucose concentration.

3.1.4.3 Calibration of the glucose analyser

The HemoCue B-Glucose Analyser (Hemocue AB, Angelholm, Sweden) was calibrated using a control cuvette before each exercise test and every 10 samples thereafter. This cuvette consists of an optical interference filter. It was used to verify that the calibration of the analyser was stable.

3.1.4.4 Rate of Perceived Exertion (RPE)

The general aim of using the 15-graded RPE scale (Borg, 1986) (Figure 3.1) is to quantify a participant's subjective perception of exertion to determine the intensity of exercise or regulate that intensity (Borg, 1998). In this way it acts as a concurrent marker to key relative physiological responses including: percentage of maximal heart rate (% HR max), percentage of maximal oxygen uptake (% $\dot{V}O_2$ max) and blood lactate. The strongest stimuli influencing a participant's RPE are breathing/ventilatory effort and sensations of strain from the muscles (Chen *et al.*, 2002). A common misunderstanding is to assume that changes in heart rate, oxygen uptake and blood lactate, are factors that influence RPE. However, a participant does not actually perceive heart rate, oxygen uptake or the accumulation of muscle and blood lactate. It is the sensations associated with increased ventilatory demand and muscle and joint strains that correspond with these physiological markers that a participant perceives (Chen *et al.*, 2002).

When the relationship between RPE and various measures of exercise intensity is known, this information could be used to quantify the exercise intensity and aid the participant or coach to select or prescribe appropriate training intensities. This could be done through a process of learning and practice with the RPE to regulate exercise intensity by effort production procedures (Eston and Thompson, 1997).

Prior to the exercise test, it was important to accustom participants to the scale. They were instructed to monitor changes in the physiological responses. It was also important to provide the participant with an understanding of the range of sensations that correspond to the scale. This is referred to as anchoring the scale and provides a context by which the sensations of intensities can be evaluated.

6	**No exertion at all**
7	**Extremely light**
8	
9	**Very light**
10	
11	**Light**
12	
13	**Somewhat hard**
14	
15	**Hard (Heavy)**
16	
17	**Very hard**
18	
19	**Extremely hard**
20	**Maximal exertion**

Figure 3.1 15-Graded Borg Rating of Perceived Exertion Scale (Borg, 1986).

3.1.4.5 Calibration of the timing equipment

The timing equipment (Venner, Electronics, TSA6614; Surrey, England) was calibrated using TTi TG5500 function generator (Thander Instruments, Huntington, Cambs, England). A start and stop signal was used to measure accuracy 1% ± 1digit (498 milliseconds). Ten practice trials were timed to calibrate the response pads.

3.2 Exercise testing procedures and protocols

3.2.1 Pre-exercise test procedures

3.2.1.1 Ethics

Prior to each study, ethics approval was sought and granted by the Faculty of Health and Wellbeing Research Ethics Committee, Sheffield Hallam University, in accordance with the declaration of Helsinki.

3.2.1.2 Informed Consent

Before each investigation, participants were given clear and concise information explaining the purpose, procedures and requirements of the study. Any questions the participants had about the study were answered verbally on a one-to-one basis. Participants had seven days to notify of participation. All participants signed a relevant informed consent form. An example of an informed consent form is provided in appendix 2, page 222.

3.2.1.3 Pre-exercise screening

All participants were required to complete a pre-exercise medical questionnaire (appendix 3, page 224) to screen for previous and/or current medical conditions or musculo-skeletal injuries.

3.2.1.4 Pre-test instructions / requirements

Prior to the undertaking of any laboratory or field based exercise test, participants were instructed to: 1) be in a 3 hour post absorptive state, 2) have maintained normal dietary intake 3) not consumed alcohol or caffeine in the 12 hours preceding the test and 4) abstained from strenuous physical activity in the 48 hours preceding the exercise test. Players (aged 18 – 24 years) did not participate in the study if they were returning from serious injury (severe tear to the thigh or hamstring muscles) within the last 2 months or who had experienced; major or minor surgery to the groin, knee, ankle or foot region in the 3 months prior to testing. Or any player recovering from a viral infection 7 days prior to testing or any illness stated in the pre medical questionnaire.

3.2.1.5 Stature

Stature was measured to the nearest 0.1 cm using a wall mounted stadiometer (Holtain, Crymych Dyfed, UK). In bare feet, participants were required to stand with heels, buttocks and shoulder blades touching the back board of the stadiometer, while their head was positioned in the Frankfort plane. Once in the correct position, participants were instructed to inhale fully while light pressure was applied to the mandibles. Stature was then recorded to the nearest mm. Calibration and accuracy of measurement was checked after every 10 participants, against a standard height.

3.2.1.6 Body mass

Body mass was recorded using a beam balance type scale (Weylux, UK) that incremented in 0.05 kg. The participants were required to wear only shorts and a T-shirt. Calibration masses totalling 100 kg were used as standard equipment.

3.2.1.7 Incremental exercise test

A continuous, incremental exercise test was performed to volitional exhaustion on a motorised treadmill (Saturn, HP Cosmos, Nussdorf - Traunstein, Germany) for the determination of $\dot{V}O_2$ max via breath-by-breath analysis of the pulmonary gas exchange. Prior to the test, all participants were accustomed to running on a motorised treadmill, the pulmonary gas exchange and HR apparatus. It was the aim of the incremental exercise test to elicit $\dot{V}O_2$ max within 8 to 12 min. Participants performed a 5-min warm-up at a running speed that elicited a HR of approximately 150 beats·min^{-1}. The initial running speed for the incremental exercise test was 8 km·h^{-1} and was increased by 1 km·h^{-1} every min until volitional exhaustion. On cessation of the test, treadmill speed was reduced to 4 km·h^{-1} for 5 min to allow the participant active recovery. Run time to exhaustion was recorded (s).

3.2.1.8 Determination of $\dot{V}O_2$max

Breath-by-breath pulmonary gas exchange data collected during the incremental exercise test were averaged on a 30-s basis. The highest $\dot{V}O_2$ attained during the incremental exercise test was taken as $\dot{V}O_2$ max if a plateau in the $\dot{V}O_2$ / exercise intensity relationship was evident. If a plateau was not present, $\dot{V}O_2$ max was only reported to have been achieved if two of the following secondary criteria (BASES, 1997) were observed: HR within ± 10 beats of age predicted maximum HR (220 – age); 2) a plateau in HR (± 2 beats·min^{-1}) with an increase in exercise intensity; 30-s a respiratory exchange ratio (RER) ≥ 1.15.

3.2.1.9 Soccer-specific intermittent treadmill protocol

This soccer-specific high-intensity intermittent treadmill test (Drust *et al.*, 2000) was performed on a motorised treadmill (Saturn, HP Cosmos, Nussdorf - Traunstein, Germany) and consisted of the different exercise intensities that were observed during match play (e.g. walking, jogging, cruising and sprinting) by Reilly and Thomas (1976). A static recovery period was also included, in which the participants remained stationary on the treadmill. Utility movements (backwards and side-ways) were not included in the protocol because of the technical limitations of the equipment and the dangerous nature of performing those particular movements on a treadmill.

The duration of each bout was determined by matching the percent total time for each separate activity pattern during the protocol (after the deduction of the total time for the treadmill speed changes) to that observed during match play, based on the data of Reilly and Thomas (1976).

Heart rate was monitored continuously at 5-s intervals and mean HR was calculated every min for each participant. Breath-by-breath pulmonary gas exchange was also measured continuously. Blood lactate and blood glucose was measured every 15-min and 5-min post exercise.

3.2.2.0 Repeated sprint test

To determine the number of sprints, sprint duration and recovery to be used, a series of pilot studies were conducted. Four male college soccer players completed two repeated sprint protocols on a motorised treadmill. Sprint speed was set at 21 $km \cdot h^{-1}$ based on the sprint bouts in the intermittent treadmill protocol (Drust *et al.*, 2000). Trial A consisted 6 x 6-s sprints (total distance = 174 m) with either a 50-s or 60-s recovery (exercise-rest ratios of 1: 8.3 and 1: 10 respectively) and Trial B consisted 8 x 8 s sprints (total distance = 368 m) with either a 20-s or 40-s recovery (exercise-rest ratios of 1:2.5 and 1: 5). The decision-making task followed each trial. Both trials were separated by seven days. Participant characteristics and results of the pilot studies are shown in tables 3.2 and 3.3.

Table 3.2 Pilot study participant characteristics (mean ± s)

Trial	n	Age (years)	Stature (m)	Body mass (kg)	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)
A	2	19 ± 0.7	1.70 ± 0.2	78.0 ± 4.6	55.4 ± 2.2
B	2	21 ± 0.1	1.69 ± 0.3	75.0 ± 6.5	56.3 ± 1.5

Table 3.3 Pilot study results (mean ± s)

Trial	N	Recovery (s)	Heart Rate ($beats \cdot min^{-1}$)	Blood Lactate ($mmol \cdot l^{-1}$)	Blood Glucose ($mmol \cdot l^{-1}$)	RPE	Response Time (ms) before	Response Time (ms) after	Response Accuracy (%) before	Response Accuracy (%) after
A	2	50	167 ± 0.3	7.8 ± 0.1	5.1 ± 0.2	12	330 0± 50	4100 ± 40	90 ± 0	75 ± 0.7
		60	165 ± 0.2	7.2 ± 0.4	5.0 ± 0.1	11	3100 ± 70	3800 ± 20	95 ± 0.7	90 ± 0
B	2	20	194 ± 0.7	13.1 ± 0.6	6.2 ± 0.4	18	3200 ± 50	4700 ± 40	95 ± 0.7	55 ± 0.7
		40	169 ± 0.6	9.2 ± 0.4	5.1 ± 0.3	13	3200 ± 40	4200 ± 40	95 ± 0.7	65 ± 0.7

The results show that longer sprints (Trial A, 8 x 8-s) and shorter recovery of 20-s increased players' response times (before 3200 ± 50 ms, after 4700 ± 40 ms) and also had a detrimental effect on response accuracy (before 95 ± 0.7 %, after 55 ± 0.7 %), possibly as a result of fatigue. However, the speed and distance covered was not soccer-specific and as all players sprint at different speeds, a protocol should take these limitations into consideration.

This prompted an investigation into increasing the number of sprints, sprint duration and altering recovery periods in line with soccer literature. Total distance covered in Trial A was 368 m, a protocol 10 x 10-s sprints (Mohr *et al.*, 2003) with either a 15-s or 30-s recovery period, sprint speeds of 21 $km{\cdot}h^{-1}$ (total distance 583 m) to 25 $km{\cdot}h^{-1}$ (total distance 694 m) which is similar with total sprint distance (600 m) reported in soccer match play (Bangsbo, 1994).

The treadmill speeds for the repeated sprints was calculated based on the participants' maximal oxygen uptake performance. All participants were accustomed to the speed and practiced it during a 5-min warm-up. Players were harnessed and sprinted at approximately 21- 25 $km{\cdot}h^{-1}$ (120% of $\dot{V}O_2$ max denotes high-intensity exercise during competitive match play) (Mohr *et al.*, 2003) for 10 x 10-s sprints, with either a 15-s or a 30-s recovery period in between, jumping and straddling the treadmill belt after every bout.

3.2.2.1 Laboratory-based decision-making protocol

Participants viewed soccer sequences, which were back projected onto a 2.5 m x 3 m mounted screen in front of them using a video projection system (Sanyo Pro-X Multimedia PLC SU2OB, Japan). Each sequence included either two central defenders marking two attacking players and a defensive midfield player marking an attacking midfield player (3-on-3), a central defender marking an attacker (2-on-1) or an attacking player running with the ball (1-on-1). The film sequences lasted approximately 6 seconds and included an attacking pattern of play ending with one of the following outcomes: 1) a pass being made to the participant's right or left side; 2) the ball apparently being played over the participant's head into the space behind; or 3) an attacking player dribbling the ball directly toward the participant.

The participant viewed each pattern of play as it developed and responded as quickly and as accurately as possible by moving right, left, forward or backwards to simulate the interception of the pass by stepping on response pads right, left, front, or back. The timing mechanism (Venner Electronics TSA6614; Surrey, England), to the nearest millisecond was activated as soon as the participant reacted to the film sequence and stopped when movement was completed. Correct and incorrect response selection was recorded.

3.3 Statistical analyses

Various methods of statistical analysis have been used in this thesis to determine: 1) the reproducibility of the timing equipment and the response pads; 2) the strength of association between measures of performance and physical function and 3) the difference between the various measures. All the statistical tests were performed using commercially available statistical software (SPSS for Windows v 15-16; SPSS Inc., Chicago, IL., USA). All data are expressed as mean and standard deviation (SD), similarly, in figures, error bars indicate SD.

3.3.1 Limits of agreement

A popular assessment of test-retest reproducibility is the 95% limits of agreement (LOA) first described by Bland and Altman (1986). The LOA is used to determine the difference between two measures (measurement errors) using simple calculations and graphical techniques. The change consists of two components: random or systematic variability. Random variability in the mean is due to sampling error and is smaller with larger sample sizes because the random errors from all the measurements contributing to the mean tend to cancel out more. Systematic variability in the mean is a non-random change in the value between two trials. In tests of human performance that depend on effort or motivation, participants could improve performance in the second trial because they want to improve. Performance can decline in a series of trials because of fatigue or loss of motivation.

The major assumption of LOA is that the difference (error) between measures is homoscedastic. That is, the differences are of the same magnitude regardless of the magnitude of the measure. A simple check for homeoscedasticity can be obtained from a scatter plot of the differences between the two tests against the grand mean of the two tests. If a relationship is visually detected between the two variables, confirmation can be achieved by calculating the correlation coefficient between the absolute differences between the two tests and the grand mean. If it found that larger errors are associated with larger measurement means, the measurement error is heteroscedastic, which requires logarithms of each measurement be performed before LOA can be applied (Atkinson and Nevill, 1998). However, provided that the previously stated assumption has been checked and the differences are homoscedastic, the LOA can be calculated without the need for logarithmic transformation, as:

$$\pm 95\% \text{ LOA} = 1.96 \times SD_{diff} \quad (7)$$

Where SD_{diff} is the SD of the differences between test 1 and test 2. The LOA in proportion to the grand mean of test 1 and 2 is calculated as:

$$\text{Measurement error (\%)} = \frac{1.96 \times SD_{diff}}{\text{Grand mean}} \times 100 \quad (8)$$

Where grand mean is (mean of test 1 + mean of test 2) / 2.

Whether the calculated LOA reflect a reproducible measure is a subjective decision that must be made by the researcher. An advantage of using LOA to assess reproducibility is that when the error is homoscedastic, the calculated values are in the original units of measurement, hence allowing direct application to the measure being assessed.

3.3.1.1 Test-retest Coefficient of Variation

An alternative and more traditionally used measure of reproducibility is the coefficient of variation (CV). This statistical test was performed to allow greater cross study comparison than would be permitted by using LOA alone. The CV (%) was calculated as follows:

$$\text{CV (\%)} = \frac{\text{SD diff}}{\text{X}} \times 100 \quad (9)$$

Where SD is the standard deviation and X is the mean.

Method error of repeated measurements

The method error is calculated using the equation

$$\frac{\text{SD difference}}{\sqrt{2}} \qquad (10)$$

Test –retest coefficient of variation

$$\frac{\text{Method error}}{(M_1 + M_2) / 2} \times 100 \qquad (11)$$

$$\text{T ratio} = \frac{\text{Mean difference}}{\text{Standard Error difference}} \qquad (12)$$

3.3.1.1.2 Standard Error of the Mean

This is a numerical value that indicates the amount of error that could occur when a random sample mean is used as a predictor of the mean of the population from which the sample was drawn (Vincent, 1999). Each sample has its own mean and standard deviation and the total group of sample means also has a mean (the mean of the means) and a standard deviation (the standard deviation of the means). This value, the standard deviation of the means, is called the standard error of the mean.

This is calculated using the equation

$$SE_M = \frac{SD}{N} \qquad (13)$$

Where SD is the standard deviation of the sample and N is the sample size.

3.3.1.1.3 Technical Error of Measurement

Technical error of measurement (TEM) gives an indication of the precision associated with measure – that is, the error of the method due to both biological and technical factors (Pederson and Gore, 1996). The TEM is a value in the same units as the variable measured and it indicates that the error of a single measure will be plus or minus the TEM two thirds of the time. The absolute and relative TEM can be determined for any comparisons or obtaining paired values.

Absolute TEM is calculated as follows:

$$\text{TEM} = \sqrt{\Sigma di^2 / 2n} \qquad (14)$$

Relative TEM. The %TEM expresses the error as a percent of the means of the original paired measures and is calculated by:

$$\%\text{TEM} = (\text{TEM}/\ M1 + M2 / 2) \text{ X } 100 \qquad (15)$$

M1 is the mean of the first series of measurements;

M2 is the mean of the second series of measurements.

A relative TEM with a precision less than 5% and is deemed acceptable.

3.3.1.1.4 Intraclass Correlation

The most common methods of intraclass correlation (ICC) are based on the terms used in the calculation of the F-value from repeated measures ANOVA (Baumgarter, 1989). The ICC can also be calculated in such a way that it is sensitive to the presence of systematic bias in the data. It is suggested that an ICC close to 1 indicates excellent reliability. Various categories of agreement based on the ICC ranging from 'questionable' (0.7 – 0.8) to 'high' (>0.9) are provided by Vincent (1995).

3.3.1.1.5 t-tests

To assess if the means of two samples differed, t-tests were performed. If the two means were generated from the same participant sample under different experimental conditions a paired sample t-test was used. For the t-test to be used the following assumptions outlined by Vincent (1995) were checked: 1) participants are randomly sampled; 2) data are normally distributed and parametric and 3) there is homogeneity of variance (i.e. the variance between groups is equal), assessed using Levene's test for equal variances. Providing the test result is non-significant, the variances can be assumed to be homogeneous.

3.3.1.1.6 Analysis of variance

Analysis of variance (ANOVA) is a set of tests used to identify if two or more means differ (Kinnear and Gray, 2000). The type of ANOVA used depends on whether the experiment has a within (repeated measures from one sample group), between (individual measures from several sample groups) or mixed (a combination of within and between measures) design. It has been suggested that it is preferable to run an ANOVA rather than multiple t-tests because: 1) multiple t-tests increase the chance of type 1 error (probability of falsely rejecting the null hypothesis); 2) Separate tests do not combine all of the available information about the population and could lead to additional errors of inference and 3) provides more informative results. In mixed-design factorial ANOVAS, comparisons can be made by way of main effects in which groups differ consistently and measures, similarly, differ consistently across time. The principal change however, is indicated by an interaction in which one group changes more than another or others. In addition to checking the standard assumptions that must be met to perform a parametric test, the sphericity of the data was also checked. This refers to whether there is compound symmetry of homogeneity of covariance (i.e. correlations between all groups are similar) and homogeneity of variance (i.e. variance of all groups are similar. Sphericity of the data was assessed using Mauchly's test of sphericity, where sphericity could be assumed if $p > 0.05$. Levene's test of homogeneity of variance was also performed.

3.3.1.1.7 Effect size

Effect size (Cohen's *d*) is calculated to estimate the magnitude of the difference between groups. This provides a way to describe the meaningfulness of the differences, especially when the sample size is small. The size of the effect was classified according to the system proposed by Cohen (1988), where an effect size of up to 0.20 represents a small effect, one of 0.21 to 0.50 represents a moderate effect and one of 0.50 to 0.80 or above represents a large effect.

Effect size is estimated by the ratio of the mean difference over the standard deviation of the control group or the pooled variance of the treatment groups if there is no control group:

$$ES = \frac{\overline{X}_1 - \overline{X}_2}{SD_{control}} \tag{16}$$

The control group is normally used as an estimate of the variance because it has not been contaminated by the treatment effect (Vincent, 1999).

3.3.1.1.8 Multivariate analysis of variance

Multivariate analysis of variance (MANOVA) is used to perform an ANOVA-style analysis on several outcome measures (OMs) simultaneously. It can also be used when there is only one predictor variable (PV) or when there are several to identify interactions between PVs and to see which group differ from each other. In comparison to ANOVA, MANOVA has several advantages: 1) It helps to protect against type I errors. In MANOVA, a new OM is formed from the linear composite of the several OM s using regression techniques. This new virtual OM is then analysed with ANOVA to determine if there are any differences among treatment groups. This is referred to as the F value. 2) With more than one OM, MANOVA offers a greater chance of determining the effects of treatment. The PV could affect one OM but not another. 3) Under certain conditions, MANOVA could be more powerful than ANOVA. However, this is usually not the case. MANOVA is frequently less powerful than ANOVA. When several of the OM s are not significant and one is barely significant, MANOVA is less powerful. The non significant OMs could mask the effects of one significant OM producing a non significant F for MANOVA.

When repeated measures are used with multiple OMs, the chances of violating the assumptions of sphericity are reduced. If the Greenhouse-Geisser or Huynh-Feldt adjustments to the p values do not adequately correct for the violation, an alternate solution using MANOVA in a doubly multivariate design is possible. Under these conditions, the assumptions of sphericity are not required (Vincent, 1999).

3.3.1.1.9 Least Products Regression

Comparative analysis of a variable measured twice should explore the existence of any fixed and proportional biases between the two measurements. Whilst LOA consider these biases together, least products regression (LPR) considers their effect independently (Mullineaux, 1999).

In plotting a LPR line, it is deemed appropriate because it minimizes errors in both x and y measurements and comparing this with the line of identity facilitates comparison between the two measurements. If the LPR does not pass through zero, then this indicates that one of the measurements is consistently different from the other. Also if the regression line does not possess a slope equal to one, then the measurements are proportionally different to each other. These 'non-zero intercept' and 'a slope not equal to one' have been defined as fixed and proportional biases, respectively (Ludbrook, 1997) and are important for interpreting the results of the comparison.

The calculation is complex and the output is in statistical terms of reference in the form of:

$$y = a + b \cdot x \tag{17}$$

Where, y is the predicted score, a is the intercept, b is the slope of the regression line and x is the predictor.

The advantages of using this technique are 1) it provides a separate assessment of the biases, 2) it provides a predictor equation, but it is more sensitive to the spread of the data and 3) it does not work with more than two repeated measurements (Mullineaux, 1999). Assumptions underpinning LPR include that the errors should be normally distributed, have a mean value of zero, be additive and that there are random errors and equal variance in both sets of measurements. When the normal distribution and additive error assumptions are violated for these tests, log-log transformations can be used to correct for these violations (Mullineaux, 1999).

However, if the normal distribution, linearity or additive error assumptions are not violated, then these transformations should not be routinely used, because they can be misleading and are more difficult to interpret (Mullineaux, 1999). A solution could be to 'weight' the calculation (Ludbrook, 1997), which is said to be beneficial because it is simple and the results remain easy to interpret.

CHAPTER 4

Reproducibility of decision-making measures in soccer

4.1 Introduction

Testing decision-making in soccer is challenging because of the dynamic nature of the sport. Complex decisions have to be made quickly and accurately, usually under pressure from opponents. As a result, both accuracy and speed of decision are important measures and provide meaningful results that can be used by managers and coaches.

Attempts to measure decision-making in soccer have used various methods and instruments. Photographic slides and voice recognition (McMorris and Graydon, 1996a, b, 1997a, McMorris *et al.*, 1999), taped soccer games and voice recognition (Campos, 1993), button pressing and voice recognition (McMorris and Graydon, 1997b) and feet response pads and soccer-specific test film (Williams and Davids, 1998).

Few studies have attempted to measure decision-making in soccer. McMorris and Graydon (1996a,b, 1997a,b); McMorris *et al.* (1999) used several techniques but contained limitations that could have affected reliability. In studies by McMorris and Graydon (1996a, 1997a); McMorris *et al.* (1999) the reliability of measures was assessed by intraclass correlation for accuracy ($r = 0.94$) and speed of decision ($r = 0.79$). McMorris and Graydon (1996b) reported $r = 0.72$ for accuracy and $r = 0.90$ for speed of decision. However, these results were biased because of the way trials of the test were developed. Each trial consisted of 10 questions, which were the same for each of the trial conditions throughout the test. The high correlations could be because players learned and recalled answers during trials. Use of trials with the same questions could also have affected the content validity of the instrument used.

Validity evidence of the instrument used (McMorris and Graydon, 1996a,b, 1997a,b); McMorris *et al.* (1999) to collect decision-making information was provided by a group of eight experienced soccer coaches, but no professional qualifications were reported. Typical situations of soccer match play were selected after all the coaches had agreed. However, as with reliability, validity could have been biased by identical situations being presented in all trials, which could explain the results reported for response accuracy and speed of decision, indicating that players were merely repeating answers in the trials as the trials of the test were the same.

Bias in results for speed of decision could also be explained by the measurement instrument used. In decision-making experiments, players seek cues from the environment and information provided and then decide on the appropriate action to take. If players are presented with the same match play situations in all trials, the decision-making process is substituted by simple recall of information from the previous trial. Therefore, players would improve their speed of decision. This pattern of results was reported in the studies.

Ecological validity was also questioned. This type of validity is the validity of a cue (e.g. perceptual variable) in predicting a criterion state of the environment (Brunswick, 1956). In essence, tests that replicate actual soccer, increase ecological validity. Ideally, all tests should be rated high in ecological validity (Fontana, 2007). However, it is difficult to construct decision-making tests that are high is this type of validity because of the large number of extraneous variables present in soccer (e.g. motivation and dynamical movements of soccer). Because of difficulties in controlling these variables and constructing an objective test, researchers have opted for laboratory studies.

Instruments used by McMorris and Graydon (1996, 1997); McMorris *et al.* (1999) show questionable ecological validity. Match play situations in which one optimal answer was present were included. This increases the objectivity of the instrument, but unfortunately, it reduces the ecological validity. A further limitation of the decision-making instrument is the inability to capture the dynamics of soccer. Furthermore, decision-making tests used consisted of static presentations of attacking situations chosen by experienced coaches set up on half of a table tennis tabletop. These attacking situations were photographed and transformed into slides which were then projected onto a wall in front of the players. Slides do not capture the dynamics involved in soccer; therefore, these tests do not simulate decision-making action in soccer.

In recent years researchers have been criticised for using small television displays and simplistic response protocols to replicate the performance setting. Artificial laboratory tasks could negate experts' advantage over novices by denying them access to information that they would normally use, limiting them to use different information to solve a particular problem (Abernethy, *et al.*, 1993; Williams *et al.*, 1999). In response to this criticism, attempts have been made to develop more realistic laboratory protocols (Ward *et al.*, 2002) and to measure anticipatory performance in situ (Singer *et al.*, 1998). However, empirical effort is still required to develop appropriate measures of decision-making performance.

Other methods of examining decision-making performance have been used. Subjective assessments by experienced coaches have been favoured. This method, however, needs to be controlled as much as possible. The coaches should be given guidelines to aid their assessment and more than one coach should be used wherever possible. Some researchers have asked players to give running commentaries, during actual competition, on why they have chosen that particular action (Williams *et al.*, 2002).

An improvement from research on decision-making can be made using video segments from real soccer matches. Although not as dynamic as actual soccer matches, video recordings are more dynamic than slides. Research instruments, consisting of video segments taken from real soccer matches (Williams and Davids, 1998) have been found to be a valid means to assess anticipation in soccer.

While other methods have been used to measure decision-making, the instrument used in this study is aimed at attempting to bridge the gap in decision-making literature in accurately measuring decision-making in soccer

4.1.1 Aim

To measure decision-making in soccer players using a soccer-specific protocol to assess decision-making and determine the reproducibility of the protocol's measures.

4.2 Participants and Methods

4.2.1 Participants

With institutional ethics approval, ten male university soccer players *mean*, *s*: (age 20, s = 1.3 years; stature 1.79, s = 0.34 m; body mass 73.6, s = 7.2 kg; $\dot{V}O_2$ max 54.4, s = 3.8 ml$\cdot$ kg$^{-1}\cdot$ min^{-1}) were recruited and participated. Players were recruited on a volunteer basis and had to have at least three years experience of playing soccer at school or college standard. Before trial instructions can be seen in chapter 3.2.1.4.

4.2.2 Habituation

Players underwent extensive practising prior to participating in the reproducibility study. In two separate sessions separated by five days, the players were accustomed to the procedures. Players performed 10 practice trials and 10 test trials during each session. The number of practice and test trials was determined from a similar study (Williams and Davids 1998).

4.2.3 Experimental design

The reproducibility of the decision-making task was determined using the test - retest method. The main trial comprised 10 practice trials followed by 10 test trials, the players rested for one hour and completed the second half of 10 trials. The players were re-tested after seven days using the same protocol.

4.2.4 Experimental protocol

4.2.4.1 Decision-making task

Apparatus

Response pads set-up (Figure 4.1) and configuration (Figure 4.2) were based on work by Williams and Davids (1998) and Smeeton *et al.* (2005) and modified for this study. Two types of pressure sensitive pad were used, A - 72 x 39 x 0.3 cm (Figure 4.3) and B - 60 x 17 x 0.3cm (Figure 4.4) and were required to respond by making a short movement (5 cm) in the anticipated direction onto a pressure response pad.

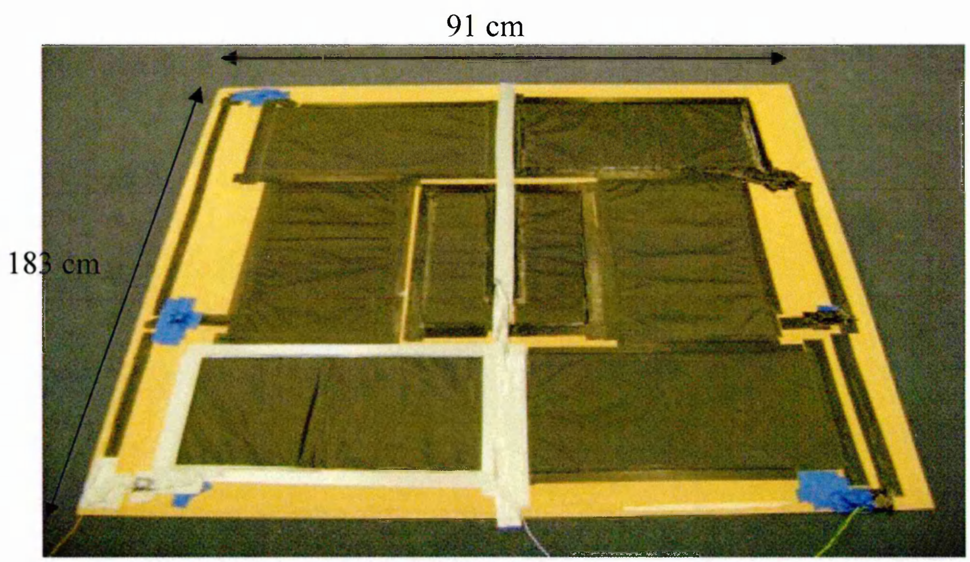


Figure 4.1 Response pads set-up.

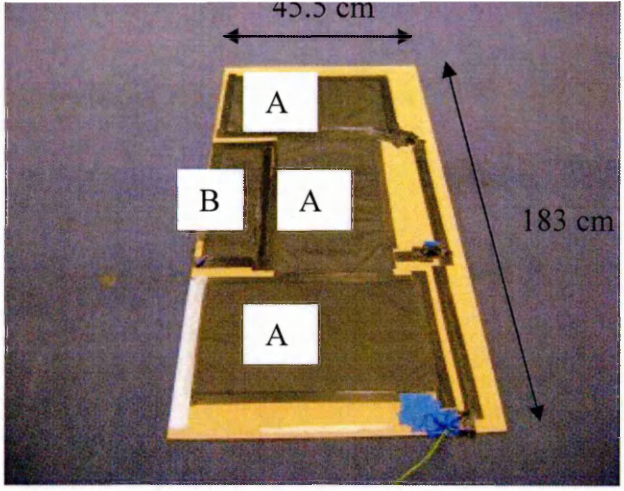


Figure 4.2 Configuration of response pads.

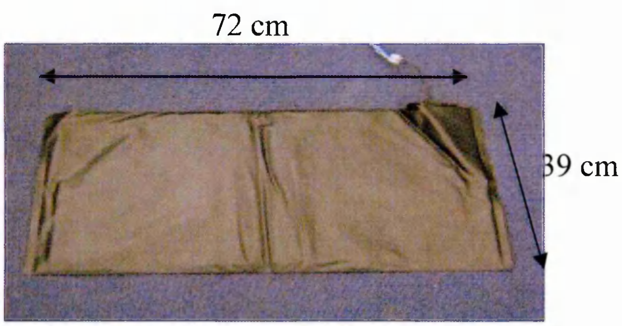


Figure 4.3 Response pad A.

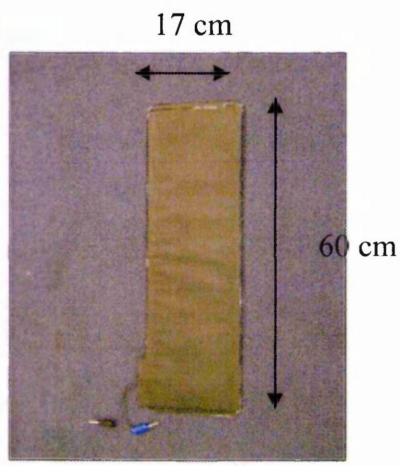


Figure 4.4 Response pad B.

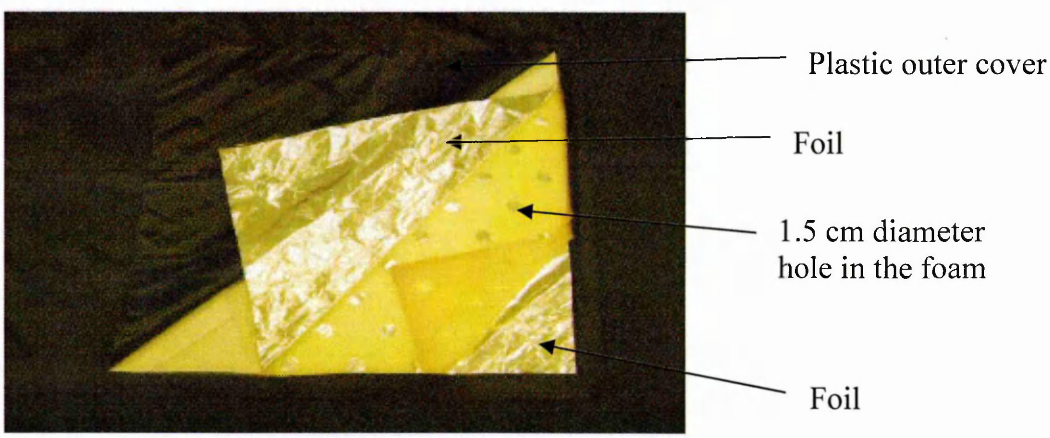


Figure 4.5 Inside view of a response pad.

When pressure was applied the two foil areas made contact through the 1.5 cm diameter holes in the foam, closed the circuit and stopped the timer (Figure 4.5).

The response pads were connected to a timing system (Venner Electronics TSA6614; Surrey, England) and a video recorder (Panasonic NV - HS900B, Japan). Encoded into the video of the film sequences were a series of 'bleeps' that signified the start of the sequence. The bleeps were detected by the timing mechanism and activated the timer that measured the participants' movement off the central response pad on to a pad in the desired direction (Figure 4.6).

The response pads were positioned 5 cm apart to aid quick movement in the shortest time. The larger pads were positioned around the central pads so the participants had a large area to move to without looking down to see where their foot was positioned, without the risk of missing the pad entirely. To minimise set-up time and to ensure the response pads were in exactly the same position for all trials, the pads were mounted on two 183 x 91 x 0.4 cm plywood boards making the unit portable and easy to set-up.

The participants stood 5 m away from a projection screen (Sanyo Pro-X Multimedia PLC SU2OB, Japan) on which the simulated images were projected. The film image subtended a visual angle of approximately 40° in the horizontal and 35° in the vertical direction, which provided life sized (Figure 4.7). These sequences contained random 3-on-3, 2-on-1 and 1-on-1 situations in which the players were required to imagine themselves as a covering defender playing in a central position between the penalty area and the centre circle.

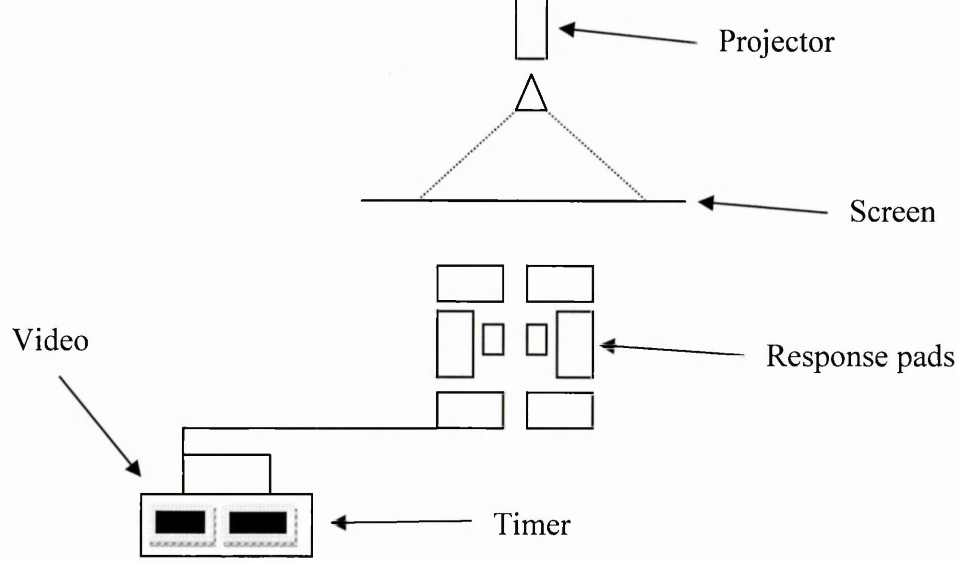


Figure 4.6 Schematic of the set-up.

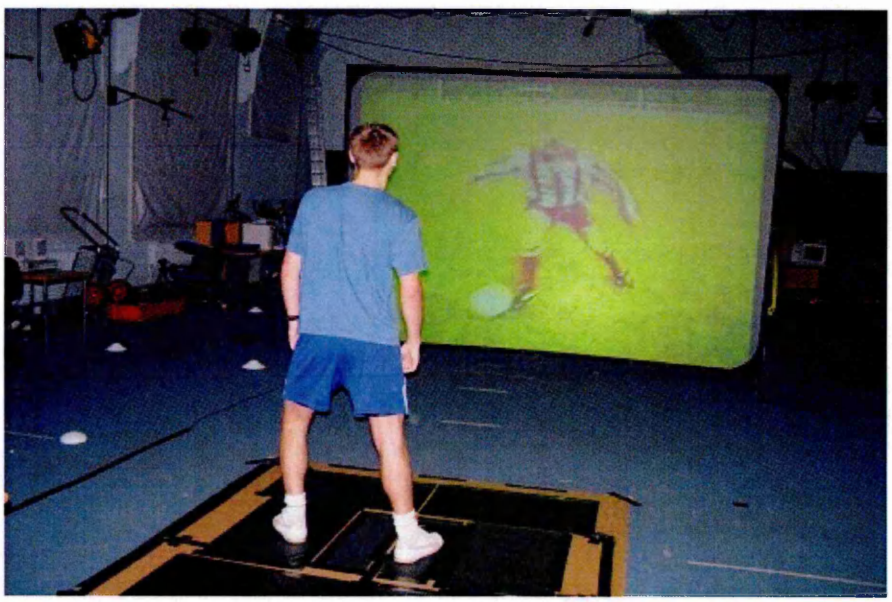


Figure 4.7 Position of a player, response pads and screen.

The film sequences were selected from actual soccer matches and simulated by skilled offensive and defensive players. The simulation was filmed at eye level (1.7m) ensuring it's from the player's customary perspective using a video camera (Panasonic NV -

GS500EB, Osaka, Japan) with an 8 mm focal length lens and a video recorder (Panasonic NV - HS900B, Japan). This position provided a visual display most representative of a covering defender's view of match play (Williams and Davids 1998). Fifteen soccer players participated in the filming sessions, thus providing a different combination of attacking and defensive players every trial.

Three experienced UEFA 'A' licence soccer coaches viewed the offensive sequences independently to ensure that each sequence was realistic and representative of actual match play. Only those film sequences on which the coaches were in complete agreement were used in the test film.

For reliability, each coach graded the sequences on a scale of 1-5 for difficulty, 1- being easy to 5- difficult. The sequences were then edited, randomised and grouped into sections of 6 equally-weighted test trials. Each set of 10 sequences carried a total rating of 34 for difficulty. This was subdivided as: 3 sequences with a rating of 2 for difficulty totalling 6; 2 sequences with a rating of 3 for difficulty also totalling 6; 3 sequences sequences with a rating of 4, totalling 12 and 2 sequences with a rating of 5, totalling 10. This ensured that the sequences were balanced for difficulty of providing appropriate response selection during the trials.

4.2.5 Data analysis

Response time and response accuracy was recorded and analysed according to the procedures outlined in chapter 3.3.

4.2.6 Statistical analysis

A paired-samples t test was used to identify possible systematic change between test and re-test scores. Statistical significance was set at $p < 0.05$. For reproducibility of measurement of the response pads and decision-making accuracy, the Intraclass Correlation Coefficient (ICC) was calculated with values above 0.90 considered high, 0.80 - 0.89 moderate and 0.70 to 0.79 acceptable. In addition, the test-retest coefficient of variation (CV) was calculated together with Bland and Altman limits of agreement (LOA, Technical Error of Measurement (TEM) both for absolute and relative values and least product regression (LPR) were also determined.

4.3 Results

4.3.1 Response performance

Test re-test response times (Figure 4.8) was 3750 ± 80 ms and 3660 ± 120 ms, $p < 0.05$ and test re-test response accuracy (Figure 4.9) was 87 ± 0.48 % and 94 ± 0.52 %, $p < 0.05$.

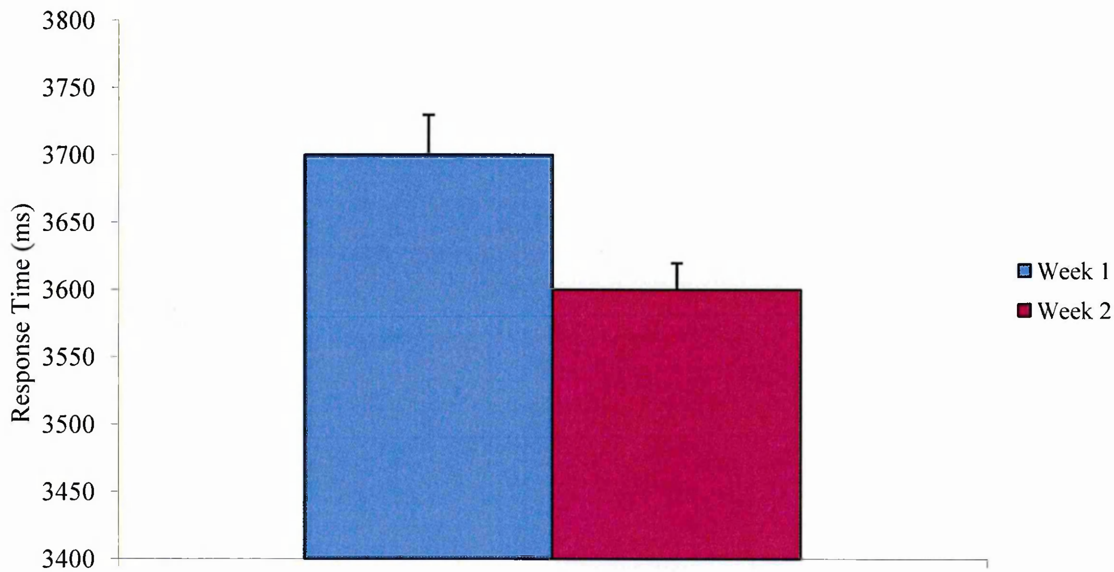


Figure 4.8 Test-retest response times.

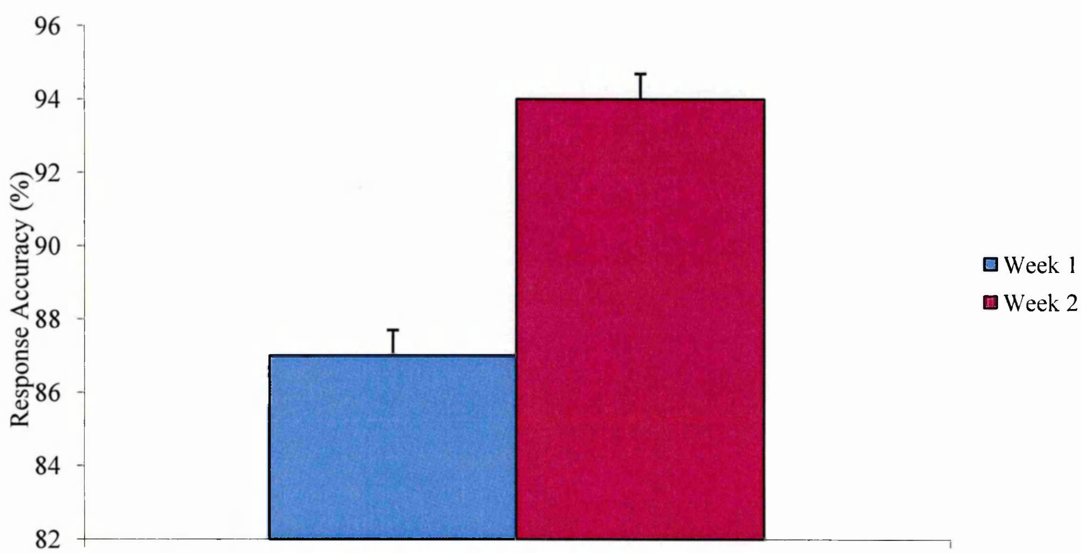


Figure 4.9 Test-retest response accuracy.

4.3.2 Reliability of measurement

Intraclass coefficient (r) was determined and the results illustrated that the measurements were highly reproducible, with response time = 0.91 and response accuracy = 0.80. The test re-test coefficient of variation (CV) for response time was 3.4% and for response accuracy 4.6% (< 5%) (Table 4.1). A built-in check for systematic differences in test results for a paired sampled t-tests, the t-ratio $p < 0.05$, $d =$ 0.12 (small) for response time and $p < 0.05$, $d = 0.20$ (small) for response accuracy indicated that mean values differed over the two testing sessions. The Bland and Altman limits of agreement ranged from –0.87 s to 1.05 s for response time (Figure 4.10) and -2.02 to 0.62 for response accuracy (Figure 4.11) were not reliable. The absolute and relative technical error of measurement (TEM) of the decision-making equipment proved reproducible over the test re-testing. The absolute TEM for response time was 0.06 s and 0.16 for response accuracy. The relative TEM for response time was 1.6% and 1.7% for response accuracy. The least products regression results for response time, intercept -0.53 and slope 1.1, for response accuracy, intercept -0.99 and slope 1.0 illustrates that the measure is reproducible.

Response Time

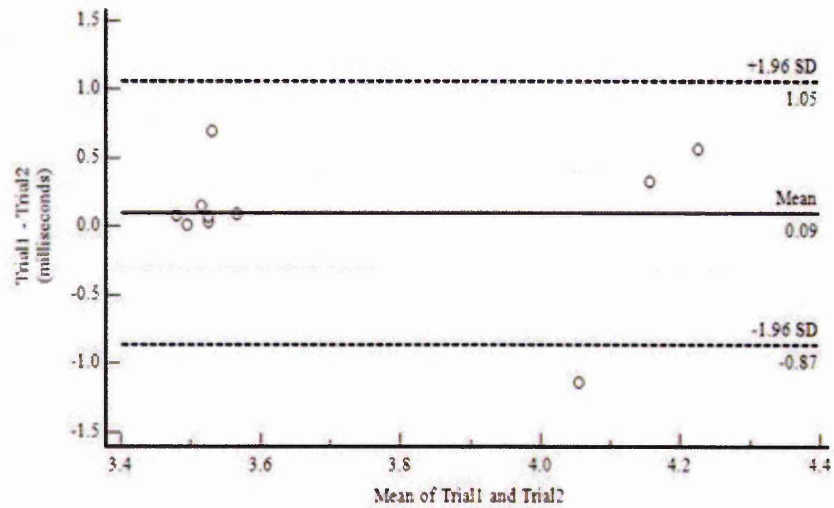


Figure 4.10 Limits of agreement plot for test-retest response time.

Response Accuracy

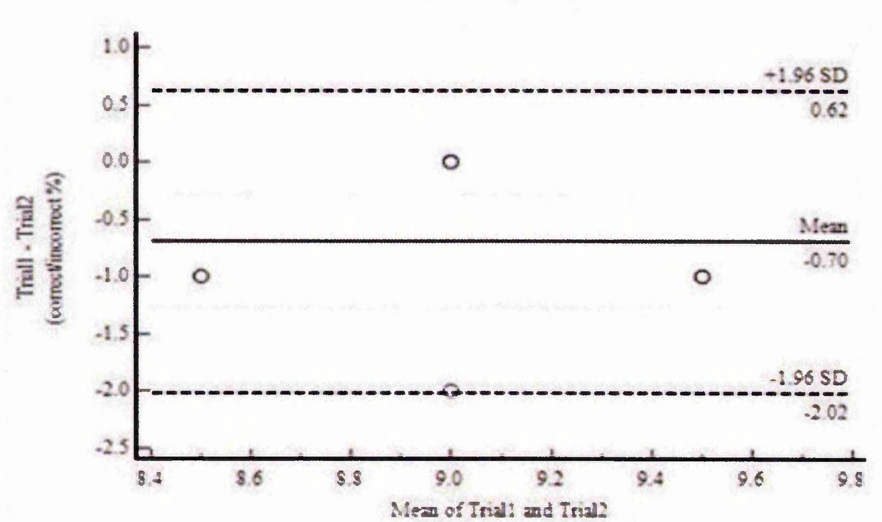


Figure 4.11 Limits of agreement plot for test-retest response accuracy.

Table 4.1 Reproducibility of measures of response time and response accuracy (n=10), values are mean, *s*.

Measure	**Mean Values (ms) ± SEM**		**Test-retest coefficient of variation %**	**t ratio *p* (*d*)**	**Bland and Altman 95% limits of agreement (ms)**	**TEM**		**Intraclass r**	**Least product regression**	
	Test	**Retest**				**Absolute**	**Relative (%)**		**Intercept**	**Slope**
Response time	3750 ± 80	3660 ± 120	3.4	0.032 (0.12)	-0.87 to 1.05	0.06(ms)	1.6	0.91	-0.53	1.1
Response accuracy (correct/incorrect)	87 ± 0.48	94 ± 0.52	4.6	0.046 (0.20)	-2.02 to 0.62	0.16	1.7	0.80	-0.99	1.0

4.4 Discussion

The aim if the study was to measure decision-making in soccer players and assess the reproducibility of measures derived from the test. No studies have provided any reproducibility data for response pads to compare, so reproducibility was conducted and compared with other stable measures e.g. stature and body mass using the test-retest method.

Response times in the test and retest occasions were 3750 ± 80 ms and 3660 ± 120 ms, indicated that quick decisions changed slightly across the trials. Similarly, response accuracy (87 ± 0.48% and 94 ± 0.52 %) demonstrated systematic variation. In spite of players being accustomed to testing procedures via several practice trials to reduce the possibility of learning effects, a small effect has still occurred.

Conversely, the coefficient of variation for the response time (3.4%) and response accuracy (4.6%) suggests that the measure had acceptable reproducibility. This result was supported by the t-ratio of $p < 0.05$, $d = 0.12$ (small) for response time and $p < 0.05$, $d = 0.20$ (small) for response accuracy indicating the response pads can be used as a measure of decision-making in soccer.

The range defined by the limits of agreement (reference range) for changes between pairs of measurements was -0.87 to 1.05 ms for response time and -2.02 to 0.62 for response accuracy suggest that the Bland and Altman data are not reliable possibly because of systematic change. Precision of measurement was calculated using the TEM. Results show that error of a single measure for the response pads was 0.06 ms two thirds of the time. Relative TEM was < 5% at 1.6% and was acceptable, indicating precision of measures. As values of least product regression intercept and slope for response time (-0.53 ms, 1.1) and response accuracy (-0.99 %, 1.0) are small and the slope encompasses 1, suggesting the decision-making equipment is reproducible.

Compared with instruments used to measure soccer players' decision-making by McMorris and Graydon (1996a,b,1997a,b); McMorris *et al.* (1999); Campos (1993), intraclass correlation for response time ($r = 0.91$) and response accuracy ($r = 0.80$) suggest that the measures were reliable. Furthermore, content validity of the instrument to measure decision-making in soccer players in this study has been demonstrated in two ways. First, the use of qualified UEFA 'A' Licence coaches to verify, randomize and grade the soccer sequences for degree of difficulty and then randomizing different soccer sequences for every test trial, negated possibility for players recalling and repeating the same actions. Second, by attempting to create a constantly changing environment with realistic soccer situations provided players opportunity to make dynamic movements involved in soccer and not answer questions from movement sequences on a table tennis-table top, which was photographed, converted into slides and projected onto a wall. The instrument used in this study, which attempts to replicate soccer situations improves the ecological validity as a tool to measure decision-making in soccer.

Advances have been made with instruments and techniques to measure decision-making in soccer. Film sequences and response pads have been used to measure anticipation in soccer, hockey and tennis (Williams and Davids, 1998; Williams *et al.*, 2002, 2003; Smeeton *et al.*, 2005) highlighting continual efforts researchers have adopted to provide realistic tests that replicate the complex nature of the sport measured.

Future research in the measurement of decision-making in soccer should contain actual field-based tasks, but researchers could encounter problems with controlling variables such as conditions and actual soccer situations, therefore, advancements will need to be made in more innovative laboratory tests.

4.5 Conclusion

Although the Bland and Altman data for response time was not reliable, systematic variation could be responsible for changes in response accuracy over the test re-test. Conversely, data from the other matrices of reproducibility indicated that the measures were reliable. It was concluded that the reproducibility of measures from the decision-making task are reproducible and can be used to measure decision-making throughout this thesis with confidence.

CHAPTER 5

Effect of high-intensity intermittent exercise on soccer-specific decision-making

5.1 Introduction

There is evidence on the effect that high-intensity intermittent exercise has a decrement in perceptual performance (Alderman, 1965). However, there has been little research on the relationship high-intensity intermittent exercise has on perceptual skill (decision-making) in soccer. Hebb (1955) has indicated that biochemical changes in the blood brought about by high-intensity exercise could interfere with the precise functioning of the cerebral cortex. Furthermore, with increased high-intensity intermittent exercise physiological responses could impact on a players' ability to respond concomitantly to perceptual tasks.

Deese (1962) has suggested that difficult perceptual tasks that require vigilance can be negatively affected by increased physiological changes in the respiratory and cardiovascular systems brought about by high-intensity intermittent exercise. Davey (1973) has used the term 'level of activation' to describe the increased level of metabolic activity in the human body resulting from high-intensity intermittent exercise. Philips (1962) has shown that the relationship between activation and performance could take the form of an inverted-U. Basically, as activation increases, performance increases along with it up to a point; with further increased activation performance decreases and players co-ordinated movements could be impaired.

With regard to movement, high-intensity intermittent exercise is thought to induce high-levels of arousal in the CNS, resulting in a negative effect on performance, as the players' ability to focus attention to the task (cognitive effort) diminishes. If cognitive effort is able to overcome the negative effects of high-intensity intermittent exercise induced arousal, the increment of change in the player's perception of the amount of cognitive effort that they produced, compared with their baseline perception, should be a predictor of increments in a decline in decision-making performance (McMorris *et al.*, 2005). However, the physiological variables could also be predictors of a decrement in decision-making performance. Therefore, examination of increments of change from rest in heart rate, blood lactate and blood glucose concentrations to assess the possible association between physiological indicators of high-intensity intermittent exercise and a decrement in decision-making performance was investigated. Furthermore, examining the physiological indicators could provide information as to the effect high-intensity exercise has on player's co-ordinated movement patterns. With decreases in speed of nerve transmission, player's movement and responses will probably be slower because of loss of power in the muscles or fatigue.

When the exercise duration exceeds 1 hour, the appearance of fatigue symptoms have been reported. Thus, it is possible that beyond 1 hour of high-intensity intermittent exercise, alterations and a decrement in perceptual performance can be seen (Brisswalter, *et al.*, 2002). Fatigue has been observed after sustained high-intensity exercise although detrimental effects on mood or mental performance are small (Brisswalter, *et al.*, 2002). It has been suggested that during prolonged high-intensity exercise, an increase in cerebral blood flow or in brain neurotransmitter concentrations could lead to an improvement in perceptual performance (Clark *et al.*, 1989). However, in contrast, Blomstrand *et al.* (1991) suggested that this was not the case and proposed that several factors such as muscle glycogen depletion, dehydration or hypoglycaemia are associated with heat stress and could lead to the appearance of muscle fatigue and central fatigue leading to a decrement in perceptual performance.

Decision-making is an integral part of perceptual performance in soccer. Common to perceptual performance in soccer is the physiological stress and possibly fatigue resulting from the high-intensity movement patterns during match play. An understanding of the relationship between decision-making performance and physiological responses to high-intensity intermittent exercise could be productive in an attempt to understand the mechanism/s that could affect decision-making performance.

Methods that can be used in competition to determine physiological stresses associated with match play are limited. The demands of match play have been examined by making observations of physiological measures during real and simulated match play and determining abilities of players on tests of performance (Bangsbo, 1994). Such information is not always associated with controlled conditions reported in experimental investigations or subject to the depth and accuracy of laboratory-based analysis (Drust *et al.*, 2000).

Researchers have devised laboratory-based exercise protocols to assess physiological and metabolic responses to intermittent exercise (Balsom *et al.*, 1992). Intermittent activity patterns used in these investigations have primarily been repeated bouts of high-intensity exercise of short duration separated by static recovery. Other studies have concentrated on physiological stresses imposed by multiple sprints (Nicholas *et al.*, 2000).

However, no studies have investigated the influence of high-intensity intermittent exercise on decision-making capability of soccer players using a soccer-specific treadmill protocol and in particular the extent to which there is a decrement in decision-making performance as a consequence of this type of exercise.

5.1.1 Aim

The aim of this study was to investigate the effects of high-intensity intermittent exercise on decision-making in soccer.

Hypothesis

It is hypothesised that high-intensity intermittent exercise will have a negative effect on decision-making.

5.2 Participants and Methods

5.2.1 Participants

With institutional ethics approval, 15 male university-standard soccer players (age mean 21.2, s = 1.6 years; stature 1.61, s = 0.21 m; body mass 73.1, s = 6.6 kg; $\dot{V}O_2$ max 55.2, s = 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$) took part. All participants were healthy and performed physical activity at least three times a week. Before the administration of any test, participants were screened for existing medical conditions that could be aggravated during the testing procedure. Participants completed an incremental test to volitional exhaustion for the determination of $\dot{V}O_2$ max, the procedure is outlined in chapter 3.2.4.1. Before trial instructions can be seen in chapter 3.2.1.4.

5.2.2 Experimental Design

The experimental trial consisted of completion of a decision-making task, before and after a sport-specific high-intensity intermittent treadmill protocol. The control trial consisted of the before and after decision-making task without the intermittent treadmill protocol. The participants were accustomed to the treadmill protocol, testing procedures and 10 decision-making practice trials during a visit to the laboratory on at least one occasion, followed by a further two visits for the experimental and control trial each separated by seven days. All participants performed an experimental and control trial in random order to minimise order effects.

5.2.3 Experimental Protocols

Soccer-specific high-intensity intermittent treadmill protocol

Participants completed four 22.5-min periods (approximately 90 min, representing the total duration of a soccer match). The protocol was designed to replicate movements of players during match play. Treadmill speeds for each activity were based on speeds observed for each specific movement category during soccer match play (Van Gool *et al.*, 1988). Speeds chosen for each activity pattern were: walking (6 $km \cdot h^{-1}$) for 35.3 s, jogging (12 $km \cdot h^{-1}$) for 50.3 s, cruising (15 $km \cdot h^{-1}$) for 51.4 s and sprinting (21 $km \cdot h^{-1}$) for 10.5 s. The protocol consisted of two identical 22.5 min cycles (each 22.5 min cycle consisted of 23 discrete bouts of activity: six bouts of walking, six bouts of jogging, three cruises and eight sprints) separated by a static recovery period of 71 s (Figure 5.1). Static recovery period was based on half of the total time players stood still during a 90-min match (Reilly and Thomas, 1976). This was followed by a second 22.5 min period that concluded the first half. There was a 15 min rest break. After the break, participants completed the second period of the test (second half), using the exact protocol as the first period. The procedure is detailed in chapter 3.2.5.

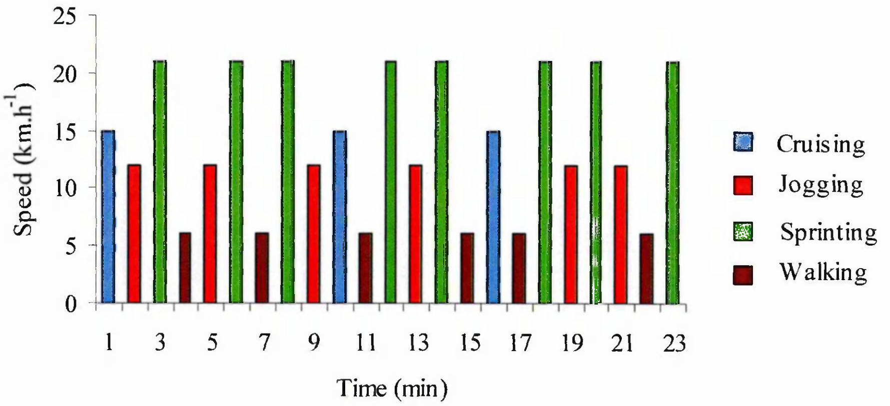


Figure 5.1. A diagrammatic representation of the soccer-specific intermittent treadmill protocol

Duration of each bout was determined by matching the proportion of total time for each separate activity pattern during the protocol (after the deduction of the total time for the treadmill speed changes) to that observed during match play, based on data by (Reilly and Thomas, 1976).

Decision-making task

Participants began the experimental trial with five practice trials followed by 10 test trials before the intermittent treadmill protocol, 10 trials after the first period and a further 10 test trials after the second period, which was a total of 30 test trials. The control trial also contained five practice trials and 30 test trials, at the same intervals as the experimental trial, but without the intermittent protocol. Procedure for the decision-making task is outlined in chapter 3.2.5.2 and has been found to be reproducible as a measure of decision-making highlighted in chapter four.

5.2.4 Data Analysis

Response time and response accuracy were recorded and analysed by means of procedures outlined in chapter 3.3. Heart rate was also recorded and analysed by means of procedures outlined in chapter 3.1.3, together with, blood lactate (chapter 3.1.4), blood glucose (chapter 3.1.4.2) and rate of perceived exertion (chapter 3.1.4.4).

5.2.5 Statistical Analysis

After verification of assumptions for parametric tests, means were compared using a fully repeated-measures factorial analysis of variance (time [before v after] v condition [control trial v experimental trial]). Statistical significance was set at $p < 0.05$. Effect size (*d*) was also calculated to assess the meaningfulness of differences between groups and was classified according to the system proposed by Cohen (1988) detailed in chapter 3.3.1.1.7 page 92.

5.3 Results

5.3.1 Response performance

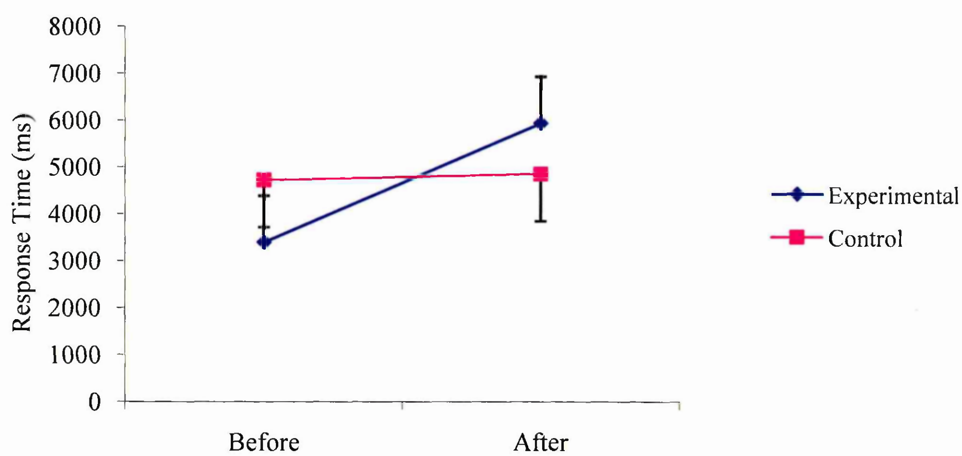


Figure 5.2 Response time for the experimental and control groups.

Response time before and after the intermittent exercise challenge for the control and experimental groups are shown in Figure 5.2. There was a group x time interaction for response time (F (1, 14) = 7.8, $p < 0.01$), $d = 0.64$ (large). There was a main effect for group (F (1, 14) = 5.6, $p < 0.05$, $d = 0.88$ (large), but there was no main effect for time (F (1, 14) = 9.42, p = 0.065). The anomaly in the main effect for group could be attributed to a combination of treatment effect and sampling error in that the groups were not equal from the outset. The intermittent exercise protocol had an adverse affect in a change in performance for the experimental group (3400 ± 110 ms and 5900 ± 100 ms) more than the control group (4700 ± 130 ms and 4900 ± 110 ms) causing an increase in response time.

Response accuracy before and after the intermittent exercise challenge for the control and experimental groups are shown in Figure 5.3. There was a group x time interaction for response accuracy (F (1, 14) = 97.3, $p < 0.01$), $d = 0.84$ (large). There was no main effect for group (F (1, 14) = 1.31, $p = 0.142$) or for time (F (1, 14) = 29.2, $p = 0.074$) Response accuracy deteriorated in the experimental group (84 ± 0.5 % and 50 ± 0.7 %) more than the control group (82 ± 0.4 % and 82 ± 0.5 %) as a consequence of the intermittent exercise protocol.

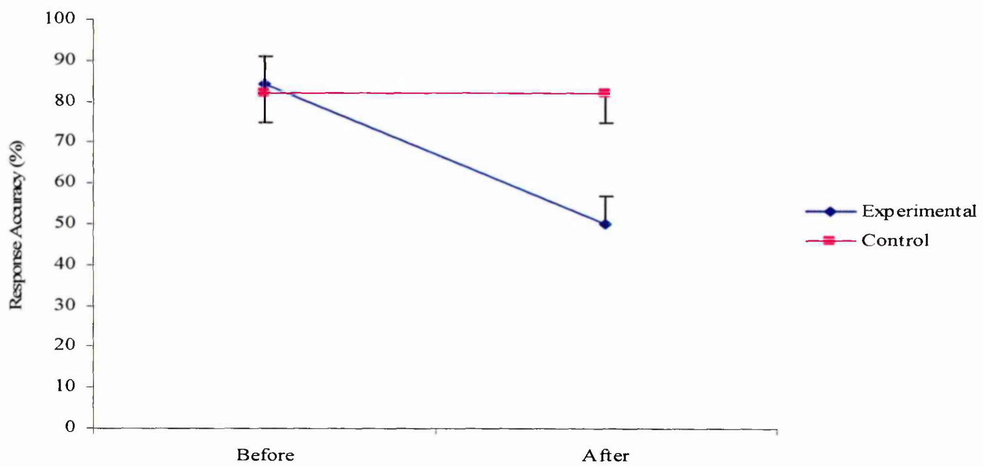


Figure 5.3 Response accuracy for the experimental and control groups.

Blood lactate before and after the intermittent exercise challenge for the control and experimental groups are shown in Figure 5.4. There was a group x time interaction for blood lactate (F (1, 14) = 17.6, $p < 0.01$), $d = 0.94$ (large). There was no main effect for group (F (1, 14) = 24.1, $p = 0.372$) or for time (F (1, 14) = 16.4, $p = 0.061$). Blood lactate concentration was greater in the experimental group (1.28 ± 0.3 mmol·l^{-1} and 8.05 ± 1.1 mmol·l^{-1}) than the control group (1.27 ± 0.4 mmol·l^{-1} and 1.74 ± 0.5 mmol·l^{-1}), which as for response time and response accuracy, illustrates the adverse affect of the intermittent exercise.

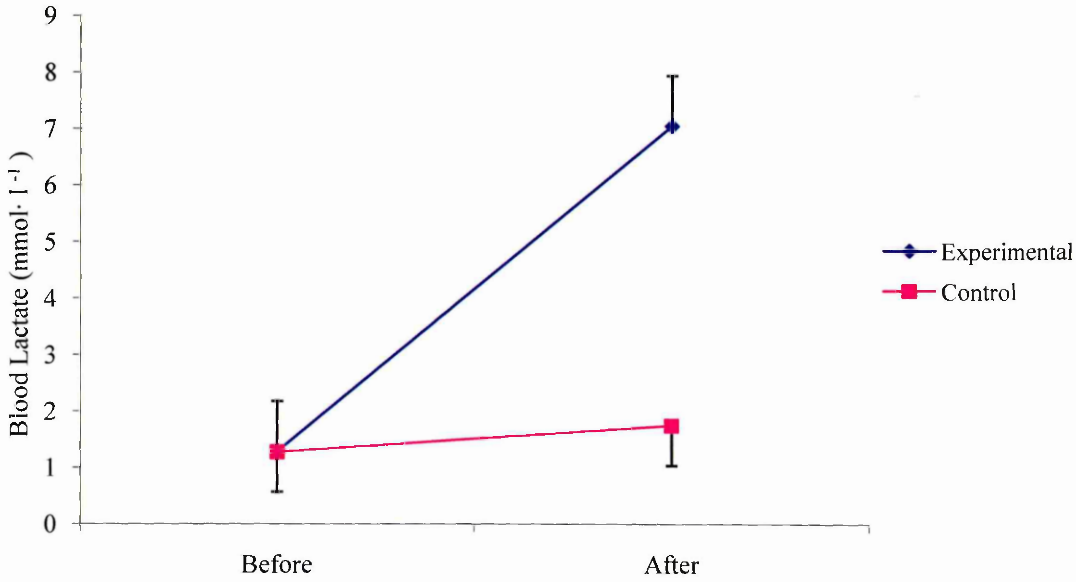


Figure 5.4 Blood lactate for the experimental and control groups.

Blood glucose before and after the intermittent exercise challenge for the control and experimental groups are shown in Figure 5.5. There was a group x time interaction for blood glucose (F (1, 14) = 7.2, $p < 0.05$), $d = 0.34$ (moderate). There was a main effect for group (F (1, 14) = 2.1, $p < 0.05$), $d = 0.20$ (small), but there was no main effect for time (F (1, 14) = 0.5, $p = 0.065$). Blood glucose concentrations increased more in the experimental group (4.41 ± .62 $mmol.l^{-1}$ and 5.65 ± 0.51 $mmol \cdot l^{-1}$) than the control group (4.79 ± 0.8 $mmol \cdot l^{-1}$ and 4.92 ± 1.1 $mmol \cdot l^{-1}$), illustrating the adverse affect by the intermittent exercise.

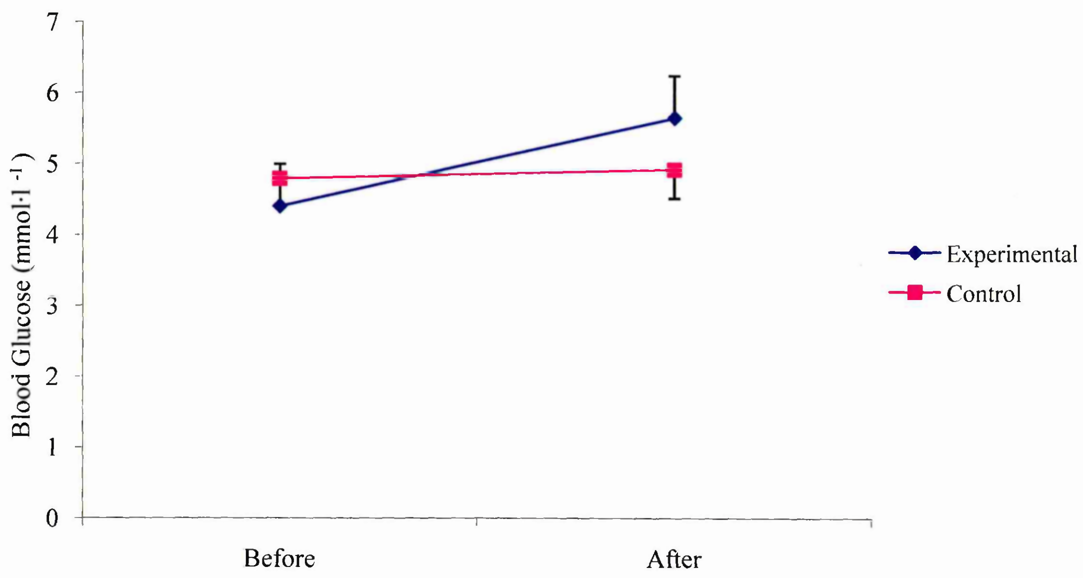


Figure 5.5 Blood glucose for the experimental and control groups.

Heart rate responses before and after the intermittent exercise challenge for the control and experimental groups are shown below in Figure 5.6. There was a group x time interaction for heart rate (F (1, 14) = 374.8, p < 0.01), d = 0.99 (large). There was no main effect either for group (F (1, 14) = 214.6, p = 0.365) or for time (F (1, 14) = 274.7, p = 0.072). Heart rate increased more in the experimental group (68 ± 4 beats·min^{-1} and 190 ± 2 beats·min^{-1}) than the control group (69 ± 4 beats·min^{-1} and 73 ± 4 beats·min^{-1}), illustrating the adverse affect by the intermittent exercise.

Rate of perceived exertion (RPE) 18.8 ± 0.07 was recorded for the experimental group only.

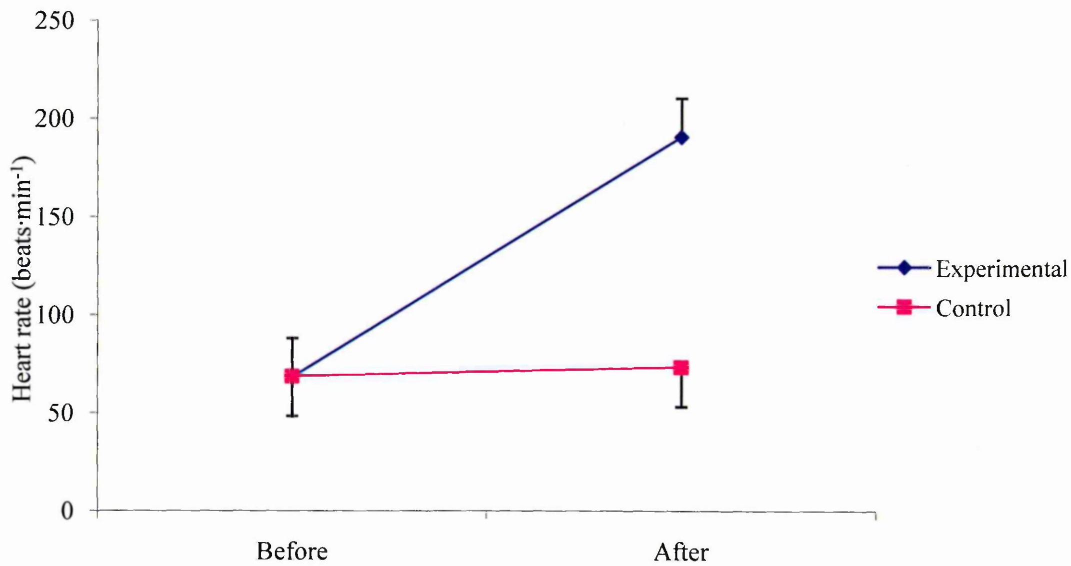


Figure 5.6 Heart rate for the experimental and control groups.

5.4 Discussion

The aim of this study was to investigate the effects of high-intensity intermittent exercise on decision-making in soccer using a soccer-specific high-intensity intermittent treadmill protocol that replicated exercise patterns observed in match play. Response time illustrated an interaction ($p < 0.01$), $d = 0.64$ (large) before and after the treadmill protocol, suggesting the treadmill protocol had a detrimental effect on the experimental group in the form of longer response times, it is unclear as to the cause of this occurrence, but physiological stress and or metabolic fatigue could be attributed to this effect.

The mechanisms responsible for the impairment in response time performance are various, given the severe strain imposed on the multiple organ system, tissues and cells by high-intensity intermittent exercise (Green, 1996). With high-intensity intermittent exercise, ATP production rates are unable to match ATP use and reduction in ATP occur accompanied by accumulation of a range of metabolic by-products such as hydrogen ions, inorganic phosphate, AMP, ADP and IMP. Selective by-products are believed to disturb Na^+ / K^+ balance, Ca^{2+} cycling and actomyosin interaction, resulting in fatigue. At the end of exercise the normalisation of cellular energy potential results in a rapid recovery of force, which are characteristics of metabolic fatigue and could, explain longer response times for the experimental group as a result of the high-intensity intermittent exercise protocol, because there could be a reduction in force output from the muscles, which could impact on co-ordinated movements supporting the inverted-U hypothesis.

Central fatigue could have adversely affected mean response accuracy ($p < 0.01$), d = 0.84 (large) as time to respond to the film sequences increased, ability to decide on the correct movement was impaired as this was shown in the experimental group mean response accuracy performance before and after the treadmill protocol.

Central fatigue can also affect player performance toward the end of the first half and in latter stages of matches (Reilly, 1996). During this state, players will tend to focus more on their tiredness than their playing role and responsibilities for the team, therefore, the more fatigued they become, the more they will focus on fatigue (Fenoglio and Jones 2000). Central fatigue could be responsible for redirecting players' attentional focus away from match-related events (for example, defending 1 v 1 and 2 v 1 situations) and ability to concentrate, look for the necessary cues or perceiving affordances can be diminished, which could result in poor decision-making accuracy, but it is unclear as to the precise mechanisms involved and further study is warranted.

Making fast accurate decisions requires players not only to make a quick search of the environment, but to perceive and decide on the correct response. Furthermore, it is not known if fatigue as a result of high-intensity intermittent exercise facilitates the CNS' ability to search for the presence of the ball, move in accordance with the body shape of the attacking player, identify the location of other players for a potential pass or the extent to which to decide to make a tackle.

Physiological responses to the high-intensity soccer-specific intermittent protocol (Drust *et al.*, 2000) were similar to responses seen in matches and can be used as a model of demands of match play. Nevertheless, there are limitations to the activity profile. These include: a lower frequency of activity changes, omission of utility movements such as backwards and sideways walking and jogging and lack of match activities (for example, kicking, heading and tackling). However, their inclusion would make it difficult to assess the physiological responses to soccer-specific intermittent exercise under controlled conditions. Despite these problems, the protocol provides a good representation of match play exercise that can be completed on a motorised treadmill.

Mean heart rate response 190 ± 2 beats·min^{-1} for the experimental group from the intermittent protocol are similar to heart rates observed during match play in university-standard players (Van Gool *et al.*, 1983). An interaction ($p < 0.01$), $d = 0.99$ (large) for mean heart rate indicates that the treadmill protocol placed a greater demand on the players' cardiovascular system in the experimental group. This could be result of elevations in heart rate during high-intensity intermittent exercise bouts and maintenance of a high heart rate during low-intensity recovery (Drust *et al.*, 2000). This is in accordance with the study by Smodlaka (1978), who reported that heart rate was above 85 % of maximum during approximately two thirds of duration of match play.

Heart rate has been shown to be an indicator of arousal level (Kennedy and Scholey, 2000) as well as being an indicator of exercise intensity. However, when the stressor causing increases in arousal is high-intensity exercise, it could be that heart rates elicited are poor predictors because of the emotional and physiological responses interact in such a way that heart rate becomes an unreliable predictor (McMorris *et al.*, 2005).

The soccer-specific intermittent treadmill protocol elicited a greater increase in mean blood lactate (8.05 ± 1.1 mmol·l^{-1}) after the treadmill protocol for the experimental group and an interaction ($p < 0.01$), $d = 0.94$ (large) for blood lactate, indicating substantial anaerobic energy production during intermittent exercise. This is not surprising, as high-intensity exercise during the soccer-specific intermittent protocol represents an intensity of approximately 110% $\dot{V}O_2$ max (Drust *et al.*, 2000). Furthermore, increased lactate concentrations could be associated with specific metabolic processes in the decrement in soccer performance, as the ability to perform high-intensity intermittent exercise is dependent on muscle's ability to derive energy from the glycogen-to-lactate pathway (Jacobs, 1981).

Mean blood lactate concentrations were also within the range obtained for Swedish second division players during match play by Ekblom, (1986). Anaerobic energy provision could have contributed to the high mean RPE (18.8 ± 0.07) suggesting players' incomplete recovery from the repeated sprints and fatigue-related residual or carryover effects resulting from high-intensity intermittent exercise (Bergeron, *et al.*, 2009).

Carbohydrate stores used during match play originate from glycogen stored in exercising muscles, but glucose extracted from blood could also be used by the muscles. During a Swedish competitive match, blood glucose concentrations were higher than at rest and no player had values below 4 $mmol \cdot l^{-1}$ (Ekblom, 1986). In addition, mean values for Swedish and Danish elite-standard players after a match were 3.8 and 4.5 $mmol \cdot l^{-1}$ respectively (Ekblom, 1986, Bangsbo, 1992). This is similar to the mean blood glucose results found after the intermittent treadmill protocol of 5.65 ± 0.51 $mmol \cdot l^{-1}$ for the experimental group. Furthermore, there was an interaction ($p < 0.05$), $d = 0.34$ (moderate) for blood glucose. Higher concentrations (6 - 7 $mmol \cdot l^{-1}$) were reported by Smaros (1980). Therefore, blood glucose concentration during high-intensity intermittent exercise could not be considered a factor associated with a decrement in decision-making performance.

5.5 Conclusion

The results suggest that physiological responses indicate that players' decision-making performance (response time and response accuracy) were impaired as a consequence of the soccer-specific high-intensity intermittent treadmill protocol. Physiological stress and or mechanisms of fatigue could be attributed to this, however, it is difficult to ascertain the precise mechanisms involved Further investigation is needed to identify the extent to which aerobic mechanisms (the ability to recover from repeated sprint bouts) influence the decline of players' decision-making performance.

CHAPTER 6

Influence of repeated sprints and sprint recovery duration on decision-making performance of soccer players.

6.1 Introduction

In soccer, decisive actions are often preceded by repeated sprints. Successful players have the ability to perceive available information and make quick decisions while fatigued. Hence, the inability to perform repeated sprints, recover quickly and possess the awareness to make quick and accurate decisions while fatigued, are important determinants for soccer performance.

Movements in soccer are intermittent and largely random, although motion analysis suggests soccer requires repeated high-intensity exercise bouts of approximately 3 - 4 seconds in duration every 30 seconds with an exercise-to-rest ratio of ~ 1: 7 (Mayhew and Wenger, 1985; Shephard, 1999; Reilly and Williams, 2003). High-intensity running constitutes only 1 - 11% of total distance covered in a match (Withers *et al.*, 1982; Bangsbo *et al.*, 1991).

In a match each player performs 1000 -1400 short activities (Mohr *et al.*, 2003) these activities include 10 – 20 sprints, high-intensity running, changes of pace and sustaining forceful muscle actions to maintain balance and control of the ball against defensive pressure (Ekblom, 1986; Bangsbo *et al.*, 1991). Withers *et al.* (1982) reported fullbacks sprinted > 2.5 times longer than central defenders, while midfielders and attackers also sprinted > 1.6 times longer than central defenders. This is in accordance with Mohr *et al.* (2003) who reported that fullbacks and attackers sprinted longer than central defenders and midfielders.

The ability to repeat sprints depend on several factors such as aerobic fitness (McMahon and Wenger 1998), the ability to buffer H^+ (Bishop *et al.*, 2004), sprint duration (Balsom *et al.*, 1992a), recovery duration (Balsom *et al.*, 1992b) and muscle glycogen concentration (Balsom *et al.*, 1999). The contribution of oxidative phosphorylation to total energy expenditure during a single short sprint is negligible; however, when these sprints are repeated and alternated with short recovery periods, aerobic contribution increases with time and possibly becomes substantial (Balsom *et al.*, 1994).

During recovery periods, oxygen uptake ($\dot{V}O_2$) remains elevated mainly to restore homeostasis via processes such as the replenishment of tissue oxygen stores, the resynthesis of PCr, the metabolism of lactate and the removal of accumulated inorganic phosphate (P_i) (Glaister, 2005). Furthermore, an exercise intensity of approximately 80% of a players' HR_{max} has been shown to remove blood lactate effectively, thus improving players' co-ordinated movements.

If PCr resynthesis is reduced, then subsequent sprint performance could be hindered, as PCr resynthesis has been correlated with subsequent sprint performance (Bogdanis, *et al.*, 1995). The results suggest that the active recovery that predominates between team sport-specific, repeated bouts (Spencer *et al.*, 2004) is likely to impair both PCr resynthesis and repeated sprint ability. However, to date, this hypothesis has not been tested.

In a repeated-sprint study, Balsom *et al.* (1992a) reported that 15 x 40 m with an exercise-to-rest ratio of approximately 1:5 - 1:6 could be a suitable protocol for soccer because in addition to the exercise-to-rest ratio, the speed decrement was comparable to a sprint protocol that simulated soccer by Abt *et al.* (2003) and total sprint distance (600

m) simulated match play (Bangsbo, 1994). However, it is unlikely that such an exercise-to-rest ratio is appropriate for all sprint distances and durations (Little and Williams, 2007). Fatigue has been shown to increase exponentially as sprint distance increases despite constant exercise-to-rest ratios (Abt *et al.*, 2003). Physiological and perceptual effects of repeated sprints on decision-making performance in soccer players warrant investigation.

Results from the previous study highlighted that there was a decline in decision-making performance after high-intensity intermittent exercise. Therefore, the present study aims to identify the extent to which anaerobic metabolism influences the decline of players' decision-making.

6.1.1 Aim

The aim of this study was to assess the influence of repeated sprints and sprint recovery duration on decision-making capability of soccer players.

Hypothesis

It is hypothesised that shorter recovery period between repeated sprints would have a detrimental effect on decision-making performance.

6.2 Participants and Methods

6.2.1 Participants

With institutional ethics approval, 10 male university soccer players (age mean 21.4, s = 1.2 years; stature 2.0, s = 0.71 m; body mass 76.5, s = 5.1 kg; $\dot{V}O_2$ max 54.3, s = 4.1 $ml \cdot kg^{-1} \cdot min^{-1}$) participated. All participants were healthy and performed physical activity on a regular basis. Prior to the administration of any test, participants were screened for existing medical conditions that could become aggravated during the testing procedure. The participants completed an incremental test to volitional exhaustion for the determination of $\dot{V}O_2$ max. The procedure is outlined in chapter 3.2.4.1. Pre-test instructions can be seen in chapter 3.2.1.4.

6.2.2 Experimental Design

Participants were habituated beforehand to the repeated sprint protocol, testing procedures, 10 decision-making practice trials and assessment of $\dot{V}O_2$ max. Two further visits were used for testing separated by seven days. The design consisted of completion of 10 x 10 s repeated sprints before and after a decision-making task on a motorised treadmill interspersed with either a 15-s or 30-s passive recovery period.

6.2.3 Experimental Protocols

Repeated sprints

The protocol for the repeated sprint test is outlined in chapter 3.2.6.1. Players were harnessed and sprinted at approximately 21- 25 $km \cdot h^{-1}$.

Decision-making task

The procedure of the decision-making task is outlined in chapter 3.2.5.2. The participants completed 10 test trials before the repeated sprint protocol and 10 trials after the protocol.

6.2.4 Data Analysis

Response time and response accuracy were recorded and analysed following the procedures outlined in chapter 3.3. Heart rate was also recorded and analysed using the procedures outlined in chapter 3.1.3, together with, blood lactate (chapter 3.1.4), blood glucose (chapter 3.1.4.2) and rate of perceived exertion (chapter 3.1.4.4).

6.2.5 Statistical Analysis

After verification of assumptions for parametric tests, means were compared using a fully repeated-measures factorial analysis of variance for the physiological measures (heart rate, blood lactate and blood glucose). Statistical significance was set at $p < 0.05$. Effect sizes (*d*) were also calculated to estimate the magnitude of the difference between groups and were classified according to the system proposed by Cohen (1988) detailed in chapter 3.3.1.1.7.

6.3 Results

6.3.1 Response performance

Response time means, *s* before and after repeated-sprint protocol for the 15-s and 30-s sprint recovery duration condition are shown in Figure 6.1. There was a group x time interaction for response time (F (1, 9) = 65.4, $p < 0.01$), $d = 0.42$ (moderate). There was no main effect for group (F (1, 9) = 31.6, $p = 0.064$), but there was a main effect for time (F (1, 9) = 12.3, $p < 0.05$), $d = 0.41$ (moderate). Response time in the 15-s sprint recovery condition (3050 ± 0.50 ms and 4710 ± 0.50 ms) was adversely affected more than the 30-s recovery condition (3250 ± 0.50 ms and 4220 ± 0.60 ms) as a consequence of the repeated sprint protocol.

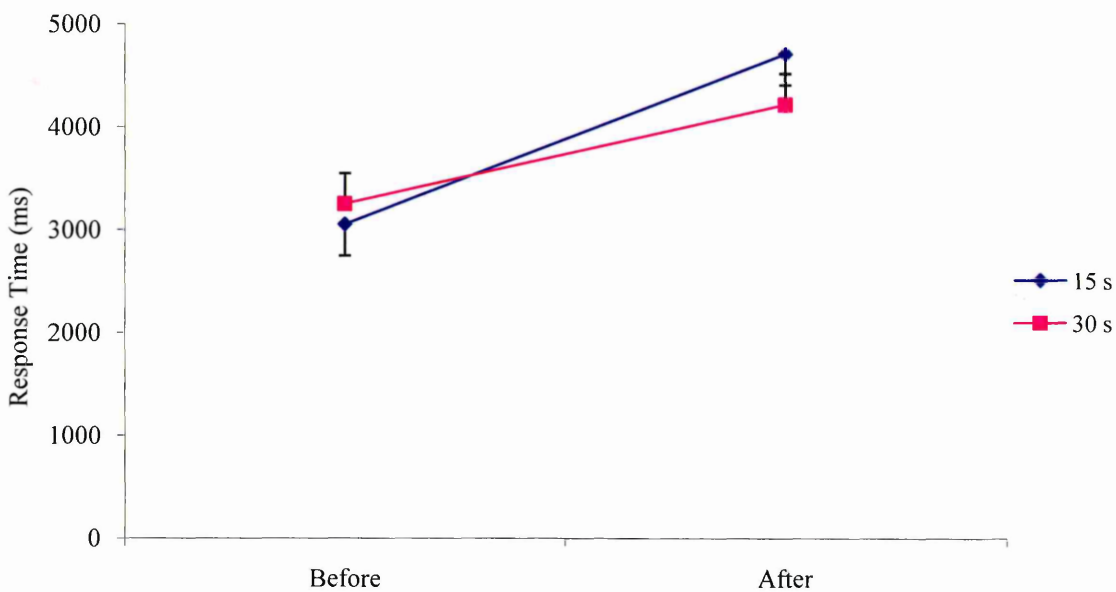


Figure 6.1 Response time for the 15-s and 30-s recovery conditions.

Response accuracy before and after the sprint protocol for 15-s and 30-s sprint recovery duration conditions are shown in Figure 6.2. There was a group x time interaction for response accuracy (F (1, 9) = 54.2, $p < 0.01$), $d = 0.85$ (large). There was no main effect for group (F (1, 9) = 44.8, $p = 0.068$), but there was a main effect for time (F (1, 9) = 18.9, $p < 0.05$), $d = 0.63$ (large). Response accuracy in the 15-s sprint recovery condition (89 ± 0.3 % and 52 ± 0.8 %) was adversely affected more than the 30-s recovery condition (86 ± 0.6 % and 76 ± 0.5 %) as a consequence of the repeated sprint protocol.

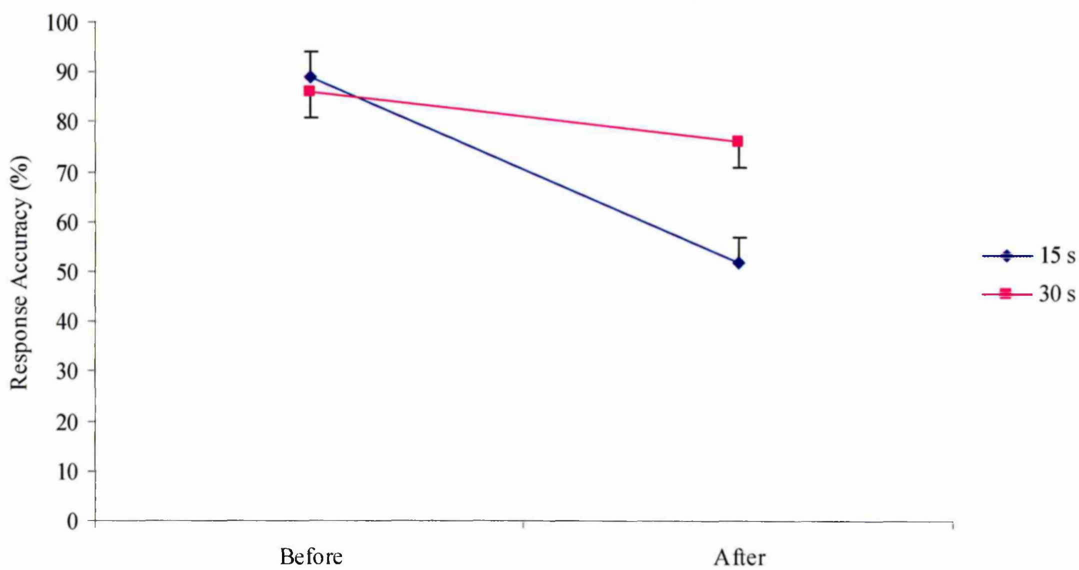


Figure 6.2. Response accuracy for the 15-s and 30-s recovery conditions.

Blood glucose concentrations before and after the sprint protocol for 15-s and 30-s sprint recovery duration conditions are shown in Figure 6.3. There was no group x time interaction for blood glucose (F (1, 9) = 0.77, p = 0.065). There was no main effect for group (F (1, 9) = 10.8, p = 0.379), but there was a main effect for time (F (1, 9) = 86.4, p < 0.01), d = 0.22 (small). Blood glucose concentrations in the 30-s sprint recovery condition (4.63 ± 1 mmol·l^{-1} and 6.24 ± 1 mmol·l^{-1}) increased more than the 15-s recovery condition (4.67 ± 0.7 mmol·l^{-1} and 6.05 ± 0.4 mmol·l^{-1}) as a consequence of the repeated sprint protocol.

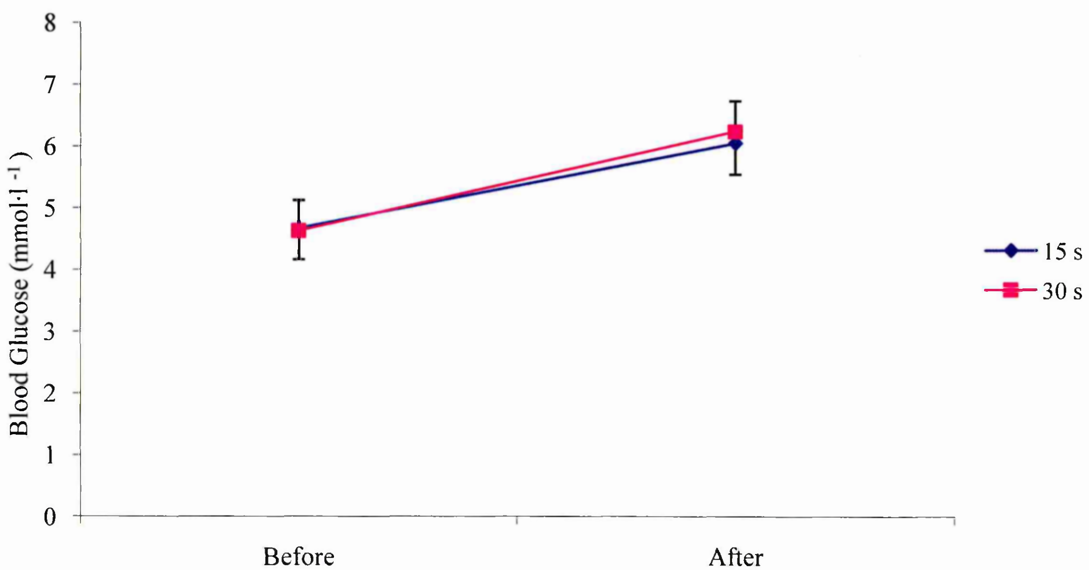


Figure 6.3 Blood glucose for the 15-s and 30-s recovery conditions.

Blood lactate concentration before and after the sprint protocol for the 15-s and 30-s sprint recovery duration conditions are shown in Figure 6.4. There were a group x time interaction for blood lactate (F (1, 9) = 218.3, $p < 0.01$), $d = 0.96$ (large). There was no main effect for group (F (1, 9) = 96.3, $p = 0.376$), but there was a main effect for time (F (1, 9) = 114.5, $p < 0.05$), $d = 0.44$ (moderate). Blood lactate concentrations in the 15-s sprint recovery condition (2.83 ± 0.7 $mmol \cdot l^{-1}$ and 13.21 ± 0.9 $mmol \cdot l^{-1}$) increased more than the 30-s recovery condition (2.84 ± 0.7 $mmol \cdot l^{-1}$ and 8.61 ± 1.1 $mmol \cdot l^{-1}$) as a consequence of the repeated sprint protocol.

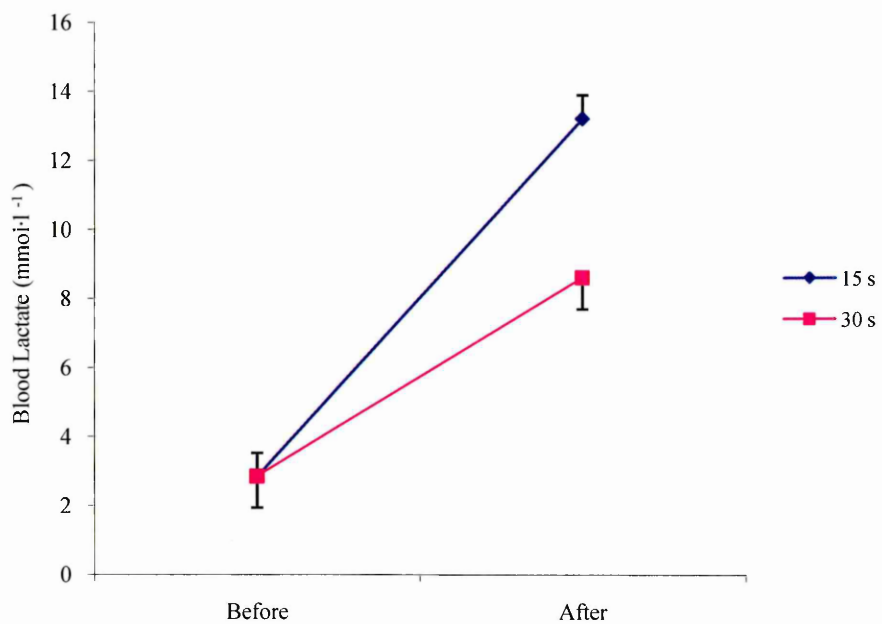


Figure 6.4 Blood lactate for the 15-s and 30-s recovery conditions.

Heart rate responses before and after the sprint protocol for 15-s and 30-s sprint recovery duration conditions are shown in Figure 6.5. There was no group x time interaction for heart rate (F (1, 9) = 88.1, p = 0.089). There was no main effect for group (F (1, 9) = 99.6, p = 0.362), but there was a main effect for time (F (1, 9) = 79.9, p < 0.05), d = 0.78 (large). Heart rate responses in the 15-s sprint recovery condition (69 ± 3 beats·min^{-1} and 192 ± 5 beats·min^{-1}) increased more than the 30-s recovery condition (68 ± 3 beats·min^{-1} and 170 ± 3 beats·min^{-1}) as a consequence of the repeated sprint protocol.

RPE was also calculated 18.0 ± 0.9 in the 15-s recovery condition and 13.0 ± 0.7 in the 30-s recovery condition.

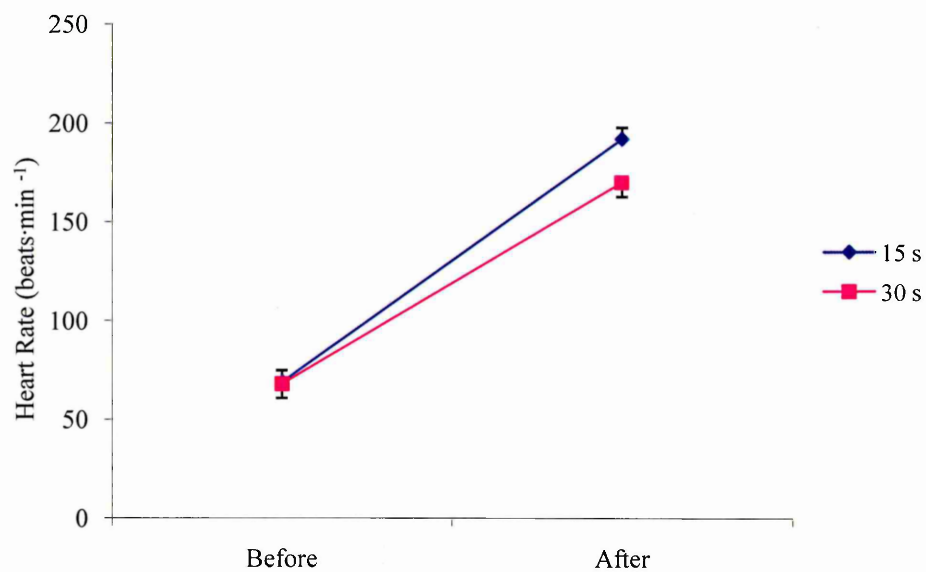


Figure 6.5 Heart rate for the 15-s and 30-s recovery conditions.

6.4 Discussion

The aim of this study was to assess the influence of repeated sprints and sprint recovery duration on decision-making performance of soccer players. While previous studies (Balsom *et al.*, 1992; Little and Williams, 2007) have assessed repeated-sprint performance and sprint recovery duration, no studies have investigated the possible detrimental effects that repeated sprints and sprint recovery duration could have on decision-making.

When recovery duration between the 10 x 10-s sprints was increased from 15-s to 30-s, a change in decision-making performance (response time and response accuracy) emerged. In the 15-s condition 3050 ± 50 ms and 4710 ± 50 ms and the 30-s condition 3250 ± 50 ms and 4220 ± 60 ms before and after the sprint protocol. There was an interaction for response time ($p < 0.01$), $d = 0.42$ (moderate). As response time in the 15-s condition was longer in the post test, suggests that players were unable to recover from the repeated sprints sufficiently, possibly affecting co-ordinated movements and having a detrimental effect on decision-making performance.

Mean response accuracy before and after the repeated sprint protocol for 15-s recovery condition was 89 ± 0.3 % and 52 ± 0.8 % and 30-s recovery condition 86 ± 0.6 % and 76 ± 0.5 %. There was also an interaction for response accuracy ($p < 0.01$), $d = 0.85$ (large) indicating response accuracy was adversely affected as a consequence of the repeated sprints, this could be because of the onset of fatigue. The 30-s recovery condition indicated that although the repeated sprint protocol was physically demanding and fatigue could be present, longer recovery (30-s) time between sprints could be sufficient not adversely affect players' response accuracy.

A possible explanation is that a greater amount of PCr is resynthesised during the longer passive recovery period, where shorter recovery contributes to a faster PCr resynthesis than active recovery, resulting in higher concentrations of PCr at the end of each recovery period (Bogdanis *et al.*, 1995; Harris *et al.*, 1976). Idström *et al.* (1985) reported that the rate of PCr resynthesis was directly related to the supply of oxygen as less oxygen being used during repeated sprints and sprint recovery would adversely affect physiological responses and co-ordinated movements associated with decision-making performance, therefore, less oxygen is used for muscle contractions. Moreover, when anaerobic metabolism increases, low rate of ATP turnover are found and resynthesis of PCr is inhibited (Quistorff *et al.*, 1992).

Blood lactate concentration before and after the sprint protocol for the 15-s recovery was 2.83 ± 0.7 $mmol{\cdot}l^{-1}$ and 13.21 ± 0.9 $mmol{\cdot}l^{-1}$ and 30-s recovery 2.84 ± 0.7 $mmol{\cdot}l^{-1}$ and 8.61 ± 1.1 $mmol{\cdot}l^{-1}$. There were an interaction for blood lactate ($p < 0.01$), $d = 0.96$ (large). A possible reason for the interaction could be that the result of the release of lactate from the contracting muscles and the clearance from the blood is influenced by the metabolism in various tissues such as the heart and the liver (Brooks, 1987). Furthermore, because the clearance rate of blood lactate is lower than the turnover of lactate in the muscle, the blood lactate concentration represents an accumulated response of the lactate production in the muscles during repeated sprints (Bangsbo, 1993). The role of increased concentrations of blood lactate and its association in the decrement of players' decision-making is unclear. Moreover, blood lactate concentrations should be considered as marker that is associated with specific metabolic processes rather than a cause of fatigue. Although the appearance of lactate in the blood does indicate lactate has been produced in the muscle, lactate production cannot be quantified based on blood lactate concentration alone (Balsom, 1995).

It is unclear to what extent the role blood glucose plays in a decrement of such performance. There was no interaction for blood glucose ($p = 0.065$). A possible reason is that only 5% of total ATP generated in the complete breakdown of a glucose molecule is formed during glycolysis (McArdle *et al.*, 2007). However, energy required for muscle action can be provided through glycolysis because of the high concentration of glycolitic enzymes and the speed of these reactions.

As an indicator of intensity during the repeated sprint protocol, RPE and heart rate was recorded. The RPE values after the sprint protocol for the 15-s recovery condition were 18.0 ± 0.9 and the 30-s recovery condition was 13.0 ± 0.7 shows that players perceived the 15-s recovery condition to be demanding, which could be related to increased blood lactate concentration, increased heart rate and the onset of fatigue. RPE can be deemed a subjective measure of intensity (BASES, 1997) and is a conscious rating of effort based on central and peripheral cues of fatigue (Robergs and Roberts, 1996). Modifying either central or peripheral factors can affect the RPE independent of heart rate involvement and further investigation is needed to substantiate its association with fatigue and a decrement in decision-making performance.

Mean heart rate after sprint protocol for the 15-s recovery condition (192 ± 5 beats·min^{-1}) suggest increased demand placed on the heart as a result of the intensity of exercise and subsequent limited recovery, compared with the 30-s recovery condition (170 ± 3 beats·min^{-1}). The latter was in accordance with Balsom *et al.* (1992a) who reported similar results (165 ± 6 -172 ± 5 beats·min^{-1}) for 30-s recovery duration in a repeated sprint protocol. Indicating, longer recovery period provided players with sufficient time to lower their heart rate.

6.5 Conclusion

The results of the study show that 10 x 10-s repeated sprints with a 15-s recovery period had a markedly detrimental effect on players' decision-making performance possibly because of the duration of the recovery period and its association with the ability to perform repeated sprints, therefore, adversely affecting not only physiological responses, but co-ordinated movements involved in decision-making performance in soccer. Caution must be made when interpreting elevated blood lactate concentration data, as it should be considered a marker that is associated with specific metabolic processes than a cause of fatigue leading to a decrement in decision-making performance. Therefore, this repeated-sprint protocol can be used in an attempt to induce fatigue in soccer players.

CHAPTER 7

Effects of perceptual training on decision-making in soccer.

7.1 Introduction

The acquisition and improvement of perceptual skill (for example, decision-making) are important processes involved in soccer. For example, being able to discriminate, identify and predict the outcome of various stimuli has implications for expertise in sports performance (Williams *et al.*, 2002). Players can learn to modulate attention to and process relevant environmental features and dimensions and group together pieces of information that were previously viewed as distinct (Goldstone, 1998). The implication of such learning is that players can be trained to reduce perceptual uncertainty, which in turn, facilitates anticipation of future events (Smeeton *et al.*, 2005).

Anticipation skill is presumed to be because of an enhanced ability to 'pick up' and process information arising from the opponent's postural orientation prior to their action. Attempts to facilitate the acquisition of perceptual skill using a variety of instructional techniques such as instruction and guided discovery have been proposed as suitable methods to facilitate this process (Williams *et al.*, 2002).

Anderson (1982, 1987) proposed that knowledge is initially stored in a declarative form and interpreted by using general procedures. Although these interpretive procedures are slow and place heavy demands on working memory, they offer adaptability and allow declarative knowledge to impact on behaviour without relinquishing control (Anderson, 1982). The prescriptive nature of explicit instruction is thought to accelerate early learning and the formation of specific productions such that time spent searching for relevant information is reduced. Also, declarative knowledge is thought to provide a structured framework for subsequent knowledge development (Chase and Ericsson, 1982). In latter stages of learning, researches have proposed that knowledge is highly proceduralised and enables complex stimuli to be processed more effectively, leading to quicker responses and potentially, greater resilience under physiological stress (Anderson, 1987) and possibly withstanding fatigue during training and periods of a match.

Theories of skill acquisition have led to the development of training programmes that are structured and prescriptive, at least early in practice, researchers have proposed an alternative method of instruction that could be more successful than learning via explicit instruction (Broadbent *et al.*, 1986) and stated that early in learning, performance improvements could be made without awareness of the rules that control the system. Furthermore, Green and Flowers (1991) suggested that instructions placed an unnecessary cognitive load on players and interfered with their proceduralization of the task.

Magill and Clark (1997) reported that withholding explicit instruction was particularly beneficial in a tracking task when the relationship between the stimulus information and response was not reliable. However, when there was no uncertainty, the use of explicit rules was not detrimental to performance, suggesting the potential benefit of less explicit instructional approach in training perceptual skill.

The advocacy of less prescriptive methods in coaching has questioned how constrained the environment needs to be for the unguided player to stumble on the answer in discovery situations (Mayer, 2004). A lack of direction when searching for regulatory information, as well as the potential for its misinterpretation, can delay acquisition in comparison to more prescriptive methods (Haider and Frensch, 1999). Guided discovery has been suggested as a refined discovery method of coaching motor (Singer, 1977), cognitive (Bransford *et al.*, 1986) and perceptual skills (Wiilams *et al.*, 1999). It can be used to train perceptual skill by constraining the player to focus attention on more informative areas of the display via instructions or visual cues. This was investigated in a study by Smeeton *et al.* (2005) to determine the extent to which the acquisition of perceptual skill in tennis could be facilitated through training. The guided discovery group were told the location of advance cues and encouraged to work out the relationship between bodily orientations and shot outcome Participants were encouraged to discover for themselves the relationship between perceptual cues and shot outcome. Practice was conducted over 4 weeks and measures of response time and response accuracy were recorded pre and post practice, during acquisition and in an anxiety provoking transfer test. A no-practice control group was tested at the same time as the experimental group on pre and post test only. The results showed that perceptual skill can be trained using guided discovery and is the most appropriate method of instruction.

Studies on perceptual skill learning from a dynamical systems perspective have examined the association of learning using interaction between constraints (organism, environment and task) and players (Williams and Hodges, 2005). Organism constraints include: stature, body mass and functional characteristics such as motivation and emotion. Environmental constraints consist of ambient temperature, sound and light during match play. Task constraints are aims and objectives of a match and also include rules and pitch dimensions. In understanding individual player characteristics, coaches can manipulate task constraints to increase player learning potential (Newell, 1986).

A constraints-led approach to coaching creates an environment that facilitates discovery by guiding a player through a range of potential movement solutions in search of the correct decision (Handford *et al.*, 1997). Individual responses are unique to each player and result in effective retention and transfer of movement skills that require a less prescriptive approach to coaching. This can be achieved through manipulation of key constraints on the player leading to a change in movement behaviour (Handford *et al.*, 1997). It is argued that a thorough grounding of the principles of task constraints forms the basis for a constraints-led approach to practice in soccer (Davids *et al.*, 2004). However, further research is needed to substantiate this claim.

An example of a constraints-led approach was adopted by the Japanese Football Association (Nakayama, 2004). It promotes the importance of coaching in which a coach should devise situation settings, control the number of players, rules and ball distribution (from the coach) in decision-making practice sessions and clarify skills to be developed. In decision-making drills seen in soccer training sessions (1 v 1, 2 v 2, 2 v 1 etc.) the coach manipulates the size of the playing area. Rink (1993) reported that effective use of this area, permits effective skill instruction and learning. Furthermore, different shape and size of play area and goal setting can change game aspects and objectives (Matsumoto and Takii, 1997). A coach is advised to vary the size of play area to reduce differences between intention (perceptual skill learning) and possible outcomes of practice (Nakayama, 2008), which in turn, could facilitate anticipation of future events (Smeeton *et al.*, 2005).

Interventions associated with perceptual skill learning could be seen as more practical than clinically-based training programmes. Although there have been several field-based studies (Adolphe *et al.*, 1997; Harle and Vickers, 2001; Smeeton *et al.*, 2005), interventions have involved video simulations that recreate players' view of the action. Film sequences were presented to players either in real time or slow motion coupled with the directive to focus on relevant cues. Relationships between key information sources and subsequent responses were highlighted and feedback about correct responses provided (Williams *et al.*, 2003).

Feedback was given via guided discovery, which has been suggested to be a refined discovery method for coaching perceptual skills (Williams *et al.*, 1999). Guided discovery can be used by constraining players to focus attention on more formative areas of a display by instruction or visual cues. This technique was used by Kirlik *et al.* (1996) to compare training methods. Players were guided either to key sources of information through visual enhancement or given explicit rules that specify the relationship between patterns of play and decision-making in American football. Although both groups improved more than a control group, the visual-enhancement group improved more than the explicit-instruction group.

A similar approach was used to improve anticipatory performance for soccer penalty kicks (Williams and Burwitz, 1993) and although the potential of perceptual video training programmes has been stated (Adolphe *et al.*, 1997; Harle and Vickers, 2001; Smeeton *et al.*, 2005), Williams *et al.* (2003) reported various shortcomings in the literature. Failure to use a placebo or a control group in addition to the training group or a retention test suggested further studies were needed to assess usefulness of such intervention programmes. Improvements in performance could be because of conformation bias or increased habituation with the test environment, rather than any meaningful treatment effects. Little is known about how important skills that underpin decision-making performance in soccer players are developed and even less about the extent to which the acquisition of perceptual skills can be facilitated through training and instruction from a constraints-led dynamical approach.

7.1.1 Aim

The aim of this study was two fold: to assess the extent to which decision-making can be trained and retained. Then to investigate the effects of perceptual video training compared with those of a soccer-specific field-based perceptual training programme.

Hypothesis

It is hypothesised that the perceptual and field-based training groups would show an improvement in decision-making performance after the 6-week intervention compared with the control and the placebo groups. Similarly, it was hypothesised that the non-instruction group would acquire the skill slower than the other groups, because of the lack of clear direction during the search process. However, in retention, the additional effort invested in the learning process by the perceptual and field-based groups was anticipated to result in retention benefits compared with the other groups. So, the interest lies in the possible acute and lasting effect of learning in retention.

7.2 Participants and Methods

7.2.1 Participants

With institutional ethics approval, 24 male university-standard soccer players (age mean 20.7, s = 1.4 years; stature 1.74, s = 0.72 m; body mass 74.4, s = 8.6 kg; $\dot{V}O_2$ max 54.4, s = 2.3 $ml \cdot kg^{-1} \cdot min^{-1}$) participated. All players were healthy and trained at least three times per week. Before the administration of any test, participants were screened for existing medical conditions that could be aggravated during the testing procedure. Participants completed an incremental test to volitional exhaustion for the determination of $\dot{V}O_2$ max. The procedure is outlined in chapter 3.2.4.1. Pre-test instructions can be seen in chapter 3.2.1.4.

7.2.2 Experimental Design

Players were divided randomly into one of four groups of 6 participants. These included a control, placebo, perceptual training and a field-based decision-making training group. Tests 1, 2 and 3 consisted of a repeated sprint protocol followed by decision-making trials. Response time, response accuracy and physiological (heart rate, blood lactate and blood glucose) measurements (A, B, C, D, E and F) were taken at specific occasions displayed on the experimental time-line (Figure 7.1). RPE was recorded (measurement B, D and F).

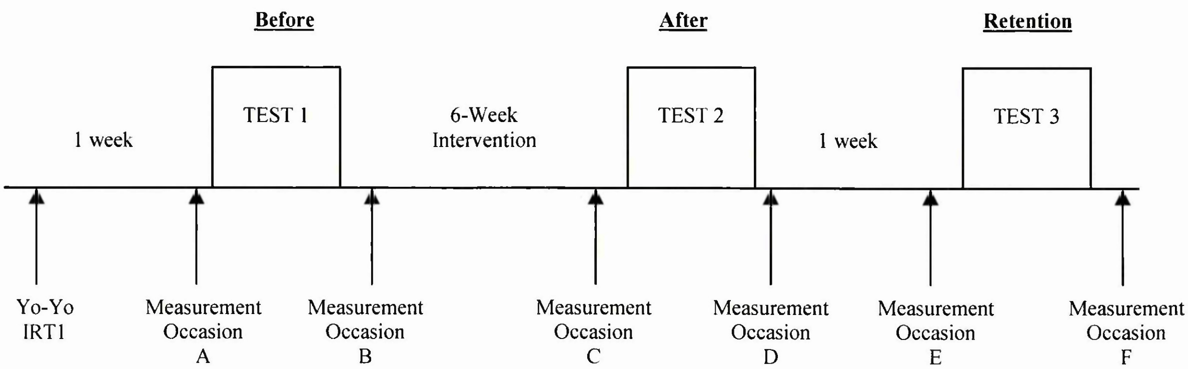


Figure 7.1 Schematic time-line of the experimental design.

7.2.3 Experimental Protocols

Yo-Yo Intermittent Recovery Test Level 1 (YIRT1)

The Yo-Yo Intermittent Recovery Test (Bangsbo, 1996) evaluates a player's ability to repeatedly perform intense exercise and the data was used as a reference for exercise intensity for the field-based decision-making group during the training intervention. This was performed at the start, before the training intervention. The test has been validated and shown to be reproducible in the detailed analysis of the physical capacity of soccer players (Krustrup *et al.*, 2003). The course of the test is presented below (Figure 7.2). All participants were accustomed to the course and practised it during a 5 min warm-up. After a 5-s countdown the test began; the player were required to perform a shuttle that consisted of running back and forth between markers A and B, adjusting their running speed so that they reached each marker in time with the audible signal generated from a cassette tape. On returning to marker A, participants had 5-s to jog around marker C and back to marker A, before the next audible signal sounded and the shuttle between markers A and B was repeated.

This intermittent running pattern remained constant throughout the test. A warning was given when the player did not complete a successful shuttle in the allocated time, the player was requested to step out the next time they do not complete a successful shuttle. The performance measure provided by the test was distance run (m).

The venue for the YIRT1 was the University outdoor Astroturf facility and was conducted on a dry evening before a training session.

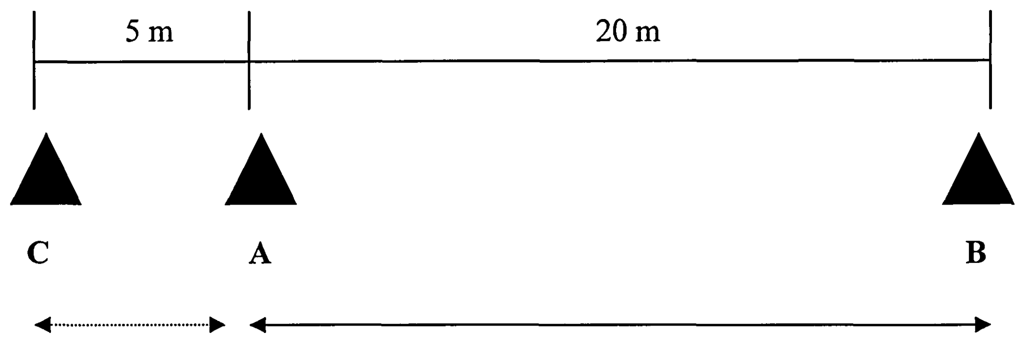


Figure 7.2 Course layout for the Yo-Yo Intermittent recovery test.

A 60-s interval on the cassette tape was timed before each test to verify the speed of the cassette player (X-670, Sony, Japan) the speed of the cassette player was deemed acceptable if the 60-s interval was within ± 1 s. Male top-class soccer players, playing matches at the highest International-standard, had greater performance on the YIRT1 (2420 m) than elite-standard (2190 m) and sub-elite players (2030 m) as well as moderately trained soccer players (1810 m) (Soccerfitness, 2007).

Repeated sprints

The protocol for the repeated sprint test is outlined in chapter 3.2.6.1.

Decision-making task

Participants began with five practice trials followed by ten test trials before the repeated sprint protocol and ten trials after the protocol. The procedure of the decision-making task is outlined in chapter 3.2.5.2.

Training intervention

The control group received no instruction or training; the placebo group watched a 20-min video of soccer match play and were informed that the training tape could have a positive effect on their decision-making performance. This procedure was undertaken to provide an expectancy set for training benefits comparable to that of the perceptual training group. No additional training information was provided.

The venue for the field-based perceptual training sessions was the University Sports Hall indoor facility.

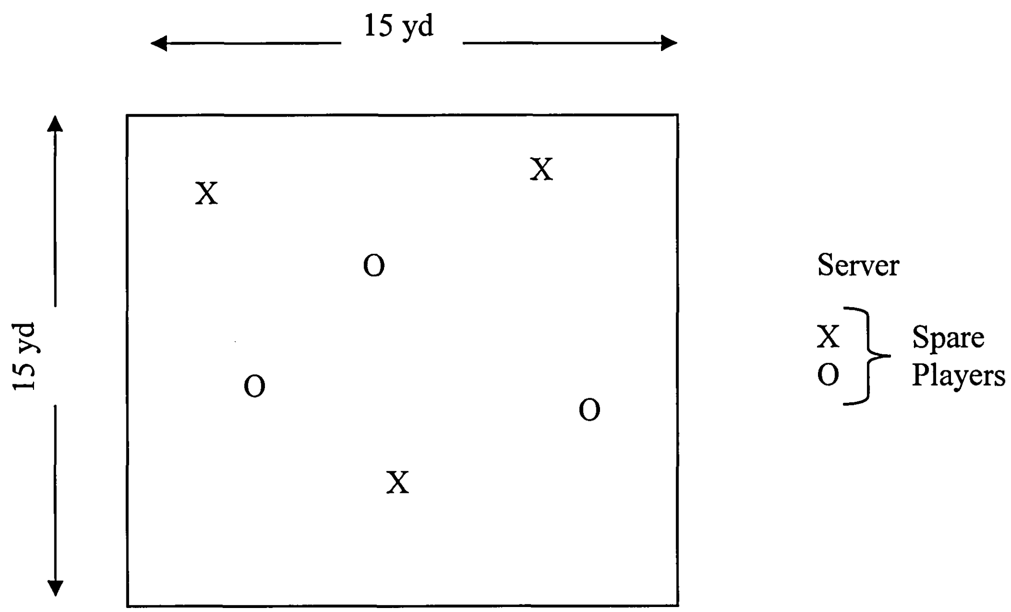


Figure 7.3. Session 1- 3 v 3 Possession.

Markers were used to outline a 15 x 15 yard area (Figure 7.3). Two equal teams of three players (X's and O's) play against each other in an attempt to keep possession of the ball from the other team within the area. An award of one point for the defending team each time they intercepted the ball, tackled an opponent with the ball or forced the attackers to play the ball out of the area. The server (who served the balls in when they went out of the area) on the outside of the area kept play continuous for one min before the teams changed roles, with the attackers becoming defenders and the defending team becoming attackers. Play continued for a further one min followed by a rest period for one min. This enabled the two spare players who were not involved in the first period of the session to change places with one attacking and one defending player. The session continued until every player had equal playing and rest time.

Throughout all of the field-based decision-making drills and during the rest periods, demonstration, instruction and feedback (in the forms of guided discovery and question and answer for no longer than 30 s) on relevant cues and decision-making performance were given on an individual basis to every player (Williams and Burwitz, 1993; Williams and Grant, 1999; Williams, 2003).

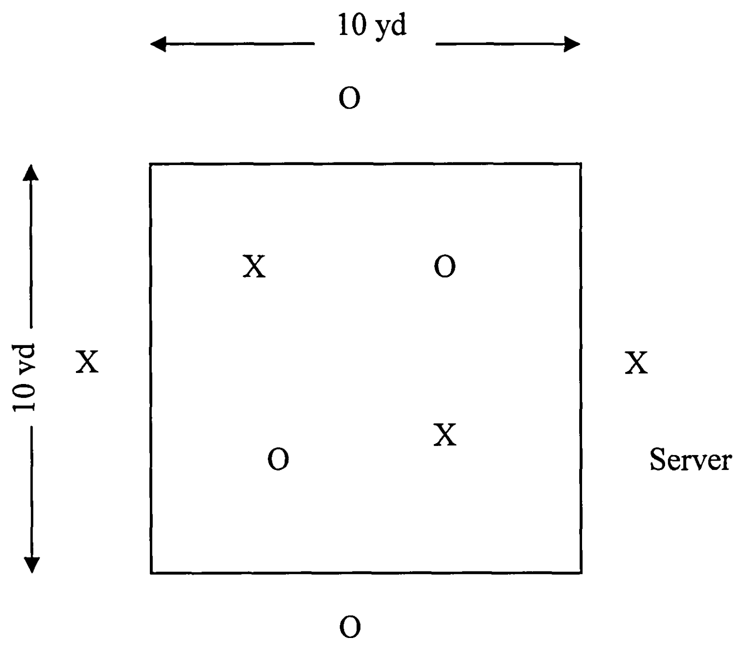


Figure. 7.4 Session two- 2 v 2 Possession.

Markers were used to outline a 10 x 10 yard area (Figure 7.4). Two equal teams of two players (X's and O's) played against each other in an attempt to keep possession of the ball from the other team within the area. An award of one point for the defending team each time they intercepted the ball tackled an opponent with the ball or forced the attackers to play the ball out of the area. The server (who served the balls in when they went out of the area) on the outside of the area kept play continuous for was for one min. Also on the outside are two remaining members of the team, who positioned themselves at opposite sides of the area. The players on the inside of the area can only play with their team member on the outside that are limited to having one touch of the ball. The session continued until every player had equal playing and rest time. Again as in session one, throughout the session and during the rest periods, tuition, instruction and feedback on relevant cues and decision-making performance was given on an individual basis to every player.

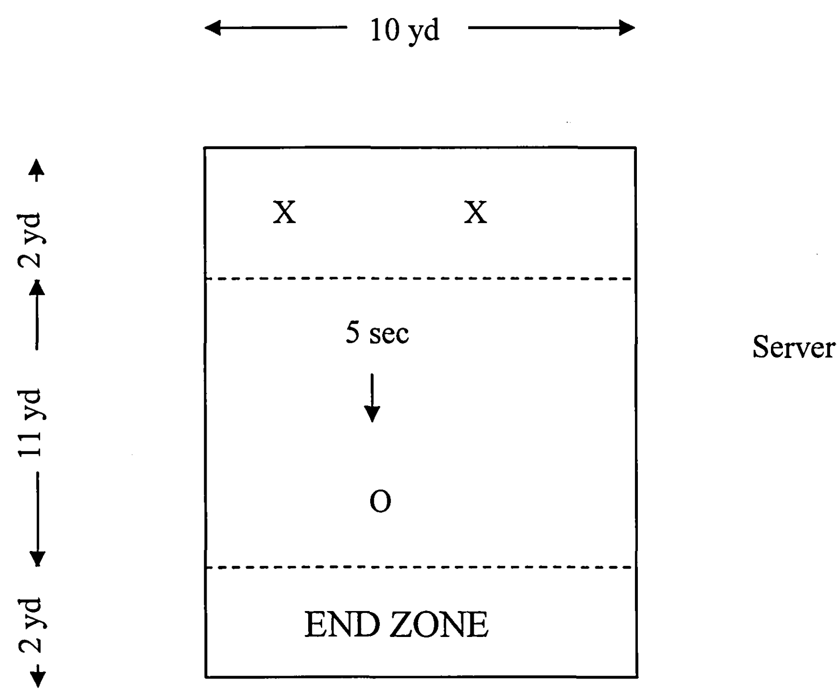


Figure. 7.5 Session three- 2 v 1 and 1 v 1End Zone.

Markers were used to outline a 15 x 10 yard area (Figure 7.5). The X's start behind the two yard start line and the defender (O) start position is in this first session (2v1), two attacking players (X's) are attacking a defender front of the end zone line, which is two yards from the edge of the area. The object of the game is for the X's to get from the start line to the end zone within five seconds after the ball has been played into them from the server. The attackers must make at least one pass in order to achieve their goal, the defender (O) must try to anticipate play and intercept the pass to stop the X's entering the end zone. Play continued and O defended for three attacks before a rest period for one min. The session continued until every player had equal playing (attacking and defending) and rest time. Throughout the session and during the rest periods, tuition, instruction and feedback on relevant cues and decision-making performance were given on an individual basis to every player. After a five min rest period the players started the second session (1 v 1) which involved one attacker X playing against one defender 0. The aim of the game is exactly as in the 2 v 1 session and again tuition, instruction and feedback was given.

Demonstrations was given first in slow motion to show the player how the components of the movement were constructed and then in real time. Clear pre-practice information about the movement pattern, outcome and feedback was provided that was appropriate to the goal. For beginners, feedback was prescriptive (telling them what they did wrong and how to put it right). Error information was given, as it encouraged the player to try new behaviours on their next attempt. If no new behaviours were attempted on the basis of intrinsic feedback alone, then some directed instruction was available. Feedback relating to the movement was made as simple as possible and conveyed important information about goal attainment. This feedback was compatible with the pre-practice information, such that error information was easily attainable to determine goal achievement and effective implementation of the pre-practice information (McMorris, 2004).

Feedback was given after every trial or if an error in decision-making was made, for no longer than 30 s. The feedback delay (the time between performing the skill and receiving feedback) can be negatively affected by interpolated activity (activity taking place during the delay). Post feedback delay (the time between receiving feedback and having another try) can be negatively affected by interpolated activity. If the post-feedback delay is too short, the player does not have time to reconstruct their action plan. Too much feedback can lead to the player becoming coach dependent. Beginners need a lot of feedback, this should be slowly reduced as the player learns the skill – this is known as the fading technique (McMorris, 2004).

They were instructed to look for postural cues, body shape, movement of the ball and the foot the player was using to control and dribble the ball. The reason for this is that it could help the player decide which way the advancing player could go, therefore aiding decision-making. It could be that 'guided discovery' instructional techniques have more practical utility for coaches than implicit learning strategies, particularly in relation to perceptual learning. In the guided discovery approach, players are directed towards relevant areas so that they can discover for themselves the regularities between various postural orientations and eventual response requirements (Smeeton *et al.*, 2005). The presumption is that through a process of learning by 'trial and error' the player becomes progressively attuned to the invariant sources of information that guide anticipation skill (Smeeton *et al.*, 2005). Guided discovery could be more effective than traditional explicit instruction strategies because the player is likely to rely on fewer explicit rules, implying that guided discovery could offer similar advantages to implicit learning. Moreover, the guided discovery approach could encourage players to explore different solutions to the problem at hand, enabling them to abstract important solution principles from multiple exemplars and increasing response flexibility and adaptability (Smeeton *et al.*, 2005).

All three sessions were verified and considered an effective way to demonstrate and practise decision-making in soccer by three UEFA 'A' Licence coaches.

Perceptual training protocol

The perceptual training consisted of participants completing 20-min of perceptual training on an individual basis. Participants viewed a training tape of randomly placed soccer sequences not used in the test film and recently recorded soccer match play. Tuition (question and answer and guided discovery for no longer than 30-s) was provided as to the important information cues underpinning decision-making performance. These information cues were derived from previous studies (Williams and Burwitz, 1993; Chapman, 2001) which included focusing on movement of the ball and body shape of the attacking player. The initial training tape was then repeated, allowing the participant the opportunity to re-assess the linkages between a particular cue and decision made.

Following this instruction, a further 10 soccer sequences were presented and feedback (question and answer) was provided as to the correct decision made. Finally, participants were required to respond to a series of a further 10 soccer sequences and feedback (question and answer and guided discovery, Williams, 2003; Smeeton *et al.*, 2005) as to their decision-making performance was provided.

7.2.4 Data Analysis

Response time and response accuracy were recorded and analysed using the procedures outlined in chapter 3.3. Heart rate was also recorded and analysed using procedures outlined in chapter 3.1.3, together with, blood lactate (chapter 3.1.4), blood glucose (chapter 3.1.4.2) and rate of perceived exertion (chapter 3.1.4.4).

7.2.5 Statistical Analysis

Groups were compared using a two-way multivariate analysis of variance, by groups (control, placebo, perceptual training and field-based perceptual training) and occasion (before and after). Response time and response accuracy were the dependent variables. Significance was set at $p < 0.05$. Effect sizes (d) were also calculated to estimate the magnitude of the difference between groups and were classified according to the system proposed by Cohen (1988) detailed in chapter 3.3.1.1.7.

7.3 Results

7.3.1 Heart rate response performance Yo-Yo IRT1

Heart rate responses for the Yo-Yo IRT1 (Figure 7.6) 189 ± 2 beats·min^{-1} for the control group; 187 ± 6 beats·min^{-1} for the placebo group; 190 ± 6 beats·min^{-1} for the perceptual group and 188 ± 3 beats·min^{-1} for the field-based group.

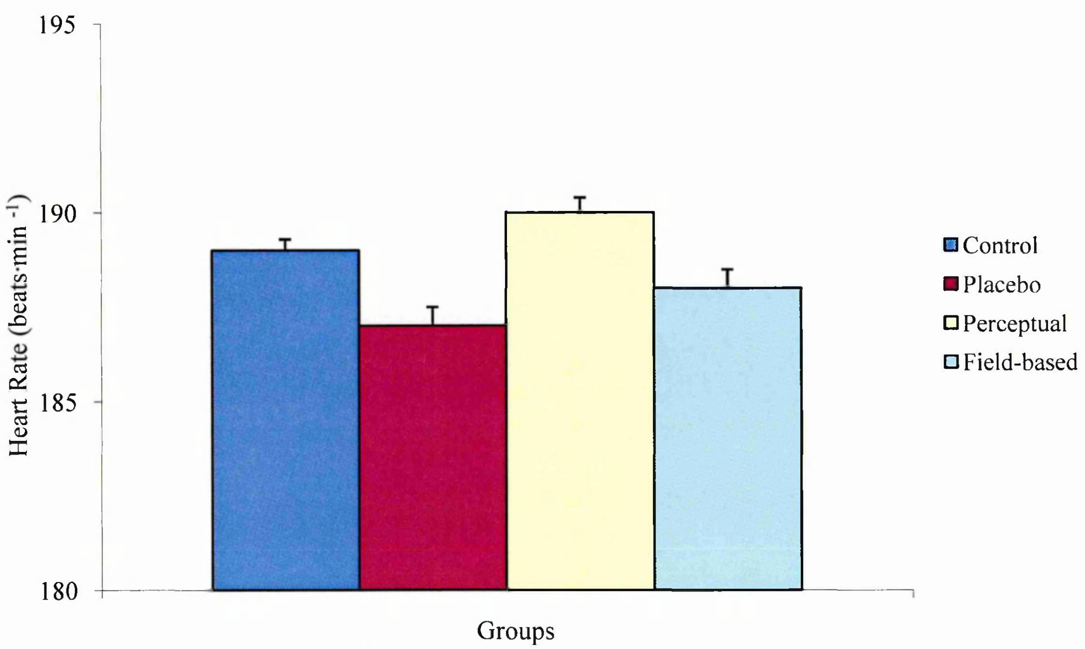


Figure 7.6 Heart rate responses for the Yo-Yo Intermittent Recovery Test Level 1.

Heart rate responses for the field-based training group (Figure 7.7) during the six-week training intervention were; week one 138 ± 4 beats·min^{-1}; week two 142 ± 1 beats·min^{-1}; week three 140 ± 4 beats·min^{-1}; week four 141 ± 2 beats·min^{-1}; week five 142 ± 3 beats·min^{-1} and week six 140 ± 5 beats·min^{-1}.

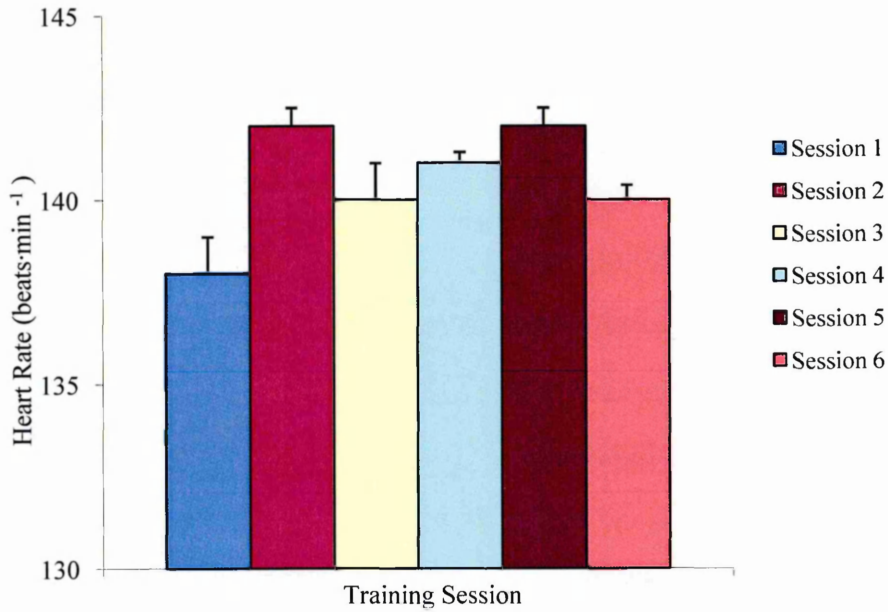


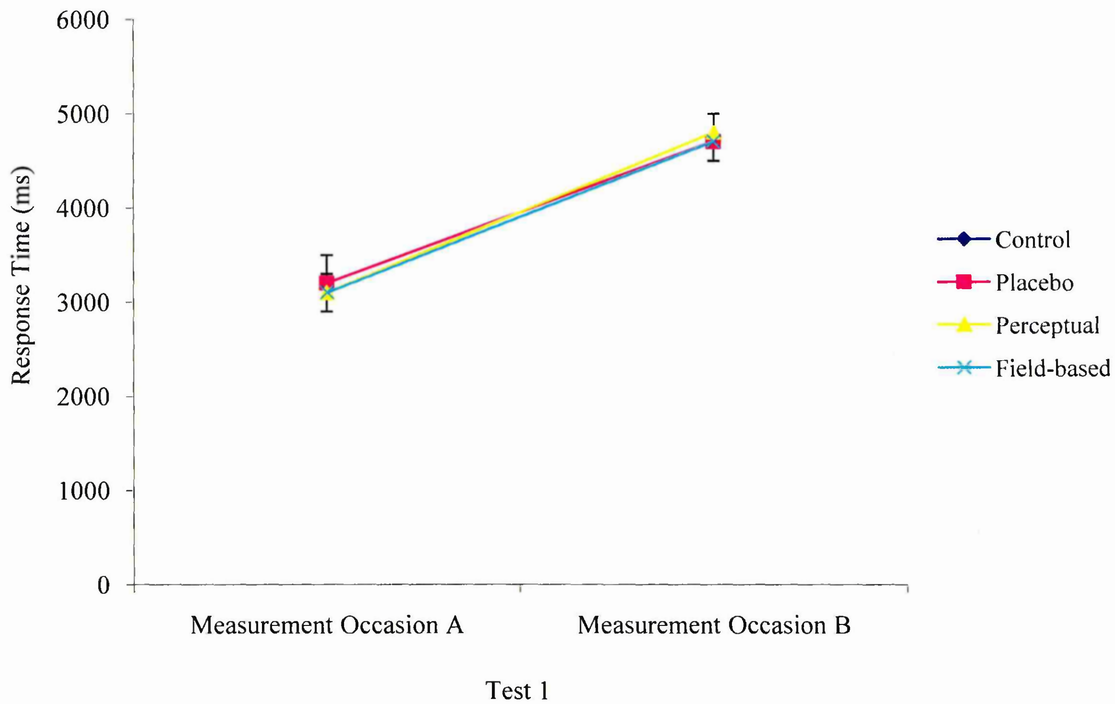
Figure 7.7 Heart rate responses for the field-based training group during the six-week training intervention.

Table 7.1 Anthropometry for the groups mean ± *s*.

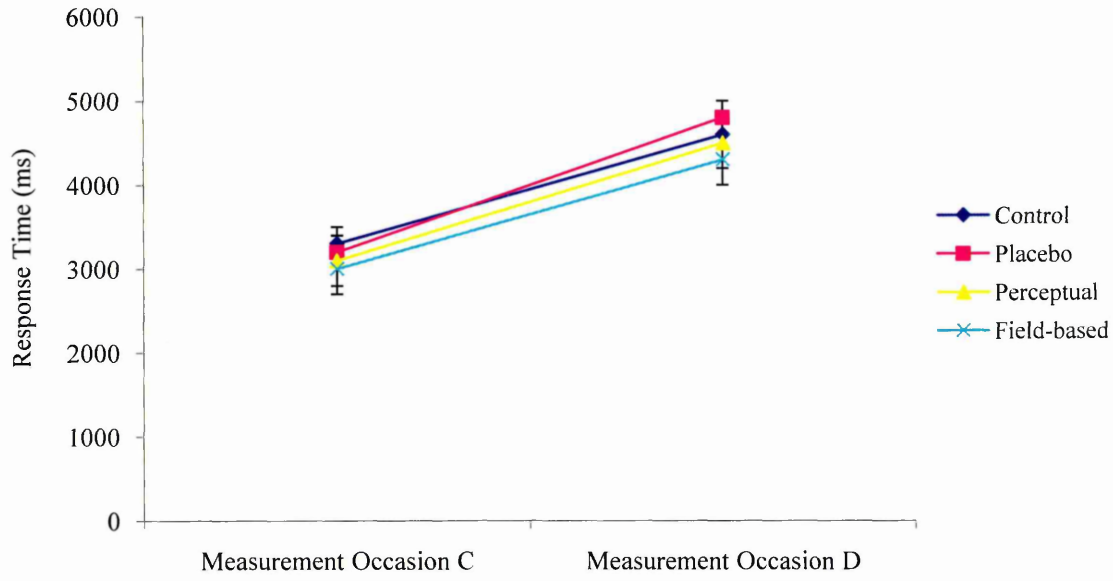
Group	N (6)	Age (years)	Stature (m)	Body mass (kg)	$\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$)
Control		20.3 ± 1.5	1.75 ± 0.7	71.7 ± 8.9	53.9 ± 2.5
Placebo		20.8 ± 1.6	1.72 ± 0.8	72.6 ± 8.6	54.5 ± 2.4
Perceptual		21.1 ± 1.4	1.76 ± 0.5	76.5 ± 6.8	54.3 ± 2.4
Field-based		20.8 ± 1.4	1.73 ± 0.7	73.8 ± 11.2	54.9 ± 2.5

Response Time

(a)

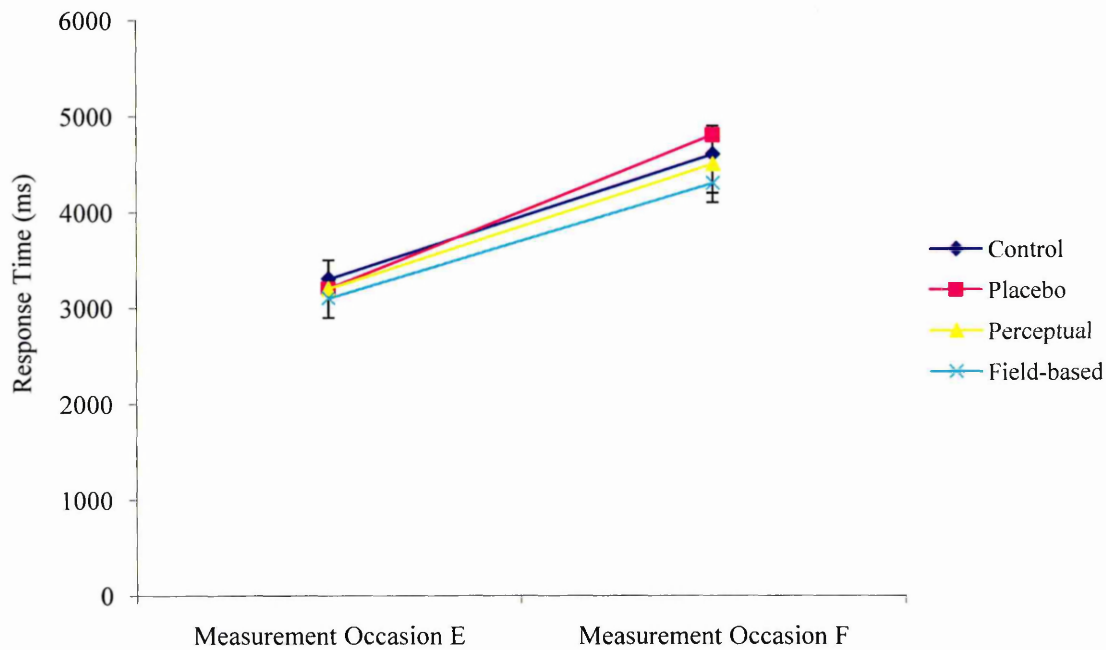


(b)



Test 2

(c)



Test 3

Figure 7.8a Response time in measurement occasions A and B immediately before and after Test 1 (a); measurement occasions C and D immediately before and after Test 2 (b) and measurement occasions E and F immediately before and after Test 3(c).

There was no group x time interaction for response time (F (3, 20) = 0.03, p = 0.994) (Figure 7.8a). There was no main effect for group (F (3, 20) = 0.74, p = 0.266), but there was a main effect for time (F (3, 20) = 15.6, p < 0.05), d = 0.38 (moderate). In measurement occasion A immediately before Test 1 for the control group was 3400 ± 50 ms and in measurement occasion B immediately after Test 1 was 4900 ± 30 ms. Response time for the placebo group was 3500 ± 2 ms and 4700 ± 10 ms, perceptual group 3600 ± 50 ms and 4800 ± 40 ms and the field-based group 3200 ± 60 ms and 4500 ± 80 ms. This illustrates that all the groups were adversely affected by the fatiguing exercise.

There was a group x time interaction for response time (F (3, 20) = 17.5, p < 0.01), d = 0.77 (large) (Figure 7.8b). There was no main effect for group (F (3, 20) = 10.3, p = 0.228), but there was a main effect for time (F (3, 20) = 5.6, p < 0.05), d = 0.42 (moderate). In measurement occasions C and D immediately before and immediately after Test 2 for the control group was 3300 ± 20 ms and measurement occasion D immediately after Test 2 was 4600 ± 40 ms, for the placebo group was 3400 ± 0.30 ms and 4800 ± 10 ms, perceptual group 3200 ± 50 ms and 4500 ± 40 ms and field-based group 3000 ± 50 ms and 4300 ± 20 ms. All the groups were adversely affected by the fatiguing exercise, the placebo group was more affected than the others.

There was a group x time interaction for response time (F (3, 20) = 15.3, p < 0.05), d = 0.44 (moderate) (Figure 7.8c). There was no main effect for group (F (3, 20) = 9.2 (p = 0.391), but there was a main effect for time (F (3, 20) = 5.3, p < 0.05), d = 0.4 (moderate). In measurement occasions E immediately before Test 3 for the control group was 3400 ± 50 ms and measurement occasion F immediately after Test 3 was 4600 ± 60 ms. For the placebo group was 3500 ± 20 ms and 4800 ± 50 ms, perceptual group 3200 ± 40 ms and 4500 ± 50 ms and field-based group 3100 ± 70 ms and 4300 ± 50 ms. A similar pattern emerged for retention, whereby all the groups were adversely affected by the fatiguing exercise. The placebo and perceptual groups being more affected than the others.

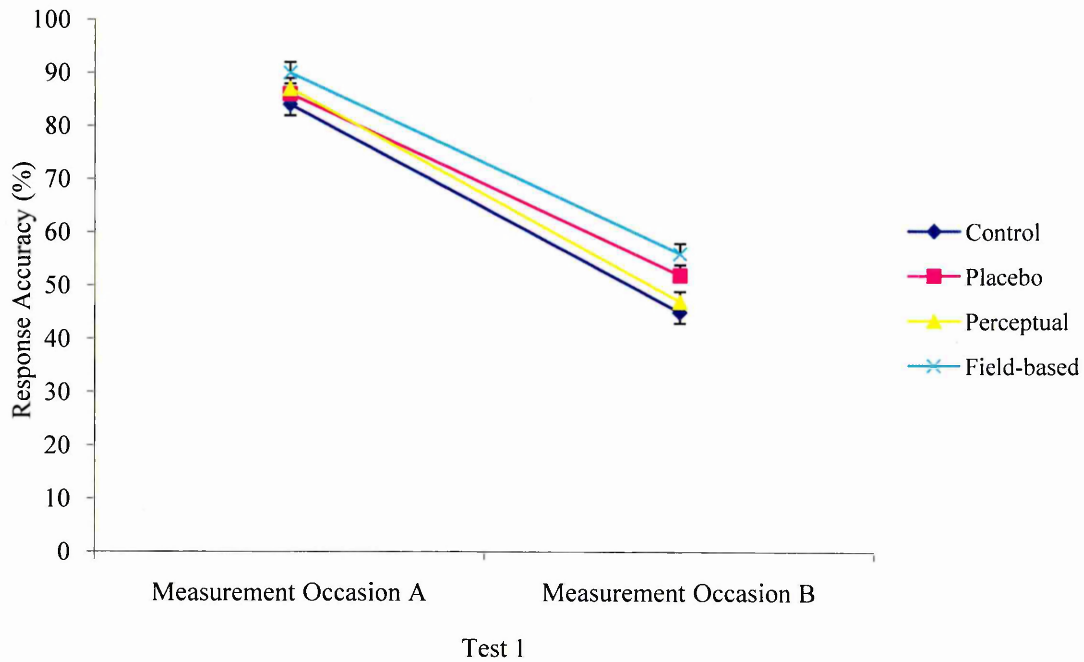
Comparison of response time between the tests

Response time for the field-based group (3000 ± 50 ms and 4300 ± 20 ms) in Test 2 (after the six-week training intervention) differed (F (1, 5) = 15.8, $p < 0.01$), $d = 0.34$ (moderate) from Test 1 (3200 ± 60 ms and 4500 ± 80 ms). Test 3 (3100 ± 70 ms and 4300 ± 50 ms) (retention) also differed from Test 1(3200 ± 60 ms and 4500 ± 80 ms) (F (1, 5) = 21.2, $p < 0.01$), $d = 0.23$ (small). Response time did not differ (F (1, 5) = 0.24, p = 0.631) between Test 2 and Test 3. The comparisons show that the field-based group response performance improved as a result of the training intervention and performance improvement was retained.

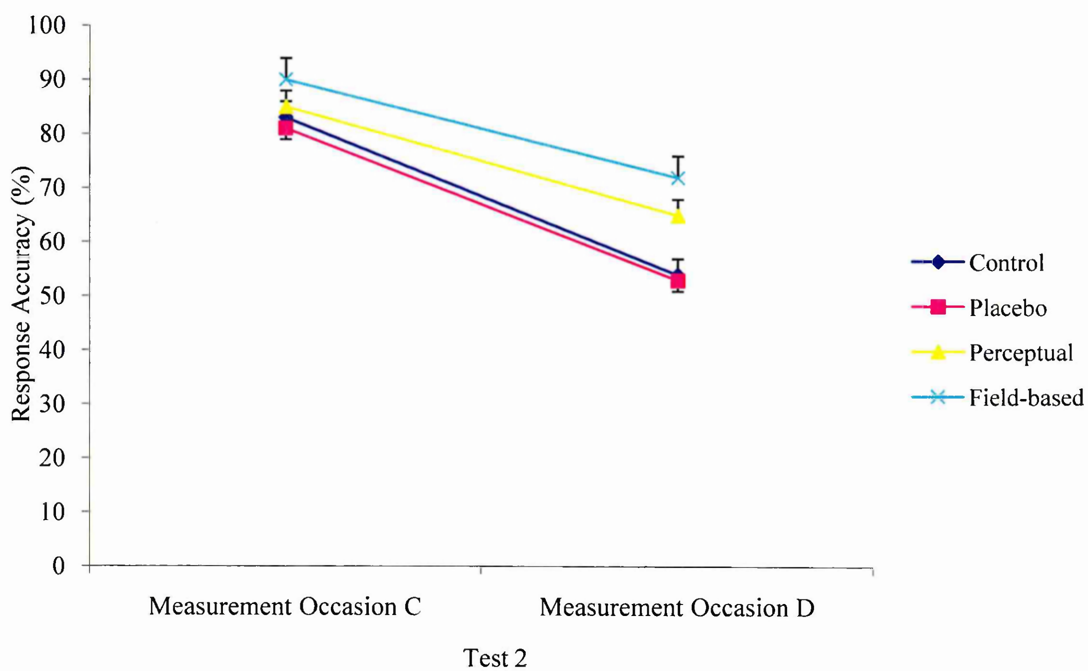
In comparison, response time for the perceptual group (3200 ± 50 ms and 4500 ± 40 ms) in Test 2 differed (F (1, 5) = 16.2, $p < 0.01$), $d = 0.20$ (small) from Test 1 (3600 ± 50 ms and 4800 ± 40 ms). Test 3 (3200 ± 40 ms and 4500 ± 50 ms) (retention) also differed from Test 1(3600 ± 50 ms and 4800 ± 40 ms) (F (1, 5) = 17.9, $p < 0.01$), d = 0.20 (small). Response time did not differ (F (1, 5) = 0.15, $p = 0.699$) between Test 2 and Test 3. As with the field-based group, the perceptual group response performance improved as a result of the training intervention and performance improvement was retained.

Response Accuracy

(a)



(b)



(c)

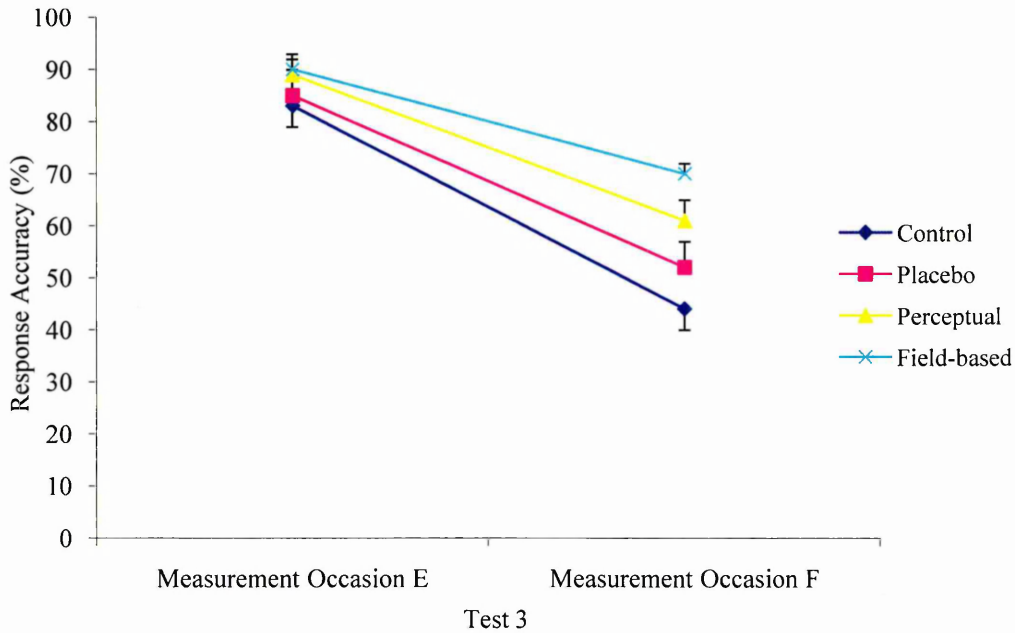


Figure 7.9 Response accuracy in measurement occasions A and B immediately before and after Test 1(a); measurement occasions C and D immediately before and after Test 2 (b) and measurement occasions E and F immediately before and after Test 3 (c).

There was no group x time interaction for response accuracy (F (3, 20) = 0.2, p = 0.713) (Figure 7.9a). There was no main effect for group (F (3, 20) = 0.4, p = 0.249), but there was a main effect for time (F (3, 20) = 2.6, p < 0.01), d = 0.56 (large). In measurement occasion A immediately before Test 1 for the control group was 84 ± 0.8 % and in measurement occasion B immediately after Test 1 was 45 ± 0.9%. For the placebo group before was 86 ± 0.5 % and after was 52 ± 0.8 %, perceptual group 87 ± 0.5 % and 47 ± 0.5% and field-based group 90 ± 0.5 % and 56 ± 0.8%. The results show that all the groups were adversely affected by the fatiguing exercise.

There was no group x time interaction for response accuracy (F (3, 20) = 3.1, p = 0.826) (Figure 7.9b). There was no main effect for group (F (3, 20) = 0.5, p = 0.382), but there was a main effect for time (F (3, 20) = 4.9, p < 0.01), d = 0.48 (moderate). In measurement occasion C immediately before Test 2 for the control group was 83 ± 0.4 % and in measurement occasion D immediately after Test 2 was 54 ± 0.8 %. For the placebo group 81 ± 0.6 % and 53 ± 0.4 %, perceptual group 85 ± 0.4 % and 65 ± 0.6% and field-based group 90 ± 0.4 % and 72 ± 0.5%. The results highlight that all groups were adversely affected by the fatiguing exercise, less so for the perceptual and field-based groups.

There was a group x time interaction for response accuracy (F (3, 20) = 6.7, p < 0.05), d = 0.58 (moderate) (Figure 7.9c). There was no main effect for group (F (3, 20) = 22.4, p = 0.431), but there was a main effect for time (F (3, 20) = 0.22, p < 0.05), d = 0.48 (moderate). In measurement occasion E immediately before Test 3 for the control group was 83 ± 0.5 % and in measurement occasion F immediately after Test 3 was 44 ± 0.5 %. For the placebo group 85 ± 0.5 % and 52 ± 0.7 %, perceptual group 89 ± 0.6 % and 61 ± 0.4 % and field-based group 90 ± 0.5 % and 70 ± 0.3% . Both the perceptual and field-based groups retained their response accuracy performance better than the other groups.

Comparison of response accuracy between the tests

Response accuracy for the field-based group (90 ± 0.4 % and 72 ± 0.5%) in Test 2 (after the six-week training intervention) differed (F (1, 5) = 40.0, p < 0.01), d = 0.88 (large) from Test 1 (90 ± 0.5 % and 56 ± 0.8%). Test 3 (90 ± 0.5 % and 70 ± 0.3%) (Retention) also differed from Test 1 (90 ± 0.5 % and 56 ± 0.8%) (F (1, 5) = 20.8, p < 0.01), d = 0.72 (large). Response accuracy did not differ between Test 2 and Test 3 (F (1, 5) = 7.35, p = 0.422). The comparisons show that the field-based group response performance improved as a result of the training intervention and performance improvement was retained.

In comparison, response accuracy for the perceptual group (85 ± 0.4 % and 65 ± 0.6%) in Test 2 differed (F (1, 5) = 16.0, $p < 0.01$), $d = 0.68$ (large) from Test 1 (87 ± 0.5 % and 47 ± 0.5%). Test 3 (89 ± 0.6 % and 61 ± 0.4 %) (Retention) also differed from Test 1(87 ± 0.5 % and 47 ± 0.5%) (F (1, 5) = 5.0, $p < 0.05$), $d = 0.72$ (large). Response accuracy did not differ (F (1, 5) = 4.3, $p = 0.093$) between Test 2 and Test 3. The perceptual group response performance improved as a result of the training intervention, but response accuracy performance was not retained as well as the field-based group.

Table 7.2 Physiological values in measurement occasions A and B immediately before and after Test 1; measurement occasions C and D immediately before and after Test 2 and measurement occasions E and F immediately before and after Test 3.

(C – Control, Pl – Placebo, Pe – Perceptual, Fb – Field-Based, n = 6 in each group) (mean ± s).

		Measurement Occasion		Measurement Occasion		Measurement Occasion	
		A	B	C	D	E	F
Heart Rate (beats· min^{-1})	C	68 ± 2	192 ± 2	69 ± 1	194 ± 3	70 ± 2	192 ± 3
	Pl	69 ± 2	192 ± 3	70 ± 2	192 ± 2	70 ± 1	193 ± 2
	Pe	70 ± 3	192 ± 3	70 ± 2	193 ± 3	69 ± 2	192 ± 2
	Fb	69 ± 2	193 ± 3	69 ± 2	193 ± 3	70 ± 2	193 ± 2
Blood Lactate (mmol·l^{-1})	C	1.1 ± 0.3	13.0 ± 1.4	1.2 ± 0.4	13.4 ± 0.7	1.3 ± 0.3	13.0 ± 0.8
	Pl	1.4 ± 0.6	13.4 ± 1.1	1.7 ± 0.5	13.5 ± 0.9	1.3 ± 0.4	13.0 ± 0.7
	Pe	1.5 ± 0.5	12.4 ± 1.1	1.5 ± 0.4	12.3 ± 0.7	1.6 ± 0.7	13.0 ± 0.7
	Fb	1.3 ± 0.6	13.0 ± 0.8	1.7 ± 0.6	13.0 ± 0.7	1.7 ± 0.7	13.0 ± 0.8
Blood Glucose (mmol·l^{-1})	C	4.1 ± 0.4	6.5 ± 0.3	4.3 ± 0.4	6.5 ± 0.4	4.3 ± 0.5	6.5 ± 0.3
	Pl	4.2 ± 0.4	6.4 ± 0.3	4.5 ± 0.3	6.5 ± 0.3	4.2 ± 0.2	6.3 ± 0.3
	Pe	4.0 ± 0.2	6.0 ± 0.3	3.8 ± 0.3	6.0 ± 0.5	4.2 ± 0.3	5.7 ± 0.4
	Fb	4.0 ± 0.2	6.0 ± 0.3	4.0 ± 0.5	6.0 ± 0.4	4.0 ± 0.5	6.0 ± 0.3

Heart rate values for the field-based group during the measurement occasions are shown in Table 7.3. There was no group x time interaction for heart rate in measurement occasions A (69 ± 2) and B (193 ± 3), (F (1, 5) = 361.2, p = 0.192). There was no main effect for group (F (1, 5) = 231.0 (p = 0.351), but there was a main effect for time (F (1, 5) = 126.3, p < 0.01), d = 0.67 (large). There was also no group x time interaction in measurements C (69 ± 2) and D (193 ± 3), (F (1, 5) = 389.1, p = 0.233). There was no main effect for group (F (1, 5) = 304.2, p = 0.376), but there was a main effect for time (F (1, 5) = 240.5, p < 0.01), d = 0.71 (large) .There was no group x time interaction for heart rate responses in measurement occasions E (70 ± 2) and F (193 ± 2), (F (1, 5) = 348.9, p = 0.251). There was no main effect for group (F (1, 5) = 234.3, p = 0.298), but there was a main effect for time (F (1, 5) = 246.7, p < 0.01), d = 0.63 (large). The heart rate responses show that the field-based group was adversely affected by the fatiguing exercise.

For the perceptual group, there was no group x time interaction for heart rate in measurement occasions A (70 ± 3) and B (192 ± 3), (F (1, 5) = 353.8, p = 0.175). There was no main effect for group (F (1, 5) = 274.0, p = 0.367), but a main effect for time (F (1, 5) = 245.0, p < 0.01), d = 0.64 (large). There was also no group x time interaction in measurements C (70 ± 2) and D (193 ± 3), (F (1, 5) = 299.1, p = 0.243). There was no main effect for group (F (1, 5) = 337.3, p = 0.349), but there was a main effect for time (F (3, 20) = 264.0, p < 0.05), d = 0.66 (large) .There was no group x time interaction for heart rate responses in measurement occasions E (69 ± 2) and F (192 ± 2), (F (1, 5) = 350.2, p = 0.193). There was no main effect for group (F (1, 5) = 256.2, p = 0.318), but there was a main effect for time (F (1, 5) = 248.3, p < 0.01), d = 0.61(large). The heart rate responses show that just like the field-based group, the perceptual group was adversely affected by the fatiguing exercise.

There was no group x time interaction for blood lactate concentrations for the field-based group in measurement occasions A (1.3 ± 0.6) and B (13.0 ± 0.8), (F (1, 5) = 496.5, p = 0.244). There was no main effect for group (F (1, 5) = 221.3, p = 0.364), but a main effect for time (F (3, 20) = 149.2, p < 0.01), d = 0.73 (large). There was also no group x time interaction in measurements C (1.7 ± 0.6) and D (13.0 ± 0.7), (F (1, 5) = 361.1, p = 0.381). There was no main effect for group (F (1, 5) = 197.5, p = 0.375), but there was a main effect for time (F (1, 5) = 156.8, p < 0.01), d = 0.69 (large) .There was no group x time interaction for blood lactate concentrations in measurement occasions E (1.7 ± 0.7) and F (13.0 ± 0.8), (F (1, 5) = 358.5, p = 0.273). There was no main effect for group (F (1, 5) = 293.6, p = 0.266), but there was a main effect for time (F (1, 5) = 210.1, p < 0.01), d = 0.65 (large). The blood lactate concentrations results show that the field-based group was adversely affected by the fatiguing exercise.

There was no group x time interaction for blood lactate concentrations for the perceptual group in measurement occasions A (1.5 ± 0.5) and B (12.4 ± 1.1), (F (1, 5) = 505.4, p = 0.301). There was no main effect for group (F (1, 5) = 358.4, p = 0.371), but a main effect for time (F (1, 5) = 263.7, p < 0.01), d = 0.68 (large). There was also no group x time interaction in measurements C (1.5 ± 0.4) and D (12.3 ± 0.7), (F (1, 5) = 617.3, p = 0.311). There was no main effect for group (F (1, 5) = 278.7, p = 0.384), but there was a main effect for time (F (1, 5) = 216.5, p < 0.01), d = 0.67 (large) .There was no group x time interaction for blood lactate concentrations in measurement occasions E (1.6 ± 0.7) and F (13.0 ± 0.7), (F (1, 5) = 446.2, p = 0.235). There was no main effect for group (F (1, 5) = 280.4, p = 0.341), but there was a main effect for time (F (1, 5) = 201.5, p < 0.01), d = 0.66 (large). The blood lactate concentrations results show that the perceptual group was adversely affected by the fatiguing exercise.

There was no group x time interaction for blood glucose concentrations for the field-based group in measurement occasions A (4.0 ± 0.2) and B (6.0 ± 0.3), (F (1, 5) = 174.2, p = 0.127). There was no main effect for group (F (1, 5) = 193.1, p = 0.332), but a main effect for time (F (1, 5) = 81.3, p < 0.05), d = 0.41 (moderate). There was also no group x time interaction in measurements C (4.0 ± 0.5) and D (6.0 ± 0.4), (F (1, 5) = 341.1, p = 0.211). There was no main effect for group (F (1, 5) = 235.9, p = 0.247), but there was a main effect for time (F (1, 5) = 141.3, p < 0.01), d = 0.48 (moderate). There was no group x time interaction for blood glucose concentrations in measurement occasions E (4.0 ± 0.5) and F (60.0 ± 0.3), (F (1, 5) = 155.8, p = 0.177). There was no main effect for group (F (1, 5) = 177.9, p = 0.213), but there was a main effect for time (F (1, 5) = 58.8, p < 0.01), d = 0.43 (moderate). The blood glucose concentrations results show that the field-based group was adversely affected by the fatiguing exercise.

There was no group x time interaction for blood glucose concentrations for the perceptual group in measurement occasions A (4.0 ± 0.2) and B (6.0 ± 0.3), (F (1, 5) = 221.1, p = 0.173). There was no main effect for group (F (1, 5) = 293.1, p = 0.370), but a main effect for time (F (1, 5) = 177.2, p < 0.01), d = 0.47 (moderate). There was also no group x time interaction in measurements C (3.8 ± 0.3) and D (6.0 ± 0.5), (F (1, 5) = 381.8, p = 0.139). There was no main effect for group (F (1, 5) = 322.0, p = 0.392), but there was a main effect for time (F (1, 5) = 186.8, p < 0.05), d = 0.45 (moderate) .There was no group x time interaction for blood glucose concentrations in measurement occasions E (4.2 ± 0.3) and F (5.7 ± 0.4), (F (1, 5) = 142.3, p = 0.111). There was no main effect for group (F (1, 5) = 175.2, (p = 0.399), but there was a main effect for time (F (1, 5) = 111.3, p < 0.05), d = 0.48 (moderate). The blood glucose concentrations results show that the perceptual group was adversely affected by the fatiguing exercise.

7.4 Discussion

The aim of this study was to assess the extent to which perceptual skill (decision-making) can be trained and retained, by comparing perceptual video training with a soccer-specific field-based perceptual training programme. Players who underwent field-based training improved their response time ($p < 0.01$), $d = 0.34$ (moderate) and response accuracy ($p < 0.01$), $d = 0.88$ (large) after the six-week training intervention. The perceptual group also improved their response time ($p < 0.01$), $d = 0.20$ (small) and response accuracy ($p < 0.01$), $d = 0.68$ (large) more than the control and placebo groups. This indicated that field-based decision-making training and perceptual training, together with appropriate instruction and feedback can develop and facilitate the acquisition of perceptual skill in soccer. It appears that the groups have acquired the operationalised knowledge to aid anticipation. The players would have possessed a degree of structured declarative knowledge that could act to support further knowledge acquisition, without the need for explicit instruction to provide such a framework (Chase and Ericsson, 1982).

The lack of difference between the perceptual and field-based perceptual training groups in terms of response time and response accuracy could be associated with the relatively small sample size per group and associated with the lack of statistical power. However, because differences were observed during acquisition it is not possible to ascertain the extent to which a larger sample size would yield group differences in retention.

There was no evidence that increased response accuracy was associated with longer response time between groups during the tests. Improvements as a consequence of the training interventions for the perceptual and field-based groups for response time and response accuracy, which supports the conclusion that improved response time was not achieved at the expense of response accuracy, therefore, eliminating the possibility of speed-accuracy trade-off.

The change in performance implies that these are improvements rather than a result of increased test habituation. The positive effects of the field-based decision-making training drills coupled with methods of instruction and feedback showed greater improvements than the perceptual training group and extend previous attempts to train perceptual skill in sport by Williams *et al.* (2003) and Smeeton *et al.* (2005). The soccer-specific field-based training enabled players to improve their technique to search for relevant postural cues and to respond quickly and accurately in soccer. These findings are supported by a previous study (Williams and Burwitz, 1993) involving training of perceptual skill in soccer. Furthermore, it appears that some degree of guidance is helpful in facilitating more rapid skill learning during early acquisition (Mayer, 2004). In contrast, there were no improvements in mean response time or response accuracy before and after the six-week intervention for the placebo or control groups, which support the practical utility of perceptual training programmes.

Furthermore, controlling decision-making training conditions is also important to players' learning. Pitch sizes for example were constrained, 15 x 15 yd for the 3 v 3 possession session; 10 x 10 yd for the 2 v 2 possession session and 10 x 15 yd for the 2 v 1 and 1 v 1 end zone session (which also included time as a constraint). Davids *et al.* (2003) indicated that decision-making training under random conditions (during which both the feed from the server and targets are changed unpredictably) could result in a form of experimentation on the part of the player that would assist their search for optimal co-ordination patterns in the constraints. The ability of the coach to manipulate key constraints in an imaginative but functional way is seen as a fundamental principle toward creating an effective learning environment and one that is central to further task development (Davids *et al.*, 2005).

Task solutions emerge from the time when the player first perceives relevant information for action to a point after which information about action (movement effect feedback) has been received. With the linking of information for action and action for information between player and environment, perception-action coupling emerge with practice and form the principal basis for structuring progressive task development training sessions that simulate match play (Davids *et al.*, 2005).

Wulf *et al.* (2002) argued that in practice, instruction and feedback from the coach are often provided in a way that induces an internal focus of attention players. Focus of attention in soccer relates to players' attention either to limb or body movements (internal-focus on movement dynamics) or on the effects of a motor pattern on the environment (an external focus), opposition player movement and ball trajectory.

However, this study has provided evidence that the combination of guiding player's attention to focus on internal and external movement dynamics is an effective way of learning for the perceptual and field-based groups. Demonstration, instruction and feedback (in the form of guided discovery and question and answer for no longer than 30 s) on relevant cues and decision-making performance were given on an individual basis, focusing on opposition player's body shape in possession of the ball and co-coordinated movement patterns to perceive and execute the correct decision, which is an important determinant of soccer performance.

Furthermore, the findings indicated that continued field-based decision-making drills, guided and discovery learning could afford the player more opportunity to explore other important external sources of information and it has been shown that this type of learning could improve players' decision-making performance. Accordingly, it would be advisable to administer decision-making training while players are under high-intensity so as to replicate the intermittent demands of match play.

Physiological responses (heart rate, blood lactate and blood glucose) for the field-based and perceptual groups revealed that the physiological strain imposed on the players was similar to the values reported in soccer literature. The physiological strain was further supported by RPE values in measurement occasion B after Test 1 of 18.5 ± 0.7; in measurement occasion D 18.6 ± 0.5 and during measurement occasion F was 18.2 ± 0.6, demonstrating that 10 x 10-s repeated sprints with a 15-s recovery period had a detrimental effect on decision-making performance of soccer players.

It is suggested that when perceptual skills are learned by using instruction used in this study, players reinvest this knowledge back into performance under conditions of physiological stress or fatigue, causing players to revert toward the more conscious control strategies to characterise early performance (Anderson, 1982).

Training players to improve decision-making while fatigued could be advantageous to coaches (improved decision-making at crucial periods of matches, before half-time and towards the end of a match) as this technique would lay the foundations and principles associated with successful performance over the course of a season. An ideal time for decision-making training would be during pre-season where 5 – 6 weeks are designated to preparing players physically and mentally for the season ahead and where co-ordinated movement patterns can evolve. Improvements could be made over a longer period instead of a 'quick fix' 2 -3 weeks training period during the season when training time could be limited because of either fixture congestion or bad weather resulting in waterlogged or icy pitches. If this was the case, then video perceptual training would be an advantage, as perceptual training could continue inside the training facility where improvements can be made and retained.

Retaining information of the perceptual skill learned will also benefit the coaching staff as time allocated to decision-making training could be limited throughout the season, particularly when teams are playing twice a week. Test 3 (retention) highlighted that response time for the field-based training group did not differ (p = 0.631) from Test 2 nor did the perceptual group (p = 0.699). The same trend was noted for response accuracy for the field-based training group did not differ from Test 2 (p = 0.422), the perceptual group did not differ either (p = 0.093); suggesting that players retained their acquired decision-making skills and were consistently more accurate than the other groups, albeit after only 1 week.

The extent to which perceptual performance continues to improve as the amount and frequency of decision-making training increases has not been widely studied (Williams and Grant, 1999). This is because it would difficult to quantify and depend on factors such as, the sport studied and standard of participants. It is suggested that perceptual training effects accrue immediately and extending practice beyond this initial stage has limited benefits. The law of practice propose that improvements are likely to be quick at first and slower as performance plateaus (Williams and Grant, 1999). Therefore, managers and coaches would have to consider how to structure perceptual training into the weekly practice schedule, so retention could continue over the course of a season and assessments made over a longer period (4 – 6 weeks), not after only one week (as weekly testing is not always logistically possible at soccer clubs). Contemporary motor learning research on variability and specificity of practice, contextual interference and practice distribution has not been applied to perceptual training from a dynamical perspective.

Improvement in decision-making performance is important to managers and coaches in understanding what training sessions can be used to improve decision-making capabilities of their players that yield greater results in the shortest possible time. It appears that some degree of guidance is needed to facilitate skill learning during early acquisition Mayer (2004) and continued guidance to retain skill acquisition.

7.5 Conclusion

The results suggest that soccer player's decision-making skills can be trained by using field-based decision-making drills, guided discovery and feedback. Furthermore, perceptual video training appears to aid the development of important knowledge structures in decision-making during soccer, but greater improvements and retention were demonstrated by the field-based decision-making group, indicating that once perceptual skill has been acquired and trained, players were able to retain this information, for at least 1 week. However, it would be valuable to see if the improvements in perceptual skill are maintained over a prolonged period of time and the extent to which perceptual processes are more robust to physiological stresses. Guided discovery learning could be the most appropriate method of instruction in training and is considered an effective method of instruction to withstand physiological stress and or mechanisms of fatigue during decision-making, as shown with improvements in decision-making performance of the perceptual and field-based groups after the intervention. Further research is required using larger sample groups to explore the relative effectiveness of this instructional technique in facilitating the acquisition of perceptual skill.

CHAPTER 8

Overall Discussion

8.1 Aim

The aim of this thesis was to identify physiological factors associated with decision-making performance of soccer players. If a decrement in decision-making was observed, a second aim was to assess the extent to which soccer players' decision-making capability could be improved and trained.

8.2 Methodological investigations

The initial study of this thesis investigated the reliability of outcome measures of a decision-making protocol. Questionable reliability in several studies instigated further investigation in which a study was conducted to measure decision-making in soccer players using a soccer-specific protocol to assess decision-making and determine the reproducibility of the protocol's measures.

Statistical analysis for reproducibility of measurement consisted of Intraclass Correlation Coefficient (ICC) with values above 0.90 considered high, 0.80 - 0.89 moderate and 0.70 to 0.79 acceptable, test-retest coefficient of variation (CV) was calculated together with Bland and Altman limits of agreement (LOA), Technical Error of Measurement (TEM) both for absolute and relative values and least product regression (LPR) were also determined. The results showed that LOA indicated that the data was not reliable, even though Hopkins (2000) suggested that, the concept of 95% confidence limits for the difference between two measurements narrows the focus of measurement error to one application: decision-making in a test-retest situation. This appears to be the only situation where limits of agreement would have an advantage over typical error, If 95% confidence limits were appropriate for decisions affecting an individual. Systematic change is a learning effect or training effect, which could account for the change in performance in response accuracy. The players performed the second trial better than the first, because they benefitted from the experience of the first trial. A possible reason for improvement, could depend on effort, motivation or because they want to improve. The ICC, CV, TEM and LPR matrices were reproducible in the test re-test, suggesting that the decision-making protocol was reliable. However, Atkinson and Nevill (1998) suggested that ICC should be interpreted with caution. This is a difficult notion to promote given the popularity of judging a high correlation as indicating adequate reliability. An implication of the poor interpretation of correlation analyses is that equipment used routinely in sport and exercise science could have been erroneously concluded as being sufficiently reliable. It would be sensible for researchers to reappraise the results of test re-test correlations and supplement this with the application of absolute indicators of reliability.

A practical recommendation for future reliability studies, is that they include an examination of how measurement error relates to the magnitude of the measured variables, irrespective of which type of absolute reliability statistic is used (e.g. TEM, CV, LOA) (Atkinson and Nevill, 1998).

8.3 Effects of high-intensity intermittent exercise on decision-making

The physiological effects of exercise on perceptual/cognitive performance have been studied, but outcomes are contradictory (Lemmink and Visscher, 2005). An important reason is the diversity of methods chosen with regard to the physical exercise mode and protocol, physical fitness, or sport experience of the players and nature and complexity of the perceptual task (Brisswalter *et al.*, 2002). Etnier, *et al.*, (1997) concluded that the overall effect of exercise on a perceptual task was small and positive, but more studies needed to be conducted with the emphasis on experimental rigor. McMorris and Graydon (2000) stated that incremental exercise had no effect on the accuracy of perceptual/cognitive performance. Tomporowski (2003) grouped empirical research studies based on the type of exercise protocol and evaluated findings in terms of a cognitive-energetic model of human information processing. He concluded that aerobic exercise had selective effects on specific aspects of information processing, but no studies investigated the effects high-intensity intermittent could have on decision-making seen in soccer. So, this study attempted to investigate the effects and its association with decision-making, furthermore, increasing existing knowledge in this area.

Success in soccer could be determined by players' physiological profile coupled with their perceptual skills (decision-making), performing these skills whilst under physiological stress or fatigue could be what separates players that play at a higher-standard.

The soccer-specific intermittent treadmill protocol (Drust *et al.*, 2000) used in chapter five was successful in replicating physiological intensities seen in match play. The protocol reinforced the intermittent aspects of soccer that was characterized by players' ability to repeatedly perform high-intensity intermittent exercise. The energy demands during intense periods were reflected by increases in players' physiological responses in heart rate, blood lactate and blood glucose concentrations. A decline in decision-making performance (response time and response accuracy) was recorded and probably attributed to physiological stress, metabolic or central fatigue, however, it was difficult to ascertain the precise mechanisms involved. Drust *et al.* (2000) concluded that the soccer-specific intermittent treadmill protocol did not increase the demands placed on the aerobic energy system, but results indicated that the anaerobic energy provision is more important during high-intensity intermittent exercise, but the role of aerobic energy provision is important in the recovery during repeated bouts of high-intensity exercise.

Therefore, Chapter six assessed the influence of repeated sprint and sprint recovery duration on player's decision-making performance. During recovery, $\dot{V}O_2$ remains elevated to restore homeostasis via processes such as the replenishment of tissue oxygen stores, the resynthesis of PCr, the metabolism of lactate and the removal of accumulated intracellular inorganic phosphate (Pi). If recovery periods are relatively short, $\dot{V}O_2$ remains elevated prior to subsequent sprints and the aerobic contribution to ATP resynthesis increases (Glaister, 2005). However, if the duration of the recovery periods is insufficient to restore the metabolic environment to resting conditions, repeated sprints could be compromised. Although the precise mechanisms of fatigue during repeated sprints are elucidate, evidence suggests to a lack of available PCr and the accumulation of intracellular Pi as the probable causes. Moreover, the fact that both PCr resynthesis and the removal of accumulated intracellular Pi are oxygen-dependent processes has led several authors to propose a link between aerobic fitness and fatigue during repeated sprints. However, whilst the theoretical basis for such a relationship is compelling, corroborative research is far from substantive (Glaister, 2005). Limitations in analytical techniques combined with methodological differences between studies have left many issues regarding the physiological response to repeated sprint exercise unresolved.

The results indicated that repeated sprints had a detrimental effect on players' decision-making performance because of the increased physiological stresses imposed on them. Physiological mechanisms responsible could alter during different periods of intense exercise (Mohr *et al.*, 2005). Elevated blood lactate concentrations reflected the production of lactate in contracting muscles but such values should be interpreted carefully (Krustrup *et al.*, 2006). Mechanisms of fatigue and factors that regulate it require further investigation. A greater understanding of mechanisms of fatigue and physiological responses to repeated sprint performance and a decrement in decision-making performance would also assist players and coaches to manage its effects and conduct training sessions to improve player's decision-making performance.

8.4 Training perceptual skill in soccer

Soccer performance is dependent on a multitude of factors. Of these, technical skill and physical capacity of players are known to exert a major influence on performance. If both these capacities could be improved and trained simultaneously using soccer-specific drills, it would be an effective use of training time and physical conditioning (Little and Williams, 2007).

Chapter seven investigated the extent to which perceptual skill can be trained using perceptual video simulation or soccer-specific field-based decision-making drills. Player's decision-making skills can be trained using field-based decision-making drills, guided discovery and feedback; this was illustrated with improved response time and response accuracy after the intervention for the field-based group. Constraints-led field-based decision-making training was shown to be an effective way to underpin important perceptual skills necessary for improved soccer performance.

The coach is fundamental in constraints-led approach. Having identified constraints on players, the coach should design progressive changes to these constraints and consider implementing further (environmental and individual) constraints to facilitate learning (Davids *et al*., 2005). It is possible to focus more on perception (detecting action possibilities) or on action (execution of action possibilities), but it would be more important to link both aspects. Furthermore, the coach should provide formation of new links between perception and action (creating new action possibilities) but maintain perception-action coupling and set different priorities according to player abilities (Araújo *et al*., 2003).

Theoretical analysis of skill acquisition in soccer from a dynamical perspective is an emergent process under constraint and is relatively new. Manipulation of variables such as practice structure and organisation to assist the learning process is fundamental to understanding the emergence of skilled behaviour. Moreover, providing feedback to players to focus on functional solutions would provide opportunities to constrain players' search for emergent task solutions during learning (Davids *et al*., 2005).

Although the model of perceptual training proposed in this study offers much potential for enhancing decision-making performance in soccer, a number of issues need to be addressed. First, eye movement data was not collected, so therefore, it is not possible to determine the extent to which improvements in decision-making performance for the two perceptual training groups was reflected by the expected changes in visual search behaviour. Few researchers have examined the extent to which, or how, visual search behaviours change during perceptual skill acquisition and consequently this is an area that warrants further investigation (Williams, 2002).

Another issue is the extent to which other perceptual skills can also be developed by using a combination of video simulation and instruction. There is evidence to suggest that pattern recognition skill can be improved through repeated exposure to a variety of related action sequences (Wilkinson, 1992). A suggestion is that exposure to specific patterns of play in soccer, for example, results in the development of specialised receptors or detectors through a process termed imprinting (Goldstone, 1998). These detectors are proposed to develop and strengthen with exposure the stimulus or stimuli resulting in increased response time, increased response accuracy and general fluency with which stimuli are processed.

Lee *et al.* (2001) questioned how practice should be structured for effective learning, which has been a topical area of debate in perceptual skill literature. The general consensus is that variability of practice and high contextual interference practice conditions are beneficial for skill acquisition. In contrast, few researchers have examined the extent to which similar principles apply in the learning of perceptual and cognitive skills (De Croock *et al.*, 1998). Similarly, Williams and Grant (1999) suggested that the optimal frequency and duration of perceptual training sessions has yet to be determined and that the average length of a session has ranged from 15 min to 2 hrs, whereas the frequency has varied from a single session to a 6-week training period. It is unclear as to the extent to which perceptual skill continues to improve with training and practice, or is there an optimal point beyond which the additional training benefits are minimal (Williams *et al.*, 2002). There is also controversy as to the extent to which perceptual training programmes should be used with experts, intermediates or novices. The answer could depend on the nature and difficulty of the skills being coached as well as the type of simulate on used (Alessi, 1988). However, some degree of guidance could be obtained from the extensive literature pertaining to the acquisition of perceptual skills, furthermore, concerted efforts involving systematic programmes of research are necessary before this area of study can provide a meaningful contribution to improvements in perceptual skill (Williams *et al.*, 2002).

8.5 Limitations

1. In chapter four, precision and accuracy of timing equipment could be improved with a direct link to a computer system (Movement Science Reaction Timer, 1993; Clinical and Biomedical Engineering, Royal Liverpool University Hospital) used by Williams *et al.* (2002). Investigation was made into purchasing the equipment, but cost was a deciding factor.

2. Players were required to stand still on the response pads prior to the presentation of soccer sequences and movement selection. This procedure was not soccer-specific and does not take into account the dynamic nature of soccer. However, standardizing the decision-making protocol in this way enabled measures to be consistently recorded.

3. Investigating other factors of physiological strain during high-intensity intermittent exercise and its association with possible mechanisms of fatigue, could have provided further meaningful results in the decline in physiological performance and subsequently a decrement in player' decision-making capabilities. But because of cost implications, this was not possible.

4. In chapter seven, bias related to feedback and instruction could have been negated, with feedback and instruction being administered by coaches not

connected with the study and not from the principal investigator. Unfortunately, highly qualified coaches were not able to fully commit their time to the study.

5. In chapter seven, assessing improvements in perceptual skill via retention tests, could be easier for coaches and yield more meaningful results if the tests were conducted after a longer period (4 – 6 weeks) and not after one week.

8.6 Future directions

The model of perceptual training proposed in this thesis offers potential for advancing existing knowledge regarding decision-making performance in soccer. Issues concerning visual search and transfer back into soccer would provide managers and coaches meaningful results, improving on previous research. Little research (Williams, 2002) have examined the extent to which, or how visual search behavior is affected during skill acquisition, but no studies have investigated the impact visual search has on soccer player' decision-making capabilities after high-intensity intermittent exercise. The use of a suitable transfer test could be incorporated into future studies, examining the extent decision-making training facilitated performance back into soccer. Designing and implementing a measure of transfer would be essential to managers and coaches as an indication of the extent to which decision-making training was effective or the possibility of modifying and improving their training sessions to assist player improvement.

CHAPTER 9

Conclusions

The findings of this thesis suggest that players' decision-making can be trained using a soccer-specific field-based training programme. However, further research is required to determine the extent to which players' decision-making capabilities can be transferred to soccer match play. The specific conclusions drawn from this thesis are:

1. Measures from the decision-making protocol were reproducible and could be reliably and accurately used to measure decision-making in soccer.

2. Physiological responses to high-intensity intermittent exercise indicated that player's decision-making performance were impaired as a consequence of high-intensity exercise.

3. 10 x 10-s repeated sprints with a 15-s recovery period had a markedly detrimental effect on decision-making performance.

4. Soccer players' decision-making can be trained using a soccer-specific field-based decision-making programme.

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Appendix 1

BASES Abstract 2007

Effects of high-intensity intermittent exercise on soccer-specific decision-making

Performance in soccer is determined by players' physiological, technical, tactical, and psychological characteristics (Bangsbo, 1994: *Acta Physiologica Scandinavica, 151*(suppl 619), 1 – 155). These factors influence each other and the psychological capability of a player could be impaired if their physiological characteristics cannot meet the needs of the game. Therefore, the aim of this study was to investigate the effects of high-intensity intermittent exercise on decision-making in soccer.

With institutional ethics approval, 15 male university-standard soccer players (mean age 21.2,s=1.6 years; stature 1.6, s=0.21 m; body mass 73.1,s=6.6 kg; $\dot{V}O_2$ max 55.2, s=4.1 $ml.kg^{-1}.min^{-1}$) participated and performed an experimental and control trial in random order. In the experimental trial, a soccer-specific decision-making task was performed .before and after a high-intensity intermittent treadmill protocol (Drust *et al.*, 2000: Journal of Sports Sciences, *18*, 885 – 892), whereas in the control trial the same decision-making task was performed but separated by 45 min of inactivity. For the decision-making task, participants viewed 10 filmed soccer sequences projected onto a mounted screen (2.563 m) that provided realistic life-sized images of random 3-on-3, 2-on-1, and 1-on-1 match situations. Players were required to respond as quickly and as accurately as possible by stepping right, left, forward or backwards on response pads to simulate an interception of a pass. Speed (s) and accuracy of decision (correct or incorrect) were recorded.

After verifying underlying assumptions such as normal distribution and homogeneity of variances, means were compared using a fully repeated measures factorial analysis of variance [time (pre-test vs. post-test) vs. condition (control trial vs. experimental trial)]. Statistical significance was set at $P \leq 0.05$. The results are illustrated in Table I. Response time was slower in the experimental trial between groups after the protocol, and response accuracy also differed between groups as a consequence of the high-intensity intermittent protocol. The results suggest that high-intensity intermittent exercise has a detrimental effect on decision-making in soccer. Interventions should be designed that enable players to delay the onset of fatigue and manage its effects.

Table I. Response time and accuracy before and after performance of the high-intensity protocol. Values are mean ± s, n =15.

Measure	Group	Before	After	P	Effect size
Response time (s)	Experimental	3.39 ± 0.75	5.93 ± 0.74	0.00	0.91
	Control	4.72 ± 1.28	4. 85 ± 0.85	0.56	0.01
Accuracy (%)	Experimental	84 ± 5	50 ± 7	0.00	0.95
	Control	82 ± 4	82 ± 5	0.47	0.00

Appendix 2

Informed Consent

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

INFORMED CONSENT FORM	
TITLE OF PROJECT: Effects of perceptual training on decision-making in soccer	
The participant should complete the whole of this sheet himself/herself	
Have you read the Participant Information Sheet?	YES/NO
Have you had an opportunity to ask questions and discuss this study?	YES/NO
Have you received satisfactory answers to all of your questions?	YES/NO
Have you received enough information about the study?	YES/NO
To whom have you spoken? .... Do you understand that you are free to withdraw from the study: • at any time • without having to give a reason for withdrawing • and without affecting your future medical care	YES/NO
Have you had sufficient time to consider the nature of this project?	YES/NO
Do you agree to take part in this study?	YES/NO

Signed .... Date ....

(NAME IN BLOCK LETTERS)..

Signature of Parent / Guardian in the case of a minor

....

PTO

FOR USE WHEN STILL OR MOVING IMAGES WILL BE RECORDED

Consent to scientific illustration

I hereby confirm that I give consent for photographic and/or videotape and sound recordings (the 'material') to be made of me. I confirm that the purpose for which the material would be used has been explained to me in terms which I have understood and I agree to the use of the material in such circumstances. I understand that if the material is required for use in any other way than that explained to me then my consent to this will be specifically sought.

1. I understand that the material will form part of my confidential records and has value in scientific assessment and I agree to this use of the material.

Signed.. Date...

Signature of Parent / Guardian in the case of a minor

....

2. I understand the material has value in teaching and I consent to the material being shown to appropriate professional staff for the purpose of education, staff training and professional development.

Signed.. Date...

Signature of Parent / Guardian in the case of a minor

....

I hereby give consent for the photographic recording made of me on...................... to be published in an appropriate journal or textbook. It is understood that I have the right to withdraw consent at any time prior to publication but that once the images are in the public domain there may be no opportunity for the effective withdrawal of consent.

Signed .... Date ....

Signature of Parent / Guardian in the case of a minor

....

Appendix 3

Pre-Test Medical Questionnaire

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Review Group

Pre-Test Medical Questionnaire

Name: ____

Date of Birth: ____________ Age: ______________Sex: ______________

Please answer the following questions by putting a circle round the appropriate response or filling in the blank.

1. How would you describe your present level of activity?
   Sedentary / Moderately active / Active / Highly active

2. How would you describe you present level of fitness?
   Unfit / Moderately fit / Trained / Highly trained

3. How would you consider your present body weight?
   Underweight / Ideal / Slightly over / Very overweight

4. Smoking Habits

Smoking Habits	Are you currently a smoker?	Yes / No
	How many do you smoke	…….. per day
	Are you a previous smoker?	Yes / No
	How long is it since you stopped?	……… years
	Were you an occasional smoker?	Yes / No
		……… per day
	Were you a regular smoker?	Yes / No
		……… per day

5. Do you drink alcohol? Yes / No

If you answered **Yes**, do you usually have?
An occasional drink / a drink every day / more than one drink a day?

6. Have you had to consult your doctor within the last six months? Yes / No
If you answered **Yes**, please give details.....................................
....
....

7. Are you presently taking any form of medication? Yes / No
If you answered **Yes**, please give details.....................................
....
....

8. As far as you are aware, do you suffer or have you ever suffered from:

a Diabetes?	Yes / No	**b** Asthma?	Yes / No
c Epilepsy?	Yes / No	**d** Bronchitis?	Yes / No
e *Any form of heart complaint?	Yes / No	**f** Raynaud's Disease?	Yes / No
g *Marfan's Syndrome?	Yes / No	**h** *Aneurysm/embolism?	Yes / No
I Anaemia	Yes / No		

9. *Is there a history of heart disease in your family? Yes / No

10. *Do you currently have any form of muscle or joint injury? Yes / No
If you answered **Yes**, please give details.....................................
....
....

11. Have you had to suspend your normal training in the last two weeks? Yes / No
If the answer is **Yes** please give details..
....
....

If blood is not being taken from you please disregard Section 12. below.

12. * Please read the following questions:
   a) Are you suffering from any known serious infection? Yes / No
   b) Have you had jaundice within the previous year? Yes / No
   c) Have you ever had any form of hepatitis? Yes / No
   d) Are you HIV antibody positive Yes / No
   e) Have you had unprotected sexual intercourse with any person from an HIV high-risk population? Yes / No
   f) Have you ever been involved in intravenous drug use? Yes / No
   g) Are you hemophiliac? Yes / No

13. As far as you are aware, is there anything that might prevent you from successfully completing the tests that have been outlined to you? Yes / No

IF THE ANSWER TO ANY OF THE ABOVE IS YES THEN:

a) Discuss the nature of the problem with the Principal Investigator.

b) Questions indicated by (*) Allow your Doctor to fill out the 'Doctors Consent Form provided.

As far as I am aware the information I have given is accurate.

Signature: ……………………………………………………………………

Signature of Parent or Guardian if the subject is under 18:

……………………………………………………………………… … … … …

Date: ……/……/……

Appendix 4

Participant Information sheet

Sheffield Hallam University

Faculty of Health and Wellbeing Research Ethics Committee
Sport and Exercise Research Ethics Operating Group

Participant Information Sheet

Project Title	Effects of perceptual training on decision-making in soccer

Supervisor/Director of Studies	Prof. Edward Winter

Principal Investigator	Wayne Allison

Principal Investigator telephone/mobile number	

Purpose of Study and Brief Description of Procedures *(Not a legal explanation but a simple statement)*

Thank you for agreeing to take part in my study into the effects of training on decision-making in soccer. You will be divided randomly into one of four groups of 6 participants each. The study will require you to attend a lab session on one occasion to determine your maximal oxygen uptake. The treadmill speeds for the repeated sprints will be calculated based on your maximal uptake, so your sprint speed will be individual to you. A week later, each group will complete a Yo-Yo intermittent recovery test level 1 (YRIT1). You'll then be required to participate in a training programme one day a week for six weeks. You will conduct a repeated-sprint protocol (15x10-s sprints interspersed with a 15-s recovery period) and the pre-test lab-based decision-making protocol. The decision-making task will comprise anticipatory movements (forwards, backwards, left or right) on reaction pads to 10, 6-s filmed soccer sequences projected onto a large screen. The sequences will be in the form of 1v1, 2v1 and 3v3 scenarios and will be displayed randomly. You will be required to imagine that you are a covering defender and anticipate pass destination or interception as quickly as possible.
The post-test will be undertaken 6 weeks later. A retention test will also be conducted after a further week During the intervening period, the four groups will follow different protocols as follows:

Group 1
This group of participants will receive no instruction or training.

Group 2
Participants will watch a 20-min video of soccer match play.

Group 3
Will complete 20 min of perceptual training on an individual basis. Participants will view a training tape of randomly placed soccer clips not used in the test film and video footage of recently recorded soccer match play. The initial training tape will then be repeated, allowing you the opportunity to re-assess the linkages between a particular cue and decision made.
Following this instruction, a further 10 soccer clips will be presented and feedback provided as to the correct decision made and any questions will be answered. Finally, participants will be required to respond to an additional series of 10 soccer clips and feedback on your decision-making performance will be provided.

Group 4

Session one- 3 v 3 Possession
Session two- 2v2 Possession
Session three- 2v1 and 1v1 End Zone Possession game

Retention test
After one week, three groups will perform the experimental protocol (pre-and post-test lab-based decision-making task, separated by the repeated-sprints protocol) in one visit to the laboratory.

All information about you during the course of the study will be kept strictly confidential and you will not be identified in any report. You will have the right to withdraw from the study at anytime without giving a reason for doing so. Additionally, you will be provided with a copy of the information sheet and a signed consent form for your records.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.

It has been made clear to me that, should I feel that these Regulations are being infringed or that my interests are otherwise being ignored, neglected or denied, I should inform Professor Edward Winter, Chair of the Faculty of Health and Wellbeing Research Ethics Committee (Tel: 0114 225 4333) who will undertake to investigate my complaint.