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Recovery in Soccer

Part I – Post-Match Fatigue and Time Course of Recovery

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Abstract

In elite soccer, players are frequently required to play consecutive matches interspersed by 3 days and complete physical performance recovery may not be achieved. Incomplete recovery might result in underperformance and injury. During congested schedules, recovery strategies are therefore required to alleviate post-match fatigue, regain performance faster and reduce the risk of injury. This article is Part I of a subsequent companion review and deals with post-match fatigue mechanisms and recovery kinetics of physical performance (sprints, jumps, maximal strength and technical skills), cognitive, subjective and biochemical markers. The companion review will analyse recovery strategies used in contemporary professional soccer. Soccer involves many physically demanding activities including sprinting, changes in running speed, changes of direction, jumps and tackles, as well as technical actions such as dribbling, shooting and passing. These activities lead to a post-match fatigue that is linked to a combination of dehydration, glycogen depletion, muscle damage and mental fatigue. The magnitude of soccer match-induced fatigue, extrinsic factors (i.e. match result, quality of the opponent, match location, playing surface) and/or intrinsic factors (i.e. training status, age, gender, muscle fibre typology), potentially influence the time course of recovery. Recovery in soccer is a complex issue, reinforcing the need for future research to estimate the quantitative importance of fatigue mechanisms and identify influencing factors. Efficient and individualized recovery strategies may consequently be proposed.

1. Introduction

In elite soccer, the number of competitive matches per season, including domestic, continental and international matches, is very high. During the 2009–10 season ending with the Fédération Internationale de Football Association (FIFA) World Cup in South Africa, several Spanish players played up to 70 competitive matches. Participation in a single match leads to acute fatigue characterized by a decline in physical performance over the following hours and days.[1,2] Several studies have reported that more than 72 hours are required to achieve pre-match values for physical performance, as well as normalizing muscle damage and inflammation among elite,[1,2] first- and second-division players.[3-5] During periods where the schedule is particularly congested (i.e. two matches per week over several weeks), the recovery time allowed between two successive matches lasts 3–4 days, which may be insufficient to restore normal homeostasis within players. As a result, players may experience acute and chronic fatigue potentially leading to underperformance and/or injury. Ekstrand et al.[6] showed that players who ‘underperformed’ at the 2002 FIFA World Cup had played a mean of 12.5 matches during the 10 weeks before the event. In comparison, those who performed above expectations had only played nine matches over the same period. In addition, Dupont et al.[7] reported a 6.2-fold higher injury rate in players who played two matches per week compared with those who played only one match per week. During congested schedules, recovery strategies are commonly used in an attempt to regain performance faster and reduce the risk of injury.

A soccer match leads to a physical performance decrement associated with the disturbance of psychophysiological parameters that progressively return to initial values during the recovery process. This article is Part I of a subsequent companion review and deals with (i) post-match fatigue mechanisms; and (ii) recovery kinetics of physical performance, subjective and biochemical markers. The companion review will analyse recovery strategies used by professional soccer teams. This review is justified, given the requirements to recover quickly in order to play mid-week matches or to train hard quicker. It aims to present a pertinent synthesis of research on the fatigue accumulated in elite players following a soccer match and the subsequent recovery process, including the influence of intrinsic and extrinsic factors on the time course of recovery. It also aims to identify relevant markers for future research.

2. Post-Match Fatigue

Soccer involves many physically demanding activities including sprinting, changes in direction and running speed, jumps and tackles, as well as technical actions such as dribbling, shooting and passing. In performing these activities, a decline in performance known as fatigue can occur. Generally, fatigue is defined as any decline in muscle performance associated with muscle activity.[8] In soccer, fatigue occurs temporarily after short-term intense periods in both halves; towards the end of the match[9] and after the match. Rampinini et al.,[10] for example, observed reductions in knee extensor maximal voluntary activation and electromyographical activity (–8%; $p<0.001$ and –12%; $p=0.001$, respectively) and knee extensor peak torque responses to paired stimulations at 10 Hz (–9%; $p<0.001$) after a match. As mechanisms that cause fatigue during a match have already been reviewed,[9,11] this section focuses mainly on the potential mechanisms that contribute to post-match fatigue. Match-related fatigue is determined by a combination of central and peripheral factors.[10,12] The decline in performance observed at the end of a match arises from a combination of several factors involving mechanisms from the central nervous system to the muscle cell itself and energy production.[13]

2.1 Dehydration

A negative fluid balance is a common feature observed after soccer matches, given that the soccer rules limit the opportunity for players to rehydrate. The level of dehydration depends upon climatic and atmospheric conditions (weather, wind, temperature, humidity and altitude). After a match played in a hot environment (31.2–31.6°C), Mohr et al.[14] reported a net fluid loss of mean ± standard error of mean (SEM) 1.5 ± 0.1 l or more than 2% of the initial body mass. In addition, a significant correlation ($r = 0.73$; $p < 0.05$) was observed between the net fluid loss during the match and the fatigue index in a post-match sprint test. Moderate fluid deficits corresponding to ~2% of body mass are common even in soccer matches played in thermoneutral conditions.[1,15] Although moderate dehydration does not impair anaerobic performance,[16,17] technical ability[17] and cognitive performance,[18,19] some studies have shown that moderate fluid loss is detrimental to endurance exercise performance.[20-22] As dehydration is associated with impaired endurance performance, the time to rehydrate appears crucial. After intermittent cycling exercise leading to a dehydration of 2% of body mass, the main factors that influenced post-exercise rehydration processes were the volume (150% of sweat loss) and composition of the fluid consumed (sodium concentration: 61 mmol/L).[23] It is likely that dehydration plays a limited role in post-soccer match fatigue, as the time to rehydrate is relatively short (6 hours) as long as guidelines are respected.[23] Nevertheless, rehydration appears a determinant factor during the post-match recovery process, as loss of intracellular fluid volume reduces rates of glycogen and protein synthesis, while high-cell volume contributes to stimulate these processes.[24,25]

2.2 Glycogen Depletion

In a soccer player, muscle glycogen is probably the most important substrate for energy production and the decrement in high-intensity distance frequently observed at the end of a match[26,27] may be related to depletion of glycogen in some muscle fibres.[11,28-30] Krustrup et al.[29] reported that before three matches played by 31 fourth division Danish players, most of all fibres (mean ± SEM 73 ± 6%) were rated as full with glycogen, whereas this value was lower ($p < 0.05$) after match (mean ± SEM 19 ± 4%). According to these authors, it is possible that such a depletion of glycogen in some fibres does not allow for a maximal effort in single and repeated sprints. The time course of muscle glycogen repletion after a high-level soccer match is between 2 and 3 days. Jacobs et al.[28] showed that muscle glycogen concentration with eight Swedish top-level players was about 50% of the pre-match value 2 days after a match. Krustrup et al.[30] observed that even when seven first- and second-division Danish players ingested a diet high in carbohydrates, muscle glycogen contents immediately and 24 hours after a match were 43% ($p < 0.001$) and 27% ($p < 0.001$) lower than pre-match values, respectively. Forty-eight hours after the match, the glycogen level was not significantly different (–9%; $p = 0.096$) to pre-match values.

2.3 Muscle Damage

During a soccer match, intense activities, such as sprints with short distances of deceleration in order to stop or change direction,[31] kick ball,[32] shots on goal,[32] tackles,[32] maximal jumps[32,33] or direct contacts with opposing players,[32] are repetitively performed. These activities involve many eccentric muscle contractions and have the potential to induce muscle damage.[34-36] Indeed, changes in direction, accelerations and decelerations are particularly damaging to muscle. In a comparison of the impact of the soccer-specific Loughborough Intermittent Shuttle Test (LIST)[37] versus a soccer match on muscle damage, Magalhães et al.[5] explained the absence of additional signs of muscle damage in the match when compared with LIST by the number of turns, including accelerations and decelerations in the LIST. Eccentric muscle contractions during these activities are considerable and may explain the marked increase in both muscle soreness and markers of muscle damage observed after the LIST.[38] A topic of interest for future studies may be the comparison of the impact of a soccer match and simulated soccer exercise[12,39,40] on muscle damage markers. Because simulated soccer exercises do not include activities such as contact, jumps, tackles and shots present during a match, these comparisons may help to identify activities that are particularly damaging to muscles. More individualized recovery strategies could be devised on the basis of muscle-damaging activities performed during the match.[41] Exercises to which players are unaccustomed can also induce muscle damage.[42] Consequently, when players stop or reduce practice during off-season or during an injury period, the restart is likely to be characterized by higher muscle damage.

Muscle damage is ascribed to mechanical disruption of the fibre, including membrane damage, myofibrillar disruptions characterized by myofillament disorganization and loss of Z-disk integrity,[43] while subsequent damage is linked to inflammatory processes and to changes in excitation-contraction coupling within muscles.[42] The severity of the muscle damage varies from microinjury of a small number of fibres to disruption of a whole muscle. Muscle damage is characterized by a temporary decrease in muscle function, an increase in intracellular proteins in blood, increased muscle soreness and an increased swelling of the involved muscle group.[44] Consequently, the main following markers are currently used to study muscle damage: maximal voluntary contraction strength, blood markers such as creatine kinase (CK) and myoglobin concentrations, muscle pain, range of motion and swelling.

Muscle damage can also disturb the time course of mechanisms linked to performance recovery after a soccer match. Asp et al.[45] observed that 2 days after eccentric exercise, the glycogen content of damaged muscle was lower compared with control muscle (mean ± SEM 402 ± 30 mmoL/kg dry weight [dw] vs 515 ± 26 mmoL/kg dw; $p < 0.05$) with a predominant effect on fast-twitch fibres. The mechanisms for the impaired glycogen synthesis following eccentric exercise remain unknown but the time course of muscle glycogen synthesis after eccentric exercise might be related to the inflammatory cell response to muscle damage.[46]

In summary, the repetition of changes of direction, accelerations and decelerations throughout a soccer match induces muscle damage leading to a marked inflammatory response and associated upregulated oxidative stress during recovery. The resulting structural changes in proteins important for force production may cause reduced maximal force-generating capacity and impaired physical performance during the hours and days following the match. Any delay in the repair of muscle damage may additionally impact the outcome of several mechanisms taking place during recovery. As a consequence, muscle damage is likely a major factor to consider in an attempt to explain post-soccer match fatigue.

2.4 Mental Fatigue

Participating in a soccer match leads to a physiological disturbance but also induces psychological stress on players due to the need for sustained concentration, perceptual skills and decision making combined with opponent pressure during the match. During a match, the playing environment is constantly changing, players must pick up information regarding the ball, teammates and opponents before deciding on an appropriate response based upon current objectives (e.g. strategy, tactics) and action constraints (e.g. technical ability, physical capacity).[47] Working on cognitively demanding tasks for a considerable time often leads to mental fatigue, which can impact performance. Numerous studies[48-50] reported that fatigued participants are still able to perform highly over-learned, automatic skills, whereas their performance significantly deteriorates when tasks require the voluntary allocation of attention. Greig et al.[51] examined the cumulative effect of completing a continuous vigilance task on the physiological responses to soccer-specific intermittent activity. They observed that performance of a vigilance task, quantified as the number of errors, deteriorated significantly during the final 30 minutes of the second half. Mental fatigue may also impact physical performance. Marcora et al.[52] measured tolerance to high-intensity cycling exercise (i.e. time-to-exhaustion test at 80% peak power output) after 90 minutes of a demanding cognitive task or 90 minutes of watching emotionally neutral documentaries acting as a control. They showed that the cognitive task induced a state of mental fatigue that significantly ($p < 0.01$) reduced time to exhaustion compared with the control condition (–15%). Studies examining the influence of soccer exercise on cognitive performance have demonstrated conflicting results.[18,22,51,53,54] Discrepancies between studies may be explained by physiological changes occurring during exercise (e.g. plasma glucose levels, core temperature and level of hydration) that may all affect cognitive performance[18] and/or the effect of exercise-induced physical arousal on cognitive performance.[51,54] Moreover, these studies selected different cognitive tests with varying sensitivity to test different aspects of the cognitive function. Finally, the influence of learning processes with the task procedures on results should not be excluded.[53] It is important that future studies take into account all these parameters to accurately evaluate the influence of soccer match-induced mental fatigue on the recovery time course of both cognitive and physical performance.

The inconvenience and stress of travel is another factor that may increase mental fatigue in players. Reported detrimental effects of travel on team-sport performance may be explained by the disruption of circadian rhythms (jet lag or arrival during the night) and/or the process of travel, along with the associated stress, restricted motion, unfamiliar sleeping surroundings leading to sleep disturbances[55] and poorer quality of sleep.[56] When the competitive fixture list is congested, there may be insufficient time in between matches for participants to recover their psychological resources,[57] potentially leading to lack of motivation and mental burnout. In a literature review, Nederhof et al.[58] stated that chronic fatigue affects cognitive performance.

Match outcome (win vs loss) may also influence mood state and affect mental fatigue post-match. Further study could investigate the effect of match result on the mental recovery process and also be included in the studies focusing on the theme of mental fatigue. Future studies are also needed to determine how acute mental fatigue induced by a soccer match and/or chronic fatigue induced by congested calendar and travel impact post-match fatigue.

2.5 Summary

Post-soccer match fatigue has many potential causes (dehydration, glycogen depletion, muscle damage, mental fatigue). Because recovery of muscle function is chiefly a matter of reversing the major cause of fatigue, focus for the future may be to identify the mechanism(s) that contribute(s) to post-soccer match fatigue and estimate their quantitative importance. Recovery strategies may consequently be targeted against the major cause of fatigue.

3. Time Course of Recovery Markers

Post-soccer match fatigue is characterized by a decline in physical performance during the hours and days following the match (tables I to IV). Recovery is considered complete when the player is able to reach or exceed his benchmark performance in a particular activity.[70] During congested periods, the recovery time between two successive matches lasts 72 hours, which may be insufficient to normalize physical performance.[1,3-5] In this section, the magnitude of fatigue induced by soccer match and the relevance of markers to track the recovery process is reviewed.

3.1 Magnitude of Fatigue

The time course of physical performance recovery following competitive match, friendly match and simulated soccer exercise is presented in tables I–IV. Sprint performance is impaired immediately after exercise by –2% to –9% (table I). Thereafter, the recovery of sprint performance differs largely between studies with completed recovery occurring between 5[1] and 96 hours.[2]

Table I. Recovery time course for single sprint and repeated-sprint ability following soccer-specific exercise[a]

Study	Subjects	Soccer-specific exercise	Performance task	Time (hours after soccer-specific exercise)[b]									
				0	5	21	24	27	45	48	51	69	72
Sprint													
Andersson et al.[1]	9 elite F	Soccer match	20 m	↑3.0	NS	NS		NS	NS			NS	
Ascensão et al.[3]	16 trained M	Soccer match	20 m	↑~7.0			↑~6.0			↑~5.0			↑~5.0
Fatouros et al.[4]			20 m				↑~8.0			↑~5.0			↑~3.0
Ispirlidis et al.[2]	14 elite M	Soccer match (68 min)	20 m				↑2.0			↑2.5			↑1.6
Magalhães et al.[5]	16 trained M	Soccer match	20 m	↑~9.0			↑~7.0			↑~6.0			↑~5.0
Rampinini et al.[10]	20 elite M	Soccer match	40 m	↑~3.0			↑~1.0			NS			
Ingram et al.[59]	11 trained M	Simulated team sport exercise[60]	20 m							↑1.7			
Magalhães et al.[5]	16 trained M	LIST[37]	20 m	↑~5.0			↑~1.0			↑~1.0			↑~1.0
RSA													
Krustrup et al.[29]	11 trained M	Soccer match	5×30 m	↑2.8									
Krustrup et al.[61]	14 elite F	Soccer match	3×30 m	↑4									
Mohr et al.[62]	16 trained M	Soccer match	3×30 m	↑2									
Bailey et al.[63]	10 trained M	LIST[37]	11×15 m							NS			
Ingram et al.[59]	11 trained M	Simulated team sport exercise[60]	10×20 m							NS			

a Blank cells indicate no data reported.

b Data presented are means (%).

F = female; **LIST** = Loughborough Intermittent Shuttle Test[37]; **M** = male; **NS** = non-significant; **RSA** = repeated-sprint ability; ↑ indicates increase.

When tested immediately after exercise, jump performance decrement ranges from no decrement to –12% (table II). Jump performance completely recovered from 48 hours[2,4] to more than 72 hours after the exercise.[1,5] Several studies have used the maximal voluntary strength of knee flexors/extensors as a recovery marker.[1,3,5,40,59,63,67,68] Irrespective of contraction mode (concentric/eccentric) and speed of assessment, the strength decrement of knee flexors immediately after exercise ranges from no decrement to –36% (table III); and the strength decrement of knee extensors immediately after exercise ranges from no decrement to –25% (table IV).

Several extrinsic/intrinsic causes are susceptible to explain differences between studies in the magnitude of acute exercise-induced performance decrement and the subsequent recovery time course of performance. First, several studies have pointed out the high variability and poor reliability of physical performance such as high-intensity running distance during soccer matches.[7,27,71] Physical performance depends not only on the fitness level but also on match contextual factors, such as match status (i.e. whether the team is winning, losing or drawing),[72] quality of the opponent (strong or weak)[72] and match location (i.e. playing at home or away).[72] The nature of the match (i.e. friendly, domestic, continental or international) may similarly influence the number and intensity of runs, collisions carried out by players during the match, as well as the intensity of sustained concentration. Other extrinsic factors potentially influencing the work rate of players are the climatic conditions and type of terrain (e.g. grassy, muddy, snowy, artificial).[73] Differences in the pattern of soccer activities such as accelerations and decelerations, changes of direction[74] and type of playing surface may possibly influence the match-induced strain on muscles and the time course of recovery. Collectively, all these factors contribute to an amount of fatigue that

Table II. Recovery time course for jump performance following soccer-specific exercise[a]

Study	Subjects	Soccer-specific exercise	Performance task	Time (hours after soccer-specific exercise)[b]									
				0	5	21	24	27	45	48	51	69	72
Andersson et al.[1]	9 elite F	Soccer match	CMJ	↓4.4	↓~2.0	↓~4.0		↓~2.0	↓~2.0		↓~2.0	↓~3.0	
Fatouros et al.[4]	20 trained M	Soccer match	CMJ				↓10.0			NS			NS
Ispirlidis et al.[2]	14 elite M	Soccer match (68 min)	CMJ				↓9.3			NS			NS
Krustrup et al.[61]	15 elite F	Soccer match	CMJ	NS									
Magalhães et al.[5]	16 trained M	Soccer match	CMJ	↓~12.0			↓~8.0			↓~8.0			↓~8.0
Thorlund et al.[64]	9 elite M	Soccer match	CMJ	NS									
Bailey et al.[63]	10 trained M	LIST[37]	SJ				↓~2.8			↓~5.6			
Magalhães et al.[5]	16 trained M	LIST[37]	CMJ	↓~12.0			↓~10.0			↓~9.0			↓~10.0
Oliver et al.[65]	10 trained M	NMT	CMJ	↓10.4									
			SJ	↓4.9									
Robineau et al.[12]	8 trained M	Soccer match modelling	CMJ	NS									
Robineau et al.[12]	8 trained M	Soccer match modelling	SJ	↓8.0									

a Blank cells indicate no data reported.

b Data presented are means (%).

CMJ = countermovement jump; **F** = female; **LIST** = Loughborough Intermittent Shuttle Test[37]; **M** = male; **NMT** = non-motorized treadmill; **NS** = nonsignificant; **SJ** = squat jump; ↓ indicates decrease.

may greatly vary from one match to another. Second, intrinsic causes such as training status, age,[75] gender and muscle fibre typology[76] may explain inter-individual differences in recovery potential among players in the same team. Identifying these intrinsic factors is a prelude to the development of individualized recovery protocols. Finally, the physical tests (volume, intensity, order) performed during the recovery process could also explain the discrepancies between studies on recovery time courses and will be studied in the next section.

3.2 Relevance of Recovery Markers

The battery of tests performed during the recovery process can affect the recovery time course. Numerous hard and long physical tests performed at frequent intervals could induce a cumulative fatigue altering the recovery kinetics of the initial exercise. In this respect, a control group with players performing physical tests but not the initial exercise should be implemented in studies.[2] An appropriate battery of tests should not affect the initial recovery process caused by the experimental condition (i.e. the match). A balance has to be found between the number, the frequency and the order of the tests to make sure these do not affect the following results. Familiarization with both the experimental condition and the battery of tests is another essential step to analyse recovery kinetics. In addition, investigators should check the fatigue induced by their test battery during the pre-test in order to make sure it does not lead to additional fatigue, as well as the reliability of the tests selected. The balance between validity of the recovery marker and its relevance to track the recovery process is another issue to be resolved. For example, 20 m sprint performance is the most ecologically valid[77] recovery marker of sprint ability, since the mean duration of a sprint during an elite soccer match is 2 seconds or about 17 m.[78] However, sprinting over 20 m is insufficient to achieve maximal speed. Conversely, the isolation of muscle groups during maximal voluntary strength assessment reduces the validity of the measurements in regard to the performance of multijoint movements,

Table III. Recovery time course for knee flexor maximal voluntary strength following soccer-specific exercise[a]

Study	Subjects	Soccer-specific exercise	Performance task (°/sec)	Time (hours after soccer-specific exercise)[b]									
				0	5	21	24	27	45	48	51	69	72
Andersson et al.[1]	9 elite F	Soccer match	K FL CON (60)	↓9.4	↓~4.0	↓~4.0		↓~6.5			NS	NS	
Ascensão et al.[3]	16 trained M	Soccer match	K FL CON (90)	↓~15.0			↓~14.0			↓~10.0			↓~8.0
Magalhães et al.[5]	16 trained M	Soccer match	K FL CON (90)	↓~15.0			↓~15.0			↓~11.5			↓~7.0
Thorlund et al.[64]	9 elite M	Soccer match	K FL (0)	↓7.0									
Bailey et al.[63]	10 trained M	LIST[37]	K FL (0)				↓21.0			↓14.0			
Delextrat et al.[66]	8 trained M	LIST[37]	K FL CON (60)	↓17.7									
			K FL CON (180)	↓36.4									
			K FL ECC (60)	↓31.4									
			K FL ECC (180)	↓26.2									
Delextrat et al.[39]	14 trained F	LIST[37] + shots	K FL ECC (120)	NS									
Greig[67]	10 elite M	MT	K FL CON (60)	NS									
			K FL CON (180)	NS									
			K FL CON (300)	NS									
			K FL ECC (180)	↓19.0									
			K FL ECC (300)	↓24.0									
Ingram et al.[59]	11 trained M	Simulated team sport exercise[60]	K FL (0)							↓8.4			
Magalhães et al.[5]	16 trained M	LIST[37]	K FL CON (90)	↓~17.5			↓~16.0			↓~13.7			↓~8.7
Rahnama et al.[68]	13 trained M	MT	K FL CON (60)	↓17.3									
			K FL CON (120)	↓15.2									
			K FL CON (300)	↓15.0									
			K FL ECC (120)	↓16.8									
Robineau et al.[12]	8 trained M	Soccer match modeling	K FL (0)	↓8.2									
			K FL CON (60)	↓12.3									
Small et al.[40]	16 trained M	SAFT90[69]	K FL CON (120)	NS									
			K FL ECC (120)	↓16.8									

a Blank cells indicate no data reported.

b Data presented are means (%).

CON = concentric; **ECC** = eccentric; **F** = female; **K FL** = knee flexors; **LIST** = Loughborough Intermittent Shuttle Test[37]; **M** = male; **MT** = motorized treadmill; **NS** = nonsignificant; **SAFT90** = 90 min soccer-specific aerobic field test;[69] ↓ indicates decrease.

but it increases the reliability of the assessment. In this section, physical performance and subjective and biochemical markers frequently used in studies related to soccer are reviewed, with emphasis on their relevance for tracking the recovery process.

3.2.1 Physical Performance Markers

A computerized literature search was performed in PubMed in April 2012. The following keywords were used in different combinations: 'soccer', 'football', 'recovery', 'test', 'sprint', 'jump', 'flexibility', 'range of motion', 'stiffness', 'endurance', 'aerobic', 'passing', 'shooting', 'dribbling', 'juggling', 'skill' and 'technical'. The physical performance markers proposed were retrieved for review on the basis of their relevance in respect to soccer performance and their reliability.

Sprints, Repeated-Sprint Ability and Agility

Short-sprinting performance is an important determinant of match-winning actions. A distance of 20 m is most commonly used to assess the ability of players to sprint during recovery after a soccer match (table I). The energy provision during a single sprint is different to that in repeated sprints performed in an intermittent exercise pattern.[79] Significant correlations were found

Table IV. Recovery time course for knee extensor maximal voluntary strength following soccer-specific exercise[a]

Study	Subjects	Soccer-specific exercise	Performance task (°/sec)	Time (hours after soccer-specific exercise)[b]									
				0	5	21	24	27	45	48	51	69	72
Andersson et al.[1]	9 elite F	Soccer match	K EX CON (60)	↓7.1	↓~2.5	↓~6.5		NS			NS	NS	
Ascensão et al.[3]	16 trained M	Soccer match	K EX CON (90)	↓~10.0			↓~10.0			↓~6.5			↓~4.0
Magalhães et al.[5]	16 trained M	Soccer match	K EX CON (90)	↓~7.3			↓~7.3			↓~6.1			↓~4.7
Rampinini et al.[10]	20 elite M	Soccer match	K EX (0)	↓~11.0			↓~6.0			NS			
Thorlund et al.[64]	9 elite M	Soccer match	K EX (0)	↓11.0									
Bailey et al.[63]	10 trained M	LIST[37]	K EX (0)				NS			NS			
Delextrat et al.[66]	8 trained M	LIST[37]	K EX CON (60)	↓16.6									
			K EX CON (180)	↓13.7									
Delextrat et al.[39]	14 trained F	LIST[37] + shots	K EX CON (120)	NS									
Greig[67]	10 elite M	MT	K EX CON (60)	NS									
			K EX CON (180)	NS									
			K EX CON (300)	NS									
Ingram et al.[59]	11 trained M	Simulated team sport exercise[60]	K EX (0)							↓5.2			
Magalhães et al.[5]	16 trained M	LIST[37]	K EX CON (90)	↓~9.5			↓~10.5			↓~8.5			↓~7.0
Rahnama et al.[68]	13 trained M	MT	K EX CON (60)	↓15.5									
			K EX CON (120)	↓8.2									
			K EX CON (300)	↓8.5									
			K EX ECC (120)	↓6.8									
Robineau et al.[12]	8 trained M	Soccer match modelling	K EX (0)	↓18.5									
			K EX CON (60)	↓12.2									
			K EX ECC (60)	↓25.4									
Small et al.[40]	16 trained M	SAFT90[69]	K EX CON (120)	NS									

a Blank cells indicate no data reported.

b Data presented are means (%).

CON = concentric; **ECC** = eccentric; **F** = female; **K EX** = knee extensors; **LIST** = Loughborough Intermittent Shuttle Test[37]; **M** = male; **MT** = motorized treadmill; **NS** = nonsignificant; **SAFT90** = 90 min soccer-specific aerobic field test;[69] ↓ indicates decrease.

between repeated-sprint ability test mean time, and very high-intensity running ($p<0.01$) and sprinting distance ($p<0.01$) quantified during official matches using a computer-aided motion analysis system.[80] Repeated-sprint ability tests may consequently be used during the recovery process to verify if a player is able to meet the high intermittent demands of a soccer match after play. Various repeated-sprint ability tests have been proposed in the literature: six 20 m maximal sprints on a 15-second cycle;[81] the repeated-shuttle-sprint ability (6 × 40 m sprints with 20 seconds of recovery between sprints);[82] the Bangsbo sprint test (7 × 34.2 m sprints with 25 seconds of active recovery periods between sprints);[83] Baker's 8 × 40 m sprint test;[84] the Intermittent Anaerobic Running Test (IAnRT; 10 × 20 m sprints with 20-second recovery periods between the sprints);[85] the Carminatti's test (repeated bouts of 5 × 12-second shuttle running at progressively faster speeds until volitional exhaustion)[86] were all found to be reliable with coefficients of variation (CV) inferior to 10% and intraclass correlation coefficients (ICC) superior to 0.80.[87] However, a repeated-sprint ability test is a more reliable method when results are expressed as the total sprint time rather than fatigue data.[81,88,89] Repeated-sprint ability tests are physically exhausting, which may explain the paucity of studies investigating the recovery time course of repeated-sprint ability (table I).[59,63] The use of repeated-sprint tests with fewer sprints[61,62] may be easier to implement during the recovery process. Further studies are still required to compare the recovery time course of repeated-sprint ability and single sprint in professional soccer players. Analysis of the time-recovery course of agility would also be pertinent.[90]

Jumps

Jumping performance is an important determinant of success in soccer.[91] Squat jump (SJ) and countermovement jump (CMJ) are the main jumps generally assessed after a soccer match (table II) and are easy and quick to implement in order to test anaerobic qualities. Vertical jumping height correlates well with maximal strength in half squats ($r=0.78$; $p<0.02$), 10 m ($r=0.72$; $p<0.001$) and 30 m sprint time ($r=0.60$; $p<0.01$).[92] Moir et al.[93] reported that the test-retest reliability for SJ and CMJ was high: ICC ranged from 0.89 to 0.95, while CV ranged from 1.9% to 2.6%. For measurement accuracy this test has to be assessed by a portable force plate and, to a lesser extent, by a contact mat;[94] jump testing procedures have to be standardized[95] and a standardized warm-up before CMJ testing should not include static stretching.[96-98] An SJ test uses a concentric-only action while a CMJ test uses a stretch-shortening cycle (SSC), with differences in the recovery kinetics between conditions.[99,100] Stretch-shortening-cycle recruitment is strongly implicated with exercise fatigue.[101] As soccer match play involves many SSC actions, CMJ performance may be more appropriate to verify if a player is ready to meet the demands of the match. Other jump tests have been proposed in the literature. The five-jump test (five forward jumps with alternating left- and right-leg contacts)[102] may be an explosive strength diagnostic tool to estimate changes in neuromuscular fatigue in athletes who complete substantial 'on legs' training.[103,104] Triple-hop distance test (three maximal hops forward on the dominant limb) and the test proposed by Bosco et al.[105] (maximal number of jumps performed during a certain period of time) are also useful and reliable tests to predict an athlete's lower limb strength and power.[106,107]

Maximal Voluntary Strength

Match-related fatigue that induces impairment of maximal voluntary strength is determined by a combination of central and peripheral factors both immediately after the match and during the recovery process.[10,12] Central fatigue appears to be the main cause of the decline in maximal voluntary strength, while peripheral fatigue seems to be more related to muscle damage and inflammation.[10] Repetition of changes of direction, accelerations and decelerations throughout a soccer match induces muscle damage. Warren et al.[108] stated that measurement of maximal voluntary contraction torque provides the best method for quantifying muscle damage as it is accurate and reliable. Many authors have reported a greater loss of strength in the knee flexors, compared with the knee extensors after fatigue induced by soccer-specific exercise.[39,40,66-68] The fact that knee flexors are particularly prone to fatigue in soccer may explain why these muscles are commonly strained in soccer (12% of the total injuries),[109] with the greatest injury rate occurring in the two 15-minute periods at the end of both halves.[110] Many authors performed the isokinetic test on the dominant leg only.[1,3,5,40,59,63,67] A justification may be that a greater number of injuries are sustained to the players' dominant side compared with the non-dominant side (50% vs 37%; $p < 0.01$).[110] Greig[67] reported the test-retest reliability of peak concentric knee extensor/flexor torque and peak eccentric knee flexor torque at isokinetic speeds of 60°, 180° and 300°/second. The reliability was good (ICC > 0.75) to excellent (ICC > 0.90) with low-velocity measures (i.e. 60°/second) proven to be the most reliable. However, these velocities are still far away from multijoint movement velocities, with velocity as high as 970°/second reported for knee flexion during sprinting.[111] Differences in reliability also exist between flexion and extension. In a meta-analytic review, Hopkins et al.[112] reported a higher CV for flexion than extension isokinetic tests leading to a ratio of CV for flexion/extension equal to 1.3. Extension is consequently a more reliable mode of isokinetic movement than flexion. The functional ratio between the eccentric strength of the knee flexors and the concentric strength of the knee extensor muscles has been considered to be indicative of the joint-stabilizing effect of the knee flexors during knee extension.[113] Simulated soccer exercise results in significant reductions in the functional hamstrings-to-quadriceps ratio ranging from 8.0% to 29.8% between the start and end of the exercise.[39,40,66-68] This ratio could be used to estimate the player's injury risk during recovery from a soccer match.

Flexibility

Contradictory findings have been reported in the literature concerning the effect of flexibility on performance and injury rate.[114] However, as range of motion provides a reliable means of quantifying the functional decrements resulting from muscle damage,[108] the use of various reliable flexibility tests (i.e. sit and reach, back-against-the-wall v-seat and reach test, leg lift from supine position, backward leg lift from a prone position, straddle in supine position and lateral leg lift while lying on the side) should be encouraged in future studies.[115] There is currently a paucity of data in the literature regarding the recovery time course of flexibility after a soccer match. Ispirlidis et al.[2] used knee range of motion as a recovery marker. They reported that the knee range of motion was decreased within the 48-hours post-match. Cone et al.[116] did not find time-related changes in lower extremity vertical stiffness in jumping after a soccer match simulation.

Aerobic Performance

As a result of the match duration, soccer is mainly dependent upon aerobic metabolism with the maximal oxygen uptake in male outfield players varying from about 50–75 mL/kg/min.[117] The assessment of aerobic performance during the recovery process after a soccer match requires careful consideration due to the fatigue induced by such tests. Future studies are required to propose indirect evaluation of aerobic fitness using other protocols such as repeated-sprint tests.[118-120] A topic of interest may also be to determine if aerobic fitness can influence the recovery time course of anaerobic markers during the hours and days following a match.

Technical Skills

Success in soccer match play is associated with performance in skill-related actions, such as dribbling, passing and shooting.[121,122] Russell and Kingsley[122] extensively reviewed soccer skill tests, which can be categorized into tests that assess ball control and tests that measure ball accuracy. Ali et al.[123] assessed the reliability of the Loughborough Soccer Passing Test (LSPT) and the Loughborough Soccer Shooting Test (LSST) – two common tests that measure ball accuracy – among elite players. They reported that shooting is the most variable skill since the LSST exhibited ICC from 0.31 to 0.64 and CV from 3.5% to 49.4%, depending on the variable whereas the LSPT exhibited an ICC of 0.42 and a CV of 11.2%. The high variability in shooting performance has also been confirmed by other authors.[124] However, shooting performance appears most susceptible to deterioration after exercise[122,125-127] than dribbling[126-128] and passing for which equivocal findings are reported.[10,126,129-133] These equivocal findings may be linked to differences in the standard of soccer players.[10,129] Fatigued players may actually be less likely to use the correct technique and thus more likely to sustain a more serious injury while performing poorly executed actions.[134] The restoration of soccer-specific skills during the recovery process and especially shooting should be followed in future studies to ensure that the recovery of players is adequate.

Summary

A battery of tests to track the recovery process should include measures of physical performance.[70] The order of the tests is an important factor to take into account: a battery of tests beginning with brief anaerobic tests (e.g. CMJ, SJ) and finishing with exhausting tests (e.g. repeated sprints or aerobic performance) seems appropriate. Evaluation of other recovery markers (i.e. cognitive, subjective and biochemical markers) is required to investigate the underlying physiology and mental component of the recovery process.

3.2.2 Cognitive Function

Perceptual abilities (such as reaction time, decision making, visual scanning, spatial awareness and anticipation) are required to execute soccer-specific skills. Nederhof et al.[58] proposed that demanding tasks of psychomotor speed (e.g. the Vienna Determination Test performed under time pressure) might be a relevant variable for the early detection of disturbed stress regeneration balance. Fatigue led to an increased number of errors and an increase in reaction time.[49] Future studies may investigate the influence of soccer match-induced mental fatigue on the recovery time course of psychomotor speed performance. Consequently, psychomotor speed may potentially be used as an additional recovery marker to track the recovery process. However, steps to ensure familiarization should be carefully followed so that the results can be considered stable and reliable. Reliability of the tests should also be checked before starting the experimentation.

3.2.3 Subjective Markers

Assessment of changes in subjective feelings of muscle soreness also constitutes a pertinent marker of recovery. It is important that subjects are fully familiarized with any perceptual rating scale. Since this is a highly individualized measurement, it should be used primarily to detect intra-individual changes. Studies related to recovery from a soccer match measured the recovery time course of subjective muscle soreness with emphasis on lower body muscles i.e. knee extensors and flexors.[2,4,38,59] Soccer players exhibit pronounced muscle soreness immediately post-exercise. Muscle soreness usually peaks 24–48 hours after exercise, an exercise-induced phenomenon referred to as delayed onset muscle soreness (DOMS).[135] To account for the multifactorial aspects of the recovery process, subjective ratings of quality of sleep, fatigue and stress may be additionally assessed.[136] Kenttä and Hassmén[137] developed the total quality of recovery scale to measure psychophysiological recovery (i.e. mood states and body signals such as sensations of soreness or heaviness). The daily analysis of life demands for athletes questionnaire is also a useful non-fatiguing measure that can be used to monitor general changes in the fatigue and recovery states.[104]

3.2.4 Biochemical Markers

Muscle proteins CK and myoglobin leak into the plasma from skeletal muscle fibres when they are damaged. Immediately after exercise, rises in CK concentration range from +70% to +250%, peak at 24–48 hours after the match and return to baseline between 48 and 120 hours after depending on the magnitude of the peak: the higher the peak, the longer the time to return to baseline (table V). Discrepancies between studies may be due to the nature of the protocol (i.e. contact or noncontact exercise).[139] Although the validity of CK as a marker of muscle damage is questionable,[38,108,140] CK is used widely as the magnitude of increase is so great relative to other proteins. Moreover, CK remains elevated for several days in comparison to other proteins such as myoglobin that normalizes before 24 hours post-exercise.[3,5,63] Professional soccer players participating in daily

Table V. Recovery time course for biochemical markers following soccer-specific exercise[a]

Study	Subjects	Soccer-specific exercise	Time (hours after soccer-specific exercise)[b]										
			0	1	21	24	45	48	69	72	96	120	144
Creatine kinase													
Andersson et al.[1]	17 elite F	Soccer match	↑152		↑~190		↑~70		NS				
Ascensão et al.[3]	16 trained M	Soccer match	↑~75			↑~300		↑~300		↑~200			
Fatouros et al.[4]	20 trained M	Soccer match	↑200			↑350		↑600		↑500			
Ispirlidis et al.[2]	14 elite M	Soccer match (68 min)	↑154			↑400		↑710		↑637	↑358	NS	NS
Magalhães et al.[5]	16 trained M	Soccer match	↑~250			↑~750		↑~500		↑~350			
Rampinini et al.[10]	20 elite M	Soccer match	↑110			↑124		↑63					
Bailey et al.[63]	10 trained M	LIST[37]	↑~70	↑~130		↑~200		NS					
Ingram et al.[59]	11 trained M	Simulated team sport exercise[60]	↑147			↑310		↑136					
Magalhães et al.[5]	16 trained M	LIST[37]	↑~225			↑~600		↑~450		↑~250			
Thompson et al.[38]	7 trained M	LIST[37]	↑108			↑283		↑94		NS			
Uric acid													
Andersson et al.[1]	9 elite F	Soccer match	↑11		NS		NS		NS				
Andersson et al.[138]	16 elite F	Soccer match	↑11		NS		NS		NS				
Ascensão et al.[3]	16 trained M	Soccer match	↑~50			↑~15		↑~15		↑~20			
Fatouros et al.[4]	20 trained M	Soccer match	NS			↑34		↑47		NS			
Ispirlidis et al.[2]	14 elite M	Soccer match (68 min)	NS			↑~20		↑~25		↑~40	↑~25	NS	NS
Magalhães et al.[5]	16 trained M	Soccer match	↑~75			NS		NS		NS			
		LIST[37]	↑~25										

a Blank cells indicate no data reported.

b Data presented are means (%).

F = female; **LIST** = Loughborough Intermittent Shuttle Test[37]; **M** = male; **NS** = nonsignificant; ↑ indicates increase.

training have persistent high-resting CK values that make the establishment of baseline values difficult. In this respect, Mougios[141] introduced valuable reference intervals for CK assayed spectrophotometrically in male soccer players (83–1492 U/L at 37°C). Gender affects the reference interval for CK, with males having higher reference limits than females but age (range 7–44) does not seem to affect the reference interval.[141]

Muscle damage initiates a local inflammatory response involving the production of cytokines. These cytokines facilitate a rapid and sequential invasion of muscle by inflammatory cell populations that can persist for days to weeks while muscle repair, regeneration and growth occur.[142,143] The local production of cytokines is accompanied by a systemic response known as the acute phase response. Interleukin (IL)-6 is produced in larger amounts than any other cytokine and has been shown to precede that of other cytokines suggesting that IL-6 plays an initial role in the cytokine cascade.[2,142,144,145] IL-6 peaks immediately after the match, rapidly declines towards pre-exercise levels and is normalized 24-hours post-match.[2,146] The increase in the acute phase c-reactive protein (CRP) is more persistent with elevation reported up to 48-hours post-exercise.[59] CRP may be more sensitive than CK, myoglobin and lactate dehydrogenase to evaluate muscle damage induced by contacts.[147]

During a soccer match, high absolute levels of mitochondrial oxygen consumption combined with ischaemia-reperfusion events in skeletal muscle lead to the generation of reactive oxygen species

(ROS).[3] The inflammatory response to exercise-induced muscle injury also enhances ROS generation.[3] The increase in ROS production may overwhelm antioxidant capacity causing oxidative stress. Uric acid is largely used as an oxidative stress marker because it accounts for nearly one-third of the total antioxidant capacity increase during exercise.[2] Rises in uric acid concentrations range from no increase to +75% immediately after exercise and remain elevated up to 96 hours post-exercise (table V). In addition to uric acid, changes in many oxidative stress markers and antioxidants have been studied following a soccer match.[2-5,138] However, comparisons across studies are difficult as the markers studied are different.

Changes in hormones have also been studied following a soccer match. In respect to cortisol, conflicting results are present in the literature,[2,148] which may be explained by the large intraindividual and interindividual variability in responses.[148] Testosterone concentrations among young soccer players are still reduced 72 hours after playing full competitive matches on consecutive days whereas reductions in cortisol concentrations were unclear.[149] Maso et al.[150] found that it is more useful to follow variations in testosterone (an anabolic hormone) than variations in cortisol (a catabolic hormone) to determine the degree of tiredness in young international rugby players.

In conclusion, biochemical markers are useful to investigate the underlying physiology of the recovery process. An ideal biochemical marker should detect a major part of muscle damage, inflammatory response or oxidative stress; the CV between different assays of the same sample should be small in comparison with the difference between subjects; its levels should not vary widely in the same subjects under the same conditions at different times; it must employ chemically robust measurement technology; it must not be confounded by diet; and it should ideally be stable on storage.[151] Since no single biochemical marker can meet all these requirements, the use of a variety of biochemical markers is important to monitor the recovery process after a soccer match.

4. Conclusion

Fatigue following a soccer match is multifactorial and related to dehydration, glycogen depletion, muscle damage and mental fatigue. The recovery process of fatigue mechanisms is highly variable and depends on several confounding factors such as the magnitude of fatigue induced by a soccer match, as well as extrinsic and intrinsic factors. Markers used to study the recovery process must be reliable. Another parameter to take into account for studies on this theme concerns the balance between monitoring the recovery process after a real match or that after soccer-specific exercise simulating match-play. As a consequence of the unpredictable changes that occur during a real match, the recovery process can present a high interindividual variability. Variability of physical performance is high and is linked to many factors that are sometimes unpredictable such as scoring one or two goals during the first 15 minutes, which could reduce the high-intensity distance in the assessed team. Thus, tracking the recovery process after a real match appears to be valid but limited in practice as the results can change according to the match. Tracking the recovery process after exercise that simulates certain conditions of the match is interesting to both control and manipulate some variables. However, the applicability of findings arising from laboratory settings can be questioned in relation to the real-match context. Recovery in soccer is a complex issue reinforcing the need for future research to (i) estimate the quantitative importance of mechanism(s) that contribute(s) to post-match soccer fatigue; and (ii) identify influencing factors, targeting the major cause of fatigue at a specific timepoint, which should provide valuable information on what recovery strategies may be the most effective to be administered at that specific timepoint. Part II of this review will deal with recovery strategies used by professional soccer teams.

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References

1. Andersson H, Raastad T, Nilsson J, et al. Neuromuscular fatigue and recovery in elite female soccer: effects of active recovery. Med Sci Sports Exerc 2008 Feb; 40 (2): 372-80
2. Ispirlidis I, Fatouros IG, Jamurtas AZ, et al. Time-course of changes in inflammatory and performance responses following a soccer game. Clin J Sport Med 2008 Sep; 18 (5): 423-31
3. Ascensão A, Rebelo A, Oliveira E, et al. Biochemical impact of a soccer match-analysis of oxidative stress and muscle damage markers throughout recovery. Clin Biochem 2008 Jul; 41 (10-11): 841-51
4. Fatouros IG, Chatzinikolaou A, Douroudos II, et al. Time-course of changes in oxidative stress and antioxidant status responses following a soccer game. J Strength Cond Res 2010 Dec; 24 (12): 3278-86
5. Magalhães J, Rebelo A, Oliveira E, et al. Impact of Loughborough Intermittent Shuttle Test versus soccer match on physiological, biochemical and neuromuscular parameters. Eur J Appl Physiol 2010 Jan; 108 (1): 39-48
6. Ekstrand J, Waldén M, Hägglund M. A congested football calendar and the wellbeing of players: correlation between match exposure of European footballers before the World Cup 2002 and their injuries and performances during that World Cup. Br J Sports Med 2004 Aug; 38 (4): 493-7
7. Dupont G, Nedelec M, McCall A, et al. Effect of 2 soccer matches in a week on physical performance and injury rate. Am J Sports Med 2010 Sep; 38 (9): 1752-8
8. Allen DG, Lamb GD, Westerblad H. Skeletal muscle fatigue: cellular mechanisms. Physiol Rev 2008 Jan; 88 (1): 287-332
9. Mohr M, Krustrup P, Bangsbo J. Fatigue in soccer: a brief review. J Sports Sci 2005 Jun; 23 (6): 593-9
10. Rampinini E, Bosio A, Ferraresi I, et al. Match-related fatigue in soccer players. Med Sci Sports Exerc 2011 Nov; 43 (11): 2161-70
11. Bangsbo J, Mohr M, Krustrup P. Physical and metabolic demands of training and match-play in the elite football player. J Sports Sci 2006 Jul; 24 (7): 665-74
12. Robineau J, Jouaux T, Lacroix M, et al. Neuromuscular fatigue induced by a 90-minute soccer game modeling. J Strength Cond Res 2012 Feb; 26 (2): 555-62
13. Bigland-Ritchie B, Woods JJ. Changes in muscle contractile properties and neural control during human muscular fatigue. Muscle Nerve 1984 Nov-Dec; 7 (9): 691-9
14. Mohr M, Mujika I, Santisteban J, et al. Examination of fatigue development in elite soccer in a hot environment: a multi-experimental approach. Scand J Med Sci Sports 2010 Oct; 20 Suppl. 3: 125-32
15. Edwards AM, Noakes TD. Dehydration: cause of fatigue or sign of pacing in elite soccer? Sports Med 2009; 39 (1): 1-13
16. Cheuvront SN, Carter 3rd R, Haymes EM, et al. No effect of moderate hypohydration or hyperthermia on anaerobic exercise performance. Med Sci Sports Exerc 2006 Jun; 38 (6): 1093-7
17. Hoffman JR, Stavsky H, Falk B. The effect of water restriction on anaerobic power and vertical jumping height in basketball players. Int J Sports Med 1995 May; 16 (4): 214-8
18. Bandelow S, Maughan R, Shirreffs S, et al. The effects of exercise, heat, cooling and rehydration strategies on cognitive function in football players. Scand J Med Sci Sports 2010 Oct; 20 Suppl. 3: 148-60
19. Cian C, Barraud PA, Melin B, et al. Effects of fluid ingestion on cognitive function after heat stress or exercise-induced dehydration. Int J Psychophysiol. 2001 Nov; 42 (3): 243-51
20. Armstrong LE, Costill DL, Fink WJ. Influence of diuretic-induced dehydration on competitive running performance. Med Sci Sports Exerc 1985 Aug; 17 (4): 456-61
21. Cheuvront SN, Carter 3rd R, Sawka MN. Fluid balance and endurance exercise performance. Curr Sports Med Rep 2003 Aug; 2 (4): 202-8
22. Edwards AM, Mann ME, Marfell-Jones MJ, et al. Influence of moderate dehydration on soccer performance: physiological responses to 45 min of outdoor match-play and the immediate subsequent performance of sport-specific and mental concentration tests. Br J Sports Med 2007 Jun; 41 (6): 385-91
23. Shirreffs SM, Taylor AJ, Leiper JB, et al. Post-exercise rehydration in man: effects of volume consumed and drink sodium content. Med Sci Sports Exerc 1996 Oct; 28 (10): 1260-71
24. Keller U, Szinnai G, Bilz S, et al. Effects of changes in hydration on protein, glucose and lipid metabolism in man: impact on health. Eur J Clin Nutr 2003 Dec; 57 Suppl. 2: S69-74
25. Waller AP, Heigenhauser GJ, Geor RJ, et al. Fluid and electrolyte supplementation after prolonged moderate-intensity exercise enhances muscle glycogen resynthesis in standardbred horses. J Appl Physiol 2009 Jan; 106 (1): 91-100
26. Mohr M, Krustrup P, Bangsbo J. Match performance of high-standard soccer players with special reference to development of fatigue. J Sports Sci 2003 Jul; 21 (7): 519-28
27. Di Salvo V, Gregson W, Atkinson G, et al. Analysis of high intensity activity in premier league soccer. Int J Sports Med 2009 Mar; 30 (3): 205-12
28. Jacobs I, Westlin N, Karlsson J, et al. Muscle glycogen and diet in elite soccer players. Eur J Appl Physiol Occup Physiol 1982; 48 (3): 297-302
29. Krustrup P, Mohr M, Steensberg A, et al. Muscle and blood metabolites during a soccer game: implications for sprint performance. Med Sci Sports Exerc 2006 Jun; 38 (6): 1165-74
30. Krustrup P, Ortenblad N, Nielsen J, et al. Maximal voluntary contraction force, SR function and glycogen resynthesis during the first 72 h after a high-level competitive soccer game. Eur J Appl Physiol 2011 Dec; 111 (12): 2987-95
31. Osgnach C, Poser S, Bernardini R, et al. Energy cost and metabolic power in elite soccer: a new match analysis approach. Med Sci Sports Exerc 2010 Jan; 42 (1): 170-8
32. Rahnama N, Reilly T, Lees A. Injury risk associated with playing actions during competitive soccer. Br J Sports Med 2002 Oct; 36 (5): 354-9
33. De Baranda PS, Ortega E, Palao JM. Analysis of goalkeepers' defence in the world cup in Korea and Japan in 2002. Eur J Sport Sci 2008; 8 (3): 127-34

34. Byrne C, Twist C, Eston R. Neuromuscular function after exercise-induced muscle damage: theoretical and applied implications. Sports Med 2004; 34 (1): 49-69

35. Howatson G, Milak A. Exercise-induced muscle damage following a bout of sport specific repeated sprints. J Strength Cond Res 2009 Nov; 23 (8): 2419-24

36. Chatzinikolaou A, Fatouros IG, Gourgoulis V, et al. Time course of changes in performance and inflammatory responses after acute plyometric exercise. J Strength Cond Res 2010 May; 24 (5): 1389-98

37. Nicholas CW, Nuttall FE, Williams C. The Loughborough Intermittent Shuttle Test: a field test that simulates the activity pattern of soccer. J Sports Sci 2000 Feb; 18 (2): 97-104

38. Thompson D, Nicholas CW, Williams C. Muscular soreness following prolonged intermittent high-intensity shuttle running. J Sports Sci 1999 May; 17 (5): 387-95

39. Delextrat A, Baker J, Cohen DD, et al. Effect of a simulated soccer match on the functional hamstrings-to-quadriceps ratio in amateur female players. Scand J Med Sci Sports. Epub 2011 Nov 23

40. Small K, McNaughton L, Greig M, et al. The effects of multidirectional soccer-specific fatigue on markers of hamstring injury risk. J Sci Med Sport 2010 Jan; 13 (1): 120-5

41. Young WB, Hepner J, Robbins DW. Movement demands in Australian rules football as indicators of muscle damage. J Strength Cond Res 2012 Feb; 26 (2): 492-6

42. Clarkson PM, Nosaka K, Braun B. Muscle function after exercise-induced muscle damage and rapid adaptation. Med Sci Sports Exerc 1992 May; 24 (5): 512-20

43. Raastad T, Owe SG, Paulsen G, et al. Changes in calpain activity, muscle structure, and function after eccentric exercise. Med Sci Sports Exerc 2010 Jan; 42 (1): 86-95

44. Howatson G, van Someren KA. The prevention and treatment of exercise-induced muscle damage. Sports Med 2008; 38 (6): 483-503

45. Asp S, Daugaard JR, Kristiansen S, et al. Exercise metabolism in human skeletal muscle exposed to prior eccentric exercise. J Physiol 1998 May 15; 509 (Pt 1): 305-13

46. Jentjens R, Jeukendrup A. Determinants of post-exercise glycogen synthesis during short-term recovery. Sports Med 2003; 33 (2): 117-44

47. Williams AM. Perceptual skill in soccer: implications for talent identification and development. J Sports Sci 2000 Sep; 18 (9): 737-50

48. Boksem MA, Meijman TF, Lorist MM. Effects of mental fatigue on attention: an ERP study. Brain Res Cogn Brain Res 2005 Sep; 25 (1): 107-16

49. Lorist MM, Boksem MA, Ridderinkhof KR. Impaired cognitive control and reduced cingulate activity during mental fatigue. Brain Res Cogn Brain Res 2005 Jul; 24 (2): 199-205

50. Sanders AF. Elements of human performance. London: Lawrence Erlbaum Associates, 1998

51. Greig M, Marchant D, Lovell R, et al. A continuous mental task decreases the physiological response to soccer-specific intermittent exercise. Br J Sports Med 2007 Dec; 41 (12): 908-13

52. Marcora SM, Staiano W, Manning V. Mental fatigue impairs physical performance in humans. J Appl Physiol 2009 Mar; 106 (3): 857-64

53. Lemmink KA, Visscher C. Effect of intermittent exercise on multiple-choice reaction times of soccer players. Percept Mot Skills 2005 Feb; 100 (1): 85-95

54. McMorris T, Graydon J. The effect of exercise on cognitive performance in soccer-specific tests. J Sports Sci 1997 Oct; 15 (5): 459-68

55. Bishop D. The effects of travel on team performance in the Australian national netball competition. J Sci Med Sport 2004 Mar; 7 (1): 118-22

56. Richmond LK, Dawson B, Stewart G, et al. The effect of interstate travel on the sleep patterns and performance of elite Australian rules footballers. J Sci Med Sport 2007 Aug; 10 (4): 252-8

57. Reilly T, Drust B, Clarke N. Muscle fatigue during football match-play. Sports Med 2008; 38 (5): 357-67

58. Nederhof E, Lemmink KA, Visscher C, et al. Psychomotor speed: possibly a new marker for overtraining syndrome. Sports Med 2006; 36 (10): 817-28

59. Ingram J, Dawson B, Goodman C, et al. Effect of water immersion methods on post-exercise recovery from simulated team sport exercise. J Sci Med Sport 2009 May; 12 (3): 417-21

60. Bishop D, Spencer M, Duffield R, et al. The validity of a repeated sprint ability test. J Sci Med Sport 2001 Mar; 4 (1): 19-29

61. Krustrup P, Zebis M, Jensen JM, et al. Game-induced fatigue patterns in elite female soccer. J Strength Cond Res 2010 Feb; 24 (2): 437-41

62. Mohr M, Krustrup P, Nybo L, et al. Muscle temperature and sprint performance during soccer matches: beneficial effect of re-warm-up at half-time. Scand J Med Sci Sports 2004 Jun; 14 (3): 156-62

63. Bailey DM, Erith SJ, Griffin PJ, et al. Influence of cold-water immersion on indices of muscle damage following prolonged intermittent shuttle running. J Sports Sci 2007 Sep; 25 (11): 1163-70

64. Thorlund JB, Aagaard P, Madsen K. Rapid muscle force capacity changes after soccer match play. Int J Sports Med 2009 Apr; 30 (4): 273-8

65. Oliver J, Armstrong N, Williams C. Changes in jump performance and muscle activity following soccer-specific exercise. J Sports Sci 2008 Jan 15; 26 (2): 141-8

66. Delextrat A, Gregory J, Cohen D. The use of the functional H:Q ratio to assess fatigue in soccer. Int J Sports Med 2010 Mar; 31 (3): 192-7

67. Greig M. The influence of soccer-specific fatigue on peak isokinetic torque production of the knee flexors and extensors. Am J Sports Med 2008 Jul; 36 (7): 1403-9

68. Rahnama N, Reilly T, Lees A, et al. Muscle fatigue induced by exercise simulating the work rate of competitive soccer. J Sports Sci 2003 Nov; 21 (11): 933-42

69. Lovell R, Knapper B, Small K. Physiological responses to SAFT90: a new soccer-specific match simulation. Poster presented at the Verona-Ghirada Team Sports Conference; 2008 Jun 7-8; Treviso

70. Bishop PA, Jones E, Woods AK. Recovery from training: a brief review. J Strength Cond Res 2008 May; 22 (3): 1015-24
71. Rampinini E, Coutts AJ, Castagna C, et al. Variation in top level soccer match performance. Int J Sports Med 2007 Dec; 28 (12): 1018-24
72. Lago-Peñas C, Rey E, Lago-Ballesteros J, et al. The influence of a congested calendar on physical performance in elite soccer. J Strength Cond Res 2011 Aug; 25 (8): 2111-7
73. Pinnington HC, Dawson B. The energy cost of running on grass compared to soft dry beach sand. J Sci Med Sport 2001 Dec; 4 (4): 416-30
74. Gains GL, Swedenhjelm AN, Mayhew JL, et al. Comparison of speed and agility performance of college football players on field turf and natural grass. J Strength Cond Res 2010 Oct; 24 (10): 2613-7
75. Fell J, Williams D. The effect of aging on skeletal-muscle recovery from exercise: possible implications for aging athletes. J Aging Phys Act 2008 Jan; 16 (1): 97-115
76. Magal M, Dumke CL, Urbiztondo ZG, et al. Relationship between serum creatine kinase activity following exercise-induced muscle damage and muscle fibre composition. J Sports Sci 2010 Feb; 28 (3): 257-66
77. Lovell R, Midgley A, Barrett S, et al. Effects of different half-time strategies on second half soccer-specific speed, power and dynamic strength. Scand J Med Sci Sports. Epub 2011 Aug 3
78. Bangsbo J, Nørregaard L, Thorsø F. Activity profile of competition soccer. Can J Sport Sci 1991 Jun; 16 (2): 110-6
79. Spencer M, Bishop D, Dawson B, et al. Physiological and metabolic responses of repeated-sprint activities: specific to field-based team sports. Sports Med 2005; 35 (12): 1025-44
80. Rampinini E, Bishop D, Marcora SM, et al. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. Int J Sports Med 2007 Mar; 28 (3): 228-35
81. Gabbett TJ. The development of a test of repeated-sprint ability for elite women's soccer players. J Strength Cond Res 2010 May; 24 (5): 1191-4
82. Impellizzeri FM, Rampinini E, Castagna C, et al. Validity of a repeated-sprint test for football. Int J Sports Med 2008 Nov; 29 (11): 899-905
83. Wragg CB, Maxwell NS, Doust JH. Evaluation of the reliability and validity of a soccer-specific field test of repeated sprint ability. Eur J Appl Physiol 2000 Sep; 83 (1): 77-83
84. Wilkinson M, McCord A, Winter EM. Validity of a squash-specific test of multiple-sprint ability. J Strength Cond Res 2010 Dec; 24 (12): 3381-6
85. Psotta R, Blahus P, Cochrane DJ, et al. The assessment of an intermittent high intensity running test. J Sports Med Phys Fitness 2005 Sep; 45 (3): 248-56
86. Da Silva JF, Guglielmo LG, Carminatti LJ, et al. Validity and reliability of a new field test (Carminatti's test) for soccer players compared with laboratory-based measures. J Sports Sci 2011 Dec; 29 (15): 1621-8
87. Atkinson G, Nevill AM, Edwards B. What is an acceptable amount of measurement error? The application of meaningful "analytical goals" to the reliability of sports science measurements made on a ratio scale. In: Communications to the Annual Conference of the British Association of Sport and Exercise Sciences (BASES); J Sports Sci 1999; 17 (1): 18
88. Fitzsimons M, Dawson B, Ward D, et al. Cycling and running tests of repeated sprint ability. Aust J Sci Med Sport 1993; 25 (4): 82-7
89. Glaister M, Howatson G, Lockey RA, et al. Familiarization and reliability of multiple sprint running performance indices. J Strength Cond Res 2007 Aug; 21 (3): 857-9
90. Sporis G, Jukic I, Milanovic L, et al. Reliability and factorial validity of agility tests for soccer players. J Strength Cond Res 2010 Mar; 24 (3): 679-86
91. Arnason A, Sigurdsson SB, Gudmundsson A, et al. Physical fitness, injuries, and team performance in soccer. Med Sci Sports Exerc 2004 Feb; 36 (2): 278-85
92. Wisløff U, Castagna C, Helgerud J, et al. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. Br J Sports Med 2004 Jun; 38 (3): 285-8
93. Moir G, Button C, Glaister M, et al. Influence of familiarization on the reliability of vertical jump and acceleration sprinting performance in physically active men. J Strength Cond Res 2004 May; 18 (2): 276-80
94. Dias JA, Dal Pupo J, Reis DC, et al. Validity of two methods for estimation of vertical jump height. J Strength Cond Res 2011 Jul; 25 (7): 2034-9
95. Brodt V, Wagner DR, Heath EM. Countermovement vertical jump with drop step is higher than without in collegiate football players. J Strength Cond Res 2008 Jul; 22 (4): 1382-5
96. Burkett LN, Phillips WT, Ziuraitis J. The best warm-up for the vertical jump in college-age athletic men. J Strength Cond Res 2005 Aug; 19 (3): 673-6
97. Holt BW, Lambourne K. The impact of different warm-up protocols on vertical jump performance in male collegiate athletes. J Strength Cond Res 2008 Jan; 22 (1): 226-9
98. Vetter RE. Effects of six warm-up protocols on sprint and jump performance. J Strength Cond Res 2007 Aug; 21 (3): 819-23
99. Jakeman JR, Byrne C, Eston RG. Lower limb compression garment improves recovery from exercise-induced muscle damage in young, active females. Eur J Appl Physiol 2010 Aug; 109 (6): 1137-44
100. Jakeman JR, Byrne C, Eston RG. Efficacy of lower limb compression and combined treatment of manual massage and lower limb compression on symptoms of exercise-induced muscle damage in women. J Strength Cond Res 2010 Nov; 24 (11): 3157-65
101. Nicol C, Avela J, Komi PV. The stretch-shortening cycle : a model to study naturally occurring neuromuscular fatigue. Sports Med 2006; 36 (11): 977-99
102. Paavolainen L, Häkkinen K, Hämäläinen I, et al. Explosive-strength training improves 5-km running time by improving running economy and muscle power. J Appl Physiol 1999 May; 86 (5): 1527-33
103. Chamari K, Chaouachi A, Hambli M, et al. The five-jump test for distance as a field test to assess lower limb explosive power in soccer players. J Strength Cond Res 2008 May; 22 (3): 944-50

104. Coutts AJ, Slattery KM, Wallace LK. Practical tests for monitoring performance, fatigue and recovery in triathletes. J Sci Med Sport 2007 Dec; 10 (6): 372-81

105. Bosco C, Luhtanen P, Komi PV. A simple method for measurement of mechanical power in jumping. Eur J Appl Physiol Occup Physiol 1983; 50 (2): 273-82

106. Hamilton RT, Shultz SJ, Schmitz RJ, et al. Triple-hop distance as a valid predictor of lower limb strength and power. J Athl Train 2008 Apr-Jun; 43 (2): 144-51

107. Bolgla LA, Keskula DR. Reliability of lower extremity functional performance tests. J Orthop Sports Phys Ther 1997 Sep; 26 (3): 138-42

108. Warren GL, Lowe DA, Armstrong RB. Measurement tools used in the study of eccentric contraction-induced injury. Sports Med 1999 Jan; 27 (1): 43-59

109. Woods C, Hawkins RD, Maltby S, et al. The Football Association Medical Research Programme: an audit of injuries in professional football: analysis of hamstring injuries. Br J Sports Med 2004 Feb; 38 (1): 36-41

110. Hawkins RD, Hulse MA, Wilkinson C, et al. The association football medical research programme: an audit of injuries in professional football. Br J Sports Med 2001 Feb; 35 (1): 43-7

111. Baltzopoulos V, Gleeson NP. Skeletal muscle function. In: Eston RG, Reilly T, editors. Tests, procedures and data (Vol. 2: Exercise physiology). London: Routledge, 2001: 7-35

112. Hopkins WG, Schabort EJ, Hawley JA. Reliability of power in physical performance tests. Sports Med 2001; 31 (3): 211-34

113. Aagaard P, Simonsen EB, Magnusson SP, et al. A new concept for isokinetic hamstring: quadriceps muscle strength ratio. Am J Sports Med 1998 Mar-Apr; 26 (2): 231-7

114. Witvrouw E, Mahieu N, Danneels L, et al. Stretching and injury prevention: an obscure relationship. Sports Med 2004; 34 (7): 443-9

115. Sporis G, Vucetic V, Jovanovic M, et al. Reliability and factorial validity of flexibility tests for team sports. J Strength Cond Res 2011 Apr; 25 (4): 1168-76

116. Cone JR, Berry NT, Goldfarb A, et al. Effects of an individualized soccer match simulation on vertical stiffness and impedance. J Strength Cond Res 2012; 26 (8) 2027-36

117. Stølen T, Chamari K, Castagna C, et al. Physiology of soccer: an update. Sports Med 2005; 35 (6): 501-36

118. da Silva JF, Guglielmo LG, Bishop D. Relationship between different measures of aerobic fitness and repeated-sprint ability in elite soccer players. J Strength Cond Res 2010 Aug; 24 (8): 2115-21

119. Aziz AR, Mukherjee S, Chia MY, et al. Relationship between measured maximal oxygen uptake and aerobic endurance performance with running repeated sprint ability in young elite soccer players. J Sports Med Phys Fitness 2007 Dec; 47 (4): 401-7

120. Dupont G, Millet GP, Guinhouya C, et al. Relationship between oxygen uptake kinetics and performance in repeated running sprints. Eur J Appl Physiol 2005 Sep; 95 (1): 27-34

121. Hughes M, Franks I. Analysis of passing sequences, shots and goals in soccer. J Sports Sci 2005 May; 23 (5): 509-14

122. Russell M, Kingsley M. Influence of exercise on skill proficiency in soccer. Sports Med 2011 Jul 1; 41 (7): 523-39

123. Ali A, Williams C, Hulse M, et al. Reliability and validity of two tests of soccer skill. J Sports Sci 2007 Nov; 25 (13): 1461-70

124. Russell M, Benton D, Kingsley M. Reliability and construct validity of soccer skills tests that measure passing, shooting, and dribbling. J Sports Sci 2010 Nov; 28 (13): 1399-408

125. Kellis E, Katis A, Vrabas IS. Effects of an intermittent exercise fatigue protocol on biomechanics of soccer kick performance. Scand J Med Sci Sports 2006 Oct; 16 (5): 334-44

126. Russell M, Benton D, Kingsley M. Influence of carbohydrate supplementation on skill performance during a soccer match simulation. J Sci Med Sport 2012; 15 (4): 348-54

127. Stone KJ, Oliver JL. The effect of 45 minutes of soccer-specific exercise on the performance of soccer skills. Int J Sports Physiol Perform 2009 Jun; 4 (2): 163-75

128. McGregor SJ, Nicholas CW, Lakomy HK, et al. The influence of intermittent high-intensity shuttle running and fluid ingestion on the performance of a soccer skill. J Sports Sci 1999 Nov; 17 (11): 895-903

129. Rampinini E, Impellizzeri FM, Castagna C, et al. Effect of match-related fatigue on short-passing ability in young soccer players. Med Sci Sports Exerc 2008 May; 40 (5): 934-42

130. Ali A, Williams C, Nicholas CW, et al. The influence of carbohydrate-electrolyte ingestion on soccer skill performance. Med Sci Sports Exerc 2007 Nov; 39 (11): 1969-76

131. Ali A, Gardiner R, Foskett A, et al. Fluid balance, thermoregulation and sprint and passing skill performance in female soccer players. Scand J Med Sci Sports 2011 Jun; 21 (3): 437-45

132. Impellizzeri FM, Rampinini E, Maffiuletti NA, et al. Effects of aerobic training on the exercise-induced decline in short-passing ability in junior soccer players. Appl Physiol Nutr Metab 2008 Dec; 33 (6): 1192-8

133. Lyons M, Al-Nakeeb Y, Nevill A. Performance of soccer passing skills under moderate and high-intensity localized muscle fatigue. J Strength Cond Res 2006 Feb; 20 (1): 197-202

134. Brooks JH, Fuller CW, Kemp SP, et al. An assessment of training volume in professional rugby union and its impact on the incidence, severity, and nature of match and training injuries. J Sports Sci 2008 Jun; 26 (8): 863-73

135. Cheung K, Hume P, Maxwell L. Delayed onset muscle soreness : treatment strategies and performance factors. Sports Med 2003; 33 (2): 145-64

136. Hooper SL, Mackinnon LT. Monitoring overtraining in athletes: recommendations. Sports Med 1995 Nov; 20 (5): 321-7

137. Kenttä G, Hassmén P. Overtraining and recovery: a conceptual model. Sports Med 1998 Jul; 26 (1): 1-16

138. Andersson H, Karlsen A, Blomhoff R, et al. Active recovery training does not affect the antioxidant response to soccer matches in elite female players. Br J Nutr 2010 Nov; 104 (10): 1492-9

139. Takarada Y. Evaluation of muscle damage after a rugby match with special reference to tackle plays. Br J Sports Med 2003; 37 (5): 416-9

140. Urhausen A, Kindermann W. Diagnosis of overtraining: what tools do we have? Sports Med 2002; 32 (2): 95-102

141. Mougios V. Reference intervals for serum creatine kinase in athletes. Br J Sports Med 2007 Oct; 41 (10): 674-8

142. Pedersen BK. Special feature for the Olympics: effects of exercise on the immune system: exercise and cytokines. Immunol Cell Biol 2000 Oct; 78 (5): 532-5

143. Tidball JG. Inflammatory processes in muscle injury and repair. Am J Physiol Regul Integr Comp Physiol 2005 Feb; 288 (2): R345-53

144. Pedersen BK, Toft AD. Effects of exercise on lymphocytes and cytokines. Br J Sports Med 2000 Aug; 34 (4): 246-51

145. Fischer CP. Interleukin-6 in acute exercise and training: what is the biological relevance?. Exerc Immunol Rev 2006; 12: 6-33

146. Andersson H, Bøhn SK, Raastad T, et al. Differences in the inflammatory plasma cytokine response following two elite female soccer games separated by a 72-h recovery. Scand J Med Sci Sports 2010 Oct; 20 (5): 740-7

147. Singh TK, Guelfi KJ, Landers G, et al. A comparison of muscle damage, soreness and performance following a simulated contact and non-contact team sport activity circuit. J Sci Med Sport 2011 Sep; 14 (5): 441-6

148. Moreira A, Arsati F, de Oliveira Lima Arsati YB, et al. Salivary cortisol in top-level professional soccer players. Eur J Appl Physiol 2009 May; 106 (1): 25-30

149. Ekblom B. Assessment of fitness and player profiles. In Dvorak J, Kirkendall DT, editors. International football and sports medicine: caring for the soccer athlete worldwide. Proceedings of the International Football and Sports Medicine Conference; 22-24 March 2002; Beverly Hills (CA). Rosemont (IL): AOSSM, 2005

150. Maso F, Lac G, Filaire E, et al. Salivary testosterone and cortisol in rugby players: correlation with psychological overtraining items. Br J Sports Med 2004 Jun; 38 (3): 260-3

151. Halliwell B, Whiteman M. Measuring reactive species and oxidative damage in vivo and in cell culture: how should you do it and what do the results mean? Br J Pharmacol 2004 May; 142 (2): 231-55

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