REVIEW ARTICLE

Sports Med 2011; 41 (7): 523-539
0112-1642/11/0007-0523/$49.95/0

Influence of Exercise on Skill Proficiency in Soccer

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Abstract

The ability to maintain technical performances (i.e. skills) throughout soccer match-play is considered to be crucial in determining the outcome of competitive fixtures. Consequently, coaches dedicate a large proportion of time to practicing isolated skills, such as passing, shooting and dribbling. Unlike other elements that contribute to team-sport performances, it is unusual for coaches to use methods other than observations to assess changes resulting from technical training. Researchers have employed various tests to measure isolated soccer skills; however, reliance on outcome measures that include number of contacts (ball juggling tasks), time (dribbling tasks) and points scored (criterion-based passing and shooting tests) means that the outcomes are difficult for coaches to interpret. Skill tests that use video-analysis techniques to measure ball speed, precision and success of soccer skills offer valid and reliable alternatives. Although equivocal results are published, skill performances can be affected by assorted factors that threaten homeostasis, including match-related fatigue, dehydration and reductions in blood glucose concentrations. While acknowledging methodological

constraints associated with using skill tests with limited ecological validity and cognitive demands, the effects of these homeostatic disturbances might vary according to the type of skill being performed. Shooting performances appear most susceptible to deterioration after exercise. Strategies such as aerobic training, fluid-electrolyte provision and acute carbohydrate supplementation have been found to improve proficiency in technical actions performed after soccer-specific exercise. However, mechanisms that cause deterioration in skill during soccer-specific exercise remain to be fully elucidated and strategies to optimize technical performance throughout match-play are warranted.

1. Introduction

Performance during soccer match-play is dependent on a range of factors that include technical, tactical, mental, physical and physiological factors.[1] The quality of technical response (skill performance) is dependent on cognitive, perceptual and motor skills, which interact in rapidly changing environments.[2] Skilled performers receive information (e.g. movement of ball and targets), rapidly analyse information and execute appropriate responses with maximum certainty and minimum outlay of time and energy.[2] In comparison with the physiology of intermittent exercise, technical responses (i.e. the performance of skills, such as passing, shooting and dribbling) to the physical demands of team sports are not well understood. This is somewhat surprising considering that the proficiency of skilled performance is often responsible for determining the outcome of competitive fixtures in sports such as soccer, rugby (league and union), field hockey and basketball. A possible reason for the scarcity of literature regarding the influence of exercise on sports skills is the lack of exercise simulations that replicate, in a controlled and repeatable manner, the movement and technical demands of team sports.

This review summarizes current research that evaluates technical response to exercise, using soccer as the main area of interest. Computerized literature searches were performed in PubMed, Google Scholar and SportDiscus databases between November 2009 and November 2010. The following keywords were used in different combinations: 'soccer', 'football', 'skill', 'technical', 'passing', 'shooting', 'dribbling' and 'juggling'. Articles evaluating technical proficiency in 'rugby' were excluded. All titles were scanned and relevant articles were retrieved for review. In addition, the reference lists from both original and review articles retrieved were also reviewed. This review will (i) describe the frequency of soccer skills during match-play; (ii) discuss the methods used to simulate and evaluate the demands of match-play, with a particular focus on the measurement of soccer skills; (iii) discuss the influence of exercise on skills; and (iv) examine the factors that affect technical responses to exercise.

2. Technical Demands of Soccer

Soccer is primarily aerobic in nature, where players have been observed to cover approximately 10 km during matches.[3-8] Nevertheless, success during soccer match-play is associated with increased high-intensity activity[9] and the quality of skilled actions, such as passing and shooting.[10] Considering that a disproportionate number of goals are scored in the last 15 minutes of a match,[11] the ability to maintain technical proficiency while engaged in prolonged high-intensity intermittent exercise is a primary determinant of success in competitive fixtures.

Although the main focus of notational analysis has been the quantification and classification of physical activities, this methodology has also revealed vital information about the frequency of occurrence of sports-specific motor skills.[12,13] Throughout a soccer match, each player completes between 50 and 110 technical involvements;[13-15] however, fullbacks have been reported to have a higher frequency of technical involvement than

all other positions.[13] In order to score a goal, a team must make between 16–30 attacks and take an average of ten shots,[16] whereas analysis of individual actions has revealed that dribbling and short passes are the most frequently performed skills during match-play.[15,17]

Despite the number of skilled actions that occur throughout match-play being a consequence of aerobic fitness, positional role and the team's league position,[13,18] relatively little information is available to evaluate the possible time-course of decay in the frequency and/or success of technical performances executed during match-play. Although half to half variations in the frequency of skilled performances have previously been reported,[18] no study has aimed to determine whether technical proficiency varies over smaller time intervals (e.g. every 15 minutes). This is surprising considering that it has been reported that lapses in concentration could partially explain the disproportionate number of goals scored in the latter stages of match-play relative to all other times during a game.[11]

Based on the technical demands of soccer, and the importance of skilled actions in defining success, it is not surprising that soccer players allocate a large proportion of their training time to improving skilled actions. Unlike other predictors of soccer success, such as a maximal aerobic capacity in excess of 60 mL/kg/min,[19] coaches do not regularly monitor the efficacy of training on technical performances using means other than empirical observations. Nevertheless, the growing interest in soccer skill among researchers has led to the development of various methods to evaluate the quality of skilled performances; however, soccer teams are yet to regularly incorporate such protocols in their testing batteries.

3. Methods Currently Employed in the Evaluation of Technical Performances in Soccer

Global measures of soccer skills (such as match results) have strong ecological validity,[1] but incorporate too much variability to consistently identify changes associated with interventional research. For example, using the number of goals scored and conceded as outcome measures, Zeederberg et al.[22] concluded that carbohydrate supplementation did not improve motor skill performance during soccer match-play. In addition to challenging the appropriateness of this global outcome measure, similarities in the plasma glucose concentrations between the carbohydrate and placebo trials suggest that the supplementation strategy was not optimal.

To overcome external factors that affect the repeatability of match-play (e.g. opponents activity profiles and success experienced throughout the season),[7,18] a number of tests have been devised that isolate the performance of soccer skills (table I).[23-33,35] These protocols can be categorized into tests that assess ball control and tests that measure ball accuracy.

3.1 Tests that Measure Ball Control

The ability of a player to control the ball during a soccer match, either when receiving a pass from a team mate or while running into an opponent's territory, is an important skill; consequently, a number of authors have designed tests that aim to assess this facet of soccer skill performance.[23-25,29,30,32,33] A method that has been used to assess ball control is ball juggling, whereby the frequency of consecutive and successful (i.e. preventing the ball from touching the ground) ball touches are counted, and higher values are deemed to represent a greater level of skill. Figueiredo et al.[33] reported that performance on a reliable ball juggling task (coefficient of reliability: 0.77) was influenced by the sexual maturity of Portuguese junior soccer players as 13- to 14-year-olds outperformed their 11- to 12-year-old counterparts (69.5 vs 25.2 touches). However, although ball juggling is commonly observed on the training ground, empirical observations of competitive match-play seldom reveal ball juggling to be a frequently

1 Ecological validity can be defined as the degree to which congruence exists between the environment that the subject in an investigation experiences and the intended properties of the environment that the investigator assumes[20] or the extent to which research emulates the real world.[21]

Table I. Summary of soccer skill tests that isolate specific technical actions

Study (year)	Skill	Measurement	Assessment method	Outcome measures
Zelenka et al.[23] (1967)	Shooting	Accuracy	Criterion-based measure	Points scored
	Dribbling	Ball control	Timing	Time
Reilly and Holmes[24] (1983)	Ball juggling	Ball control	Frequency of successful touches	Number of touches
	Dribbling	Ball control	Timing	Time
	Wall volley	Ball control	Frequency of successful touches	Number of continuous touches
	Shooting	Accuracy	Criterion-based measure	Points scored
McGregor et al.[25] (1999)	Dribbling	Ball control	Timing	Time
Northcott et al.[26] (1999)	Passing	Accuracy	Criterion-based measure	Points scored
	Shooting	Accuracy	Criterion-based measure	Points scored
Cox et al.[27] (2002)	Shooting	Accuracy	Criterion-based measure	Points scored
Finnoff et al.[28] (2002)	Passing	Accuracy	Manual distance measurement	Distance
Ali et al.[29] (2007a)	Passing	Accuracy and ball control	Criterion-based measure and timing	Time
	Shooting	Speed, accuracy, ball control	Radar speed gun, criterion-based measure, timing	Speed and points scored
Mirkov et al.[30] (2008)	Throw-in	Maximal upper body power	Manual distance measurement	Maximal distance
	Kicking	Maximal lower body power	Manual distance measurement	Maximal distance
	Dribbling	Ball control	Timing	Time
Rostgaard et al.[31] (2008)	Passing	Accuracy	Criterion-based measure	Points scored
Currell et al.[32] (2009)	Dribbling	Ball control	Timing	Time
	Kicking	Accuracy	Criterion-based measure	Points scored
	Heading	Maximal height	Height measurement	Maximal height
Figueiredo et al.[33] (2010)	Ball juggling	Ball control	Frequency of successful touches	Number of continuous touches
	Dribbling	Ball control	Timing	Time
	Passing	Accuracy and ball control	Criterion-based measure	Points scored
	Shooting	Accuracy	Criterion-based measure	Points scored
Williams et al.[34] (2010)	Shooting	Accuracy	Criterion-based measure	Points scored
Russell et al.[35] (2010)	Passing	Speed, accuracy, ball control	Video digitization	Ball speed, precision, success rate
	Shooting	Speed, accuracy, ball control	Video digitization	Ball speed, precision, success rate
	Dribbling	Speed, accuracy, ball control	Video digitization	Ball speed, precision, success rate

occurring skill. Therefore, as a marker of technical proficiency, the ecological validity of ball juggling is questionable compared with more match-specific actions such as dribbling.

A 20 m timed sprint dribble identified that fluid abstinence caused a 5% reduction in dribbling performance when compared with a trial where fluid was provided.[25] Subsequent studies have incorporated similar tests;[36] however, the outcome measure from timed dribbling tasks is speed, with no measure of the quality of the skill (e.g. precision or success). Although some people would argue that a shorter time to complete such tests represents a more skilled action, this is not necessarily the case. For example, a skilled dribbler is able to keep the ball close to the desired position while travelling at high speed and a lack of ball control will increase the likelihood of losing possession of the ball. Consequently, the ability to quantify the actual ball position in relation to the desired position (precision) and the ability to complete the desired task without mistakes (success rate) are additional outcome measures that provide further information about the proficiency of this technical action. Recently, we have confirmed the validity and reliability of soccer skill tests that use video-analysis techniques to produce outcome measures of ball speed, precision and success rate for soccer dribbling, passing and shooting skills.[35] These tests require players to kick a moving ball to one of four randomly identified targets (passing and shooting) and to manoeuvre a ball as fast and as accurately as possible between cones (dribbling). In addition to providing outcomes with better absolute and relative reliability than comparable traditional criterion-based methods, these tests provide outcome measures with strong ecological validity that are easily interpreted by coaches, players and researchers. Therefore, authors of future research may wish to explore the use of such analysis methods when examining the technical response to exercise.

3.2 Tests that Measure Ball Accuracy

The precision of skill performances influences the winning and losing of possession during soccer match-play; therefore, it is not surprising that the majority of soccer skill tests incorporate a measure of accuracy (table I). However, most skill tests in soccer research are those that produce accuracy outcomes from criterion-based measurements, whereby discrete (i.e. outcomes can only take certain values) as opposed to continuous (i.e. outcomes can take any value) data are produced. Consequently, conclusions drawn from the use of such tests are heavily influenced by the values assigned in the scoring criteria and may not necessarily reflect the relative difficulty of the tasks performed.

For example, the Loughborough Soccer Shooting Test (LSST) allocated the greatest number of points to shots placed in the corners of a goal as this limits the chance of the goalkeeper saving the shot.[29] However, a similar shooting task devised by Currell et al.[32] assigned the lowest number of points when shots were placed towards the corners. Consequently, conclusions derived from tests that rely on criterion-based outcomes are heavily dependent on the scoring criteria used and limit the like-for-like comparison of data between different tests that aim to assess the same variables of skilled performance.

The Loughborough Soccer Passing Test (LSPT), described by Ali et al.,[29] requires participants to aim passes towards coloured targets while negotiating a coned area. Performance is determined by the time taken to complete the task plus any additional penalty points accumulated. Although the LSPT has been used to examine the influence of a number of interventions on soccer passing performance in both male[37-39] and female players,[40] the outcome measure lacks ecological validity as the outcome of the test, which is designed to measure kicking accuracy and is expressed in time(s) rather than distance.

Compared with outcomes derived from criterion-based soccer skill tests, relatively few authors have published data concerning the accuracy of skills involving kicking. Finnoff et al.[28] reported a median deviation of approximately 90 cm over a 6.1 m distance when ball impacts were measured manually, whereas Young et al.[41] implemented video-analysis procedures to yield deviations of 80–90 cm when Australian football players kicked a ball towards a target that was 16 m away.

The omission of match-specific cognitive processes (such as decision making and visual searching), where a ball is kicked towards a target in a pre-planned manner, and differences in the motor skills between football codes limit the application of these earlier studies to soccer research. However, video-analysis techniques have recently been used to quantify ball speed, precision and success rates in soccer skill tests that incorporate match-specific cognitive processes.[35] These methods demonstrated construct validity, where shooting and passing accuracy of youth players from a UK-based championship soccer team were superior to university-standard players. Therefore, alternative methods exist to the criterion-based outcome measures that have previously dominated soccer skill research.

3.3 Additional Issues Concerning the Use of Isolated Skills Tests

While attempting to maintain experimental control through standardized test protocols, some researchers have designed skill tests that require the kicking of a static ball.[26] At the time of their development, these tests provided novel findings to support the use of selected ergogenic aids when aiming to maintain skilled performances; however, such tests focus on technique rather than skill because the use of a stationary ball fails to include cognitive aspects of match-play (e.g. decision-making and visual searching processes).[2,29] The array of technical movements involved in match-play further complicates the practice of testing soccer skills in isolation; consequently, consideration should be given to various factors that influence isolated skill tests (table II). In addition, a range of environmental factors (e.g. location, wind and playing surface) should also be considered.

Since the quality of a skill is dependent on the interaction between speed and accuracy of execution,[42] and given that success is a valuable outcome, information concerning these subcomponents of skilled actions could provide independent outcome measures that are of relevance to players, coaches and sports scientists. Criterion-based tests determine accuracy in terms of

Table II. Factors to consider when designing isolated skill tests

Skill	Testing considerations
Clearance	Standardization of ball delivery
	Player movement at the start and throughout the test
	Outside interference when clearing the ball
	Position of ball clearance
Corner	Type of corner (e.g. cross, short)
	Speed, accuracy and success of outcome
Cross	Standardization of ball delivery
	Player movement at the start and throughout the test
	Outside interference when crossing the ball
	Speed, accuracy and success of outcome
Dribble	Standardization of ball delivery
	Player movement at the start and throughout the test
	Path covered (e.g. distance, directional, turns)
	Cessation of test (skill at the complete task, e.g. pass)
	Speed, accuracy and success of outcome
Free kick	Type of free kick (e.g. pass, shot, cross, position)
	Outside interference when taking the kick (e.g. defensive wall)
	Speed, accuracy and success of outcome
Header	Standardization of ball delivery
	Player movement at the start and throughout the test
	Outside interference when heading
	Type of header (e.g. towards opponents goal or team mate)
	Speed, accuracy and success of outcome
Pass	Standardization of ball delivery
	Player movement at the start and throughout the test
	Type of pass (e.g. foot, chest, head, long, short)
	Outside interference when passing
	Speed, accuracy and success of outcome
Penalty	Speed, accuracy and success of outcome
Shot	Standardization of ball delivery
	Player movement at the start and throughout the test
	Outside interference when shooting
	Type of shot (e.g. long or short range, power or placement)
	Speed, accuracy and success of outcome
Tackle	Standardization of ball delivery
	Player movement at the start and throughout the test
	Success of outcome
Throw-in	Type of throw (e.g. long, short, position of target)
	Ball trajectory on release
	Speed, accuracy and success of outcome

total points scored and rarely determine speed; however, video-analysis techniques have been demonstrated to provide these outcome measures a soccer skill test battery with confirmed validity and reliability.[35] Therefore, future research in this field should employ analysis methods that quantify skilled performances in terms of continuous data (as opposed to discrete data) and provide outcome measures in ecologically valid units.

4. Simulating Soccer-Specific Exercise

As a sport with worldwide participation and the most popular of the football codes,[43] the commercial value of findings from soccer research are potentially high; consequently, several exercise protocols have been developed that aim to replicate the demands of competition.[34,44-48] The primary reason for developing an exercise simulation is to control the movement requirements and thereby standardize the physiological demands. In doing so, the variation in responses that usually exist between matches is limited and the effects of exercise become repeatable. The most obvious benefit of simulation protocols is that they minimize external variation and allow for more prominent effects to be identified in sometimes subtle physiological changes that result from supplementation protocols, strength and conditioning regimes and/or other performance-altering interventions.

Studies aiming to assess the validity of exercise protocols, which were designed to replicate the demands of soccer match-play, have generally compared simulation data with the results of notational analysis studies collected during match-play in a different subject pool. According to Drust et al.,[49] if an exercise simulation is to be validated against the demands of match-play, then a single group of participants would be required to undergo both experimental conditions (i.e. match-play and the simulation) and their responses subject to statistical analysis. However, few researchers have adopted this approach when assessing the validity of an exercise simulation. Thatcher and Batterham[48] demonstrated the comparability of physiological responses between individuals participating in actual match-play and a non-motorized treadmill protocol. However, the lack of lateral and backwards movements performed in unidirectional treadmill protocols, limits the ecological validity of this protocol.

The Loughborough Intermittent Shuttle Test (LIST) is a commonly employed intermittent exercise simulation that has been used to examine the effects of various ergogenic aids on exercise performance.[50-52] The LIST consists of 75 minutes of intermittent activity followed by a shuttle run to exhaustion. This free-running exercise simulation that replicated the movement demands of soccer was a valuable progression from unidirectional treadmill-based protocols.[44] However, the omission of a half-time period and the lack of game-specific skills, some of which have been previously found to have an energy-consuming consequence (e.g. dribbling),[53] reduces the ecological validity of the LIST and compromises the integrity of the physiological strain imposed by this protocol when compared with match-play.

The inclusion of soccer skills during exercise protocols designed to replicate the demands of a soccer match was rare in early research. Although this might be surprising considering the influence that soccer skills have in defining success, players with lower skill might lack the ability to maintain skills throughout the exercise simulation, thereby compromising the overall exercise intensity. In a research field where the recruitment of large numbers of homogenous participants is already acknowledged as a major challenge, it is not surprising that the technical responses of soccer players have received relatively little attention; nevertheless, more recent studies have attempted to include soccer skills into exercise simulations.

Soccer skills tests have been completed before and after exercise. In a study evaluating the effects of dehydration on soccer skill, participants performed a timed dribbling task before and after 90 minutes of soccer-specific exercise.[25] Similarly, Ali et al.[39] investigated the ergogenic potential of carbohydrate-electrolyte provision relative to a non-electrolyte placebo beverage on passing and shooting skills performed before and after a modified LIST protocol. Consequently, some

authors have investigated the effects of exercise and various ergogenic aids on the quality of skilled performances in soccer.[25,39] However, only assessing soccer skills at these timepoints does not examine the time-course of decay in technical proficiency throughout the duration of a match while players are simultaneously engaging in high-intensity intermittent exercise; furthermore, information concerning the skilled response when assessed at the end of 90 minutes of exercise is only applicable to players who are about to enter a period of extra time.

More recent work has sought to rectify this problem by incorporating the performance of isolated soccer skills throughout exercise protocols.[32,34,37,38,54,55] For example, Ali and Williams[37] required fasted and previously glycogen-depleted players to perform a criterion-based passing test (LSPT) every 15 minutes throughout a 90-minute modified LIST protocol, whereas Currell et al.[32] assessed kicking accuracy by means of a criterion-based shooting task on six occasions throughout a 90-minute exercise simulation. These protocols suggest that soccer skills decline during the second half of exercise; however, criterion-based outcomes limited the ecological validity of these findings. Difficulties in interpreting the results from these tests, particularly the magnitude of effect and the element of the skill that is influenced by fatigue, means that there is a need to utilize soccer-specific exercise simulations that include regular assessment of soccer skills throughout the duration of a match; furthermore, the skill tests should provide outcome measures that quantify the speed, precision and success rate of skill performance.

5. The Effects of Exercise on Soccer Skills

The reduction in physical performance throughout match-play has been the focus of a number of research articles.[5,9,12,13,47,56,57] Challenges to homeostasis, such as core temperature changes[57] and the accumulated effects of match-related fatigue,[9,58] are generally thought to explain these performance decrements. However, considerably fewer articles have investigated the effects of exercise on technical performances involved in team sports, such as soccer. As mentioned previously in section 2, a disproportionate number of goals are scored in the last 15 minutes of a match;[11] therefore, it is plausible that a link exists between match-related fatigue and the technical proficiency of soccer players.[36]

Rampinini et al.[18] reported that the number of involvements with the ball, short passes and successful short passes decreased from the first to the second halves in Italian Serie A matches. When these data were expressed as a function of the fatigue experienced during a game, using the decrement in high-intensity running throughout the match as an indicator of fatigue, the differences between halves were no longer evident. This finding suggests that fatigue reduces the quality of skills executed during match-play.[18] Similarly, game-related events such as kicking, heading and tackling have been observed to decrease by 11% in the second half when compared with the first half during Australian league matches.[14] These findings support the existence of an association between fatigue and soccer skill proficiency during match-play. Further attempts to elucidate the effects of exercise on soccer skills have used isolated skill tests, primarily incorporating tests of dribbling, passing and shooting.

5.1 Dribbling Performance

Dribbling is considered a valuable skill in soccer because players have the potential to advance deeper into an opponent's territory while maintaining possession of the ball. Despite the importance of this skill, the effect of exercise on dribbling performance has received relatively little attention.[25,36,59] Using a 20 m timed sprint-dribbling test, McGregor et al.[25] observed reductions in performance as a consequence of 90 minutes of soccer-specific exercise performed under conditions of fluid abstinence. However, when the same sprint-dribbling task was performed in a more ecologically valid scenario, where players consumed a fluid-electrolyte solution during exercise, skill was maintained. Consequently, dribbling speed is maintained throughout soccer-specific exercise scenarios that replicate the hydro-nutritional practices; however, no data exist to

evaluate the influence of fatigue on other aspects that affect the quality of dribbling (e.g. precision and success) during match-play or simulations of soccer.

5.2 Passing Performance

It has been reported that the top five teams in the Italian Serie A league complete more short passes (<37 m) than their less successful counterparts[18] and longer passing sequences are associated with an increased number of goals per possession in successful teams.[10] Additionally, an early study assessing passing proficiency in international competitions[60] found that 57% of goals were scored after a period of play that includes short passes; therefore, the maintenance of passing proficiency throughout the duration of a match probably contributes to the scoring of goals. However, studies examining the effects of exercise on isolated soccer passing performances have produced conflicting findings.

McMorris et al.[61] investigated passing performance at rest and following cycle ergometry at moderate (70%) and high (100%) percentages of maximal power output. Results indicated that moderate-intensity exercise yielded improvements in passing performances, which exceeded all other intensities. In contrast, passing performance has been observed to decrease following a bout of high-intensity, lower-body resistance training.[62] Variations in the intensity of exercise, mode of exercise, and the interaction between exercise and cognitive processes (i.e. inverted U theory)[63] might explain the lack of agreement between authors. Consequently, the practical application of these findings are limited due to the likely differences that exist between the effects of fatigue induced by isolated bouts of high-intensity exercise compared with exercise that is similar to that encountered during match-play.

With this in mind, other authors have used exercise protocols that simulate soccer match-play to evaluate the influence of fatigue on passing performances;[39,40,64] however, equivocal findings exist – some researchers support this observation,[64] while others disagree.[39,40] Rampinini et al.[64] showed that the frequency and success of short passes were reduced during the second half when compared with the first half of match-play. Conversely, Ali et al.[40] showed that participation in 90 minutes of a modified LIST protocol did not influence overall performance measures in the LSPT,[29] despite a 2.2% reduction in body mass (BM) in a fluid-abstinence trial. The use of analysis methods with greater application to on-field performances, in conjunction with the use of exercise simulations that better replicate the patterns of soccer activity, could improve our understanding of the technical response to exercise with respect to soccer passes performed throughout the duration of a match.

5.3 Shooting Performance

Shooting is arguably the most valuable skill because it directly determines the outcome of match-play. Empirical observations and research demonstrates that shooting is also the skill that exhibits the most variability, where coefficient of variance values have been found to exceed 20% in isolated shooting tasks that use a moving ball.[29,35,40] At first glance, this degree of variation appears to be high compared with generally accepted standards; however, even the most prolific of goal scorers exhibit considerable variation in goal scoring success between matches. Due to the dynamic nature of shooting, tests that incorporate decision-making and visual searching processes will incorporate more variation than tests that focus on technique alone;[29] however, the use of such tests are warranted by the enhanced ecological validity that they offer in relation to tests that incorporate a stationary ball.

It has been consistently observed that shooting performances are reduced under conditions associated with physical fatigue. After 6 minutes of stepping exercise, reduced coordination between the upper and lower leg was proposed to cause a reduction in shot speed.[65] This finding has since been confirmed using a more sports-specific exercise protocol.[66] However, during soccer, the ball must be aimed towards areas within the goal that increase the chance of scoring.[29] Therefore, visual search and decision-making processes are vital contributors to success in soccer shooting;

unfortunately, such factors have not always been included in previous research.[65,66]

The assessment of shot speed before and after 90 minutes of soccer-specific exercise led to initial reports that shooting performance was maintained following exercise.[39] However, the exclusion of shots that were slower than an arbitrary value resulted in significant reductions in shooting performance being observed. Unfortunately, no justification was provided for determining the threshold at which these shots were excluded and the number of shots remaining in subsequent analyses was not reported. Consequently, employing analysis methods that produce continuous rather than discrete data has the potential to extend earlier findings. For example, we have recently devised a shooting test that provides outcome measures to quantify precision, success rate and ball speed.[35]

Therefore, the literature demonstrates that under physiological conditions that threaten homeostasis, a 'speed-accuracy trade-off'[42] exists in skills that contribute to success in soccer. Similar responses have been observed in other high-intensity intermittent sports, such as tennis, where players alter specific subcomponents associated with skill execution in favour of preserving either accuracy or speed.[67]

In summary, given the lack of research that documents absolute measures of technical proficiency, it is difficult to evaluate the skilled response to exercise. Nevertheless, it appears that the exercise-induced effects of fatigue vary according to the soccer skill. Shooting appears to be the most susceptible to modification by exercise-induced fatigue. Given the importance of skills during exercise and the evidence that exists concerning the decline in skilled sporting actions due to match-related fatigue, it is important that coaches account for factors that can affect the proficiency of technical performances throughout exercise.

6. Factors Affecting Technical Skills Executed during Exercise

6.1 Aerobic Fitness

It has previously been suggested that a maximal aerobic capacity in excess of 60 mL/kg/min is one of many physiological attributes that predicts success in elite soccer.[11,19] In addition to separating teams in terms of physical performances, aerobic fitness influences technical performances during soccer match-play, specifically during the latter stages. The decline in passing proficiency after a bout of high-intensity running has been correlated to aerobic fitness levels.[64] Although the physiological mechanisms of soccer fatigue remain unclear, and are likely to be multifaceted in origin, this study suggests that there is a role for sport-specific fitness training to reduce the decline in the quality of skilled performances that occurs during periods of the game where homeostasis is disturbed. This claim is further substantiated by the observation that a period of aerobic interval training increased involvement with the ball during match-play[68] and maintained passing performance following a period of high-intensity running.[69] Moreover, it has been reported that the aerobic fitness of soccer players fluctuate throughout a season.[70] Given the link that exists between aerobic fitness and the decline in skilled performances that result from fatigue, the efficacy of a mid-season aerobic training plan to counteract the decline in skill performance presents itself as a research opportunity.

6.2 Hydration Status

During exercise, metabolic heat produced via contracting musculature causes elevations in core temperature. This leads to increased sweat production and modified blood flow to the periphery for heat dissipation.[71] Even moderate hypohydration (1–2% BM loss) can impair exercise[72-74] and cognitive[73-75] performances, which are both crucial to high-intensity intermittent sports.[67] Similar magnitudes of hypohydration have been observed in soccer players who were free to voluntarily consume fluids during training and competition;[71] therefore, efforts to maintain euhydration are vital when aiming to optimize soccer performance as thirst alone is not a good enough indicator of fluid loss.[76]

Despite the potential for dehydration in soccer, few studies have examined the effects of modified hydration status on the technical aspects of the

game; this is surprising considering that it is common practice for teams to seek more thermally challenging climates (i.e. increased daytime temperatures) to complete part of their pre-season preparations in which technical work will account for a large proportion of their training time. Nevertheless, the effects of fluid restriction on a timed dribbling task completed before and after intermittent running has been investigated.[25] The increased cardiovascular strain associated with dehydration resulted in the elevation of a number of physiological measures that are associated with thermal stress in the no-fluid trial (i.e. serum osmolality, serum cortisol concentrations and heart rate). Moreover, 5% deterioration in dribbling performance occurred when players abstained from fluid intake.

Additionally, shooting performances have been observed to reduce in fasted and previously glycogen-depleted players who exercised for 90 minutes while consuming a non-electrolyte placebo beverage.[39] Although the practical applications from these studies are difficult to interpret due to the limited ecological validity of the methods used to assess skill and the fluid-intake regimens employed, the link between hypohydration and impaired soccer performance is strengthened by the fact that attributes key to success in the game such as strength, power and anaerobic endurance are also compromised by hypohydration.[72,77,78] However, a recent study by Ali et al.[40] failed to substantiate these findings with respect to passing performances (assessed by the LSPT) in female soccer players.

Baker and colleagues[74] examined the effects of hypohydration on basketball shooting drills. The authors concluded that gradual hypohydration impaired skilled performance, with the critical threshold at which a statistically significant decline in skills was achieved being 2% BM loss. Despite this study not being specific to soccer, both sports include intermittent bouts of high-intensity activity repeated over a prolonged period of time while executing sports-specific skills. It is reasonable to assume that the effects of hypohydration observed by previous researchers in other multi-sprint sports (i.e. basketball)[73,74] could impact on skill performances in soccer. Consequently, players should aim to limit water loss to within 2% BM and adhere to guidelines regarding hydration strategies during exercise.[71]

6.3 Blood Glucose Concentrations

Impaired blood glucose availability is considered to be a mechanism responsible for the deterioration of both cognitive[79-89] and physical[39,90-93] performances. Given that team sports such as soccer require the execution of sports-specific skills while performing high-intensity intermittent exercise, and that the brain is primarily dependant on blood glucose for maintenance of cerebral function,[94] reductions in blood glucose concentrations during exercise probably influence performances in soccer; particularly with respect to the skills executed during match-play.

A substantial body of evidence from non-exercise settings demonstrates that markers of cognitive function, including reaction time, arithmetical ability, verbal fluency, hand-eye coordination and visual scanning, are consistently impaired when blood glucose concentrations fall between 2.0 and 3.0 mmol/L.[80-83,86-88,95] Furthermore, complex cognitive tasks are more sensitive to reductions in blood glucose concentrations than simple tasks.[96] Although match-play has been demonstrated to reduce blood glucose concentrations,[97] the mean values of soccer players have not been reported to fall below 3.0 mmol/L. Nevertheless, serum glucose concentrations appears to be an important determinant of cognitive function before, at half-time and after soccer match-play in the heat,[98] where higher glucose concentrations were associated with faster visual discrimination, faster fine motor speed and faster psycho-motor speed. Soccer requires the simultaneous execution of cognitive, perceptual and motor skills in a rapidly changing environment.[2] Therefore, transient reductions in blood glucose could influence cognitive function and the performance of soccer-specific skills during a match, which could influence the outcome of the game.

Although studies that induce hypoglycaemia have provided information concerning the influence of blood glucose concentration on cognitive performance, the stepped hyperinsulinaemic

glucose clamp technique enabled researchers to determine the threshold at which blood glucose concentrations impair cognitive function. In non-diabetic adults, almost immediate reductions in cognitive performance occur when blood glucose concentrations fall below 3.4 mmol/L;[79-83,86-89,95] concentrations which, although below average, have been reported to occur during soccer match-play.[97]

As cognitive processes are crucial to skilled actions involved in competitive team sports,[67] and the role that blood glucose plays in maintaining cerebral function,[94] it is plausible that carbohydrate supplementation regimens could maintain selected soccer skills in the latter stages of a soccer match.[11,14,18] However, the influence of additional carbohydrates (either with or without simultaneous electrolyte provision) on the skilled performances during high-intensity intermittent sports has resulted in equivocal findings, where some studies support carbohydrate supplementation[26,32,36,39,73,90,91,99,100] and others do not.[22,101] Table III summarizes the studies that examine the effects of carbohydrate supplementation on technical aspects involved in the game of soccer.

Contradictory findings currently exist concerning the effects of carbohydrate usage in attenuating a decline in aspects of technical performance. It is likely that early methods of skill evaluation such as the use of global measures of skilled performance (i.e. the number of goals scored or conceded during match-play) were too variable to consistently detect the subtle changes involved in supplementation research and this may account for the inconsistent findings.[22,102] Similarly, studies with self-perceived exercise intensities[26] and/or criterion-based outcome measures have also failed to agree on the effects of carbohydrate provision on various skills performed before, after and during exercise.[26,32,37,39]

Ali and Williams[37] suggested that exogenous carbohydrate must be supplied at a minimum rate of 50 g/hour in order to improve motor skill performance. This statement was based on the findings of previous authors.[26,90] Interestingly, supplementing fasted and previously glycogen-depleted participants with 52 g/hour of carbohydrates yielded no benefit to LSPT performance when assessed before, after and during exercise.[37] This finding supports previous work from the same laboratory where passing was assessed before and after exercise and carbohydrates were supplied at a rate of 30 g/hour.[39] However, 30 g/hour of carbohydrate was beneficial to shooting performances post-exercise when compared with a non-electrolyte placebo trial. Although these results should be interpreted carefully due to methodological limitations regarding the skilled performance outcome measures and the hydro-nutritional status of the players pre-exercise (i.e. fasted and previously glycogen-depleted), the results suggest that the effects of carbohydrate provision can differ according to the type of skill being performed. Therefore, determining the critical blood glucose concentration at which skilled performance is challenged presents itself as a future research opportunity.

It appears that the dose of carbohydrate is important when seeking to improve soccer skill performance. However, the optimal dose of carbohydrate has not been elucidated when seeking to maintain soccer skill proficiency in the latter stages of a match. Given that a dose-response relationship exists between carbohydrate provision and cognitive function in the non-exercise setting,[103] it remains to be determined whether higher doses of carbohydrates ingested during exercise will further increase the performance of skills. If so, caffeine, which has previously been reported to enhance the absorption[104] and oxidation[105] of co-ingested carbohydrates, might be of interest to team-sports players given the concomitant influence that this ergogenic aid has on the CNS. However, adding 3.7 mg/kg BM caffeine to a 6% carbohydrate-electrolyte solution did not improve performance in the LSPT.[55]

The consumption of a high-glycaemic index carbohydrate in the hour before exercise can lower blood glucose levels 15–30 minutes after starting exercise.[106,107] Although the effects of exercise-induced hypoglycaemia have been reported to reduce performance,[108] more recent research suggests that physical performance is not adversely influenced.[106,107] Studies involving non-exercising participants have demonstrated that almost immediate reductions in cognitive performance occur

Table III. The influence of acute carbohydrate supplementation on skilled performances of soccer players

Study (year)	Subjects	Supplements	Timing (and dose) of supplements	Exercise protocol	Measurement of skill	Effect on skilled performance
Muckle[102] (1973)	NA	350–450 Kcal glucose syrup	30 min prior (NA)	90 min match	Frequency of ball contacts, goals scored or conceded, ball involvements per player	CHO ↑ goals scored, CHO ↑ defensive performances in last 30 min
Zeederberg et al.[22] (1996)	11 M	6.9% glucose polymer-electrolyte beverage or PL	15 min prior (5 mL/kg BM), half-time (5 mL/kg BM)	90 min match	Subjective evaluation of controlling, passing, dribbling, heading, tackling and shooting	No effects of CHO
Northcott et al.[26] (1999)	10 M	8% glucose-polymer or water PL	15 min prior (8 mL/kg BM), half-time (8 mL/kg BM)	90 min match simulation	CBM of various lengths of passing (10, 20 and 30 m) and shooting (15 m)	CHO ↑ skill proficiency in last 15 min compared with PL
Ostojic and Mazic[36] (2002)	22 M	7% CHO-electrolyte beverage or plain water PL	Immediately prior (5 mL/kg BM), every 15 min during exercise (2 mL/kg BM)	90 min match	Timed dribbling test (see McGregor et al.[25])	CHO ↑ dribbling performance compared with PL
Ali et al.[39] (2007b)	16 M	6.4% CHO-electrolyte beverage (Lucozade Sport™) or a non-electrolyte PL	Immediately prior (5 mL/kg BM), every 15 min during exercise (2 mL/kg BM)	90 min match simulation	CBM of passing and shooting	CHO ↑ shooting performance compared with PL post-exercise No effect of exercise or CHO on passing
Ali and Williams[37] (2009)	17 M	6.4% CHO-electrolyte beverage (Lucozade Sport™) or a non-electrolyte PL	Immediately prior (8 mL/kg BM), every 15 min during exercise (3 mL/kg BM)	90 min match simulation	CBM of passing	No effects of CHO
Currell et al.[32] (2009)	11 M	7.5% maltodextrin beverage or PL	30 min prior (6 mL/kg BM), half-time (4 mL/kg BM), every 12 min during exercise (1 mL/kg BM)	90 min match simulation	Timed dribbling test, CBM of shooting and a maximum jump height heading task	CHO ↑ dribbling and shooting performances in each trial

BM = body mass; **CBM** = criterion-based measure; **CHO** = carbohydrate; **M** = males; **NA** = data not available; **PL** = placebo; ↑ indicates significant improvement ($p \leq 0.05$).

when blood glucose concentrations fall below 3.4 mmol/L;[79-83,86-89,95] furthermore, restoration of euglycaemia after a hypoglycaemic episode does not lead to immediate recovery of cognitive function, with delays of up to 90 minutes before cognitive function is restored to pre-hypoglycaemic levels.[95,109] It is, therefore, plausible that even transient reductions in blood glucose concentration might adversely affect decision making, other cognitive functions and ultimately the performance of skills. Nevertheless, the influence of reduced blood glucose concentrations on skill performance during high-intensity intermittent exercise remains to be evaluated.

7. Conclusions and Future Research Recommendations

The purpose of this article was to provide the reader with current information concerning the frequency and type of skills performed during a soccer game, discuss the methods used to simulate and evaluate the demands of soccer match-play (focusing on the measurement of soccer skills), explore the effects of exercise on these skills, and to examine the factors that influence skill proficiency during soccer-specific exercise. This article aims to inform researchers and coaches about soccer skill investigations and to initiate future research in this field. Nevertheless, it should be noted that the issues raised in this review are not exclusive to soccer and the application of these findings to other high-intensity intermittent sports is encouraged.

The unpredictable nature of soccer limits the suitability of match-play as an exercise protocol when examining the effects of interventions on performance; consequently, a number of soccer-specific exercise simulations have been developed to elicit repeatable responses to exercise. Despite the frequent application of simulation protocols in scientific research, the ecological validity of these protocols is questionable. This problem is further complicated by the array of skilled movements involved in soccer and problems associated with performing such movements under controlled laboratory conditions. Thus, the majority of research in this field employs methods of skill assessment where the ball is aimed towards a target, with the performance judged and scored according to set criteria.[26,29,64,69] Although the use of skill tests that produce criterion-based outcome measures has overcome some of the problems associated with assessing skills throughout match-play, the results are difficult to interpret. Therefore, researchers are encouraged to incorporate skill tests with increased ecological validity and outcome measures of a continuous (as opposed to discrete) nature.

Factors that contribute to the decline in physical performances in soccer (e.g. fitness, dehydration and hypoglycaemia) might also moderate skill proficiency during match-play, particularly in the latter stages. Early research, in combination with findings from other high-intensity intermittent sports, supports further investigation into interventions such as aerobic training, fluid-provision and carbohydrate-electrolyte supplementation to attenuate the decline in technical performance that is associated with fatigue. However, because the mechanism(s) responsible for the deterioration in skill performance remain unclear, more research is required to develop appropriate strategies to maintain skill proficiency throughout soccer match-play.

Acknowledgements

No sources of funding were used to assist in the preparation of this review. The authors have no conflicts of interest that are directly relevant to the content of this review.

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