The University of the Sunshine Coast
School of Health and Sport Sciences
Faculty of Science, Health, Education, and Engineering

The effect of recovery duration on muscle oxygenation, heart rate, perceived exertion, time motion descriptors, and technical proficiency during small sided games of football

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The effect of recovery duration on muscle oxygenation, heart rate, perceived exertion, time motion descriptors, and technical proficiency during small sided games of football.

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Statement of Original Authorship

The research presented in this thesis is original and is the candidate's own research, except where referenced otherwise. The research has not been submitted for a degree at any other university.

Scott McLean

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Abstracts

This thesis was comprised of two research studies. The common component was the change in the duration of the recovery periods separating the SSG bouts, with the first study based on the physiological components of the SSG, and the second study based on the technical skill components of the SSG. The data for both studies were collected from the same participant group.

Study 1

Purpose. Small sided games (SSG) of football are an effective and efficient format to simultaneously train the physiological, technical, and tactical components of football. The duration of the recovery period between bouts of SSG will affect the physiological response to subsequent bouts. It was hypothesised that decreasing the duration of recovery periods separating serial SSG bouts would increase physiological, and perceptual responses, and decrease high speed running, and total distance covered during the SSG bouts.

Methods. Twelve experienced footballers (mean ± SD; age 21 ± 3 ys; VO2peak 64 ± 7 ml · min · kg⁻¹; playing experience 15 ± 3 ys) completed two SSG sessions. Each SSG consisted of 3 vs 3 players and 6 bouts of 2 min duration, with bouts separated by either 30 s recovery (REC-30) or 120 s recovery (REC-120). Deoxygenated haemoglobin (HHb) in the vastus lateralis muscle (VL) (using near infrared spectroscopy), heart rate (HR) and time motion descriptors (TMD) (speed and distance) were measured continuously during the SSG sessions and perceived exertion (RPE) was measured for each bout.

Results. During the recovery periods, in REC-30 compared to REC-120, there was a significant (p < 0.05) main effect of a higher HHb and HR. During the bouts, in REC-30 compared to REC-120, there were no significant differences in HHb, HR, RPE, or TMD, but
within both REC-30 and REC-120 there were significant increases as a function of bout number in RPE.

**Conclusions.** Although a four-fold increase in recovery period allowed a significant increase in the recovery of HHb and HR, this did not increase the physiological, and perceptual responses, or time motion descriptors during the bouts. These results could have been due to the regulation of effort (pacing), in these experienced players performing an exercise task to which they were well adapted.

**Study 2.**

**Purpose.** Small sided games (SSG) are an effective, and time-efficient football training method. The aim of this study was to determine the effect of increasing the duration of the recovery period separating serial SSG bouts on technical skill (TS) execution, heart rate (HR), rating of perceived exertion (RPE) and time motion descriptors (TMD). It was hypothesised that decreasing the duration of recovery periods would decrease TS execution.

**Method.** Twelve semi-professional footballers (mean ± SD; age 21 ± 3 ys; VO\text{2peak} 64 ± 7 ml · min · kg\(^{-1}\); playing experience 15 ± 3 ys) completed two SSG sessions, each consisting of 3 vs 3 players and 6 bouts of 2 min, with the bouts separated by either 30 s recovery (REC-30) or 120 s recovery (REC-120). Multiple individual technical skill and team performance measures, HR, RPE, and TMD were measured.

**Results.** There was a significantly (p < .05) higher HR during recovery in REC-30 compared to REC-120. The number of successful tackles was significantly higher (p <0.05), and the average time each team maintained possession was significantly lower in REC-120 compared to REC-30. There were no significant differences for all other technical skill or performance measures, or in HR, RPE, or TMD between the recovery conditions. There were significant increases in RPE as a function of bout number within both REC-30 and REC-120.
Conclusions. In contrast to previous research, the four-fold increase in the duration of
recovery separating SSG bouts did not alter the individual technical skill execution of players
or team performance. These results could be explained by the high experience and skill level
of the players, which would have allowed them to adapt to the demands of the SSG
irrespective of the different recovery periods, and to regulate their effort to enable the
maintenance of technical skill execution.

Conclusions

1. Increasing the duration of recovery from 30 s to 120 s (four-fold) separating serial
   SSG bouts, allowed for an increased physiological recovery, as indicated by a
   significant decrease in HR and HHb.

2. Increasing the duration of recovery from 30 s to 120 s separating serial SSG bouts,
   does not affect the physiological or perceptual responses, time motion descriptors, or
   execution of technical skills, of experienced, and trained football players.

3. Experienced and trained football players are apparently able to regulate (pace) the
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### List of Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>s</td>
<td>second</td>
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<tr>
<td>min</td>
<td>minute</td>
</tr>
<tr>
<td>m</td>
<td>metre</td>
</tr>
<tr>
<td>m.s(^{-1})</td>
<td>metre per second</td>
</tr>
<tr>
<td>cm</td>
<td>centimetres</td>
</tr>
<tr>
<td>km.hr(^{-1})</td>
<td>kilometre per hour</td>
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<td>ys</td>
<td>years</td>
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<tr>
<td>µm</td>
<td>micromoles</td>
</tr>
<tr>
<td>mmol.L(^{-1})</td>
<td>millimoles per litre</td>
</tr>
<tr>
<td>O(_2)</td>
<td>oxygen</td>
</tr>
<tr>
<td>CO(_2)</td>
<td>carbon dioxide</td>
</tr>
<tr>
<td>SSG</td>
<td>small sided games</td>
</tr>
<tr>
<td>B</td>
<td>bout</td>
</tr>
<tr>
<td>vs</td>
<td>versus</td>
</tr>
<tr>
<td>HR-V0(_2)</td>
<td>Heart rate and oxygen consumption relationship</td>
</tr>
<tr>
<td>NIRS</td>
<td>near infrared spectroscopy</td>
</tr>
<tr>
<td>VL</td>
<td>vastus lateralis</td>
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<tr>
<td>HR</td>
<td>heart rate</td>
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<tr>
<td>%HR(_\text{max})</td>
<td>percentage of maximal heart rate</td>
</tr>
<tr>
<td>bpm</td>
<td>beats per minute</td>
</tr>
<tr>
<td>RPE</td>
<td>rating of perceived exertion</td>
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<tr>
<td>GPS</td>
<td>global positioning system</td>
</tr>
<tr>
<td>TMD</td>
<td>time motion descriptors</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
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<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>HHb</td>
<td>deoxygenated haemoglobin</td>
</tr>
<tr>
<td>Δ [HHb]</td>
<td>change in deoxygenated haemoglobin concentration</td>
</tr>
<tr>
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<td>oxygenated haemoglobin</td>
</tr>
<tr>
<td>tHb</td>
<td>total haemoglobin</td>
</tr>
<tr>
<td>ml.minkg⁻¹</td>
<td>millilitre per minute per kilogram</td>
</tr>
<tr>
<td>VO₂peak</td>
<td>maximal rate of oxygen consumption</td>
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<tr>
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<td>adenosine triphosphate</td>
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<tr>
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</tr>
<tr>
<td>n</td>
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<tr>
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</tr>
<tr>
<td>ANOVA</td>
<td>analysis of variance</td>
</tr>
<tr>
<td>ηp²</td>
<td>partial eta-squared (effect size)</td>
</tr>
<tr>
<td>β</td>
<td>statistical power</td>
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Introduction

Football is the most popular sport in the world and is played by more than 200 million people from 209 Federation Internationale de Football Association (FIFA) registered countries, along with countless street and park football players (1, 2). In addition, football is a multi-billion dollar industry, in 2013 FIFA’s total revenue was USD 1.386 billion with a total expenditure of USD 1.314 billion. Of this total expenditure, 72% was invested directly back into football, into areas such as football development. Furthermore, the 2010 FIFA World Cup held in South Africa was watched by a global television audience of 3.2 billion people (3).

Football is predominantly a high intensity intermittent exercise sport played over 90 min. at intensities ranging from low intensities including standing and walking, to maximal intensities including high speed running(2, 4). Performance in football requires players to possess physical, technical, decision making, tactical, and psycho-social abilities (1, 4). One factor that separates football from many other sports is that footballers do not need to excel in all these performance components to perform well in football (1, 4, 5), although a good level in each component is ideal. For example, a footballer with exceptional decision making ability and technique but with average speed can still perform at a high level. Additionally, a football player with physiological qualities such as high speed and endurance, but with average technique can become an elite player, although a good level in each component is ideal. This is one reason why football is such a popular sport among millions of people, there is no ‘one size fits all’ in football. Different footballing traits, anthropometric characteristics and physical capacities of players can be suited to a variety of different playing positions and coaching philosophies (1, 4, 5).
During the past several decades football has received increased interest from the scientific community, aimed at improving our knowledge of football, and methods to improve football training, and subsequently football players (6). In addition to research on the technical and tactical components of football there has been a large amount of research dedicated to the benefits of improving the physical component of football players (4, 7). This research includes attempts to determine the contribution and rates of energy provision by the aerobic and anaerobic energy systems (1), fatigue, recovery, nutrition, player activity, and muscle metabolic processes. From this, we have gained knowledge to improve the performance of football players, as well as the training methods adopted by coaches (1, 4).

Within the past decade there has been a shift away from the traditional football training methods that tended to isolate the physical, technical and tactical components of football, which were not necessarily representative of actual match play (8). Game based training or small sided games (SSG) have largely replaced the traditional training approaches so that the key performance variables are not trained in relative isolation (8, 9). Small sided games are football games played with reduced numbers of players on reduced size pitches, and generally played in a series of repeat bouts, interspersed with recovery periods (10). The benefit of SSG is they provide concurrent training of the physical, technical and tactical components of football which closely represents football match play (8, 9). There are numerous SSG variables that can be modified which will affect the technical and tactical performance variables, as well as the physical component, including the exercise intensity of SSG training. Modifiable variables such as altering the number of players, pitch size, the use of goals and goalkeepers, rule modifications, coach encouragement and bout duration directly affect the exercise intensity of SSG training (11-14). The ability to modify the exercise intensity of SSG has importance for coaches when planning and delivering training sessions so that the desired training outcomes are achieved. However, there is a gap in the literature
regarding the effect of the duration of recovery periods separating serial SSG bouts, on the physical responses during the bouts. Only one study, using youth football players, has investigated the effect of changing the duration of recovery periods separating serial SSG bouts on physiological and perceptual responses, time motion descriptors, and technical proficiency of players (see Recovery Duration section) (15).

From a practical perspective, coaches planning to train technical and tactical football components using SSG could initially increase recovery durations so that players are able to adequately perform technical actions across subsequent bouts. This is relevant because technical proficiency of footballers is shown to reduce after exhaustive exercise (16). However, to increase the physical capacity of players using SSG training, coaches could decrease the duration of the recovery periods. As physiological adaptations to training are induced with physiological stresses (17), not allowing players to fully recover increases the physiological stress which subsequently increases the physical capacity of players. Therefore, the ultimate aim for coaches should be to progressively decrease the recovery duration between SSG bouts, so that the players adapt to executing technical actions while under fatigue, to prepare them for the occurrence of match related fatigue.

A better understanding of the physiological, perceptual, time motion characteristics, and technical proficiency of football players during serial SSG of varied recovery durations will provide coaches with valuable information for planning SSG training. The exercise intensity during SSG has been described by using global systemic measures such as heart rate (HR), and rating of perceived exertion (RPE). Investigating specific regional muscle metabolism will provide further information into the physiological demands during SSG. Near infrared spectroscopy (NIRS) provides measurements of oxygenated haemoglobin (O₂Hb), deoxygenated haemoglobin (HHb) and total haemoglobin (tHb) to determine the balance of oxygenation at the site of investigation (18, 19). Understanding the pattern of response for
specific muscle tissue oxygenation, to different recovery durations has implications for the
design of SSG training. For repeated sprint running, reducing the duration of recovery
between repeated sprints increases deoxygenated haemoglobin (HHb) concentrations, which
results in slower repeat sprint times (20). Therefore, measuring regional muscle oxygenation
status, heart rate (HR), perceptual responses, time motion descriptors, and technical
proficiency during serial SSG of varied recovery durations will further advance our
knowledge of SSG training.

Aims

This thesis was comprised of two research studies. The common component was the change
in the duration of the recovery periods separating the SSG, with the first study based on the
physiological components of the SSG, and the second study based on the technical skill
components of the SSG. The specific aims of the project were to determine the effect of
changing the duration of the recovery period separating SSG bouts on:

Study 1
(1) Oxygenation in the vastus lateralis (VL) muscle using Near Infrared Spectroscopy (NIRS)
(2) Heart rate.
(3) Perceived exertion.
(4) Time motion descriptors of speed and distance, using Global Positioning System (GPS).

Study 2
(1) Technical proficiency
(2) Heart rate
(3) Perceived exertion
(4) Time motion descriptors of speed and distance, using Global Positioning System (GPS).
Chapter 1- Review of the Literature

This literature review will give an overall description of the physical demands of football match play, followed by how the exercise intensity can be altered using SSG. The literature used in this review is of male football players, and covers male football matches. Only literature specific to football was used where possible, with the exception to the NIRS and the technical skill components. Because the use of NIRS in a specific team sport environment has yet to be researched, it was not possible to use literature specific to football. Therefore, different exercise modes including running and cycling have been referred to in this review. For the technical component, the theories underlying skill acquisition apply across many different sports. Therefore, for the purpose of this review, components of skill acquisition research outside of football have been used.

Physiology of Football

Physical Demands

The physical demands placed on football players during match-play are dependent on variables such as the level of competition (21), league type (6, 22-24), player position (6, 21) but also as a function of exercise duration, where changes in the physical demands of players are seen within a match (i.e. between halves) (6, 21).

Standard of Competition

Analysis of the activity profile of elite and non-elite footballers during match-play has made it possible to establish the specific match activities that distinguishes players from different standards of competition (25). Running activity such as total distance covered, and the amount of high speed running and sprinting has been analysed since the 1960’s to gain an understanding of the physical demands of football (1, 21, 26, 27). It is generally agreed upon
that distances covered by outfield players ranges from approximately 10-13 km during a match, most of which is performed at low speeds, and does not differentiate the playing standard (1, 28). However, it is the amount of distance covered at high speeds where a consistent difference is seen between elite and non-elite footballers. Mohr, Krustup (21) revealed time spent by elite players running at high speed (18km.hr$^{-1}$) and sprinting (30 km.hr$^{-1}$) was 28% and 58% greater respectively than non-elite players. This equates to distances of 2430 m and 1900 m for high speed running and 650 m and 410 m for sprinting between the elite and non-elite footballers. Danish first division players performed a larger percentage of total playing time at high speed (2.5% vs 1.6%) and sprinting (0.8% vs 0.5%) compared to Danish second division players (1). Likewise, Ingebrigtsen, Bendiksen (29) measured more high speed running in players from the top teams (rank 1-4) compared to middle (rank 5-8) and bottom (rank 9-12) teams of the Danish Premier League. The top ranked teams performed 30-40% more high speed running and sprinting than the lower ranked teams (29). Ekblom (26) also measured increased high speed running in the higher level competitions of the top four Swedish divisions.

Contrasting the above results are two studies comparing the high speed running of players from the English Premier league (EPL) and lower divisions of English football (30, 31). Bradley, Carling (30) measured less high speed running (19.8-25.1 km.hr$^{-1}$) from players in the EPL compared to players from the two leagues directly below the EPL (Division 1 and 2). Players in the EPL covered an average of 929 m during a match compared to 1111 m and 1242 m of the players from division 1 and 2 respectively (30). Similarly, Di Salvo, Pigozzi (31) measured greater average distances covered in high speed running and sprinting by players in Division 1 (750 m and 273 m) than by EPL players (693 m and 258 m).

In conclusion, professional football players cover total distances of approximately 10-13 km during a football match (1, 21, 26). However, the high speed running and sprinting performed
by players during a match emerges as one difference between elite and non-elite players (1, 21, 26, 29). Despite the results seen in English football, the majority of the literature states that in higher standards of competition, players perform more high speed running and sprinting during a match. This is relevant because it is in these periods of high intensity activity where the outcome of a match is often decided (4).

League Type

Football styles and coaching philosophies are different between countries, as a result each country has a unique style of playing football. Depending on the league played in, the activity profile of players during a match will vary. Computerised match analysis from several of Europe’s leading competitions; English Premier League (EPL) (22, 23), Spanish La Liga (SLL) (23), French Ligue 1 (FL1) (24), and a leading Italian Serie A team (6) have shown differences in physical demands of players between these leagues. Analysis of two major European leagues (EPL and SLL) found that although total distances covered by players during matches from both leagues was non-significant (EPL 11 095 m and SLL 10 893 m), the total amount of high speed running (21-24 km.hr⁻¹) and sprinting (>24km.hr⁻¹) was significantly higher in the players from the EPL (23). When combining all playing positions, on average the EPL players ran 294 m at high speed and 254 m sprinting compared to the SLL players who ran 278 m at high speed and 230 m sprinting (23). Greater differences in sprinting are seen when analysing the distance covered sprinting by players in their individual playing positions. The EPL central defensive midfielders (246 m), central attacking midfielders (267 m), fullbacks (263 m) and forwards (278 m) all covered significantly greater distances sprinting than the SLL players of the same positions (203 m, 222 m, 249 m and 260 m respectively). Practically, these differences in distance might not differentiate winning or losing matches, but they show that different playing styles elicit different demands of players.
A separate analysis of EPL players’ running activity by Di Salvo, Gregson (22) measured high speed running (19.8-25.2 km.hr⁻¹) distances noticeably higher than Dellal, Chamari (23) with an average of 907.4 m, whereas mean sprinting (> 25.2 km.hr⁻¹) distances were similar (288.8 m). In the FL1, total distances covered by players are comparable to those of the EPL and SLL players. The average total distance covered per match, calculated based on playing position values by Dellal, Wong (24) was 11 213 m. High speed running (296 m) in the French league was equal to the EPL and 3% higher than SLL, however sprinting (237 m) was approximately 7% lower in the French league compared to the EPL but 3% higher than SLL (24). Match analysis from a leading Italian Serie A team revealed total distance covered during a match to be 10 964 m which is similar with that of the EPL, SLL and FL1 (6).

The lack of a standardised running intensity classification within the literature makes it difficult to compare the high speed running and sprinting of the Italian team to other leagues. This was also seen between the two EPL studies (22, 23), where the exercise intensity classification varied. Vigne, Gaudino (6) defined high speed running as 16-19 km.hr⁻¹ and sprinting >19 km.hr⁻¹, which is lower compared to other study’s’ classifications of high speed running (21-24 km.hr⁻¹) and sprinting (>24km.hr⁻¹) (23, 24), and high speed running (19.8-25.2 km.hr⁻¹) and sprinting (> 25.2 km.hr⁻¹) (22). The contribution of high speed running of the Italian team was 8.4% and sprinting 9.8% of total match activity. These values are much higher than EPL, SLL and FL1 probably due to the lowered speed classifications.

In conclusion, different league types from around the world are differentiated by the amount of high speed running, and sprinting that players perform, and not total distances players cover in a match. (6, 22-24).
Player Position

The running activity profile and physical demands of footballers during a match are playing position dependant (25). Within elite football players, midfielders and wide fullbacks cover the largest total distances in a match with ranges of approximately 10 000 to 12 000 m (1, 21, 22, 24). Defenders and forwards cover approximately 9000 m to 11 000 m, and distances covered by goalkeepers is approximately 4000 m (4). Accompanied by differences in total distances covered by players of different positions within a match, are differences in varied running speeds of different positions (6). Midfield play is characterised as being the link between the defenders and forwards and involves attacking and defending. This requires sustained running at varied intensities across the entire pitch (1). A result of the sustained running by midfielders, on top of covering the greatest total distance among all positions, is they spend the least time at low speeds (recovering from high intensity actions) (6). Vigne, Gaudino (6) measured recovery after high speed running, using walking distance, to be the lowest in midfielders compared to all other out-field playing positions. Midfielders walked an average of 3226 m during a match compared to defenders and forwards who walked 3791m and 3409 m. Unlike the sustained running of midfielders, forwards’ running is differentiated by the large amount of distance covered in sprints (24). Running patterns of defenders are comparable to that of forwards, which is not surprising as it is the role of defenders to match the running of forwards to prevent them from scoring (21). Dellal, Wong (24) established that forwards run the longest distances sprinting at >24 km.hr\(^{-1}\) with a total distance of 290 m. In addition, attacking central midfielders and wide midfielders cover the longest distance (approximately 335 m) at high speed running (21-24 km.hr\(^{-1}\)) during competitive match-play. Mohr, Krstrup (21) observed central defenders performed the least amount (1690 m) of high speed running (18 km.hr\(^{-1}\)) compared to midfielders (2230 m), wide fullbacks (2460 m) and forwards (2280 m). In the same study, sprinting (30 km.hr\(^{-1}\)) by forwards and wide fullbacks
was 690 m and 640 m respectively, which was greater than defenders and midfielders who covered 440 m each. It should be noted that different teams adopt different playing formations and no standardised formation is indicated in the literature.

Likewise, definitions of playing positions are reported differently. Dellal, Wong (24) divided midfield roles into attacking central midfielders, defending central midfielders and wide midfielders and found significant differences in running duration and speeds between these positions. Whereas Vinge, Gaudino and Mohr, Krstrup (6, 21) grouped all midfield positions together despite distinct differences seen in running duration and speeds between different midfield roles (24). The same was seen with defenders regardless of the disparities in the running between wide and central defenders (24).

In conclusion, the running activity of different playing positions shows distinct differences in total distances covered and distances covered at varied speeds. This is important for coaches when planning SSG training sessions. Coaches should understand the running activity of different playing positions and apply the appropriate SSG variations (e.g. pitch size, player numbers) that will simulate the running that occurs during a match.

**Within Match Physical Demands (i.e. between halves)**

Comparisons of running analysis between halves has revealed decreases in total distance covered, high speed running and maximal sprinting by players in the second half compared to the first half regardless of playing position, level of competition and league type (1, 6, 21). Vigne, Gaudino (6) identified decreases in total distance covered, speeds at all intensities (walking, jogging, 13-16 km.hr\(^{-1}\), 16-19 km.hr\(^{-1}\), >19 km.hr\(^{-1}\)), and increases in the frequency of recovery periods >120 seconds in the second half, compared to the first half. The final fifteen minutes of a match is the period where players run the least distance in total and at high intensities, suggesting fatigue is most evident in players from approximately 75-90 min
of the match. (1, 4, 6, 21). Mohr, Krstrup (21) divided both 45 min halves into 15 min intervals and measured significant differences in high speed running and sprinting distances between the first four 15 min periods and the last 15 min of the match. Reductions in total running distances and at high intensities in the final 15 min may be related to the fact that the likely outcome of a match may have already been decided at this time-point in a match. Also, the difference in running distances during the first and second halves may be misrepresented in Vinge, Gaudino, and Mohr, Krstrup (6, 21) due to the inclusion of substitutes. It is common in football for substitutes to be introduced towards the end of the second half (32). It is has been shown that substitutes cover more total distance, and distance at high intensities than players who were involved in the match from kick-off (32). When analysing the running activity of substitutes Mohr, Krstrup (21), and Bradley, Lago-Penas (32) measured more high speed running in substitutes than those players who started the match, supporting the findings that players experience fatigue towards the end of a match. It may be that the differences in running analysis between the first and second halves would be even greater without the inclusion of substitutes. Players experiencing fatigue towards the end of a match is supported by Krstrup, Mohr (33) who investigated the 30 m sprint times of Danish 4th division football players pre-match, at half time and post-match. There was no significant difference between the mean pre-match and half time sprints (4.60 s vs 4.61 s). However, significant differences between mean pre-match and post-match 30 m sprint times were seen (4.60 s vs 4.72 s). The reduction seen in total running distances covered and at high intensities, as well as increases in 30 m sprint time toward the end of the match is evidence of the development of fatigue as a match progresses and changes the physical demands on players.

A contributing factor to match related fatigue may be the reduction of muscle glycogen. Muscle glycogen is an important energy substrate for footballers during a football match (34).
The reduction of muscle glycogen by 40%-90% in muscle fibres is possibly the main contributor to match related fatigue towards the end of a football match (34). Although several other factors such as decreased muscle creatine phosphate, increased muscle lactate, decreased muscle pH, accumulation of muscle potassium and dehydration may play a part in match related fatigue (34).

**Physiological Load During Football Match-play**

The exercise performed in football is intermittent high intensity exercise, in which the energy demands are high. Average heart rates of 85% of maximal values and an oxygen consumption of approximately 70-80% of maximal oxygen uptake are typically seen in football players during a match (21). Furthermore, players perform approximately 150 to 250 short duration high intensity actions which suggest a large anaerobic energy turnover during a football match. This indicates that the aerobic and anaerobic energy transfer systems are highly taxed during a football match (4, 5). The energy provided by aerobic metabolism is largely responsible for fuelling the less intense (submaximal) actions of tracking opposition runs, field positioning and moving into space to receive the ball, as well as aiding in the recovery from high intensity actions (1, 4). During submaximal exercise the energy demands of the working muscles are met by the production of ATP from aerobic metabolism. During high intensity exercise (maximal and supra-maximal) as in duels, dribbling, shooting, jumping, and sprinting is the energy is provided by anaerobic metabolism (1, 4). During maximal and supra-maximal exercise, the energy required by the working muscles exceeds the rate of which energy can be provided by aerobic metabolism, and anaerobic energy transfer contributes to the exercise demands. However, a result of anaerobic metabolism is the accumulation of lactate which reduces muscle function and mechanical efficiency and can lead to exercise termination (35). From a physiological perspective, this may explain the
intermittent nature of exercise in football, as it would be physiologically impossible to sustain the high intensity exercise used in football for the duration of a match. Exercising at such intensities would also be unnecessary, as there are often times of non-involvement during a match. Therefore, the majority of exercise performed during a match is submaximal which allows the players to recover by removing anaerobic by-products post maximal and supra-maximal exercise. These recovery periods facilitate further maximal and supra-maximal exercise during the match (4).

In summary, it is necessary for players to possess sufficient aerobic and anaerobic capacities in order to meet the physical demands of football. Therefore it is important to understand the exercise intensity during match-play in order to determine physiological loads on players, which will help advance training methods to enhance performance. The following sections provide an overview of the direct and indirect measures that have been used to determine physiological load in football, including heart rate (HR), blood lactate concentration [La] oxygen uptake (VO₂) and the HR-VO₂ relationship (1, 2, 4, 21-23, 26, 36)

**Heart Rate and VO₂**

Average HR during match-play ranges from 80-90% of maximal heart rate (HRₘₐₓ). During the most intense periods of a match players can reach their individual HRₘₐₓ. Approximately two thirds (65%) of a match is spent at 70-90% HRₘₐₓ and seldom drops below 65% HRₘₐₓ (1, 2, 4, 22, 23, 26).

Indirect calorimetry using open circuit spirometry to measure metabolic rate is rare in football due to the bulk of equipment that can potentially restrict player’s movement and vision (2, 4) As such, values of 47-49% of VO₂ₘₐₓ reported by (37) have potentially underestimated the physiological load of footballers due to the impractical method of using a 200 L Douglas bag weighing 1.2 kg. Technological advances have reduced the bulk of open circuit spirometry equipment making them a more practical option for real-time measures of
VO2max during football training and matches. However, the portable open circuit spirometry devices are not permitted in official matches and their validity in training and research is questionable as these situations are not fully representative of competitive match situations (2). Gatterer, Faulhaber (38) equipped two midfield players with a Cosmed K4 portable gas analyser (800g) to obtain VO2 during match-play. The mean VO2 during the match was 37.4 ml min⁻¹ kg⁻¹ and 34.3 ml min⁻¹ kg⁻¹ for the players. This represents 57% and 61% of the players VO2max. Expressing VO2 as an average of game duration may not provide an accurate indication of intensities attained during intermittent sports such as football. Values close to the players VO2max were measured in Gatterer, Faulhaber (38) during the most intense exercise periods of the match. Thus specific information about the intensity of intermittent periods of football is lost when averaging VO2 across the entire match.

Metabolic load can be estimated during exercise based on the relationship between HR and oxygen consumption (HR-VO2), using small and easily worn HR monitors. Several studies have relied on the HR-VO2 relationship to determine oxygen utilisation during football matches (1, 4, 5, 26, 39). Estimates of 70-80% of VO2max have been reported in football using the HR-VO2 relationship (1, 4, 36, 39). Some limitations of the HR-VO2 relationship arise from the intermittent nature of football match-play. The calculation for HR-VO2 is based on continuous submaximal treadmill running conducted in a laboratory (1). Therefore, HR might not always provide an accurate indication of VO2 during a match due to the large effects of thermal and psychological stresses on the regulation of HR, also due to muscular contractions prevalent in matches during duels, jumping and directional changes known to increase HR independently of VO2 (1, 2, 4, 38). Despite the above mentioned limitations, there is support for the validity of the HR-VO2 relationship in football. Esposito, Impellizzeri (39) measured no difference in oxygen uptake between the estimated VO2 using the HR-VO2 relationship and respiratory gases measured by a portable gas analyser during football specific and
laboratory based exercises. The football specific tests were completed on a circuit representing the movement patterns of a football match, involving intermittent running, kicking, jumping, passing and kicking, and the laboratory based test was an incremental exercise test on a treadmill. During both tests the players wore a portable gas analyser to measure respiratory gases and HR monitors to measure HR. Mean VO$_{2\text{max}}$ measured by the portable gas analyser was 48.1 ml · min · kg$^{-1}$ in the football specific condition and 51.7 ml · min · kg$^{-1}$ in the laboratory condition and was not different to the HR-VO$_2$ relationship.

The oxygen uptake of players during a competitive football match has not yet been established because the equipment required to measure oxygen uptake is prohibited during competitive match-play. However, this methodology has been used in football simulations and during football activities (25). At this point, measurements of VO$_2$ via portable gas analysers during football-like activities and estimates by the HR-VO$_2$ relationship give the best estimation of the oxygen uptake during a football match. However, as discussed these methods contain limitations that need to be considered when attempting to determine the oxygen uptake during football.

**Physiology of Recovery from High Intensity Intermittent Exercise**

The ability to maintain a high exercise intensity across multiple exercise bouts is dependent on the recovery from the previous exercise bout(s) (40). This is influenced by the exercise intensity and duration of both the bouts, and the recovery periods (41). Furthermore, reductions in high speed running, power output, and increases in RPE indicates that fatigue accumulates as a results of multiple exercise bouts (42, 43). During recovery from exercise, oxygen consumption remains elevated to replenish the intramuscular high energy phosphates required to perform high intensity exercise, to pre-exercise levels, or to the level that the duration and intensity of the recovery period allows (40, 41, 44). As football involves brief (2
frequent periods of maximal intensity exercise during a match (1, 4, 21), the subsequent recovery duration between these exercise periods may not be sufficient to fully resynthesise the intramuscular high energy phosphates (40, 45). Progressive depletion of adenosine triphosphates (ATP) and phosphocreatine (PCr) stores increases the reliance on energy provided from anaerobic glycolysis, resulting in increased H+ and reduced pH levels (41, 46). This redistribution of sources of energy is associated with decrements in repeat sprint times, accelerations, mean running speed and power output across subsequent exercise bouts (40, 46). Decreased oxygen availability is thought to be the limiting factor of ATP and PCr resynthesis during the initial period (up to 30 s) of recovery from exercise (44, 47). Compared to normoxic conditions, there is a decreased rate of PCr recovery in hypoxic conditions, and an increased rate of PCr recovery in hyperoxic conditions (44), and PCr is not replenished when circulation is occluded (48). These studies indicate the importance of O2 availability for recovery from exercise.

**Lactate Analysis During Football Matches**

Between 150 and 250 high intensity intermittent exercise actions are performed during a football match (21). Within this, players perform short (2-4 sec) high intensity actions every 30-60 s and perform a sprint of less than 20 m on average every 90 seconds (4, 5, 24, 49-51). As such, the anaerobic metabolism provides the energy required to fuel the high intensity actions. The result of these high intensity actions is an increase in lactate production at the site of the working muscles, which is then released into the blood for removal (1). Once in the blood, samples can be easily taken at the capillaries of the fingertip to give the blood lactate concentration of players. Sampling blood lactate concentrations during half and full time in football is a simple method of estimating the intensity of the match. Blood lactate concentration values ranging from 2-14 mmol.L⁻¹ have been observed during football match-play (1, 2, 21, 26).
However, measurements of blood lactate concentration may not accurately reflect the muscle lactate produced following periods of intense exercise. Blood lactate is not correlated with lactate produced within the active muscles during intermittent exercise such as in football (1, 33, 52). Krustrup, Mohr (33) observed no correlation between blood and muscle lactate taken from blood samples and muscle biopsies of footballers during three friendly football matches. After periods of intense action in the first and second halves muscle lactate was 15.9 and 16.9 mmol.kg⁻¹ d.w., which was approximately four times greater than resting values. Blood lactate sampled in the same match periods showed values of 6.0 mmol.L⁻¹ and 5.0 mmol.L⁻¹. The lack of a correlation between muscle lactate and blood lactate concentrations arise from several factors, such as, the uptake of released muscle lactate by the heart, liver, kidneys and inactive muscles in the time from cessation of exercise to the time of sampling. Furthermore, the rate of lactate clearance from the blood is variable between and within individuals (33). Additionally, the timing of sampling is important to consider when interpreting blood lactate concentrations, as the activity of the players immediately before sampling will be varied within a team (36). It is evident that the high intensity intermittent exercise during football matches is responsible for increased blood lactate concentrations in players, as lactate production is greater than lactate clearance during these periods (4, 33, 36). However, the blood lactate concentration may not accurately reflect the muscle lactate produced during football matches. Therefore, when using blood lactate concentration as a measure of exercise intensity during football, consideration of the above mentioned limitations need to be considered.
Aerobic Capacity

The aerobic capacity (VO$_{2\text{max}}$) of football players ranges from 50 mL.kg.min$^{-1}$ to 75 mL.kg.min$^{-1}$ (4, 5, 53). Midfielders generally have the highest values of VO$_{2\text{max}}$ followed by wide fullbacks, forwards, central defenders and goalkeepers (1, 4, 5, 53). Strong correlations exist between distance covered by players during a match and the aerobic capacity of players (7). Additionally, players in higher ranked teams have been shown to possess greater aerobic capacity than those in lower ranked team (53, 54). Furthermore, improving the aerobic capacity of players increases the frequency of high speed running and involvements with the ball, which suggests that a higher aerobic capacity increases performance (7). This is an important aspect for football, as the outcome of a match is often decided as a result of high intensity actions (4). Lastly, the consistent reporting of values close to 60 mL.kg.min$^{-1}$ and above for professional football players have led some researchers to suggest the existence of a VO$_{2\text{max}}$ threshold for accession to an elite level of competition (5, 53).

Rating of Perceived Exertion (RPE)

Due to the large number of players in team sports, prescribing individual training programs is difficult and time consuming. As such, it is common in team sports for coaches to prescribe the same external training load to the entire squad of players. This method is time efficient and allows the coach to have greater control of the training sessions. However, physiological adaptations are induced by the internal physiological stresses and not the prescribed external training load (55). Therefore, it is important for coaches and conditioning staff to be able to monitor and quantify the individual internal training load of players. Hoff, Wisloff (56) found that when an external training load was prescribed to a group of footballers (5 vs 5 SSG format), players with the highest aerobic capacity recorded the lowest percentage of VO$_{2\text{max}}$ during the SSG. These results suggest that prescribing an external training load for the whole squad may not always benefit players of different fitness levels. This information is important
for coaches to understand that while players with a low aerobic capacity may be under high internal physiological stress during training, players with a higher aerobic capacity may not. Therefore, a method of quantifying internal training load and intensity is required for coaching staff to monitor individual player responses to training.

Measuring the exercise intensity in football is most commonly determined by monitoring players' HR and applying the HR-VO₂ relationship, however, this method has limitations during intermittent high intensity exercise such as football (see HR and VO₂ section). Despite this, several HR based methods are used to quantify exercise intensity and internal training load in football (55). However, HR monitoring equipment can be expensive and often requires sport science experts to interpret the data for coaches (55, 57). An alternative measure of exercise intensity and internal training load is RPE (58). RPE is a simple, inexpensive and time efficient method of measuring exercise intensity during football training (57). RPE has strong correlations with physiological exercise intensity measures of VO₂, respiratory rates, blood lactate, glycogen depletion, HR and EMG across a broad range of exercise modes and intensities (57, 59). In addition, RPE is representative of the psychological status of players which is not measurable by individual physiological responses (57, 60). In SSG research, RPE (Borg 6-20 and Borg CR 1-10 scales) is a common and valid measure of exercise intensity (14, 61, 62). Considering the many variations of SSG formats and their effect on exercise intensity during SSG, a detailed RPE analysis is given in (Section 6). Because of psychobiological nature of RPE, it is considered to be an accurate indicator of global exercise intensity and internal training load during football training and match play (55, 57, 58, 60).
**Small Sided Game Introduction**

Football is defined as a high intensity intermittent sport, as such players need to have well-developed physiological capacities to cope with the physical demands of the game (9, 63). In addition to having well-developed physical capacity, footballers need to possess technical skills and decision making ability (9, 64). To develop these qualities in players, football coaches are constantly looking for the most effective training methods to improve performance (9, 61). The most effective training methods for gaining maximal performance and for the development of players are achieved when the training stimulus is similar to the specific demands of competition (9, 65). As a result, game based training has become increasingly popular with coaches due to the concurrent training of the physical, technical and tactical components required of the sport (9). One form of game based training in football is SSG, which are modified football games played with reduced numbers of players on reduced size pitches (10, 66).

SSG are recognised as an important training method for football players in the development of the physical, technical and tactical components of football (10, 14, 67). As such, SSG have been implemented into several national football curriculums including the Dutch, and Australian Football Federations as a method for player development (10). SSG games hold many advantages over traditional football training methods. Traditional training methods have generally isolated the physical, technical and tactical components of football into separate practise drills, which does not accurately represent the movement patterns and decision making that occurs in football match-play (8). Isolation of technical actions in a predictable environment, as often used in traditional practice drills, does not prepare players for the decision making and technique execution required in an unpredictable competitive football environment (8). Additionally, players have a higher perception of effort when the physical component is trained in isolation compared to SSG training (9, 68). In contrast to
isolating football components, SSG provide a stimulus that accurately replicates the physical, technical and tactical demands of football (8, 66). Furthermore, the concurrent training of all football components in SSG is time efficient and reduces the training load of players (69). Additionally, SSG facilitate a competitive training environment between players because of the game-like situations, such as competing for possession and scoring goals. Furthermore, the exercise intensity of SSG is able to be modified to meet the desired outcome intended by the coach in the training session (9, 10, 66).

**Variables Affecting Exercise Intensity of SSG**

Increasing the exercise intensity of a training stimulus is considered an important variable to induce physiological adaptations (70). However, controlling the intensity of SSG games is difficult for coaches because of the intermittent and spontaneous self-paced exercise activity in SSG (12). Therefore, in order for coaches to have greater control of SSG exercise intensity, it is important they understand the effect that modifying specific SSG variables has on exercise intensity (10). Modifying variables such as pitch size, player numbers, bout and recovery durations, rule modifications, coach encouragement and the use of goals and goalkeepers each have a direct impact on the exercise intensity of SSG (10, 66). As such, comprehension of the variables affecting exercise intensity will assist coaches to optimally plan and deliver SSG training that will develop the physical, technical and tactical capacities of players.

Exercise intensity of SSG has previously been quantified by measures of HR response, blood [La], rating of perceived exertion (RPE) and time-motion analysis via global positioning systems (GPS) (10, 14, 71). The assessment of HR response is a valid indicator of exercise intensity during SSG and has frequently been used in SSG research (10). HR responses measured in SSG are similar to or exceed the HR response values seen in full scale match-
Mean HR responses measured in SSG often achieves the appropriate level (~ 90% \( \text{HR}_{\text{max}} \)) to increase aerobic capacity in players, endorsing SSG as an aerobic training stimulus (7).

Measurements of blood \([\text{La}]\) of players during SSG are frequently used to determine the exercise intensity (11, 57, 61, 72-74). However, as previously stated (see lactate analysis during football section) blood \([\text{La}]\) is not an accepted indirect measure of lactate produced at the active muscle (33). Additionally, blood \([\text{La}]\) is considered to be a poor indicator of exercise intensity in football because of the intermittent exercise performed (10). Despite the limitations of blood \([\text{La}]\) as a measure of exercise intensity, many researchers have measured exercise intensity in SSG via blood \([\text{La}]\) and so it is important to review the findings of this measure with respect to football. A further measure of the exercise intensity used in SSG research is RPE (see rating of perceived exertion section) (12-14, 42, 57, 61, 62, 67, 72, 75-78).

Time motion analysis via Global Positioning System (GPS) in SSG is a commonly used measure to quantify exercise intensity during SSG (69, 72, 75). GPS provides a comprehensive analysis of numerous variables that allow coaches and conditioning staff to monitor training and matches (79). The variables of particular interest in SSG are the measurements of total distances covered as well as distances and time spent in different running speed zones by players during SSG. However, the accuracy of GPS is reliant on the sampling speeds (69, 79). The majority of GPS analysis in SSG and football has used 1 Hz and 5 Hz sampling rates, however GPS technology has advanced and an increase in 10 Hz data in football is being reported. Higher sampling rates (10 Hz) provide more accurate data than the previously low sampling rates (1 Hz and 5 Hz) used for time motion analysis of football (75). During walking and low running speeds (< 1.8 m.s\(^{-1}\)) the slower sampling rates (1 Hz and 5 Hz) have acceptable accuracy (75, 79, 80). However, during high running speeds
 (> 6ms\(^{-1}\)) over short distances as often seen in SSG, the data from the slower sampling rates have reduced accuracy (75, 80). Thus, GPS devices sampling at higher rates (10 Hz) provide more accurate measures of time motion characteristics in SSG (72, 79). The standard error of a 10 m sprint recorded by 1 Hz and 5 Hz GPS systems was 32.4% and 30.9% respectively, whereas the standard error of a 15 m sprint recorded by 10 Hz GPS was 10.9% (79). GPS has been used extensively in SSG research as a measure of external exercise intensity. However, consideration of the sampling rates and the classification of the speed zones is needed to ensure acceptable reliability of the measurements (69, 72, 75, 79).

The following sections will discuss the effect of modifying pitch size, player numbers, bout, and recovery durations, rule modifications, coach encouragement and the presence of goals and goalkeepers on exercise intensity during SSG. This information is valuable for coaches to plan SSG training sessions that facilitate the desired outcomes (physical, technical and tactical) of the session. The particular focus of the following sections is to discuss how altering the exercise intensity of SSG effects the selection of the appropriate recovery duration.

**Pitch Size**

Regulations for pitch dimensions set by football’s world governing body (FIFA) are a minimum of 90 m and maximum of 120 m in length and a minimum of 45 m and maximum of 90 m in width (3). However, coaches often use variations of smaller pitches in training to alter the exercise intensity of SSG (10). Modifying pitch dimensions has a direct impact on exercise intensity and metabolic demands of players during SSG (11, 14, 66).

Rampinini, Impellizzeri (14) investigated the differences in exercise intensity, as measured by HR response, blood [La] and RPE of players during various SSG formats (3 vs 3, 4 vs 4, 5 vs 5, and 6 vs 6 teams) played on small, medium and large pitch sizes. As pitch sizes vsteam
(Table 1.1). Similarly, Casamichana and Castellano (78) measured the exercise intensity during SSG on small, medium and large playing areas during a 5 vs 5 SSG format. SSG exercise intensity was measured by HR response and the percentage of time spent in different HR intensity zones, along with RPE (Borg CR 10) during the SSG. Significant differences in percentage of HRmax were measured during games on the small size pitch compared to, but not between the medium and large size pitches (Table 1.1). Furthermore, players spent more time in the moderate HR intensity zone 75-84% HRmax during the small SSG format (27.9%) compared to the medium (19.4%) and large (10.0%) SSG formats. Time spent in the highest intensity zone (> 90% HRmax) was significantly less in the small SSG (41.3%) compared to the medium (57%) and large (50.8%) SSG formats. The average of the player’s RPE was less on the small pitch compared to the medium and large size pitches (Table 1.1). A further study investigating pitch size variations in SSG by Aslan (76) examined the HR response and RPE during 5 vs 5 and 7 vs 7 teams on small and large size pitches. Mean HR values of both the 5 vs 5 and 7 vs 7 formats were less during the SSG on the small field compared to the SSG played on the large pitch (Table 1.1). No differences in RPE were measured across the conditions (Table 1.1). In contrast to the increasing HR responses of players during SSG when pitch sizes are larger are results of Kelly and Drust (81). The authors found no difference in HR response (mean and maximum HR) on varied SSG pitch sizes when player number remained constant at 4 vs 4 (Table 1.1).

Despite the contrasting results of Kelly and Drust (81), the majority of research on the effect of pitch size on exercise intensity in SSG suggests that larger sized pitches elicit a higher physiological and perceptual response in players compared to the smaller sized pitches (11, 14, 75). An explanation is that players on larger sized pitches are able to cover more total distance and have time and space to achieve higher running velocities. Understanding the effect different pitch sizes have on exercise intensity is valuable information for coaches for
the planning of SSG training sessions. It will allow coaches to determine the appropriate
duration of the SSG bouts and recovery times required to induce physiological adaptations.

Table 1.1 Physiological and Perceptual Response of Players During Varied SSG Pitch
Dimensions.

<table>
<thead>
<tr>
<th>Author</th>
<th>Player Number</th>
<th>Pitch Size (m)</th>
<th>% HR max</th>
<th>Mean HR b.min⁻¹</th>
<th>Blood [La] (mmol.L⁻¹)</th>
<th>RPE</th>
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<td>-</td>
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<td>-</td>
<td>5.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 x 35</td>
<td>94.6</td>
<td>-</td>
<td>-</td>
<td>6.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>62 x 44</td>
<td>94.6</td>
<td>-</td>
<td>-</td>
<td>6.7</td>
</tr>
<tr>
<td>Aslan (2013) (76)</td>
<td>5 vs 5</td>
<td>44 x 23</td>
<td>97.7</td>
<td>164.3</td>
<td>-</td>
<td>12.4*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57 x 30</td>
<td>99.2</td>
<td>167.0</td>
<td>-</td>
<td>13.2*</td>
</tr>
<tr>
<td></td>
<td>7 vs 7</td>
<td>44 x 23</td>
<td>96.7</td>
<td>161.2</td>
<td>-</td>
<td>12.3*</td>
</tr>
<tr>
<td></td>
<td></td>
<td>57 x 30</td>
<td>96.3</td>
<td>163.5</td>
<td>-</td>
<td>12.8*</td>
</tr>
<tr>
<td>Kelly &amp; Drust (2009) (81)</td>
<td>5 vs 5 (plus goalkeepers)</td>
<td>30 x 20</td>
<td>91.0</td>
<td>175</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>40 x 30</td>
<td>90.0</td>
<td>173</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 x 40</td>
<td>89.0</td>
<td>169</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
Values in Rampinini et al., (2007) are without coach encouragement, as was used in this project. RPE values are in Borg CR 10, # denotes Borg 6-20 RPE scale. – denotes not measured.

Player Number

Modifying player numbers of SSG teams is a common method of altering the exercise intensity during SSG training (11, 14, 69, 75, 82). Coaches generally alter player numbers in SSG to replicate situations that occur during full scale match-play. Brandes, Heitmann (69) and Koklu (82) investigated the effect of altering player numbers (2 vs 2, 3 vs 3, 4 vs 4) on exercise intensity during SSG. Exercise intensity in both studies was measured by HR response and blood [La]. Contrasting results were observed in the two studies. Koklu (82) identified the 3 vs 3 SSG format produced the highest HR response from players compared to 2 vs 2 and 4 vs 4 (Table 1.2). Whereas, Brandes, Heitmann (69) found the 2 vs 2 SSG elicited the highest HR response in players compared to the 3 vs 3 and 4 vs 4 formats (Table 1.2). Despite HR response peak values occurring in different SSG formats in the two studies, blood [La] was highest in the 2 vs 2 SSG format in both studies (Table 1.2). The discrepancy between the studies could be due to several factors, for example playing formats (pitch size, bout number and duration etc.), physical capacity of players, and age of players. These were different between the studies or the information is not available for the studies, which makes it difficult to provide a definite explanation of the discrepancy in the results.

A similar study using recreational players, with the addition of a 5 vs 5 format by Aguiar, Botelho (75) examined modifying player numbers per team to assess the effects on exercise intensity during SSG. The heart rate response and RPE (Borg 6-20) were used to determine exercise intensity. During the 3 vs 3 SSG format the players had significantly higher % HRmax values compared to 4 vs 4 and 5 vs 5 formats, but not the 2 vs 2 format (Table 1.2).
Additionally, players in the 3 vs 3 SSG format spent significantly more time in the highest HR intensity zone (> 90% HRmax) compared to the 5 vs 5 SSG format. Identical mean RPE values were observed in the 2 vs 2 and 3 vs 3 SSG, which were significantly greater than 4 vs 4 and 5 vs 5 SSG (Table 1.2). A less common SSG format used by coaches is 1 vs 1, maybe because sustained 1 vs 1 play in football is rare. Another possible explanation for the lack of 1 vs 1 research maybe that 1 vs 1 duels are able to be trained within the larger formats of SSG. However, Koklu, Asci (83) measured the highest levels of blood [La] in the 1 vs 1 SSG format compared to 2 vs 2, 3 vs 3 and 4 vs 4 formats. Interestingly, the HR response measured in the 1 vs 1 SSG format was lower than the 2 vs 2, 3 vs 3 and 4 vs 4 formats (83).

Within the literature the exercise intensity in SSG is consistently higher when player numbers are small (1 vs 1 and 2 vs 2). Increasing the number of players on the pitch during SSG reduces the number of involvements per player of game time, resulting in a decrease in exercise intensity when players are added (83). Also, the more frequent high intensity actions in the lower player number SSG formats does not allow players to fully recover, resulting in reduced creatine phosphate stores and increased lactate accumulation (83). The increased blood lactate levels in the smaller numbered teams indicates that anaerobic energy turnover and muscle lactate production is high in these SSG formats. This provides coaches with an additional tool to alter the demands of SSG training. Due to the different physiological response to different sided games, bout and recovery durations need to be considered by coaches when planning SSG training to optimise the desired physical conditioning.
Table 1.2. Physiological and Perceptual Responses of SSG Formats with Different Player Numbers.

<table>
<thead>
<tr>
<th>Author</th>
<th>Player number</th>
<th>% HR max</th>
<th>Blood [La] mmol.L⁻¹</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brandes et al, (2012)</td>
<td>2 vs 2</td>
<td>93.3</td>
<td>5.5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>91.5</td>
<td>4.3</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4 vs 4</td>
<td>89.7</td>
<td>4.4</td>
<td>-</td>
</tr>
<tr>
<td>Koklu et al, (2012)</td>
<td>2 vs 2</td>
<td>88.6</td>
<td>7.8</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>92.0</td>
<td>6.8</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4 vs 4</td>
<td>90.1</td>
<td>6.7</td>
<td>-</td>
</tr>
<tr>
<td>Aguiar et al (2013)</td>
<td>2 vs 2</td>
<td>87.5</td>
<td>-</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>89.6</td>
<td>-</td>
<td>17.0</td>
</tr>
<tr>
<td></td>
<td>4 vs 4</td>
<td>85.9</td>
<td>-</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>5 vs 5</td>
<td>84.6</td>
<td>-</td>
<td>13.5</td>
</tr>
<tr>
<td>Koklu et al, (2011)</td>
<td>1 vs 1</td>
<td>86.1</td>
<td>9.4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>2 vs 2</td>
<td>88.0</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>92.8</td>
<td>7.5</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4 vs 4</td>
<td>91.5</td>
<td>7.2</td>
<td>-</td>
</tr>
</tbody>
</table>

RPE is Borg 6-20 scale. – denotes not measured.

**Bout Duration**

The effect of bout duration on exercise intensity is not well established in SSG research. Within SSG literature, no consistency exists regarding bout duration, or the number of successive bouts performed by players during SSG training. Only one study has investigated the effect of bout duration on exercise intensity, while keeping player numbers and pitch size constant throughout the SSG. Fanchini, Azzalin (12) altered bout duration (2, 4 and 6 min) interspersed with 4 min of recovery in a 3 vs 3 SSG format on a 37 m x 31 m pitch. Exercise intensity was determined by measures of HR and RPE (CR 10) across the series of three
bouts. The 4 minute bout duration SSG format elicited the highest HR response from players (89.5% HR$_{\text{max}}$) compared to 2 and 6 minute bout durations (88.5 and 87.8% HR$_{\text{max}}$), however these values were not significantly different. Players mean RPE of the three bouts in both the 4 and 6 minute condition were 6.8 and 6.7 for the 2 minute bout. However, during the final bout the RPE values were significantly different and progressively higher in each condition (2 min 7.2, 4 min 7.3 and 6 min 7.5). Although, players perceived the 6 minute SSG format as the most intense, it was in this format that the lowest percentage of HR$_{\text{max}}$ was recorded. The percentage of HR$_{\text{max}}$ in the 6 minute bout was significantly lower than in the 4 min bout and lower but not at a significant level in the 2 min bout. Despite the significant drop in HR from 6 min to 4 min, the small changes may not be substantial to affect training adaptations, and therefore bouts of 2 - 6 min can be used interchangeably by coaches (12).

In a study on the time motion characteristics of SSG, Aguiar, Botelho (75) measured decreases in accelerations of players after two minute periods. The authors recommended that bout durations should be planned for 2 minute periods with brief interspersed recovery periods, to increase physiological stress. This information is useful for coaches when planning SSG training, coaches can use shorter bout durations of high intensity exercise to develop the players’ physiological capacity and longer bout durations of lower intensity to develop match-specific technical and tactical demands (12, 75)

**Recovery Duration**

Only one study has investigated the effect of changing the duration of the recovery periods separating multiple SSG bouts on exercise intensity, technical performance, and time motion descriptors (15). Exercise intensity during the bouts, was determined by HR, blood [La], and RPE. However, no exercise intensity data was reported from the recovery periods. This would have provided direct evidence that changing the duration of recovery separating the
bouts had an effect on the exercise intensity measures during the recovery periods. There is no indication that changing the duration of recovery affected HR or blood [La], during the recovery periods, which may have affected the HR, blood [La], and RPE during the bouts. Technical variables included, touches in possession, the number of total passes, successful passes, tackles, and passes received. The time motion descriptors were distance covered in various speed zones and the distances covered for each bout.

Increasing the recovery duration from 1 min, 2 min, 3 min, and 4 min separating 4 x 4 min bouts in a 3 vs 3 SSG format decreased exercise intensity and increased technical performance in 15 year old football players. The %HR\textsubscript{max} was significantly higher during the SSG played with 1 min recovery (91.4 %HR\textsubscript{max}), compared to 3 min recovery (89.2 %HR\textsubscript{max}), and 4 min recovery (88.6 %HR\textsubscript{max}). There was no significant difference between the conditions for RPE and blood [La]. The timing of RPE, and blood [La] collection is a limitation of this study. The RPE was measured two min after the final 4 min bout. A bout by bout analysis of perceived exertion would have given the necessary specific information of the psychophysiological response of players for the different durations of the recovery separating the SSG. Blood [La] was collected 3 min after the final SSG bout (see section 4.2 for limitations on blood [La] sampling in football, and issues regarding the timing of collection).

Furthermore, technical performance was decreased during the shorter duration recovery periods (1 min and 2 min recovery periods). The number of total passes, successful passes, tackles, and passes received were significantly lower in the SSG played with 1 min recovery compared to 3 min, and 4 min recovery periods. Touches of the ball per possession were significantly less in the SSG played with 1 min, and 2 min recovery compared to 3 min recovery.
Lastly, the distance covered at 0 – 6.9 km.h\(^{-1}\) was significantly less in the SSG games played with 2 min (760 m), and 4 min (697 m) recovery compared to 1 min recovery (806 m), and distance at > 18 km.h\(^{-1}\) were the higher in the SSG played with 3 min (81 m) compared to 1 min (42 m) recovery duration. There was no difference in the total distances covered during the SSG played in all conditions.

The authors suggest that SSG played with 1 min or 2 min recovery duration should be used to develop physiological capacity, and 3 min and 4 min recovery to develop technical skills (15).

**Rule Modifications**

Altering the number of individual ball contacts per possession and playing with and without goals and goalkeepers has an effect on the exercise intensity of SSG. Restricting the number of individual ball contacts develops the technical component of football, but also varies the exercise intensity of SSG (13, 42, 61, 65). In two comprehensive studies on SSG rule modification, Dellal, Lago-Penas (42) and Dellal, Hill-Haas (61) measured differences in exercise intensity of SSG when players were given restricted ball contacts per possession (1 and 2 contacts) as well as unlimited ball contacts. Firstly, Dellal, Lago-Penas (42) measured exercise intensity by using RPE (CR 10), % HR\(_{\text{max}}\), and blood [La] in 4 vs 4 SSG across 4 bouts of SSG while enforcing ball contacts per possession rules. RPE in the SSG with restricted contacts were higher than SSG with unlimited contacts (table 1.3). Blood [La] values of players in the free play SSG format elicited higher mean blood [La] than the restricted contacts (Table 1.3). The highest mean HR response (% HR\(_{\text{max}}\)) of players across the 4 bouts, occurred in the 1 contact compared with 2 contacts and unlimited contacts SSG format. Averaged data from the four individual bouts were used for HR, RPE and blood [La] in (Table 1.3).
Secondly, Dellal, Hill-Haas (61) measured the exercise intensity during SSG while enforcing the same ball contact per possession rule modifications as in the previous study. On this occasion using professional and amateur football players, while concurrently altering player numbers per team (2 vs 2, 3 vs 3 and 4 vs 4). The same exercise intensity measures were used. Regardless of playing level and number of players, 1 ball contact per possession was the most intense of the SSG conditions. Blood [La] measures and RPE were the highest in this condition and decreased as ball contacts were increased to 2 contacts and decreased further in unlimited ball contacts. HR response (%HR\text{max}) of players slightly decreased from 1 ball contact to unlimited contact, however only subtle decreases were seen between HR responses of the different rule modifications (Table1.3).

Altering individual ball contacts per possession has an impact on the exercise intensity in SSG (42, 61). As shown, one ball contact per possession consistently measured the highest exercise intensity (42, 61). This information allows coaches to modify SSG rules that will induce changes to physiological loads on players during SSG. Therefore, when planning SSG training, coaches should consider the appropriate bout and recovery durations for the desired outcome of the session.
Table 1.3. Physiological and Perceptual Responses of Footballers During SSG Formats with Rule Modifications.

<table>
<thead>
<tr>
<th>Author</th>
<th>Team No.</th>
<th>No. of touches</th>
<th>%HR max</th>
<th>Blood [La] mmol.L⁻¹</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dellal et al, (2011) (42) (47)</td>
<td>4 vs 4</td>
<td>1 touch</td>
<td>87.6</td>
<td>2.97</td>
<td>7.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 touch</td>
<td>85.9</td>
<td>2.85</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>Free play</td>
<td></td>
<td>84.6</td>
<td>3.33</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>2 vs 2</td>
<td>1 touch</td>
<td>90.3</td>
<td>92.3</td>
<td>3.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 touch</td>
<td>90.1</td>
<td>91.5</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>Free play</td>
<td></td>
<td>90</td>
<td>91.6</td>
<td>3.5</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>1 touch</td>
<td>90</td>
<td>91.2</td>
<td>3.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 touch</td>
<td>89.4</td>
<td>90</td>
<td>3.4</td>
</tr>
<tr>
<td></td>
<td>Free play</td>
<td></td>
<td>89.6</td>
<td>89.5</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>4 vs 4</td>
<td>1 touch</td>
<td>87.6</td>
<td>87.4</td>
<td>3.0</td>
</tr>
<tr>
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<td>2 touch</td>
<td>85.6</td>
<td>86.6</td>
<td>2.9</td>
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<tr>
<td></td>
<td>Free play</td>
<td></td>
<td>84.7</td>
<td>85.1</td>
<td>2.8</td>
</tr>
</tbody>
</table>

HR, RPE and blood [La] values from Dellal et al., (2011) are averaged from the four individual bouts of SSG. * Professional (Pro), #Amateur (Am).

**Goals and Goalkeepers**

The inclusion or exclusion of goals/goalkeepers is an additional rule modification which coaches commonly use in SSG training formats to vary the exercise intensity. Including goals/goalkeepers requires teams to attack and defend with a specified direction of play. The focus of SSG that exclude goals/goalkeepers is possession based with no set direction of play, with the aim of keeping the ball for as long as possible (65). To date, three studies have investigated the direct effect of these rule modifications on exercise intensity in SSG and have revealed contrasting results (65, 71, 84).
Castellano, Casamichana (84), and Mallo and Navarro (65) reported lower values of mean HR and %HR\textsubscript{max} in players during SSG with goals/goalkeepers than without, suggesting the possession based SSG format is played at a higher intensity. An explanation for the decrease in exercise intensity of SSG with goals/goalkeepers is that players are more organised and structured to prevent the opposition scoring. Playing with more structure defensively reduced the intensity of the game. Players spent less time in the 86-95\% HR\textsubscript{max} intensity zone when goals/goalkeepers were included in the SSG (65). However, Dellal, Chamari (71) identified increases of 12\% in HR reserve during an 8 vs 8 SSG when goals/goalkeepers were included in the SSG. Increases of exercise intensity may be caused by increased motivation of players to score goals, as well as preventing the opposition scoring goals (71).

From the evidence presented, the inclusion or exclusion of goals and goalkeepers appears to have an effect on the exercise intensity of SSG (65, 71, 84). However, contrasting results have been reported in the three studies investigating the effect of goals/goalkeepers on exercise intensity. It is unclear if the use of goals and goalkeepers increases or decreases the exercise intensity during SSG due to the limited research on this rule modification. Player motivation to score goals or not to concede goals may influence the exercise intensity. Nevertheless, using goals and goalkeepers gives coaches another SSG training tool that replicates specific match demands. As such, the use of goals and goalkeepers may have a more important role for tactical play rather than as a physical conditioning tool.

**Coach Encouragement**

Exercise intensity in SSG is influenced by verbal coach encouragement (14, 85). Rampinini, Impellizzeri (14) measured increased exercise intensity (%HR\textsubscript{max}, blood [La] and RPE), when verbal coach encouragement was given to players during various SSG formats (Table 1.4). Similar results were reported by Sampio, Garcia (85), who measured significant increases in
RPE when coach encouragement was included in the SSG. Despite the increases in RPE there was no significant differences in HR_{max} of the players during the SSG (Table 1.4). It is important for coaches to understand that encouraging players during SSG in training will increase the exercise intensity of the training session. This may impact upon the length of bout duration and recovery times used in the SSG, depending on the focus of the training session (i.e. physical, tactical or technical).

**Table 1.4. Physiological and Perceptual Responses of Footballers During SGG Formats With and Without Coach Encouragement.**

<table>
<thead>
<tr>
<th>Author</th>
<th>Team No.</th>
<th>Pitch size (m)</th>
<th>%HR_{max}</th>
<th>Blood [La] (mmol.L^{-1})</th>
<th>RPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rampinini et al, (2007) (14)</td>
<td>3 vs 3</td>
<td>12 x 20</td>
<td>89.5</td>
<td>6.0</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 x 25</td>
<td>90.5</td>
<td>6.3</td>
<td>8.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>18 x 30</td>
<td>90.9</td>
<td>6.5</td>
<td>8.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 x 24</td>
<td>88.7</td>
<td>5.3</td>
<td>7.6</td>
</tr>
<tr>
<td>4 vs 4</td>
<td>20 x 30</td>
<td>89.4</td>
<td>5.5</td>
<td>4.3</td>
<td>7.9</td>
</tr>
<tr>
<td></td>
<td>24 x 36</td>
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<td>6.0</td>
<td>4.7</td>
<td>8.1</td>
</tr>
<tr>
<td></td>
<td>20 x 28</td>
<td>87.8</td>
<td>5.2</td>
<td>3.9</td>
<td>7.2</td>
</tr>
<tr>
<td>5 vs 5</td>
<td>25 x 35</td>
<td>88.8</td>
<td>5.0</td>
<td>4.1</td>
<td>7.6</td>
</tr>
<tr>
<td></td>
<td>30 x 42</td>
<td>88.8</td>
<td>5.8</td>
<td>4.6</td>
<td>7.5</td>
</tr>
<tr>
<td></td>
<td>24 x 32</td>
<td>86.4</td>
<td>4.5</td>
<td>3.4</td>
<td>6.8</td>
</tr>
<tr>
<td>6 vs 6</td>
<td>30 x 40</td>
<td>87.0</td>
<td>5.0</td>
<td>3.9</td>
<td>7.3</td>
</tr>
<tr>
<td></td>
<td>36 x 48</td>
<td>86.9</td>
<td>4.8</td>
<td>3.6</td>
<td>7.2</td>
</tr>
<tr>
<td>Sampio et al, (2007) (85)</td>
<td>2 vs 2</td>
<td>30 x 20</td>
<td>83.7</td>
<td>-</td>
<td>15.5</td>
</tr>
<tr>
<td></td>
<td>3 vs 3</td>
<td>30 x 20</td>
<td>80.8</td>
<td>-</td>
<td>15.8</td>
</tr>
</tbody>
</table>

*Coach encouragement (CE), No coach encouragement (No CE), – denotes note measured.*
Limitations of SSG Training

Despite numerous advantages of SSG training some potential limitations to SSG training do exist. 1) Prescribing an external training load may not always benefit players of different fitness levels. This information is important for coaches to understand that while players with a low aerobic capacity may be under high internal physiological stress during training, players with a higher aerobic capacity may not. Hoff, Wisloff (56) found that when an external training load was prescribed to a group of footballers (5 vs 5 SSG format), players with the highest aerobic capacity recorded the lowest percentage of VO\textsubscript{2max} during the SSG. 2) Less skilled players might not have the technical, tactical or physical capacities to maintain a high level of exercise intensity which may be counterproductive to performance during SSG training (10). 3) The competitive, match specific demands of SSG may increase the risk of contact injuries to players (10). 4) The reduced sized pitches may not always allow players to replicate the running distances, durations and speeds as those seen on a full sized pitch. Therefore, additional training to replicate the longer sprint distance and durations players perform may be necessary to ensure training is representative of match play (86).

In conclusion, there are possible limitations to SSG training that coaches should be aware of. However, coaches can reduce the impact of these limitations with appropriate planning of SSG training, knowledge of player’s physical, technical and tactical capacities and the variables that affect the exercise intensities of SSG.
Time Motion Analysis of SSG

The use of global positioning system (GPS) devices on players allows coaches and sport scientists to analyse the time motion characteristics of football players during SSG (10). Time motion characteristics in SSG are an external measure of exercise intensity in addition to internal physiological measures (84). GPS devices are a reliable and valid method of obtaining the total distances covered, time spent in a variety of different speed zones and accelerations of players during SSG (10, 69, 72, 84). Determining the amount of time players spend at various speeds in different SSG formats is important for coaching staff to be able to monitor training load and develop training situations that will replicate the movement characteristics of actual match-play.

Brandes, Heitmann (69) measured the time motion characteristics of players via GPS in 2 vs 2, 3 vs 3 and 4 vs 4 SSG formats. Speed zones from walking to maximal sprinting were measured (Table 1.5). Apart from the lowest speed zone (<5.3 km.hr⁻¹), as the number of players per team increased, players spent more time (as a mean percentage of game duration) in the higher running speed zones (Table 1.5). Additionally, as player numbers and pitch sizes increased, mean maximal sprint duration and mean maximal sprint distance were augmented. A further study by Aguiar, Botelho (75) investigated the time motion characteristics of 2 vs 2, 3 vs 3, 4 vs 4 and 5 vs 5 SSG formats, while keeping the relative pitch area per player constant. The players in the 2 vs 2 SSG format ran significantly less total distance than the larger SSG formats (Table 1.5), which was probably due to the smaller individual pitch area in the 2 vs 2 SSG format (75). Players in the 3 vs 3 SSG format spent more time and covered more distance in the three highest running speed zones (Table 1.5).

The most common protocol of SSG uses intermittent bouts of exercise interspersed with recovery periods, although continuous SSG formats are occasionally used by coaches as a
method of physical training (72). The time motion characteristics of intermittent SSG versus continuous SSG training using 2 vs 2, 4 vs 4, and 6 vs 6 SSG formats identified differences between the two protocols (72). Players in the intermittent compared to continuous SSG covered more total distance and spent more percentage of total playing time in three of the four speed zones measured (Table 1.5). Furthermore, players in the intermittent SSG had a significantly higher sprint activity ratio (72) (Table 1.5). The authors attribute the higher exercise intensity in the intermittent SSG to physiological recovery during the 1.5 minute recovery periods that interspersed the exercise bouts. During recovery, the removal of metabolic by-products and PCr resynthesis allowed players to perform more repeat sprints than the continuous SSG with no designated recovery periods (72).

It is difficult to compare results of the above studies, as the measured speed zones vary between studies. Also the number of exercise bouts and bout duration between the studies differ. Furthermore, different GPS sampling rates were used, 5 Hz sampling rates were used by Aguiar, Botelho (75), and 1 Hz sampling rates by Brandes, Heitmann (69), and Hill-Haas, Rowsell (72). The slower sampling rates (1-5 Hz) are considered to be reliable only when players are moving in the slower speed zones. However, when players begin to move into the high speed zones, the reliability of the slower sampling rates is poor (69, 80).

Despite this some noticeable similarities of the time motion characteristics of the various SSG formats are seen. Players consistently spent the most time in the lowest speed zones which may suggest that this zone is used for recovery from high intensity actions. Total distance covered by players in SSG is restricted by the constraints of the pitch area, and therefore is probably not an accurate indicator of work rate in SSG (69, 72). As such, the time spent in the various speed zones may best be represented as a percentage.
Table 1.5. Time Motion Analysis of Footballers During Different SSG Formats.

<table>
<thead>
<tr>
<th></th>
<th>Speed zones (km.hr(^{-1}))</th>
<th>Team size</th>
<th>&lt; 5.3</th>
<th>5.3-7.7</th>
<th>7.7-10.3</th>
<th>10.3-14</th>
<th>14-17.2</th>
<th>17.2-26.8</th>
<th>&gt;=26.8</th>
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<tr>
<td>Brandes et al,</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 vs 2</td>
<td></td>
<td></td>
<td>46.2%</td>
<td>21.2%</td>
<td>14.5%</td>
<td>11.2%</td>
<td>4.5%</td>
<td>2.5%</td>
<td>0.0%</td>
</tr>
<tr>
<td>3 vs 3</td>
<td></td>
<td></td>
<td>42.8%</td>
<td>20.6%</td>
<td>15.4%</td>
<td>13.3%</td>
<td>4.9%</td>
<td>3.1%</td>
<td>0.1%</td>
</tr>
<tr>
<td>4 vs 4</td>
<td></td>
<td></td>
<td>41.1%</td>
<td>21.0%</td>
<td>15.8%</td>
<td>13.6%</td>
<td>5.2%</td>
<td>3.3%</td>
<td>0.1%</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Speed Zones (km.hr(^{-1}))</th>
<th>Team size</th>
<th>0-6.9</th>
<th>7-9.9</th>
<th>10-12.9</th>
<th>13-15.9</th>
<th>16-17.9</th>
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<tr>
<td>Aguiar et al,</td>
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</tr>
<tr>
<td>(2013) (75)</td>
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<td></td>
<td></td>
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<tr>
<td>2 vs 2</td>
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<td></td>
<td>291.84</td>
<td>137.41</td>
<td>95.19</td>
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<td>15.58</td>
<td>10.48</td>
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<td></td>
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<td></td>
<td>(48.7%)</td>
<td>(22.9%)</td>
<td>(15.8%)</td>
<td>(8.09%)</td>
<td>(2.60%)</td>
<td>(1.74%)</td>
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<tr>
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<td>278.44</td>
<td>141.14</td>
<td>126.30</td>
<td>79.51</td>
<td>30.91</td>
<td>29.42</td>
<td>685.71</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(40.6%)</td>
<td>(20.5%)</td>
<td>(18.4%)</td>
<td>(11.5%)</td>
<td>(4.50%)</td>
<td>(4.29%)</td>
<td></td>
</tr>
<tr>
<td>4 vs 4</td>
<td></td>
<td></td>
<td>272.74</td>
<td>163.73</td>
<td>128.38</td>
<td>72.59</td>
<td>23.61</td>
<td>21.09</td>
<td>682.14</td>
</tr>
<tr>
<td></td>
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<td></td>
<td>(40.0%)</td>
<td>(24.0%)</td>
<td>(18.8%)</td>
<td>(10.6%)</td>
<td>(3.46%)</td>
<td>(3.09%)</td>
<td></td>
</tr>
<tr>
<td>5 vs 5</td>
<td></td>
<td></td>
<td>285.30</td>
<td>143.10</td>
<td>117.09</td>
<td>67.40</td>
<td>25.09</td>
<td>21.99</td>
<td>659.98</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(43.2%)</td>
<td>(21.7%)</td>
<td>(17.7%)</td>
<td>(10.2%)</td>
<td>(3.80%)</td>
<td>(3.33%)</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Speed zones (km.hr(^{-1}))</th>
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<th>0-6.9</th>
<th>7-12.9</th>
<th>13-17.9</th>
<th>&gt;18</th>
<th>Total</th>
</tr>
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<tr>
<td>Hill-Hass et al,</td>
<td></td>
<td>Intermittent</td>
<td>1150 m</td>
<td>950 m</td>
<td>444 m</td>
<td>67 m</td>
<td>2621 m</td>
</tr>
<tr>
<td>(2009) (72)</td>
<td></td>
<td>SSG</td>
<td>(43.9%)</td>
<td>(36.2%)</td>
<td>(16.9%)</td>
<td>(2.55%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Continuous</td>
<td>1143 m</td>
<td>975 m</td>
<td>417 m</td>
<td>53 m</td>
<td>2596 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SSG</td>
<td>(44.0%)</td>
<td>(37.5%)</td>
<td>(16.1%)</td>
<td>(2.04%)</td>
<td></td>
</tr>
</tbody>
</table>

Note: Values in Brandes et al, (2012) are percentage of game duration.

Values in Aguir et al, (2013), and Hill-Hass et al, (2009) are distance covered (m) and percentage of game duration (parentheses).
It is also important to establish whether various SSG training formats are representative of the movement activity patterns of actual match-play. Two studies exist that compare the differences in movement characteristics between SSG and full scale friendly football matches (FM) (68, 86).

Casamichana, Castellano (86) investigated the differences in time motion characteristics of players in SSG (3 vs 3, 5 vs 5 and 7 vs 7 SSG formats) and FM. Players in the SSG spent significantly more time in the 13-17 km.hr⁻¹ speed zone than in the FM, but significantly less time in the speed zones 0.0-6.9 km.hr⁻¹ and > 21 km.hr⁻¹. As previously indicated, the most important moments in football matches are determined by high intensity actions (4). Thus, a detailed analysis of the differences between SSG and FM in the sprinting zone (21 km.hr⁻¹) may give an insight into the effectiveness of SSG as a training method for high intensity sprinting. Comparisons between mean sprinting distance and duration of players in SSG and FM revealed lower values in the SSG (4.4 m) and (0.7 s) compared to FM (15.3 m) and (2.3 s). Furthermore, large differences of maximum sprint distance and duration were seen between SSG (4.8 m and 0.8 s) and FM (34.4 m and 5.1 s). Differences in sprinting distance and duration are probably attributed to the reduced individual playing area of SSG. The reduced size fields may not be large enough for players to generate enough speed to enter the high speed categories.

Players’ acceleration off the mark is decisive in critical moments that often decide the outcome of a match (5). An advantage of SSG over FM is that players perform more accelerations at varied speeds in SSG (68). Castellano and Casamichana (68) measured the accelerations of players during SSG and FM in four speed zones (1-1.5 m.s⁻², 1.5-2.0 ms⁻², 2.0-2.5 m.s⁻², and > 2.5 m.s⁻²). Players in SSG performed more accelerations in all speed zones, with significant differences in all but the > 2.5 m.s⁻², compared to the players in the
Most aspects of SSG training are football specific. However, additional training to replicate the longer sprint distance and durations players perform may be necessary to ensure training is representative of match play (86).

**Technical Skill and Decision Making in Football and SSG**

Well-developed physiological capacity is essential for high performance in football (4, 21, 25). However, physiological capacity alone is not the determining factor for successful performance in football. Technical skill and decision making ability are equally important qualities players need to possess for successful performance in football (61, 87). Football players are constantly required to perform technical actions and decision making skills in rapidly changing environments, under physiological stress and while coping with the pressures of game related situations (9, 88, 89).

It is well accepted that accumulated fatigue, especially in the second half, has a deleterious effect on physical performance during football match-play (see section 3.1) (28, 33). Unfortunately, the mechanisms responsible for the accumulation of fatigue in players during football match-play is complex and not well understood (16). Depletion of glycogen, decreased muscle creatine phosphate, increased muscle lactate, decreased muscle pH, accumulation of muscle potassium and dehydration are all suggested to contribute to accumulated fatigue in football match-play (36).

The effect of accumulated fatigue on technical skill and decision making ability during football match-play has not received much attention from researchers, despite the importance of these components for successful football performance (87). To assess whether changes in technical skill and decision making ability during matches is related to fatigue, technical measures have been compared across periods of a match. The typical measures used in
assessing the effect of fatigue include involvements with the ball, number of passes, percentage of successful/unsuccesful passes, duels, tackles, possessions, interceptions and number of balls lost (87, 90). There is a decrease in the number of involvements with the ball, number of short passes and number of successful short passes between the first and second halves by Italian Serie A players (87). There was a significant decline in physical performance from the first half to the second half, suggesting that fatigue may have been responsible for the decline in technical measures (87). In contrast, Carling and Dupont (90) measured no difference in the technical skills of midfielders in French Ligue 1 between first and second halves. However, there were decreases in the number of passes, ball possessions and duels between the first five and the last five min of the match, although this may have been influenced by the reduced amount of time that the ball was in play during the last five min of the game. As such, these results should be interpreted with caution, as reduced time of ball in play was likely to have influenced the amount of opportunities for involvements with the ball (90). Comparisons of results between the two studies is difficult, mainly because Rampinini, Impellizzeri (87) grouped all player positions, whereas Carling and Dupont (90) measured midfielders only. Midfielders typically cover more distance during a game and generally have a greater aerobic capacity than defenders and forwards (1, 4). This may have affected the technical scores, as fitter players have been shown to be more resistant to fatigue and therefore less likely to be affected by fatigue induced decrements of technical skills (7, 16). Although some limitations exist, the strength of these studies is that they analysed performance in the context of an actual game, thereby providing a representative setting from which to draw meaningful conclusions that are more likely to generalise to similar real world environments. In contrast, many football studies claiming to assess the relationship between technical and decision making abilities and fatigue are conducted in laboratory based football simulations (16, 88, 91, 92). Despite these methods being highly controlled and reproducible,
they often take away the decision making and information processing specific to actual match-play. They therefore become studies of technique in a relatively constrained environment, rather than studies of skills that are representative of the sporting domain (93). The distinction between technique and skill is an important consideration in experimental design because the former refers to an isolated movement pattern or specific football action, for example making a pass or controlling the ball. Whereas, skill is the involvement of cognitive, perceptual and motor skills during the rapidly changing environment of a football match (89, 93). However, during training it is not always possible to play full scale matches that replicate competition, hence the recent popularity of game based training or SSG (94). SSG provide players with the opportunity to develop skills representative of competition matches. In addition, the ability to modify exercise intensity makes SSG an ideal training method to develop skill while under fatigue (8, 9). Modifying SSG constraints such as pitch size, player numbers and bout/recovery durations creates variability in training which challenges decision making and technique execution (8). Increased variability of practise improves the retention of learning and allows players to experience changes in decision making and information processing (8, 61, 67, 81).

The number of players per SSG team impacts the technical measures of players during SSG. Generally, fewer players per SSG team tends to increase a player’s involvement in the match, due to reduced passing and receiving options (69, 75, 82). In contrast, increasing player numbers per SSG team reduces the number of technical actions performed per player, but increases the total number of technical actions during the SSG. Modifying the pitch size is another factor that can influence technical actions of players during SSG (14, 76). Reducing the pitch dimensions decreases the interpersonal distance between attackers and defenders (95). Smaller interpersonal distances between defenders and attackers increases the number of duels and interceptions compared to when the pitch size is larger and the interpersonal
distance between attackers and defenders is increased (78, 96). Increasing the pitch
dimensions increases the interpersonal distance between attackers and defenders, which
results in less duels and interceptions (78, 81, 96). Kelly and Drust (81) found no differences
in several technical actions (passing, receiving, turning, dribbling or heading) across varied
pitch sizes while keeping player numbers constant.

Small sided games in training are most commonly performed as intervals comprised of
several bouts of exercise interspersed with recovery periods (10). It is important for coaches
to understand the effect that repeat bouts have on SSG in terms of changes in technical
actions, in order to guide the design of appropriate training sessions. Only two studies have
investigated if changes occur in technical actions over the course of several bouts of SSG (81,
96). Kelly and Drust (81) measured the changes in technical actions across four 4 minute
bouts of SSG playing 5 vs 5 (including goals and goalkeepers). Significant declines in the
frequency of passes, receives, turns and tackles were measured from bouts one and two
compared to bouts three and four. The frequency of dribbles, shots and target passes in the
first SSG bout were significantly higher than the corresponding bouts (81). The higher
technical actions seen in the first and second bouts of SSG suggest that fatigue may have
been a factor for the decline in the frequency of technical actions. Despite measuring reduced
frequencies of technical actions, the authors did not measure the success of the technical
actions performed or the amount of time the ball was in play across the SSG bouts. It may
have been that the decreased frequency of technical actions was due to the ball being in play
less during the later bouts as noted by Carling and Dupont (90). Additionally, the success of
technical actions across SSG bouts is an important variable to understand in the planning of
SSG training sessions. If technical actions are less successful across bouts due to fatigue
coaches may need to modify recovery periods so that players are less fatigued and able to
perform with greater success. However, Dellal, Drust (96) did measure declines in successful
passes from bouts one and two to bout four during varied SSG formats. Additionally, the number of lost balls and total number of duels were significantly increased from bout one to bout four. These results exemplify that decreased frequency of technical actions and success of passing may be due to accumulated fatigue across multiple bouts of SSG. In both studies the physical activity was reduced as the number of bouts increased, suggesting that players were fatiguing.

SSG training involving multiple bouts of exercise typically results in decreases in high intensity running, increases of physiological stress, and reduced volumes of technical actions (96). However, no study has investigated the effect on technical actions, time motion characteristics or physiological responses by varying the exercise: recovery ratio conditions during SSG. This is important for coaches to consider when planning SSG training sessions. It could be that reduced recovery time across multiple bouts of SSG will illicit increased physiological responses and therefore improve the physical capacity of players. However, as seen in other research (81, 96) this may be responsible for a reduction in technical proficiency. Coaches may be able to increase the recovery times between the SSG bouts to reduce the fatigue of players and increase the success of technical actions. This will allow coaches to plan training sessions to develop the physical and technical aspects of players according to the coach’s football philosophy.

**Systemic Oxygen Uptake**

Systemic oxygen uptake during exercise relies on the continual interactions of the pulmonary, cardio-vascular and neuromuscular systems to transport oxygen to the mitochondria of working muscles to sustain exercise (97, 98). During light to moderate exercise, oxygen consumption (VO₂), pulmonary minute ventilation (Vₑ) carbon dioxide (CO₂) production increase linearly. After this initial rapid rise in oxygen consumption (fast component) a
plateau in oxygen consumption occurs when exercise remains at a constant load. This levelling off in O\textsubscript{2} consumption (steady rate/slow component) reflects the balance between energy provided by aerobic metabolism and the energy demands of working muscle. Any lactate that is produced during steady rate exercise is removed by oxidisation (~75%) or converted to glucose (~20%) (97-99). However, as exercise intensity increases there is a mismatch between the metabolic demands of the active muscle and the capacity to provide energy by aerobic metabolism. At maximal exercise capacity (maximum rate of oxygen consumption measured during exercise), cardiac output is believed to be the limiting factor responsible for the mismatch between oxygen supply to the active muscles (100). As such, active muscles are forced to produce energy by anaerobic metabolism to sustain exercise. This provokes a disproportionate increase in pulmonary minute ventilation due to the buffering of lactate that begins to accumulate from increased anaerobic glycolysis (97-99).

The maximal rate of oxygen uptake (VO\textsubscript{2max}) is a frequently used variable in exercise physiology to determine the cardio-respiratory fitness of athletes (101). The VO\textsubscript{2max} represents the highest level of O\textsubscript{2} consumption by an exercising individual, despite increases to power output and exercise duration. During a football match the average oxygen consumption of players is estimated to be 70\% of VO\textsubscript{2max} (4, 25).

**Regional Tissue Oxygenation**

Obtaining VO\textsubscript{2max} values from pulmonary measurements is representative of whole body VO\textsubscript{2} and does not differentiate specific regional skeletal muscle oxygen uptake (102). The assessment of regional muscle oxygen uptake assesses the metabolic activity of the active muscle tissue under investigation, separate from whole body VO\textsubscript{2}. The exercise during football match-play and training is heavily reliant on the muscles of the lower limb. Direction changes while running and kicking in football simulations have shown increased surface
electromyography (EMG) activity of the quadriceps muscle group (103, 104). Furthermore, at the onset of exercise, blood flow to active muscles increases. During leg extension exercise Andersen and Saltin (100) found a linear increase in blood flow and increased exercise intensity in the quadriceps muscles group. This hyperaemic response to exercise reflects the increased metabolic activity in the active tissue (105).

Several techniques to determine skeletal muscle oxygenation have been developed including magnetic resonance imaging (MRI), indicator dilution methods, plethsmography and ultrasonography (106). However, these methods are often invasive and have practical limitations regarding their use during exercise. The near infrared spectroscopy (NIRS) technique for assessing tissue oxygenation is non-invasive, continuous and functions in real time (107). The following sections will focus on measurement of regional tissue oxygenation using the NIRS method.

**Near-Infrared Spectroscopy (NIRS)**

Near infrared spectroscopy (NIRS) is a light-based method of assessing the oxygenation status of living biological tissue (108). Biological tissue is relatively transparent to light in the near infra-red (NIR) spectrum (700-1000 nm), allowing the penetration of NIR light several centimetres through biological tissue (18, 108). Estimations of tissue oxygenation are made by evaluating the amount of NIR light absorption by chromophores, particularly haemoglobin (primary transporter of O2), using the modified Beer-Lambert method to account for the scattering of light. There are three different types of NIRS techniques; 1) continuous wave technique, which measures light attenuation through tissue with continuous illumination of the tissue under investigation, 2) the frequency domain technique, which illuminates tissue with intensity modulated light and measures the attenuation and phase shift of the light, and
3) the time-domain technique, which illuminates the tissue under investigation with brief pulses of light to detect the shape of the pulse after propagation through tissue (109).

The initial use of NIRS was to assess cerebral oxygenation (110). However, advancements in technology since the initial NIRS research have allowed research to expand to the assessment of tissue oxygenation in other tissues and in sport and exercise (18, 108). NIRS measures microvascular $O_2$ extraction, in particular the relative changes in oxygenated haemoglobin ($O_2$Hb) and deoxygenated haemoglobin (HHb).

Typically, as exercise intensity is increased there is a decrease in $O_2$Hb and an increase in HHb, suggesting an increase in aerobic metabolism at the site of measurement.(107).

**Skeletal Muscle Response**

The continuous wave near infrared spectroscopy (NIRS) technique allows non-invasive investigation into regional muscle and cerebral tissue oxygenation changes during exercise (20). The relative changes in oxygenated haemoglobin ($O_2$Hb) and deoxygenated haemoglobin (HHb) can be used to understand the physiological response to high intensity exercise such as SSG. With technological advances, NIRS devices have become wireless and portable and therefore able to be used in the field during sport specific exercise (111). Portable NIRS devices are sensitive enough to detect haemoglobin changes of the medial gastrocnemius during high intensity running in rugby players (111). During a rugby specific shuttle running test including forwards and backwards running with multiple changes of directions, as is common in football, decreases in $O_2$Hb and increases in HHb were measured (111). However, during the recovery periods increases in $O_2$Hb, and decreases in HHb were measured, indicating that oxygen utilisation was decreased. Despite the capabilities of NIRS
to measure oxygenation changes of muscle tissue in a sport specific environment, there is very limited NIRS research in an applied sports setting.

The only NIRS research that could be considered relevant to football has been with variations of repeated sprint running by participants (20, 112, 113). Two studies investigating muscle tissue oxygenation during repeat sprinting, identified increases in HHb during sprint bouts and decreases in HHb during recovery periods in the vastus lateralis (VL) muscle (20, 113). HHb was measured in both studies, due to HHb being independent of changes to blood volume during exercise. Participants performed maximal running in two conditions; straight line maximal running and maximal running with 180° direction changes. Despite no difference in muscle HHb between conditions there were increases in HHb during the sprint efforts and decreased levels of HHb during the recovery periods (113). These results indicate an increase in oxygenation in the tissue of the VL muscle during the exercise bouts compared to recovery.

A further study compared active and passive recovery periods between sprint efforts (20). HHb results were consistent with the previous study (113). However, during the active recovery condition HHb did not recover to the same levels as during the passive recovery. Mean HHb levels were 94.4% of maximal HHb levels in active recovery compared to 83.4% of maximum during passive recovery. These results suggest that active recovery is associated with higher oxygen uptake than passive recovery (20). The active recovery was also associated with a decline in repeat sprint ability. These findings have implications for football training methods, as recovery from high intensity actions in football is mostly active. Implementing passive recovery periods between exercise bouts in training will facilitate muscle re-oxygenation and may be an effective strategy to improve sprint performance (20). Furthermore, allowing the appropriate time for muscle re-oxygenation during recovery
periods in training may also be an effective strategy to improve the technical actions of footballers. However, no research investigating this question currently exists.
Chapter 2- The Effect of Recovery Duration on Muscle Oxygenation, Heart Rate, Perceived Exertion and Time Motion Descriptors During Small Sided Football Games.

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Author Contributions
Conceived and designed the experiment: SM, CS, HK, AG
Performed the experiment: SM, HK
Analysed the data: SM, HK, CS, GPL
Wrote the paper: SM, CS, HK, AG, GPL

Abstract

Purpose. Small sided games (SSG) of football are an effective and efficient format to simultaneously train the physiological, technical, tactical components of football. The duration of the recovery period between bouts of SSG will affect the physiological response to subsequent bouts. It was hypothesised that decreasing the duration of recovery periods separating serial SSG bouts would increase physiological, and perceptual responses, and decrease high speed running, and distance during SSG bouts. Methods. Twelve experienced footballers (mean ± SD; age 21 ± 3 ys; VO₂peak 64 ± 7 ml · min · kg⁻¹; playing experience 15 ± 3 ys) completed two SSG sessions. Each SSG consisted of 3 vs 3 players and 6 bouts of 2 min duration, with bouts separated by either 30 s recovery (REC-30) or 120 s recovery (REC-120). Deoxygenated haemoglobin (HHb) in the vastus lateralis muscle (VL) (using near infrared spectroscopy), heart rate (HR) and time motion descriptors (TMD) (speed and distance) were measured continuously during the SSG sessions and perceived exertion (RPE)
was measured for each bout. **Results.** During the recovery periods, in REC-30 compared to REC-120, there was a significant (p < 0.05) main effect of a higher HHb and HR. During the bouts, in REC-30 compared to REC-120, there were no significant differences in HHb, HR, RPE, or TMD, but within both REC-30 and REC-120 there were significant increases as a function of bout number in RPE. **Conclusions.** Although a four-fold increase in recovery period allowed a significant increase in the recovery of HHb and HR, this did not increase the physiological, and perceptual responses, or time motion descriptors during the bouts. These results could have been due to the titration of effort (pacing), in these experienced players performing an exercise task to which they were well adapted.

**Keywords:** Football; Small sided games; NIRS; Recovery; Pacing

**Introduction**

Small sided games (SSG) are a form of football training used to simultaneously train the physiological, technical, and tactical components of football (10, 61, 78). Typically, SSG are used in an interval training format, consisting of a series of bouts and recovery periods (14, 42, 81, 114). A commonly used SSG format is played with 3 vs 3 players (14, 15, 114, 115). In a 3 vs 3 SSG format, during the bouts, there are average heart rate (HR) responses of higher than 80% of maximal HR values (%HR$_{max}$), blood lactate concentration [La] values ranging from 5 mmol$^{-1}$ to 8.5 mmol$^{-1}$, and ratings of perceived exertion (RPE) of 8.5 (CR-10) and 16.3 (Borg 6 -20) (14, 65, 115-118). In addition to the physiological and perceptual measures of exercise intensity during SSG, time motion descriptors (TMD) (speed and distance) achieved by players, measured by global positioning systems (GPS) permits estimations of external exercise intensity (13, 42, 69, 84). The high values of these direct and indirect exercise intensity measures during SSG bouts, indicate that SSG are an effective training stimulus for increasing the aerobic power of football players (7).
Several modifiable variables of SSG are known to influence the exercise intensity of SSG (10). Decreasing the players per team (69, 75, 83), increasing the pitch size (14, 76, 81), decreasing the amount of touches per individual possession (42), including verbal coach encouragement (14), and decreasing bout duration (12) all increase the exercise intensity of SSG. These modifiable SSG variables allow SSG to be adapted to train specific components of football.

However, only one study has investigated the effect of different recovery durations between serial bouts on physiological, perceptual, time motion and technical variables during SSG (15). Using inexperienced participants, the SSG format consisted of 3 vs 3 players per team with recovery durations of 1 min, 2 min, 3 min and 4 min separating 4 x 4 min SSG. The shorter recovery durations (1 and 2 min), compared to longer recovery durations (3 and 4 min), induced higher HR and blood lactate values, decreased successful technical actions, and participants covered more distance in the lower speed zones. There was no difference in the participants RPE between the conditions. Direct comparisons of physiological responses between inexperienced and experienced footballers during SSG has not been investigated. However, experienced athletes are better able to regulate effort during exercise to ensure optimal performance (119, 120), which may account for differences in physiological responses between experience levels.

The ability to maintain a high exercise intensity across multiple exercise bouts is dependent on the recovery from the previous exercise bouts (40). This is influenced by both the exercise intensity during the bouts, and the duration of the recovery periods (41). During recovery from exercise, oxygen (O2) consumption remains elevated to replenish the intramuscular high energy phosphates required to perform high intensity exercise, to pre-exercise levels (40, 41, 44). As football involves brief (2 - 4 s), frequent periods of maximal intensity exercise during a match (1, 4, 21), the subsequent recovery duration from these efforts may be insufficient to
fully resynthesise the intramuscular high energy phosphates (40, 45). Progressive depletion of adenosine triphosphates (ATP) and phosphocreatine (PCr) stores increases the reliance on energy provided from anaerobic glycolysis, resulting in increased H⁺ and reduced pH levels (41, 46). This is associated with decrements in repeat sprint times, accelerations, mean running speed and power output across subsequent exercise bouts (40, 46). Decreased oxygen availability is thought to be the limiting factor of ATP and PCr resynthesis during the initial period (up to 30 s) of recovery from exercise (44, 47). Compared to normoxic conditions, there is a decreased rate of PCr recovery in hypoxic conditions, and an increased rate of PCr recovery in hyperoxic conditions (44), and PCr is not replenished when circulation is occluded (48). These studies indicate the importance of O₂ availability for recovery from exercise. Therefore, the assessment of specific muscle tissue oxygenation is necessary to understand local muscle metabolism during football specific exercise.

Near infrared spectroscopy (NIRS) allows portable and non-invasive investigation of specific regional tissue oxygenation changes during exercise (109). Measurements of oxygenated haemoglobin (O₂Hb), deoxygenated haemoglobin (HHb) and total haemoglobin (tHb) are used to determine the balance between oxygen (O₂) supply and utilisation at the site of investigation (18, 19). During exercise that utilises aerobic energy transfer there is an increased demand for O₂ in the active muscles, resulting in increased HHb and decreased O₂Hb (18). However, during recovery from exercise this balance is reversed, due to decreased extraction of oxygen at the tissue (18). Regional muscle tissue oxygenation has been assessed during repeat sprint running, and cycling (20, 113, 121). Regardless of the exercise mode, there was a consistent increase in [HHb] during exercise, and decreased [HHb] during recovery periods (20, 113).

There is currently no research specific to local muscle oxygenation changes during football specific activities such as SSG, and the effect of different recovery durations. During running,
active recovery, compared to passive recovery of the same duration, separating repeated sprints elicited higher \([\text{HHb}]\) in the VL (20). The higher \([\text{HHb}]\) was associated with increased repeated sprint times during subsequent sprints (20). During repeat cycling sprints, \([\text{O}_2\text{Hb}]\) increased and \([\text{HHb}]\) decreased with longer recovery durations, irrespective of whether active or passive recovery was utilised (121). This increase in \([\text{O}_2\text{Hb}]\) was associated with reduced decrements in the percentage of peak power outputs across subsequent sprints (121). Therefore, when using SSG as interval training it is necessary to control the duration of the recovery periods separating bouts, so that the desired training effect is achieved.

The aim of this project was to determine the effect of increasing the recovery duration in a 3 vs 3 player SSG format on VL oxygen utilisation, HR, RPE and time motion responses in experienced footballers. It was hypothesised that: 1) During the SSG recovery periods, a 120 s recovery duration compared to a 30 s recovery duration, would decrease VL \([\text{HHb}]\) and HR. 2) During the serial SSG bouts, a 120 s recovery period compared to a 30 s recovery period, would decrease VL \([\text{HHb}]\), HR and RPE, and players would cover more total distance and spend more time in high speed zones.

**Methods**

**Ethical Approval**

This project was approved by the Human Research Ethics Committee at the University of the Sunshine Coast (HREC: S/14/661), and participants provided written informed consent.

**Participants**

Twelve experienced male footballers of the same team, playing in the second tier of football in Australia participated in the project (Table 2.1). Participants trained three times per week for an approximate weekly total of 240 min and competed in one match per week of 90 min duration. Inclusion in the study required the successful completion of a medical health questionnaire (PAR-Q).
**Table 2.1. Participant Characteristics.**

<table>
<thead>
<tr>
<th>Age (ys)</th>
<th>Mass (kg)</th>
<th>Height (cm)</th>
<th>HR peak (beats·min⁻¹)</th>
<th>VO₂peak (ml·min·kg⁻¹)</th>
<th>Playing experience (ys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.3 ± 2.9</td>
<td>75.0 ± 7.1</td>
<td>179.5 ± 6.9</td>
<td>190 ± 10.2</td>
<td>63.6 ± 7.4</td>
<td>14.6 ± 3.1</td>
</tr>
</tbody>
</table>

Data are (mean ± SD) (n = 12), for VO₂peak (n = 11).

**Project design**

The project was conducted using a one-group, repeated measures design. The independent variables were the two different recovery durations, 30 s (REC-30), 120 s (REC-120), and the number of bouts (1-6). The dependent variables measured were oxygenated haemoglobin (O₂Hb), deoxygenated haemoglobin (HHb), total haemoglobin (tHb), heart rate (HR), rating of perceived exertion (RPE) (Borg CR-10) and time motion descriptors (TMD) (speed and distance). Participants completed the SSG sessions, a peak aerobic capacity test in laboratory conditions, and a test of maximal running speed over 20 m. All testing and data collection was completed in an 11 week period during the participant’s competitive season. One 3-a-side team was equipped with the NIRS devices for each SSG, and only data from these participants were used for this project.

**Small Sided Games**

Each participant completed REC-30 and REC-120 under the same SSG format consisting of 3 vs 3 players with 6 x 2 min bouts played on a 15 m x 20 m natural grass pitch. Each participant was tested in two separate sessions, separated by a minimum of two days and maximum of five days, and the order of conditions was counter-balanced. The SSG testing was completed in eight sessions over five weeks. The SSG testing sessions were completed at the beginning of the participant’s normal football training session and at the same time of day to avoid variations to circadian rhythm. The SSG teams were selected by the two experienced team coaches to ensure that similar levels of technical ability and physical capacity of players
were evenly distributed throughout the teams. The same team membership was used for all testing sessions. The objective of the SSG was to maintain possession as a team, with unlimited ball contacts per possession, no goals and goalkeepers and no coach encouragement. Additional balls were placed around the pitch to minimise time lost for balls out of play. Prior to testing participants performed a standardised warm up. Immediately post warm up the participants were fitted with NIRS, HR straps and GPS devices before beginning the SSG. During the recovery periods participants were instructed that they could walk within the playing grid after their RPE was recorded.

**Oxygenation in Vastus Lateralis Muscle**

Oxygenation in the VL was assessed by portable wireless (Bluetooth) NIRS devices (Portamon, Artinis, Medical system, Zetten, The Netherlands) using a two wave length continuous wave system. The relative changes in HHb, O2Hb, and tHb were measured at 10 Hz using the differences in absorption of light at 750 and 850 nm. Due to the uncertainty of the proton path in biological tissue, a fixed differential path length correction factor was applied as recommended by the manufacturer. The NIRS measurements were conducted on the VL of the left leg. The VL was the chosen site because of its large contribution to running, directional changes, and kicking in football (103, 104). The location of the NIRS device was one third of the distance from the lateral femoral epicondyle and the greater trochanter of the femur and adjusted medially to be positioned on the belly of the VL. This position was recorded for each participant at the first testing session and reproduced in the subsequent sessions. The NIRS device was fixed to the skin of the participant by elastic adhesive bandage. Skinfold thickness at the site of measurement was measured (British Indicators Ltd, Burgess Hill UK) to ensure optimal illumination of the muscle tissue (< 17 mm was required in this study).
Analysis of HHb was conducted because it is relatively independent of blood volume changes during exercise (20, 113). A moving average filter width of 1 s was applied to the raw data to reduce high frequency noise before exporting. A 5 s moving average filter was applied to the data to minimise variability in the individual data, before calculating the average for the total duration of each bout and recovery periods to allow for the determination of the pattern of response over time. The NIRS data is the relative change in concentration from baseline (30 s standing rest before each testing session), and expressed in micromolar units (µm). Baseline was the average of the 30 s (standing rest inside the playing area), measured immediately prior to commencement of the first bout of each testing session. To determine the between test reliability of the HHb data from the NIRS system, absolute (Typical Error 0.92), and relative (Intra-class Correlation .702) reliability of the baseline data were used (122). Previous research has shown that the NIRS method provides acceptable reliability (123).

**Heart Rate**

During the SSG, HR was recorded continuously (Polar strap and Catapult MinimaxX S4 recorder; Catapult Sports, Melbourne). The HR responses of participant recorded during the SSG were averaged for the bout and recovery periods and are expressed as a beats per minute. HR data was n = 8 for REC-30, and n = 9 for REC-120.

**Rating of Perceived Exertion**

During the first 10-15 s of each recovery period, participants RPE (Borg CR-10) response was recorded to measure the global perceived effort (intensity) of the previous bout of SSG. Participants were familiarised with the RPE scale during normal training sessions in the two weeks leading up to the testing sessions.
**Time Motion Descriptors**

The distance covered and speed attained by participants during the SSG was measured at a 10 Hz sampling rate by portable GPS units (MinimaXS4, Catapult sports, Melbourne), and analysed in Catapult Sprint 5.01 software. The GPS devices were worn in a harness on the upper back. The total distance covered in the SSG session, distance covered in each bout, and percentage of time spent in four speed zones (0–6.9 km·h⁻¹, 7–12.9 km·h⁻¹, 13–17.9 km·h⁻¹, >18 km·h⁻¹) were analysed (15).

**Peak Exercise Test**

An incremental intensity treadmill (T200, Cosmed, Rome Italy) exercise test to volitional cessation was conducted to obtain the participants peak aerobic capacity. During the peak exercise test, expired ventilation and oxygen and carbon dioxide utilisation, carbon dioxide production and the respiratory exchange ratio were measured, using a two-way, non-rebreathing valve (series 2700, Hans-Rudolf, Kansas City, USA) and an automated open-circuit spirometry metabolic analysis system (True One 2400, Parvo Medics, Sandy UT).

Stages 1 – 3 of the continual peak exercise test were conducted at 1% incline (6km·h⁻¹ for 3 mins, 8 km·h⁻¹ for 1 min, and 10 km·h⁻¹ for 1 min). For stages 3 – onward speed was constant at 10 km.hr⁻¹ and gradient increased by 2% each min until volitional cessation.

The maximal exercise test was used to obtain the maximal HR of participants. A polar heart rate strap and open-circuit spirometry metabolic analysis system (True One 2400, Parvo Medics, Sandy UT) recorded continuous HR via short range telemetry. The RPE (Borg CR-10) was recorded during the last 20 s of each one minute stage, beginning at 5% incline until completion of the test.
**Peak Speed Test**

To set a realistic maximum limit for the speed data from the GPS, the maximal running speed achievable by participants (n = 5) within the playing area (15 m x 20 m) was determined. Five participants performed three maximal sprints of 20 m through a series of electronic timing gates (Smartspeed, Fusion Sports). The group average of the participant’s fastest trials, with an added 5% was then used to set an upper limit (34.38 km.hr⁻¹) for the GPS velocity data analysis. During pilot testing, some unrealistically high speed values from the GPS data were identified, the speed limit was set to remove any of these data prior to analysis.

**Statistical Analysis**

The data analysed in this project was only from participants that were wearing the NIRS devises during the SSG. Sample size calculations using the mean difference (5.5 μm) and standard deviation (4.7 μm) in HHb from baseline to exercise in a comparable study (113), and using a power of 0.80 and probability of 0.05, indicate that a total of eight participants would provide sufficient statistical power. Statistical analysis were performed using SPSS (version 22, IBM Corporation, Armonk NY, USA). Data are reported using mean ± SD, and the level of significance was set at p < .05. A two-way repeated-measures ANOVA was used to assess the effect of condition (REC-120 and REC-30), bout (1-6), and Condition x Bout interactions for all dependent variables. A paired t-test was used to compare the total distances covered for the SSG sessions. Assumptions of sphericity using Maulchy’s W test was used, and in all cases where Maulchy’s W was significant, the Greenhouse-Geisser correction of degrees of freedom was used. Post hoc pairwise comparisons were used to follow-up significant interactions, and were conducted using the least significant difference (LSD) method with no adjustments for multiple comparisons. Calculations of p value, partial eta-squared (as an indicator of effect size, noted $\eta^2_p$) and statistical power (ß) were reported.
Results

*Vastus Lateralis Oxygenation*

Individual oxygenation changes during the SSG sessions (Figure 2.1). The VL oxygenation followed the expected pattern of change of increased HHb and decreased O₂Hb during the bouts, and increased O₂Hb and decreased HHb during the recovery, with the associated intra-individual and inter-individual variability (Figure 2.1.)

![Figure 2.1. Individual Oxygenation Changes During the SSG Sessions. Panel (A) Δ [HHb] during REC-120. Panel (B) Δ [HHb] during REC-30. Panel (C) Δ [O₂Hb] during REC-120. Panel (D) Δ [O₂Hb] for REC-30.](image)

![Figure 2.1. Individual Oxygenation Changes During the SSG Sessions. Panel (A) Δ [HHb] during REC-120. Panel (B) Δ [HHb] during REC-30. Panel (C) Δ [O₂Hb] during REC-120. Panel (D) Δ [O₂Hb] for REC-30.](image)
Deoxygenated Haemoglobin (HHb)

Recovery

For HHb there was a significant main effect of condition \( (p = .000; \eta^2 = 0.725; \text{power} = 0.998) \), and bout number \( (p = .001; \eta^2 = 0.457; \text{power} = 0.965) \), with an increase of the average HHb during the recovery periods (Figure 2.2). There was no significant Condition x Bout interaction for the average HHb \( (p = .295; \eta^2 = 0.105; \text{power} = 0.302) \) during the recovery periods (Figure 2.2).

Figure 2.2. Relative Change from Baseline of vastus lateralis (VL) Muscle Deoxygenated Haemoglobin (HHb) Concentration During SSG Recovery Periods. There was a significant main effect \( (p < .05) \) of condition, and bout number, with an increase of the average HHb. There was no significant \( (p > .05) \) condition x bout interaction for the average HHb. Data are mean ± SD.
**Bouts**

For HHb there was no significant main effect of condition ($p = .935$; $\eta^2_p = 0.000$; power = 0.050), or bout number ($p = .231$; $\eta^2_p = 0.126$; power = 0.284) for the average HHb during the bouts (Figure 2.3). There was no significant Condition x Bout interaction for the average HHb ($p = .306$; $\eta^2_p = 0.101$; power = 0.404) during the bouts (Figure 2.3).

![Figure 2.3](image.png)

*Figure 2.3. Relative Change from Baseline of Vastus Lateralis (VL) Muscle Deoxygenated Haemoglobin (HHb) Concentration During SSG Bouts.* There was no significant main effect ($p > .05$) of condition, or bout number for the average HHb. There was no significant ($p > .05$) Condition x Bout interaction for the average HHb. Data are mean $\pm$ SD.
**Heart Rate (HR)**

**Recovery**

For HR there was a significant main effect of condition ($p = .001$; $\eta^2 = 0.849$; power = 0.997), and bout number ($p = .000$; $\eta^2 = 0.838$; power = 1.000), with an increase of the average HR (bpm) during the recovery periods (Figure 2.4). There was no significant Condition x Bout interaction for the average HR (bpm) ($p = .591$; $\eta^2 = 0.111$; power = 0.233) during the recovery periods (Figure 2.4).

![Figure 2.4. Average Heart Rate (bpm) During SSG Recovery Periods.](image)

There were significant main effects ($p < .05$) of condition, and bout number, with an increase of the average HR (bpm). There was no significant ($p > .05$) Condition x Bout interaction for the average HR (bpm). Data are mean ± SD.
Bouts

For HR there was no significant main effect of condition for the average HR (bpm) (p = .295; \( \eta_p^2 = 0.180; \) power = 0.163) during the bouts (Figure 2.5). There was a significant main effect of bout number, with an increase of the average HR (bpm) (p = .000; \( \eta_p^2 = 0.883; \) power = 1.000) across the bouts (Figure 2.5). There was no significant Condition x Bout interaction for the average HR (bpm) (p = .133; \( \eta_p^2 = 0.236; \) power = 0.548) during the bouts (Figure 2.5).

Figure 2.5. Average Heart Rate (bpm) During SSG Bouts. There was no significant main effect (p > .05) of condition for average the HR (bpm). There was a significant main effect (p < .05) of bout number, with an increase of the average HR (bpm) across the bouts. There was no significant Condition x Bout interaction (p > .05) for the average HR (bpm). Data are mean ± SD.
Rating of perceived exertion (RPE)

For RPE there was no significant main effect of condition (p = .824; $\eta^2 = 0.005$; power = 0.055) during the bouts (Figure 2.6). There was a significant main effect of an increase across the bouts (p = .000; $\eta^2 = 0.610$; power = 1.000), For RPE there was a significant Condition x Bout interaction (p = .016; $\eta^2 = 0.218$; power = 0.836) (Figure 2.6). The post hoc pairwise comparisons indicate that in REC-120 RPE increased from B1 to B5 (p = .048), and B6 (p = .033). In REC-30 RPE increased from B1 to B4 (p = .008), B5 (p = .000) and B6 (p = .000), from B2 to B5 (p = .008) and B6 (p = .000), from B3 to B5 (p = .040) and B6 (p = .003), and from B4 to B6 (p = .027) (Figure 2.6). There were no significant (p > 0.05) differences between the conditions for each bout.

Figure 2.6. Rating of Perceived Exertion (RPE) During SSG Bouts. There was no significant main effect (p > .05) of condition on RPE. There was a significant main effect (p < .05) of bout number, with an increase in RPE across the bouts. There was a significant (p
<.05) condition x bout interaction for RPE. Data are mean ± SD. Symbols denote significant differences from post hoc pairwise comparisons (€) to B1, (£) to B2, ($) to B3 and (@) to B4.

**Time motion descriptors**

*Total distance covered during the SSG session*

For total distance covered during the SSG session there was no significant (p = .638) difference between REC-30 (1365 ± 37.7 m) and REC-120 (1347 ± 37.7 m).
**Distance covered during the SSG bouts**

For total distance covered during the bouts there was no significant main effect of condition (p = .795; ƞ² = 0.006; power = 0.057), or bout number (p = .914; ƞ² = 0.026; power = 0.117) (Figure 2.7). There was no significant Condition x Bout interaction for total distance covered during the bouts (p = .515; ƞ² = 0.072; power = 0.284) (Figure 2.7). Data are mean ± SD.

**Figure 2.7. Total Distance Covered During SSG Bouts.** There was no significant main effect (p > .05) of condition, or bout number for total distance covered during the bouts. There was no significant (p > .05) Condition x Bout interaction for total distance covered during the bouts. Data are mean ± SD.
**Percentage of time spent in speed zones during SSG bouts**

There was no significant (p > .05) main effect of condition, or bout number for percentage of time spent in all speed zones. There was no significant (p > .05) Condition x Bout interaction of bout number for percentage of time spent in all speed zones.

**Table 2.2. Percentage of Time Spent in Speed Zones.** There was no significant (p > .05) main effect of condition, or bout number for percentage of time spent in all speed zones. Data are mean ± SD.

<table>
<thead>
<tr>
<th>Speed zone (km \cdot h^{-1})</th>
<th>B1 (%)</th>
<th>B2 (%)</th>
<th>B3 (%)</th>
<th>B4 (%)</th>
<th>B5 (%)</th>
<th>B6 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>REC-30</td>
<td>0 - 6.9 60 ± 14</td>
<td>66 ± 7</td>
<td>63 ± 9</td>
<td>64 ± 9</td>
<td>64 ± 12</td>
<td>64 ± 9</td>
</tr>
<tr>
<td></td>
<td>7 - 12.9 36 ± 13</td>
<td>31 ± 6</td>
<td>32 ± 9</td>
<td>32 ± 9</td>
<td>31 ± 10</td>
<td>31 ± 8</td>
</tr>
<tr>
<td></td>
<td>13 - 17.9 3 ± 2</td>
<td>3 ± 2</td>
<td>5 ± 3</td>
<td>3 ± 2</td>
<td>4 ± 3</td>
<td>4 ± 3</td>
</tr>
<tr>
<td></td>
<td>&gt;18 1 ± 1</td>
<td>0 ± 0</td>
<td>1 ± 2</td>
<td>1 ± 2</td>
<td>0 ± 0</td>
<td>1 ± 2</td>
</tr>
<tr>
<td>REC-120</td>
<td>0 - 6.9 62 ± 10</td>
<td>58 ± 12</td>
<td>63 ± 9</td>
<td>63 ± 11</td>
<td>62 ± 9</td>
<td>61 ± 8</td>
</tr>
<tr>
<td></td>
<td>7 - 12.9 34 ± 8</td>
<td>36 ± 9</td>
<td>33 ± 8</td>
<td>33 ± 8</td>
<td>34 ± 7</td>
<td>35 ± 8</td>
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<tr>
<td></td>
<td>13 - 17.9 4 ± 3</td>
<td>6 ± 4</td>
<td>4 ± 2</td>
<td>4 ± 4</td>
<td>4 ± 2</td>
<td>3 ± 2</td>
</tr>
<tr>
<td></td>
<td>&gt;18 0 ± 1</td>
<td>0 ± 1</td>
<td>0 ± 0</td>
<td>0 ± 1</td>
<td>0 ± 1</td>
<td>0 ± 1</td>
</tr>
</tbody>
</table>
Discussion

This project was designed to determine the effect of two different recovery durations, separating six, 2 min bouts of a 3 vs 3 player SSG on physiological, and perceptual responses, and speed and distance. The two main results were that: 1) increasing the recovery duration from 30 s to 120 s between serial SSG bouts allowed [HHb], and HR to significantly decrease during the recovery periods, and 2) despite this increased physiological recovery, there was no significant difference in [HHb], HR, RPE, or running speed, and distance, between REC-30 and REC-120, during the bouts.

Oxygenation in Vastus Lateralis

The primary and unique dependent variable for this project was the HHb measured in the VL. The results of the project supported the hypothesis that during the REC-30 recovery periods, [HHb] would remain significantly higher than during the REC-120 recovery periods. In repeat sprint cycling, increasing the recovery duration from 25 s to 100 s between ten, 5 s maximal effort cycling sprints increased [O2Hb] and decreased [HHb] (121). However, contrary to our hypothesis of a higher [HHb] in REC-30 compared to REC-120, was the absence of a significant difference in [HHb] between REC-30 and REC-120, during the bouts.

Heart Rate

A secondary and expected finding of this project was that during the recovery periods, HR significantly decreased as recovery duration was increased from 30 s to 120 s. Also, the average HR measured during the recovery period increased in both conditions, but because there was no significant condition x bout interaction, pairwise comparisons were not conducted. One study using four SSG bouts measured a significant decrease in HR of approximately 10 bpm during the final recovery period (81). However, during running and
cycling interval protocols, an upwards drift in the HR response continued across subsequent recovery periods were identified (124, 125).

During the bouts, there was no significant main effect of condition on the average HR. The participants maintained a HR of approximately 80% to 90% of maximal HR values throughout the SSG sessions. The HR values measured during the bouts in the current study are comparable to HR values from previous SSG studies (14, 75). However, the HR results of the current study are contrary to those in the only other study that has investigated the effect of different recovery durations separating serial SSG bouts on physiological responses (15). Koklu, Alemdaroglu (15) reported that a recovery duration of 1 min compared to 3 min and 4 min, induced a significantly higher average HR during SSG exercise bouts. The contrasting results could be attributed to a difference in SSG formats, or playing experience of the participants, as it is known that experienced athletes are able to regulate effort during exercise compared to less experienced athletes (126, 127). Similar HR responses to those in the current study were measured in experienced runners during self-paced treadmill running (6 x 4 min bouts) separated by either a 1 min, 2 min, or 4 min recovery duration, where no difference was measured in the HR between the three different recovery conditions (124).

**Perceived Exertion**

The RPE results of this project did not support our hypothesis that participants would have higher perceived effort during bouts subsequent to a 30 s compared to a 120 s recovery duration. The current RPE results are supported by there being no significant difference between the 1 min, 2 min, 3 min, and 4 min recovery periods separating SSG bouts (15). In both the current study, and one other (15), RPE ranged from “hard” to between “hard” and “very hard”. However, the RPE in Koklu, Alemdaroglu (15) was measured two minutes after the final 4 min bout. To provide more detail of the psychobiological response of players when subjected to different recovery durations separating SSG, a bout by bout analysis of RPE was
performed in the current project. The significant increase of RPE across the bouts in this project, and in a 4 vs 4 SSG format, with constant bout (4 x 4 min) and recovery (3 min) durations (42), reflects the increasing perception of effort across serial bouts. Additionally, the lower RPE response in REC-30 compared to REC-120 during the first three bouts of the SSG session, in this project, may result from pre-exercise expectations (120, 128) of REC-30 to be a more physically demanding condition.

**Speed and Distance**

The current time motion results did not support our hypothesis that participants in REC-30 compared to REC-120, would cover less distance and spend less time in the high speed zones. Instead, no difference was measured for total distances covered, or time in all four speed zones, between the two conditions. The speed and distance results of the current project cannot be directly compare to those of other SSG projects because of differences in the methods, such as bout duration, pitch size, and player number (13, 69, 78). However, in a study that altered the work: rest ratio during touch football SSG, a decrease in the work: rest ratio (more frequent recovery periods) was associated with increases in moderate, to very high-speed movements (129). The current results indicate that the participants were able to regulate their running speeds and distances in order to complete the SSG session without compromising physical performance.

**Combined Responses**

The HHb and HR results in this study indicate that the SSG bouts, within and between conditions, were performed at a similar exercise intensity, as a higher exercise intensity would have increased both HR and HHb (130). The TMD results indicate that the total amount of work performed, and time spent in specific speed zones was similar, within and between conditions. An explanation for these unexpected results could be that the participants...
regulated their effort (paced), to delay the occurrence of fatigue (131), to complete the SSG sessions without compromising performance (120, 132, 133).

It is accepted that athletes use pacing strategies during continuous exercise such as long distance running, and cycling (120, 134). However, the unpredictability of the high intensity intermittent exercise in team sports like football makes pacing more difficult to implement (132, 133, 135). Nevertheless, when implemented, the pacing strategies used by athletes in team sports are influenced by prior knowledge of the exercise duration, playing experience, playing standard, and physical fitness (132, 133, 135). Deceiving the participants of the duration of exercise provides evidence that the knowledge of the exercise duration influences pacing (131, 132). Greater amounts of high speed running is performed when a shorter duration of exercise is anticipated, and a greater amount of low speed activity is seen when the exercise duration is unknown (132). These findings indicate that athletes preserve energy for any unexpected and unpredictable events (135). In the unpredictable environment of team sports, this energy preservation allows for exercise intensity to be up or down regulated depending on the match status (135). In the current study the participants were informed of the duration of exercise and recovery periods of the SSG, which would have allowed a conscious decision to be made for the appropriate exercise intensity to complete the SSG session, while maintaining performance. This decision, of these experienced participant’s, would likely have been based on prior knowledge of the task (134), as SSG were a regular component of their training.

The high level of exercise capacity, and playing standard of the current participants may explain the RPE results. The RPE continued to increase across the bouts, despite no increases in HR and HHb, and with no change in the TMD across the bouts. These results indicate that although participants perceived the work to be harder towards the final bouts, they were able to tolerate the workload and maintain the exercise intensity. It has been shown that players of
a high playing standard and exercise capacity, pace themselves at high levels of exercise intensity (133). This phenomenon was indicated in the current study as HR was maintained at 80 to 90% HR$_{\text{max}}$, across the bouts in both conditions.

**Conclusion**

It is concluded that, a four-fold increase of recovery duration between serial SSG bouts did not affect the physiological, perceptual or time motion descriptors of experienced, and trained footballers during SSG bouts. The current results suggest that using a recovery duration ranging from 30 s to 120 s between serial SSG bouts will have a similar training effect for experienced and trained footballers. Coaches planning SSG training, may need to alter recovery durations outside of this range to increase the training stimulus. Lastly, experienced and trained footballers adopt pacing strategies during serial SSG sessions to maintain performance levels. Therefore, coaches should account for experience level when designing SSG training.

**Limitations**

One limitation of this project is that pacing was not anticipated in the current design, and a subjective measure of pacing could have directly indicated if pacing was consciously used. Secondly, only one format of SSG was used, modifying the player numbers, pitch size, number of bouts and recovery periods, using goals and goalkeepers may have provided further insight of the effect of altering recovery duration on different SSG formats.

**Implications and Future Research**

Implications of the current results for coaches planning SSG, is that the recovery duration of 30 s to 120 s does not affect physiological and perceptual responses, or speed and distance during the SSG bouts. However, future research should investigate how the technical
component of SSG in experienced footballers is affected by increasing the recovery period from 30 s to 120 s.

Acknowledgments

Thank you to Kevin Ahern-Evans, and the Sunshine Coast Football Club for providing the participants involved in this project. Thank you to Mitchell Naughton and Jessica Ebbersten for assisting in collecting RPE.
Chapter 3. The Effect of Recovery Duration on Technical Proficiency During Small Sided Games of Football.

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Author contributions

Conceived and designed the experiment: SM, CS, HK, AG
Performed the experiment: SM, HK. MN
Analysed the data: SM, HK, CS, GPL, AG, MN
Wrote the paper: SM, CS, HK, AG, GPL

Abstract

Purpose. Small sided games (SSG) are an effective, and time-efficient football training method. The aim of this study was to determine the effect of increasing the duration of recovery separating serial SSG bouts on technical skill (TS) execution, heart rate (HR), rating of perceived exertion (RPE) and time motion descriptors (TMD). It was hypothesised that decreasing the duration of recovery periods would decrease TS execution Method. Twelve semi-professional footballers (mean ± SD; age 21 ± 3 ys; VO₂peak 64 ± 7 ml · min · kg⁻¹; playing experience 15 ± 3 ys) completed two SSG sessions, each consisting of 3 vs 3 players and 6 bouts of 2 min, with the bouts separated by either 30 s recovery (REC-30) or 120 s recovery (REC-120). Multiple individual technical skill and team performance measures, HR, RPE, and TMA were measured. Results. There was a significantly (p < .05) higher HR during recovery in REC-30 compared to REC-120. The number of successful tackles was
significantly higher (p < .05), and the average time each team maintained possession was significantly lower in REC-120 compared to REC-30. There were no significant differences for all other technical skill or performance measures, or in HR, RPE, or TMD between the recovery conditions. There were significant increases in RPE as a function of bout number within both REC-30 and REC-120. **Conclusions.** In contrast to previous research, the four-fold increase in the duration of recovery separating SSG bouts did not alter the individual technical skill execution of players or team performance. These results could be explained by the high experience and skill level of the players, which would have allowed them to adapt to the demands of the SSG, irrespective of the different recovery periods, and to titrate their effort to enable the maintenance of technical skill execution.

**Keywords:** Small sided games, Recovery, Technical skill, Pacing.

**Introduction**

The execution of technical skills are the fundamental component of football (4, 136), whereby players must apply cognitive, perceptual and motor skills in a process where decisions are made, organised, initiated, controlled, and executed in a rapidly changing environment (88, 93, 137). Ultimately, the successful execution of technical skills including passing, maintaining possession, ball control, tackles, dribbling, and shooting are the primary determinants of performance, and will decide the outcome of a match (21, 93, 136).

However, successful technical skill execution by football players is challenged by the fatigue that occurs during a match (92, 136). Players experience temporary fatigue following phases of high intensity exercise during a match, and progressive fatigue across the duration of a match (28). The mechanisms responsible for the accumulation of fatigue in players during match play are complex and not completely understood (16, 36). Depletion of muscle glycogen, muscle creatine phosphate (PCr), and muscle pH, and increased muscle lactate, and
potassium, and dehydration have all been proposed to contribute to the accumulation of fatigue during a football match (36). Despite the lack of a definitive conclusion on the mechanisms of fatigue during a match, it is implied that a decline in technical proficiency in the later stages of a match is attributable to fatigue (16, 90).

Investigations of the relationship between fatigue, technical skills, and decision making are often conducted in non-football specific laboratory based football simulations (16, 88, 91, 138). As such, the participants do not experience the same sensory state as in an actual match, therefore reducing arousal levels and subsequent performance (139). Small sided games (SSG) combine the physiological, technical, and decision making components of football (10, 61, 78), thereby providing a more representative test environment compared to laboratory based studies. This game format is also an effective training method, using conditions that are representative of match demands (9). Typically, SSG are used in an interval format, consisting of a series of bouts and recovery periods (14, 42, 81, 114).

The accumulation of fatigue that occurs across serial bouts of SSG, as indicated by progressive increases in heart rate (HR), rating of perceived exertion (RPE), blood lactate [La], and decreased high intensity running, has been associated with decreased execution of TS (15, 42, 81, 96). During repeat sprinting in experienced runners, increasing the recovery duration separating the sprints, allows HR, and sprint performance to be maintained (40). Our research group have shown that increasing the duration of the recovery period separating serial SSG bouts from 30 s to 120 s increases physiological recovery, both centrally (heart rate) and peripherally (vastus lateralis muscle). However, only one study has investigated TS during SSG using different recovery durations of 1 min, 2 min, 3 min, and 4 min separating the bouts (15). An increased recovery duration improved TS, suggesting that the longer recovery duration reduced progressive fatigue without compromising cognitive processing (88, 140) allowing TS to be maintained (15). As exercise intensity is increased to very high
levels, arousal levels narrow attentional processes, resulting in players missing important cues necessary for successful skill execution (88, 139). Increasing the duration of recovery periods separating serial bouts may reduce physiological stress in subsequent bouts and therefore, maintain optimal arousal levels and the subsequent attention levels required for successful TS execution (88).

Despite only five technical variables measured in Koklu, Alemdaroglu (15), the results indicate that a shorter duration of recovery decreases TS execution, at least in the youth aged participants in the study. To obtain a more comprehensive understanding of the effect of recovery duration separating SSG bouts on technical skill, it is necessary to assess additional technical variables, and use experienced players. First touch passing, the number of individual touches occurring during possession, and time in possession for individuals and teams, need to be analysed to establish if changes occur when using different recovery periods separating SSG bouts. First touch passing involves high technical difficulty, and information processing required prior to receiving possession to recognise the positioning of team members and defenders (42). Knowing the number of touches a player self-selects per possession, and the duration of time that each individual possesses the ball during SSG, provides additional details on the technical features that are influenced by fatigue. Furthermore, it is possible that experienced athletes are able to maintain skill execution while under physiological stress by adapting to the changing demands of the game (139).

Therefore, the aim of this project was to investigate the effect of changing the recovery duration during a 3 vs 3 SSG format on multiple individual, and team technical variables, including new variables, in experienced football players. It was hypothesised that during serial SSG bouts, a 120 s recovery period compared to a 30 s recovery period, would allow for (less fatigue and therefore) an increase in the technical proficiency of players and teams.
Furthermore, it is expected that a decrease in HR, and RPE, and an increase in high speed running, and distance covered would be seen in REC-120 compared to REC-30.

Methods

Participants

Twelve experienced male footballers, playing in the same team and competing in the second tier of football in Australia, participated in the project (see Table 1). Participants trained three times per week for an approximate weekly total of 240 min and competed in one match per week of 90 min duration. The project received institutional ethical approval and participants provided written informed consent.

Table 3.1. Participant Characteristics.

<table>
<thead>
<tr>
<th>Age (ys)</th>
<th>Mass (kg)</th>
<th>Height (cm)</th>
<th>HR peak (beats·min⁻¹)</th>
<th>VO₂peak (ml·min·kg⁻¹)</th>
<th>Playing experience (ys)</th>
</tr>
</thead>
<tbody>
<tr>
<td>21.3 ± 2.9</td>
<td>75.0 ± 7.1</td>
<td>179.5 ± 6.9</td>
<td>190 ± 10.2</td>
<td>63.6 ± 7.4</td>
<td>14.6 ± 3.1</td>
</tr>
</tbody>
</table>

Data are (mean ± SD) (n = 12), for VO₂peak (n = 11).

Project Design

The project was conducted using a one-group, repeated measures design. The independent variables were the two different recovery durations, 30 s (REC-30), 120 s (REC-120), and the number of bouts (1 - 6). The dependent variables measured were the individual and team technical skill variables (Table 2), heart rate (HR), rating of perceived exertion (RPE; Borg CR-10), and time motion descriptors (TMD; speed and distance). Participants completed the SSG sessions, and a peak aerobic capacity test under laboratory conditions. All testing and data collection was completed in an 11 week period during the participants’ competitive season.
Small Sided Games

Each participant completed REC-30 and REC-120 under the same SSG format consisting of 3 vs 3 players with 6 x 2 min bouts played on a 15 m x 20 m natural grass pitch. Each participant was tested in two separate sessions, separated by a minimum of 2 days and maximum of 5 days, and the order of conditions was counterbalanced. The SSG testing was completed in eight sessions during a 5-week period. The SSG testing sessions were completed at the beginning of the participants’ normal football training session and at the same time of day to avoid variations to circadian rhythm. The SSG teams were selected by the two experienced team coaches to ensure that similar levels of technical ability and physical capacity of players were evenly distributed throughout the teams. The same team membership was used for all testing sessions. The objective of the SSG was to maintain possession as a team, with unlimited ball contacts per possession, and no goals and goalkeepers, and no coach encouragement. Additional balls were placed around the pitch to minimise time lost for balls out of play. Prior to testing, participants performed a standardised warm up. Immediately post warm-up, the participants were fitted with HR straps and GPS devices before beginning the SSG. During the recovery periods, participants were instructed that they could walk within the playing grid after their RPE was recorded.

Technical Skills Analysis

The SSG were recorded on a high definition video recorder (Sony HDR-CX130) positioned on a tripod at approximately 3m above the playing surface, at the centre of the 20 m length of the playing area and approximately 10 m from the boundary of the playing area. Post hoc analysis of the video recordings were used to analyse the TS of participants. Technical actions were divided into 14 different categories (refer to Table 3.2 for definitions). Intra and inter-observer reliability were assessed by analysis of three randomly selected bouts for each
observer reliability method. Intra class correlations were used for the intra-observer reliability (values ranged from .801 to .985). Cohen’s Kappa was used for the inter-observer reliability (values ranged from .814 to .837). The reliability results indicated a very high level of agreement. (81).

**Tables 3.2. Technical Skill Definitions.**

<table>
<thead>
<tr>
<th>Technical action</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (s) in possession (individual)</td>
<td>The amount of time (s) an individual player has possession.</td>
</tr>
<tr>
<td>Touches in possession (individual)</td>
<td>The number of occasions an individual player has contact with the ball (using the foot, thigh, head, or chest) per possession.</td>
</tr>
<tr>
<td>Time (s) in possession (team)</td>
<td>The amount of time (s) a team has possession.</td>
</tr>
<tr>
<td>Successful passes (team)</td>
<td>The number of passes each team completes for each possession</td>
</tr>
<tr>
<td>Successful pass (%)</td>
<td>The percentage of successful passes completed during the bouts (both teams)</td>
</tr>
<tr>
<td>Intercept</td>
<td>A player from the non-possession team gains possession by intercepting a pass from the team in possession.</td>
</tr>
<tr>
<td>Deflection</td>
<td>A player makes unintentional contact with the ball, resulting in a change/no change of team possession, or the ball goes out of play.</td>
</tr>
<tr>
<td>Unsuccessful pass</td>
<td>The incompletion of an intentional pass between players of same team.</td>
</tr>
<tr>
<td>Term</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Successful pass</td>
<td>The completion of an intentional pass between players of the same team.</td>
</tr>
<tr>
<td>Unsuccessful 1st touch pass</td>
<td>The incompletion of an intentional 1st touch pass between players of same team.</td>
</tr>
<tr>
<td>Successful 1st touch pass</td>
<td>The completion of an intentional 1st touch pass between players of the same team.</td>
</tr>
<tr>
<td>Successful tackle</td>
<td>A player from the non-possession team involved in a duel gains possession of the ball.</td>
</tr>
<tr>
<td>Unsuccessful tackle</td>
<td>A player in possession remains in possession after a duel.</td>
</tr>
<tr>
<td>Lost possession (miscontrol)</td>
<td>A player loses ball possession due to miscontrol</td>
</tr>
<tr>
<td>Total possessions per bout</td>
<td>The number of individual possessions, during the bouts (all players)</td>
</tr>
<tr>
<td>Time (seconds) ball is out of play.</td>
<td>Time from when the ball leaves the playing area until a new ball is played back into the playing area.</td>
</tr>
</tbody>
</table>

**Heart Rate**

During the SSG, HR was recorded continuously (Polar strap and Catapult MinimaxX S4 recorder; Catapult Sports, Melbourne), and averaged for the bout and recovery periods and expressed as beats per minute. Due to missing or incomplete HR data, HR data was n = 10 for REC-30, and n = 10 for REC-120.
**Rating of Perceived Exertion**

During the first 10-15 s of each recovery period, participants RPE (Borg CR-10) response was recorded to measure the global perceived effort (intensity) of the previous bout of SSG. Participants were familiarised with the RPE scale during normal training sessions in the 2 weeks leading up to the testing sessions.

**Time Motion Descriptors**

The distance covered and speed attained by participants during the SSG was measured at a 10 Hz sampling rate by portable GPS units (MinimaXS4, Catapult sports, Melbourne), and analysed in Catapult Sprint 5.01 software. The total distance covered in the SSG session, distance covered in each bout, and percentage of time spent in four speed zones (0- 6.9 km.hr⁻¹, 7-12.9 km.hr⁻¹, 13-17.9 km.hr⁻¹, > 18 km.hr⁻¹) were analysed (15).

**Peak Exercise Test**

A standard incremental intensity exercise test to volitional cessation was conducted to obtain the participants (n = 5) peak aerobic capacity using a treadmill (T200, Cosmed, Rome Italy). The maximal exercise test was used to obtain the maximal HR of participants. A polar heart rate strap and open-circuit spirometry metabolic analysis system (True One 2400, Parvo Medics, Sandy UT) recorded continuous HR via short range telemetry.

**Statistical Analysis**

Statistical analysis were performed using SPSS (version 22, IBM Corporation, Armonk NY, USA). Data are reported using mean ± SD, and the level of significance was set at p < .05. A two-way repeated-measures ANOVA was used to assess the effect of condition (REC-120 and REC-30), bout (1-6), and Condition x Bout interactions for all dependent variables. Assumptions of sphericity using Maulchy’s W test was used, and in all cases where
Maulchy’s W was significant, the Greenhouse-Geisser correction of degrees of freedom applied. A paired t test was used to compare the total distances covered for the SSG sessions. Post hoc pairwise comparisons were used to follow-up significant interactions, and were conducted using the least significant difference (LSD) method with no adjustments for multiple comparisons. Calculations of $p$ value, partial eta-squared (as an indicator of effect size, noted $\eta_p^2$) and statistical power ($\beta$) were reported.
Results

Technical skill

For technical skill there was a significant main effect of condition for the number of successful tackles \( (p = .023; \eta^2 = 0.071; \text{power} = 0.313) \), with an increased number of tackles performed in REC-120. There was also a main effect for the average time of team possessions \( (p = .038; \eta^2 = 0.807; \text{power} = 0.660) \) with possessions being lower in REC-120. There were no significant \( (p > .05) \) main effects for condition or, bout number, and no Condition x Bout interaction for all other technical variables (see Table 3.3).
### Table 3.3. Technical Actions (Mean and Frequency)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Condition</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
<th>SSG</th>
<th>Session</th>
<th>Condition (p value)</th>
<th>Bout (p value)</th>
<th>Interaction (p value)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean ± SD of technical actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time in possession (s)</td>
<td>REC-30</td>
<td>2.2 ± 1.0</td>
<td>2.1 ± 0.9</td>
<td>2.1 ± 1.2</td>
<td>1.9 ± 0.8</td>
<td>2.2 ± 1.1</td>
<td>2.7 ± 3.2</td>
<td>2.2 ± 1.3</td>
<td>.495</td>
<td>.368</td>
<td>.881</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>2.1 ± 1.1</td>
<td>1.9 ± 1.3</td>
<td>1.8 ± 0.8</td>
<td>1.9 ± 0.9</td>
<td>2.1 ± 0.9</td>
<td>2.3 ± 1.2</td>
<td>2.0 ± 1.0</td>
<td>.497</td>
<td>1.106</td>
<td>.193</td>
<td></td>
</tr>
<tr>
<td>Touches in possession (%)</td>
<td>REC-30</td>
<td>3.3 ± 0.9</td>
<td>3.4 ± 0.9</td>
<td>3.3 ± 1.0</td>
<td>2.8 ± 0.5</td>
<td>3.4 ± 1.2</td>
<td>4.1 ± 2.3</td>
<td>3.4 ± 1.3</td>
<td>.140</td>
<td>.099</td>
<td>.586</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>3.3 ± 1.4</td>
<td>3.1 ± 1.3</td>
<td>3.0 ± 0.8</td>
<td>3.2 ± 0.6</td>
<td>3.4 ± 1.1</td>
<td>3.6 ± 1.5</td>
<td>3.3 ± 1.1</td>
<td>.189</td>
<td>1.961</td>
<td>.617</td>
<td></td>
</tr>
<tr>
<td>Average team Possession (s)</td>
<td>REC-30</td>
<td>7.3 ± 3.4</td>
<td>9.3 ± 2.6</td>
<td>6.8 ± 1.9</td>
<td>7.9 ± 1.8</td>
<td>6.7 ± 2.0</td>
<td>9.8 ± 6.9</td>
<td>7.9 ± 3.4</td>
<td>.038 *</td>
<td>.424</td>
<td>.908</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>5.9 ± 2.0</td>
<td>7.0 ± 2.7</td>
<td>6.5 ± 2.6</td>
<td>6.9 ± 4.5</td>
<td>6.5 ± 1.6</td>
<td>7.0 ± 1.9</td>
<td>6.6 ± 2.4</td>
<td>12.510</td>
<td>1.053</td>
<td>.296</td>
<td></td>
</tr>
<tr>
<td>Pass/possession (team)</td>
<td>REC-30</td>
<td>1.8 ± 1.1</td>
<td>2.8 ± 0.3</td>
<td>1.9 ± 0.5</td>
<td>3.0 ± 2.0</td>
<td>1.6 ± 0.3</td>
<td>2.9 ± 2.7</td>
<td>3.2 ± 1.4</td>
<td>.557</td>
<td>.510</td>
<td>.348</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>1.4 ± 0.5</td>
<td>1.9 ± 1.1</td>
<td>2.4 ± 1.2</td>
<td>3.5 ± 3.4</td>
<td>1.4 ± 0.3</td>
<td>1.7 ± 0.9</td>
<td>2.0 ± 1.6</td>
<td>.434</td>
<td>.893</td>
<td>1.218</td>
<td></td>
</tr>
<tr>
<td>Successful pass (%)</td>
<td>REC-30</td>
<td>79 ± 20</td>
<td>85 ± 12</td>
<td>84 ± 18</td>
<td>82 ± 15</td>
<td>82 ± 25</td>
<td>80 ± 15</td>
<td>80 ± 15</td>
<td>.305</td>
<td>.710</td>
<td>.992</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>71 ± 29</td>
<td>81 ± 16</td>
<td>81 ± 18</td>
<td>77 ± 23</td>
<td>79 ± 23</td>
<td>76 ± 17</td>
<td>77 ± 21</td>
<td>1.157</td>
<td>.586</td>
<td>.099</td>
<td></td>
</tr>
<tr>
<td>Frequency ± SD of technical actions</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interceptions</td>
<td>REC-30</td>
<td>5 ± 0.7</td>
<td>5 ± 0.7</td>
<td>4 ± 0.7</td>
<td>5 ± 0.7</td>
<td>5 ± 0.5</td>
<td>2 ± 0.4</td>
<td>26 ± 0.6</td>
<td>.223</td>
<td>.089</td>
<td>.602</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>10 ± 0.8</td>
<td>7 ± 0.7</td>
<td>3 ± 0.5</td>
<td>4 ± 0.5</td>
<td>8 ± 0.9</td>
<td>1 ± 0.3</td>
<td>33 ± 0.7</td>
<td>1.669</td>
<td>2.028</td>
<td>.732</td>
<td></td>
</tr>
<tr>
<td>Deflections</td>
<td>REC-30</td>
<td>0 ± 0.0</td>
<td>2 ± 0.4</td>
<td>0 ± 0.0</td>
<td>2 ± 0.4</td>
<td>4 ± 0.7</td>
<td>3 ± 0.5</td>
<td>11 ± 0.4</td>
<td>.078</td>
<td>.698</td>
<td>.163</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>6 ± 1.2</td>
<td>6 ± 0.5</td>
<td>5 ± 0.7</td>
<td>0 ± 0.0</td>
<td>4 ± 0.5</td>
<td>3 ± 0.6</td>
<td>24 ± 0.7</td>
<td>3.786</td>
<td>.603</td>
<td>1.646</td>
<td></td>
</tr>
<tr>
<td>Unsuccessful pass</td>
<td>REC-30</td>
<td>11 ± 2.9</td>
<td>5 ± 1.4</td>
<td>5 ± 1.4</td>
<td>11 ± 2.9</td>
<td>7 ± 2.0</td>
<td>9 ± 2.5</td>
<td>48 ± 0.8</td>
<td>.226</td>
<td>.183</td>
<td>.966</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>14 ± 3.7</td>
<td>8 ± 2.1</td>
<td>9 ± 2.4</td>
<td>15 ± 4.1</td>
<td>11 ± 3.0</td>
<td>10 ± 2.8</td>
<td>67 ± 1.1</td>
<td>1.647</td>
<td>1.572</td>
<td>.071</td>
<td></td>
</tr>
<tr>
<td>Successful pass</td>
<td>REC-30</td>
<td>38 ± 2.3</td>
<td>48 ± 1.7</td>
<td>33 ± 1.5</td>
<td>38 ± 1.3</td>
<td>29 ± 1.6</td>
<td>37 ± 2.4</td>
<td>223 ± 1.8</td>
<td>.523</td>
<td>.330</td>
<td>.246</td>
<td></td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>29 ± 1.6</td>
<td>35 ± 1.8</td>
<td>37 ± 1.4</td>
<td>31 ± 1.0</td>
<td>34 ± 1.4</td>
<td>39 ± 1.5</td>
<td>205 ± 1.4</td>
<td>.435</td>
<td>1.181</td>
<td>1.465</td>
<td></td>
</tr>
<tr>
<td>Condition</td>
<td>REC-30</td>
<td>REC-120</td>
<td>REC-30</td>
<td>REC-120</td>
<td>REC-30</td>
<td>REC-120</td>
<td>REC-30</td>
<td>REC-120</td>
<td>REC-30</td>
<td>REC-120</td>
<td>REC-30</td>
<td>REC-120</td>
</tr>
<tr>
<td>---------------------------</td>
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<td>---------</td>
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<td>---------</td>
<td>--------</td>
<td>---------</td>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>Unsuccessful 1st touch</td>
<td>1 ± 0.3</td>
<td>5 ± 0.5</td>
<td>4 ± 0.5</td>
<td>4 ± 0.7</td>
<td>4 ± 0.7</td>
<td>8 ± 0.5</td>
<td>21 ± 0.6</td>
<td>29 ± 0.6</td>
<td>1.000</td>
<td>.664</td>
<td>.502</td>
<td>.652</td>
</tr>
<tr>
<td>Successful 1st</td>
<td>18 ± 1.3</td>
<td>18 ± 1.6</td>
<td>20 ± 1.3</td>
<td>20 ± 1.3</td>
<td>13 ± 0.9</td>
<td>23 ± 1.5</td>
<td>16 ± 0.8</td>
<td>24 ± 1.0</td>
<td>114 ± 1.2</td>
<td>.128</td>
<td>.614</td>
<td>.310</td>
</tr>
<tr>
<td>Successful tackle</td>
<td>6 ± 0.7</td>
<td>7 ± 0.7</td>
<td>3 ± 0.5</td>
<td>13 ± 1.1</td>
<td>11 ± 0.7</td>
<td>6 ± 0.7</td>
<td>4 ± 0.8</td>
<td>4 ± 0.7</td>
<td>61 ± 1.0</td>
<td>6.962</td>
<td>2.164</td>
<td>1.219</td>
</tr>
<tr>
<td>Unsuccessful</td>
<td>10 ± 1.1</td>
<td>9 ± 0.8</td>
<td>7 ± 0.7</td>
<td>11 ± 0.9</td>
<td>10 ± 0.7</td>
<td>9 ± 1.1</td>
<td>4 ± 0.5</td>
<td>51 ± 0.8</td>
<td>.652</td>
<td>.323</td>
<td>.780</td>
<td>.493</td>
</tr>
<tr>
<td>Successful tackle</td>
<td>6 ± 0.7</td>
<td>3 ± 0.5</td>
<td>5 ± 0.7</td>
<td>3 ± 0.5</td>
<td>8 ± 0.9</td>
<td>2 ± 0.4</td>
<td>27 ± 0.6</td>
<td>.112</td>
<td>.227</td>
<td>.462</td>
<td>.462</td>
<td>1.000</td>
</tr>
<tr>
<td>Lost possession</td>
<td>11 ± 12</td>
<td>6 ± 0.8</td>
<td>11 ± 1.1</td>
<td>4 ± 0.5</td>
<td>5 ± 0.9</td>
<td>6 ± 0.5</td>
<td>43 ± 0.9</td>
<td>2.983</td>
<td>1.434</td>
<td>.982</td>
<td>.146</td>
<td>.197</td>
</tr>
<tr>
<td>Total possession per bout</td>
<td>89 ± 3.0</td>
<td>90 ± 2.5</td>
<td>65 ± 1.6</td>
<td>90 ± 2.3</td>
<td>70 ± 1.9</td>
<td>85 ± 2.4</td>
<td>489 ± 2.4</td>
<td>.982</td>
<td>.146</td>
<td>.197</td>
<td>.197</td>
<td>.197</td>
</tr>
</tbody>
</table>

* Significant main effect of condition
**Exercise Intensity (HR, RPE, TMD)**

During the recovery periods, a significant main effect of condition ($p = .001; \eta^2 = 0.795$; power = 0.998) revealed, an increase in the average HR (bpm) during REC-30 compared to REC-120 (see Table 4). However, during the bouts, there was no significant main effect of condition for the average HR (bpm) ($p = .201; \eta^2 = 0.195$; power = 0.234), RPE ($p = .079; \eta^2 = 0.254$; power = 0.422), or distance covered ($p = .861; \eta^2 = 0.003$; power = 0.053) (see Table 3.4). There was no significant difference for distance covered during the SSG session (all bouts) ($p = .814$) REC-120 (1064.5 ± 148.8 m) and REC-30 (1053 ± 175.2 m). There was no significant main effect of condition for time spent in all four speed zones 0 - 6.9 km.hr$^{-1}$ ($p = .577; \eta^2 = 0.029$; power = 0.082), 7 – 12.9 km.hr$^{-1}$ ($p = .702; \eta^2 = 0.014$; power = 0.065), 13 – 17.9 km.hr$^{-1}$ ($p = .400; \eta^2 = 0.065$; power = 0.126), and >18 km.hr$^{-1}$ ($p = .985; \eta^2 = 0.000$; power = 0.050). For RPE, there was a significant main effect of bout number ($p = .000; \eta^2 = 0.693$; power = 1.000), revealing that, in general, the latter bouts were perceived to be more physically demanding (see Table 3.4). There was also a Condition x Bout interaction ($p = .003; \eta^2 = 0.272$; power = 0.935). When comparing across the bouts for the two conditions there was a significant difference, with REC-30 perceived as more physically demanding than REC-120, in B5 ($p = .009$), and B6 (.025).
### Table 3.4. Exercise Intensity. Heart rate (HR), rating of perceived exertion (RPE), and time motion descriptors (TMD).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Condition</th>
<th>B1</th>
<th>B2</th>
<th>B3</th>
<th>B4</th>
<th>B5</th>
<th>B6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recovery HR (bpm)</td>
<td>REC-30</td>
<td>159 ± 12</td>
<td>163 ± 14</td>
<td>166 ± 13</td>
<td>169 ± 11</td>
<td>171 ± 9</td>
<td>173 ± 10</td>
</tr>
<tr>
<td></td>
<td>REC-120 *#</td>
<td>125 ± 20</td>
<td>134 ± 15</td>
<td>141 ± 13</td>
<td>141 ± 12</td>
<td>141 ± 13</td>
<td>140 ± 12</td>
</tr>
<tr>
<td>Bouts HR (bpm)</td>
<td>REC-30</td>
<td>151 ± 12</td>
<td>162 ± 13</td>
<td>164 ± 14</td>
<td>166 ± 14</td>
<td>166 ± 13</td>
<td>168 ± 13</td>
</tr>
<tr>
<td></td>
<td>REC-120 #</td>
<td>139 ± 26</td>
<td>151 ± 25</td>
<td>160 ± 10</td>
<td>160 ± 11</td>
<td>158 ± 11</td>
<td>161 ± 12</td>
</tr>
<tr>
<td>RPE</td>
<td>REC-30</td>
<td>3.6 ± 0.8</td>
<td>4.6 ± 0.8 a</td>
<td>5.0 ± 1.0 a</td>
<td>5.4 ± 1.0 a</td>
<td>6.2 ± 1.0 a,b,c</td>
<td>6.4 ± 1.1 a,b,c,d</td>
</tr>
<tr>
<td></td>
<td>REC-120 #$</td>
<td>4.2 ± 1.9</td>
<td>4.4 ± 1.4</td>
<td>4.4 ± 0.7</td>
<td>4.8 ± 0.7</td>
<td>5.0 ± 1.0</td>
<td>5.4 ± 1.1 a,b,c</td>
</tr>
<tr>
<td>Distance (m) covered in each bout</td>
<td>REC-30</td>
<td>237 ± 39</td>
<td>210 ± 41</td>
<td>216 ± 41</td>
<td>212 ± 38</td>
<td>203 ± 41</td>
<td>213 ± 46</td>
</tr>
<tr>
<td></td>
<td>REC-120</td>
<td>236 ± 39</td>
<td>214 ± 39</td>
<td>215 ± 37</td>
<td>218 ± 32</td>
<td>210 ± 38</td>
<td>208 ± 34</td>
</tr>
</tbody>
</table>

Note: * main effect of condition, # main effect of bout number, $ condition x bout interaction.

Post-hoc pairwise comparisons: a different to B1, b different to B2, c different to B3, d different to B4. (p < .05) in all cases.

Data: Mean ± SD
Discussion

This project was designed to determine the effect of increasing the recovery duration from 30 s to 120 s on TS during a series of 3 vs 3 SSG bouts. The aim was to investigate a comprehensive set of skill-related variables in highly experienced participants. The main result was that the overall technical skill was not influenced by increasing the recovery duration from 30 s to 120 s. This finding did not support the hypothesis that increasing the duration of the recovery separating serial SSG bouts would increase players’ TS.

From the 14 technical skills that were analysed in the current project, only two variables were significantly different: duration of team possessions (shorter), and the number of successful tackles (higher) in REC-120 compared to REC-30. The absence of an overall change in technical skill occurred despite an increased physiological recovery, as indicated by a significantly decreased HR, during the REC-120 compared to the REC-30 condition. The current results are in contrast with those of the only other study that has used different recovery durations separating SSG bouts (15). Koklu, Alemdaroğlu (15) found an increase in total passes, successful passes, passes received, and tackles during bouts interspersed with recovery durations of 3 min, and 4 min compared to 1 min. In addition, the HR in the 3 min and 4 min recovery condition was significantly lower than in the SSG played with 1 min recovery, suggesting that the decreased HR was associated with increased TS execution (15).

A characteristic of highly trained and skilled athletes is that they are able to adapt to the demands to which they are exposed, such as the maintenance of skill execution while under fatigue (139). In a 3 vs 3 SSG format with unlimited ball touches, professional compared to amateur footballers, lost possession less, and had a greater number of successful passes and duels (61). In the current project the players maintained skill execution despite the increased physiological demands of a reduced recovery period. In support of the current results, no
declines were observed in the technical skill execution of professional midfield players during full scale matches (90). This was despite players enduring end game fatigue, as indicated by significant declines in high speed running towards the end of the game (90).

Although we did not qualitatively measure technique (patterns of movement required to execute technical skill) (93) in the current project, skilled athletes are highly capable of adapting their technique to cope with game demands (139). One of the critical attributes of highly skilled performers is their capability to continually adapt to the demands of the performance context (141-143). During a shooting task performed under progressively increasing fatigue, highly skilled water polo players were able to maintain shooting accuracy and ball speed despite decreases in the players’ technique (139). It is suggested that highly skilled athletes can compensate for changes in the performance environment to maintain consistent performance outcome goals (139). This could be a possible explanation for the maintenance of skill execution between REC-30 and REC-120 in the current project.

A secondary finding was that during the bouts there was no difference between REC-30 and REC-120 for HR, RPE, and time motion descriptors (speed and distance). This contrasted with our hypothesis that REC-120 compared to REC-30 would elicit a lower HR and RPE, and increase time motion descriptors. These results indicate that the work performed, and exercise intensity in both REC-30 and REC-120 were similar. This result is supported by previous research from our laboratory that indicates that experienced and highly trained football players, who are familiar with SSG training use a pacing strategy to regulate physical effort so that performance is maintained across serial SSG bouts. The ability to pace is enhanced when individuals are highly trained, have task specific experience, and possess knowledge of the exercise endpoint (119, 134, 135). The experience level (14.6 ys), training status (VO$_2$ of 64 mL.minkg$^{-1}$), and experience in SSG of the current participants, in addition
to the known exercise endpoint, lends further support that players used a pacing strategy. To provide additional support for this conclusion, it is recommended that future studies include a subjective measure of pacing.

In the current project, technical skill execution was not affected as a function of serial bouts. This is despite increases in perceived exertion across the bouts. Successful passing was 80% (REC-30), and 77% (REC-120) for the session, and did not decline across the subsequent bouts. This is contrary to other 3 vs 3 SSG formats with unlimited ball touches per possession (42), where the percentage of successful passes significantly decreased from bout 1 (76%) to the fourth and final bout (70%), and HR was significantly higher in the fourth bout compared to the first bout (42). This contrasts with the current results and indicates that the current participants regulated their effort to maintain technical performance.

Successful skill execution in football is a process that integrates accurate decision making, good technique, and the ability to assess information from the ball, team members, and opponents. This involves a rapidly changing environment, and continual changes in exercise intensities (88, 93). Exercise and cognition theory suggests that physical arousal increases with increasing exercise intensity, to an optimal point (88, 140). Thereafter, as exercise intensity is further increased, a narrowing of attentional processes results in missing cues necessary for the execution of technical skill (88, 139). In the current project, the average level of exercise intensity of participants, for the bouts was regulated to remain at submaximal levels, which may have prevented declines in cognitive performance, and the subsequent declines in TS execution across the multiple bouts.

In addition to previously measured technical variables of passing success, tackles, intercepts, balls lost in SSG research, this project analysed 4 novel technical variables. For successful first touch passes there was no significant difference between the conditions, however,
successful first touch passing was responsible for approximately 50% of total successful passes in both conditions. First touch passing requires high levels of information processing, and increases the pace of a game, both of which are characteristics of elite level football (42). The high number of successful first touch passing in the current project indicates that SSG played with 3 vs 3 is an appropriate stimulus to develop information processing ability of players.

A novel finding of the current project is that players take three ball touches when instructed to play with unlimited ball touches per individual possession. This is higher than the amount of touches taken during professional matches (defenders 1.74 and attacking midfielders 2.26) (42). The differences may be explained by the reduced number of passing options that are available in a 3 vs 3 format. Although a higher number of individual touches were taken in the current project, compared to professional matches, the information processing acquired by playing 3 vs 3 may transfer to full scale matches, where space is typically greater than in SSG. The mean number of individual ball possessions in the current project was approximately 6-7 per bout, for a mean duration of 2.2 s (REC-30), and 2.0 s (REC-120) for each possession. The current results equate to approximately over 80 s of ball possession, condensed into 12 min of SSG training. During a full scale 90 min match, the average time in individual possession is 78 seconds (42). Thus, a 3 vs 3 SSG format provides players with a training stimulus that exceeds the amount of time in individual possession compared to matches. This increased time in possession during training is time efficient, and could enhance player development.
Conclusion

It is concluded that, increasing the recovery duration from 30 s to 120 s separating serial SSG bouts, does not affect technical skill execution of experienced and trained football players. Highly skilled and trained footballers are able to adapt to the increased physical demands of the shorter recovery duration to maintain skill execution. This is likely facilitated by pacing, where players regulate their effort to maintain performance. Furthermore, during a 3 vs 3 SSG format, experienced and trained football players choose to take three touches of the ball while in possession, maintain possession for approximately 2 seconds, and use a high number of first touch passing.

Limitations

One limitation of the current project is that only one SSG format was used. Changes to the modifiable SSG variables would provide further information of the effect of using different recovery periods. Secondly, a subjective measure of pacing would have helped to determine if the players paced themselves during the serial SSG bouts. Pacing was not anticipated in the current project. Lastly, no comparison to a lower skilled group was conducted in the study.
Chapter 4. General Discussion

In the following chapter the main and unique findings of both studies in this project, and their contribution to the research topic, both independently and when combined, are discussed. Practical implications of the current project with regard to football training, and coaching are discussed.

Physiological Measures

This project is the first to assess muscle tissue oxygenation during football specific exercise. A primary finding was that it is possible to assess muscle tissue oxygenation during a dynamic team sport consisting of various speed running, rapid and frequent changes of direction, kicking, jumping, and isometric muscle contractions. Secondly, an increased duration of recovery allows a greater decline of HHb, which is consistent with previous NIRS research investigating muscle tissue oxygenation during straight line and treadmill running, and cycling (121). However, during the bouts HHb was not different between REC-30 and REC-120. Although HHb levels are not a direct measure of exercise intensity, increased exercise intensity is associated with an increase HHb (130). Therefore, the absence of a difference of HHb between conditions during the bouts, indirectly indicates that the SSG in the two conditions were played at the same intensity.

Participants’ HR was used to assess exercise intensity during the bouts, and the magnitude of recovery from the SSG bouts. An expected decline in HR was measured as recovery was increased from 30 s to 120 s. However, as with HHb, there was no significant difference for HR between REC-30 and REC-120 during the bouts. Participants’ HR was maintained at approximately 80% to 90% of maximal values throughout the SSG sessions. Although we measured a significant main effect of bout number, the lack of a statistically significant condition x bout interaction prevented the analysis of HR across the bouts. However, visual
examination indicates that the movement was likely to have occurred from B1 to B2. During REC-120, the increase in HR from B1 to B2 was 80% of the total increase from B1 to B6, and for REC-30 the increase in HR from B1 to B2 was 64% of the total increase. The HR results of two separate SSG studies reported significant increases from B1 to B2, followed by non-significant HR changes for the subsequent bouts (15, 81).

**Perceived Exertion**

Participants’ RPE was measured to determine psychophysiological load during the SSG bouts. The current RPE values are consistent with previous SSG research, and team sport in general (14, 42, 78, 135). Although, there was no significant difference between conditions, RPE increased as a function of bout number. In contrast with the visual plateau from B2 to B6 in HR, RPE continued to increase across the SSG session. This finding suggests that despite a potential plateau in physiological measures, the participants perceived an increase in exertion across the bouts.

**Time Motion Descriptors**

The GPS measurements of speed and distance were used to measure external exercise intensity, and work performed during the bouts. We found no difference between conditions, for distance covered in the session and for each bout, and for time spent in each speed zone. These results indicate that participants performed the same amount of work at the same intensity during the bouts in REC-30 and REC-120. Consistent with previous SSG research is that most time was spent in the lower speed zones (15). It is likely that the time spent in the low speed zones is to recover from the frequent high intensity actions associated with SSG. The minimal time spent at >18 km.hr⁻¹ is likely due to the small pitch size, which would not allow players the space to achieve high speeds. The utility of the >18 km.hr⁻¹ speed zone
could be questioned in SSG research, as the small playing area does not allow players to reach such speeds.

**Technical Skill**

For this project, we analysed 14 technical variables, which included three technical variables novel to multiple bout SSG research. The novel technical variables, the amount of touches in individual possession, time in individual possession, first touch passing proficiency, in addition to several previously measured technical variables provided a comprehensive analysis of TS execution during serial SSG. Only the number of successful tackles (higher), and the average time each team maintained possession (lower) in REC-120 compared to REC-30, were significantly different. There were no significant difference between the two conditions for any other technical variable, indicating that the players were able to maintain TS execution despite the reduced duration of recovery in REC-30 compared to REC-120. Although we measured no difference between conditions for successful first touch passing, this was responsible for approximately 50% of total successful passes in both conditions. First touch passing requires high levels of information processing, and increases the pace of a game, both of which are characteristics of elite level football (42).

**Combined Responses**

The absence of any significant differences between REC-30 and REC-120 for all dependant variables measured during the bouts in the current project, may be explained by assessing them together, and in combination with the participant characteristics. The participants in the current project were highly trained (VO$_{2peak}$ 64 ± 7 ml.minkg$^{-1}$), experienced (14.6 ys), and the team played SSG as part of regular training, and participants were informed of the duration of the bouts and recovery periods. The HR and perceived exertion results, indicate that the SSG were played at a submaximal exercise intensity, suggesting that the participants
regulated their exercise intensity, or paced. Pacing prevents large disruptions to homeostasis that would decrease performance (119). Regulating the intensity and amount of work performed would have allowed the maintenance of technical skill execution, since fatigue is attributed to the decline in technical skill execution (16, 28).

**Limitations**

One limitation of this project is that pacing was not anticipated in the current design, and a subjective measure of pacing could have directly indicated if pacing was consciously used. Secondly, only one format of SSG was used. Modifying the player numbers, pitch size, number of bouts and recovery periods, using goals and goalkeepers may have provided further insight into the effect of altering recovery duration on different SSG formats.

**Conclusions**

1. Increasing the duration of recovery from 30 s to 120 s (four-fold) separating serial SSG bouts, allowed for an increased physiological recovery, as indicated by a significant decrease in HR and HHb.

2. Increasing the duration of recovery from 30 s to 120 s separating serial SSG bouts, does not affect the physiological or perceptual responses, time motion descriptors, or execution of technical skills, of experienced, and trained football players.

3. Experienced and trained football players are apparently able to regulate (pace) the exercise intensity and work performed, during multiple bout SSG to maintain performance.
Practical Implications

An important aspect in the design of this project was to ensure the testing environment was representative of an actual SSG training session. Football research is often conducted using non-football specific laboratory based football simulations, which is not representative of match situations. Therefore, the practical implications provided for training in this section are from the results of a testing environment representative of football, which provide a representative setting from which meaningful conclusions can be drawn that are more likely to be generalizable to similar real world environments.

1. Coaches should consider playing experience, and training status of players when designing SSG training sessions. Only the current project, and one other (15) have investigated the effect of different recovery durations separating SSG bouts on physiological, perceptual and technical proficiency of football players. The current project used experienced and trained football players, with contrasting results to Koklu, Alemdaroglu (15) who used youth players. It is known that task specific experience enhances the ability of individuals to regulate effort to perform tasks without a decline in performance.

2. The training effect (physiological, and technical) of playing six bouts of SSG with either a 30 s or 120 s recovery duration will be similar for experienced, and trained football players. Therefore, a 30 s recovery duration is a more time efficient training method.

3. The high frequency of first touch passing in the current project indicates that playing this format of SSG provides an opportunity for players to perform frequent complex decision making processes associated with first touch passing.

4. Coaches often impose restrictions on players’ touches in training to encourage playing with fewer touches. Taking fewer touches increases the pace of the game, and is a common characteristic of professional players. When playing the current SSG format, players chose to
take three touches, and spend approximately 2 s in possession. Although this is important information for coaches, this could be expected to change with increases in pitch size, and player number. Therefore, future research investigating the technical component of football, should include these measures to broaden the knowledge regarding SSG design.
References


