Intensity and Duration of Intermittent Exercise and Recovery During a Soccer Match

Michael S. Orendurff,[1] Jason D. Walker,[2] Mladen Jovanovic,[3] Kirsten L. Tulchin,[1] Morris Levy,[4] and David K. Hoffmann[5]

[1]Movement Science Laboratory, Texas Scottish Rite Hospital for Children, Dallas, Texas; [2]Department of Mechanical Engineering, University of Southern California, Los Angeles, California; [3]Department of Strength Training and Conditioning, School of Sports and Physical Education, University of Belgrade, Belgrade, Serbia; [4]Department of Health and Physical Education, University of Minnesota, Duluth, Minnesota; and [5]Department of Athletics, University of Dallas, Irving, Texas

Abstract

Orendurff, MS, Walker, JD, Jovanovic, M, Tulchin, KL, Levy, M, and Hoffmann, DK. Intensity and duration of intermittent exercise and recovery during a soccer match. *J Strength Cond Res* 24(x): 000–000, 2010—Soccer is a sport consisting of high-intensity intermittent exercise, with players making forays across their anaerobic threshold for tactical advantage followed by periods of recovery. The intensity and duration of these work and recovery bouts were defined during a men's soccer match using StepWatch Activity Monitors recording step rate for each 3-second period. The data were coded by custom software to separate work bouts (step rate ≥ 4) from recovery bouts (step rate < 4), and a square wave of the pattern of bouts was plotted for 5 players: center forward, central midfielder, wing midfielder, central defender, and wing defender. Four values were calculated for each work and recovery bout identified: duration, and mean, maximum, and minimum step rate (intensity). This novel technique provided detailed graphical information on the duration and exercise intensity of each position throughout the match. The center midfielder was able to sustain work and recovery bout characteristics throughout the match and appeared to recover at higher intensity levels than other players. The forward showed the consequence of accumulated fatigue late in the match and was unable to sustain the duration of high-intensity work bouts observed earlier in the match. The central defender attenuated the intensity of his work and recovery bouts late in the match staying closer to a more moderate work rate with fewer high- or low-intensity bouts. Having objective data qualifying players' work and recovery bout characteristics might prove valuable for tactical decision making, substitution timing, and for planning future training sessions.

Key Words football, training, workload, rest, sports

Introduction

Soccer is a sport with a wide range of movement intensities. Some moments of the game are relatively relaxed and progress slowly, whereas other moments of the play demands maximal bursts of intense exercise. High-intensity movements (running, cruising, sprinting, and cutting) and low-intensity movements (jogging, walking, shuffling, and standing) occur in varying lengths and intensities in soccer, depending upon an array of factors. The skill level, style of play, tactical strategies, playing position, and the physical capacity of the individual players on both teams all have some impact on the interval work rate of soccer matches. The intensity of these sprint, cruise, and run activities usually constitute forays across a player's lactate threshold for tactical advantage, and then a period of lower intensity activity is desired to allow for some recovery before the next bout of high-intensity activity can begin again (2). These high-intensity intermittent exercise (HIIE) bouts have not been expressly quantified for soccer matches. More specific training to ensure repeated sprint endurance throughout the match may be possible once the high-intensity interval work characteristics of soccer are known.

There have been a number of investigations that have used time-motion data to quantify player's movement during soccer matches, primarily for highly skilled participants. Several authors have divided players' intensity into a number of categories based on player speed (5,14) or observed gait category (6,8,14) by using time-motion analysis. This process uses video of matches to track player's movements either using computer algorithms automatically (5,22,23) or using an observational notation systems performed manually (6,11,14,25,27), which is labor intensive and time consuming. The above match analyses quantify the various levels of exercise intensity in matches, but they do not relate these

Competing interest: none to declare.

Address correspondence to Michael S. Orendurff, michael.orendurff@tsrh.org.

0(0)/1–10

Journal of Strength and Conditioning Research

intervals together in any meaningful way that might provide the details for the design of insightful interval training protocols. Soccer players may run approximately 11 km during a 90-minute match, but training players to run approximately 11 km in 90 minutes is clearly not specific enough to meet the intermittent exercise challenges typically encountered during soccer matches. Some further effort is needed to understand the intensity and duration of the intermittent exercise in soccer matches.

Current training protocols have been developed by making logical assumptions about the work rate and recovery periods performed in match play without any objective data to define specific training characteristics (intensity, duration, and frequency) that would closely mimic the typical or most intense challenges of elite soccer matches. Bloomfield et al. (8) has examined with great detail the types of movements that English Premier League soccer players perform during a match and reports that defenders spend significantly less time sprinting and running than midfielders or strikers. If the intensity, duration, and frequency of the high-intensity activities of a soccer match were known, perhaps more specific training situations could be created, which might remedy the deficit observed. For example, if a player takes too long to reach their top sprint speed, specific strength, speed, or agility training could be undertaken to improve their acceleration (10). If a player is unable to maintain the duration of intense sprints in the later portions of a match, specific interval training could be designed to improve their repeated-bout sprint endurance (15). The most detailed analysis to date with regard to intensity, frequency distribution, and duration of high- and low-intensity periods in soccer matches has been conducted by Gabbet et al. (14). This research has estimated that for elite women soccer players, during international matches, high-intensity work bout duration was about 3 ± 2 seconds of intense work and 30–45 seconds of recovery but with considerable variability within and between players. A method to document each player's HIIE profile during a match might facilitate more individualized training program design to produce the specific physiologic adaptation necessary for successful play for that individual or might permit the manipulation of small-sided games to more closely mimic full-field play (20).

The purpose of this project was to present a method to quantify the duration and intensity of each work bout and the duration and intensity of each recovery bout during a soccer match and to compare these parameters between different positions on the pitch (field).

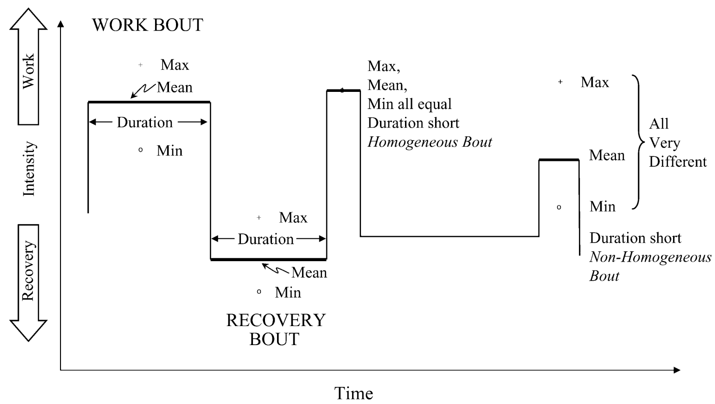

Figure 1. Square wave graph demonstrating a "WORK BOUT" (upward column) with mean intensity, maximum intensity, and minimum intensity during the bout, and a "RECOVERY BOUT" (downward column) with mean intensity, maximum intensity, and minimum intensity. Column width represents the duration of the bouts.

TABLE 1. The percent of total time spent at 7 different levels of intensity.

	Forward (%)	Center midfielder (%)	Wing midfielder (%)	Central defender (%)	Wing defender (%)	Referee (%)
Sprinting	0.5	1.1	1.5	0.8	0.0	0.9
Cruising	18.8	15.4	11.2	8.4	9.9	22.2
Running	34.6	42.7	35.2	23.2	31.3	39.1
Jogging	22.0	24.0	27.1	29.0	31.4	24.3
Walking	9.5	7.2	11.3	20.8	11.3	7.3
Shuffling	6.3	4.1	7.0	9.7	7.1	3.1
Standing	8.3	5.6	6.8	8.1	9.0	3.1

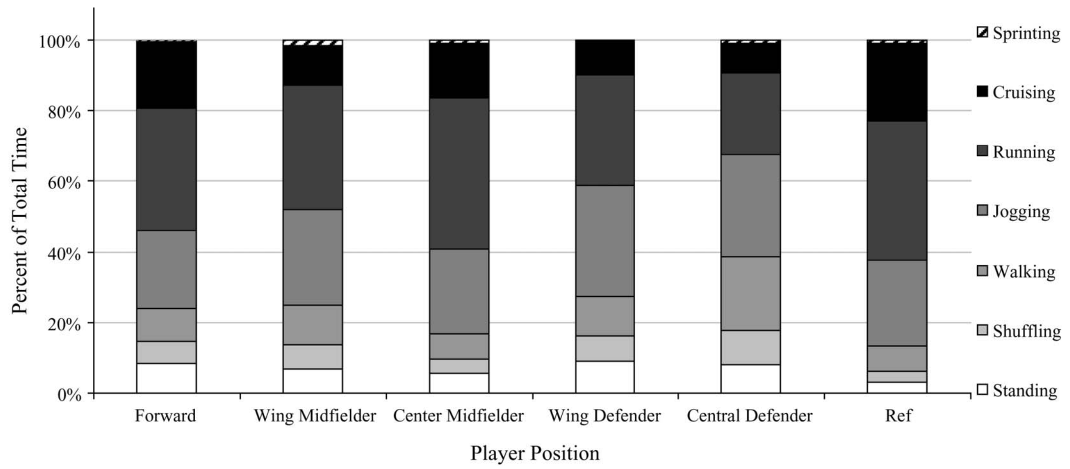

Figure 2. The percent of time each player was standing, shuffling, walking, jogging, running, cruising, and sprinting during the soccer match.

Methods

Experimental Approach to the Problem

Step count data were collected during a soccer match using StepWatch Activity Monitors (SAM; OrthoCare Innovations, Mountlake Terrace, WA). The protocol was approved by the human subject's institutional review board. After having the protocol and risks explained to them, the individuals gave their informed consent to participate. These small (5 × 7 × 1 cm) accelerometer-based devices were held on to the players' right ankles just above the lateral malleolus with a soft Velcro strap. StepWatch Activity Monitors have an accuracy of better than 98% (13,19,26) and cannot be fooled into counting steps during foot-shaking behavior. StepWatch Activity Monitors count an acceleration that occurs once during the gait cycle (usually foot contact or foot off) and then lock out for a time equivalent to cycle time. Our video taped analysis of step counts revealed an error of less than 1%, an acceptable level compared with other time-motion data collection methods (6,11,14,25,27). StepWatch Activity Monitors were programmed to record steps in each 3-second interval, with sensitivity set to 13 and cadence set to 30.

Subjects

The players who wore the SAMs were from a competitive National Collegiate Athletic Association division III college team, experienced but not elite. No data were collected on the opposition, which was an elite Player Development League team of players younger than 19 years. Both teams had the skills to maintain possession under pressure in their own half, to mount organized attack-withdraw campaigns, and to respond to their opponents with deliberate defensive strategies.

Data from 5 players were analyzed. The 5 players consisted of a central defender, a wing defender, a center midfielder, a wing midfielder, and a center forward. The head referee also wore a SAM to quantify the overall intensity of the game.

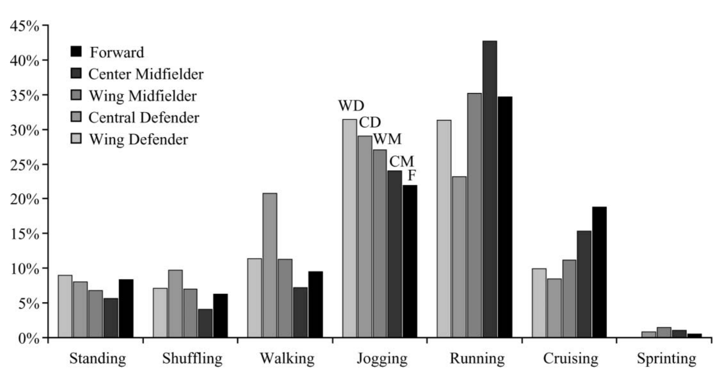

Figure 3. The distribution of movement intensity for each position throughout the match. Note that the center midfielder and referee have similar distributions, possibly because both of these positions are more involved with all movements of the ball than other positions. All positions have the majority of their movements in the moderate to moderately high ranges and less at the extreme ends of the intensity scale. Although this graph shows the distribution of movement intensity during the soccer match, it does not show how these runs are linked together or how often individuals are likely to exceed their anaerobic threshold for a tactical advantage during a critical period of play and then require a period of rest before attempting another high-intensity effort.

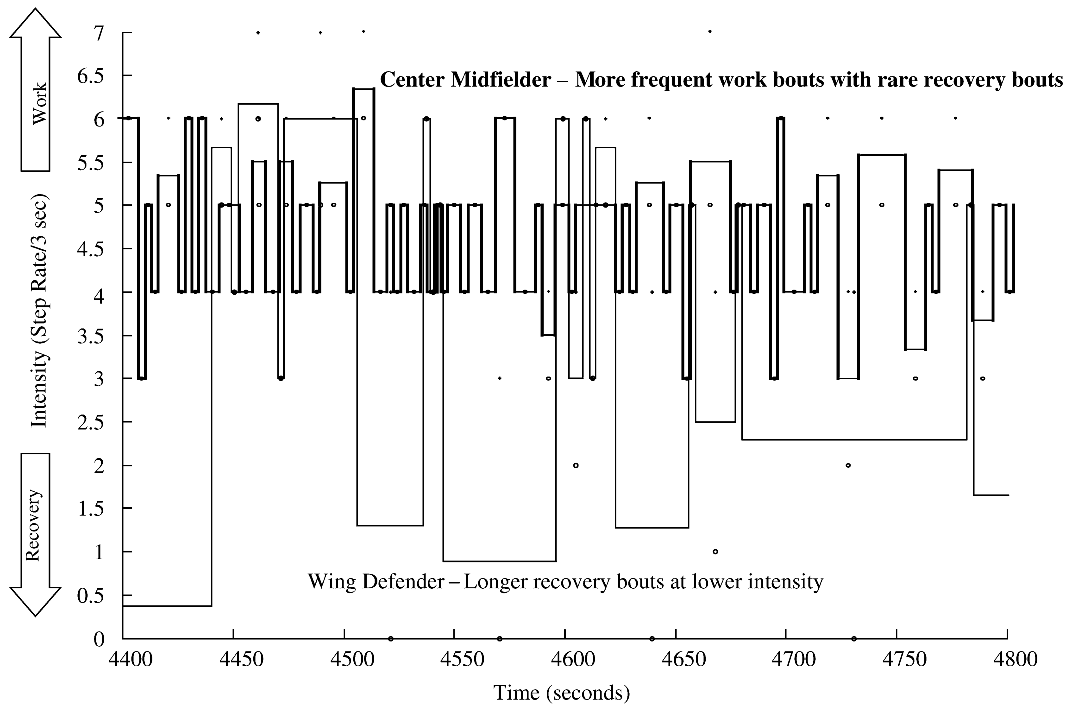

Figure 4. Square wave graph of work and recovery for the center midfielder (thick line) and wing defender (thin line). Upward bars are work bouts, and downward bars are recovery bouts. Bar width is the duration of the bout. The small dots are minimum and maximum step rates within each bout. The height of each bar is the mean step rate in that bout. Note that the center midfielder has many moderate bouts with few high-intensity sprints and few long recovery periods, this position is dominated by constant moderate running. The wing defender shows more variation between work and recovery bouts, with several very high-intensity bouts and several long recovery periods with very low intensity where the maximum > mean > minimum.

TABLE 2. The duration, mean intensity, minimum intensity, maximum intensity of work, and recovery bouts for the 5 player positions.*

	Duration (s)	Mean (step rate)	Minimum (step rate)	Maximum (step rate)
Work bouts				
Forward	9.6 ± 9.4	5.3 ± 0.3	5.1 ± 0.3	5.5 ± 0.6
Wing midfielder	9.1 ± 8.5	5.3 ± 0.4	5.1 ± 0.4	5.6 ± 0.6
Center midfielder	8.8 ± 7.6	5.2 ± 0.3	5.1 ± 0.3	5.5 ± 0.6
Wing defender	6.4 ± 5.7†	5.2 ± 0.4	5.1 ± 0.3	5.4 ± 0.5
Central defender	6.3 ± 4.9†	5.2 ± 0.3	5.1 ± 0.3	5.3 ± 0.5
Recovery bouts				
Forward	9.4 ± 13.6	3.4 ± 1.0	3.0 ± 1.5	3.8 ± 0.6
Wing midfielder	5.9 ± 6.7‡	3.5 ± 0.8	3.3 ± 1.2	3.8 ± 0.6
Center midfielder	8.6 ± 13.4	3.6 ± 0.8	3.3 ±1.3	3.8 ± 0.5
Wing defender	7.6 ± 9.1	3.5 ± 0.7	3.2 ± 1.2	3.8 ± 0.4
Central defender	8.6 ± 10.9	3.5 ± 0.8	3.2 ± 1.2	3.9 ± 0.5

*Values are averages ± *SD*.
†Statistically significant differences between the defenders and other positions.
‡Statistically significant difference between wing midfielder and forward.

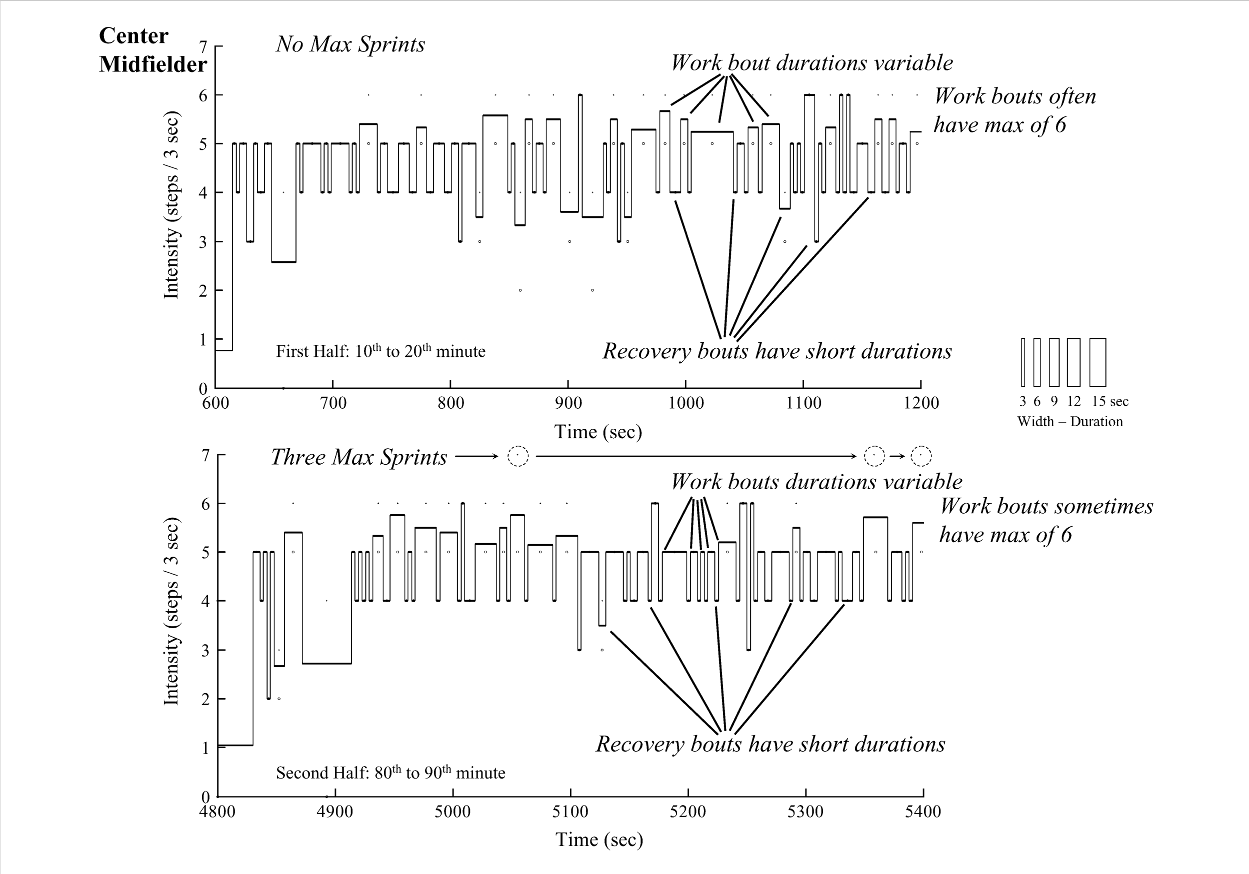

Figure 5. Square wave graphical display of running intensity for the center midfielder for 2 different 10-minute periods of the match, the 10–20th minute (upper graph) and the 80–90th minute (lower graph). Note that the work bouts (upward bars) have long durations in both segments, suggesting adequate fitness to create or respond to the pace of the match. Recovery bouts do not become lengthened as the match progresses, suggesting that the center midfielder can recover from each work bout at moderately high intensities. Note also the 3 maximum intensity sprints (dashed circles) that occur only late in the match. Perhaps these efforts are needed because the center midfielder is exploiting an opportunity developing because of the opponent's fatigue or in response to the final efforts of the opponent. Is any case, the center midfielder appears to have the fitness to reach his highest intensity running even in the final minutes of the match.

Data Processing

Seven categories were established based on the step rate data (≥6 = sprinting, 5 = cruising, 4 = running, 3 = jogging, 2 = walking, 1 = shuffling, and 0 = standing). Each player's data were analyzed for percent of time at each particular intensity level so that comparisons to previous literature could be made to validate the current novel approach.

Data were further analyzed using custom code written in MATLAB (The Mathworks, Natick, MA). This code was designed to quantify each period with step rates ≥ 4 as a *work bout* and each period < 4 as a *recovery bout.* For each subject and each bout, 4 values were calculated: bout duration; mean step rate, maximum step rate, and minimum step rate. These data were used to plot the intensity of movements for each player in a square wave pattern: blocks of high intensity (upward) and then low intensity (downward) vs. time (Figure 1). The height (or depth) of the block represents the mean step rate during the bout, and the width of the block represents the duration of the bout. This square wave forms a continuous series, which represents each high- and low-intensity exercise bout that occurs during the match. Square wave graphs were plotted with time on the *x*-axis and intensity on the *y*-axis (Figure 1) with minimum and maximum step rates as small dots within each bout.

Statistical Analysis

The processed SAM data were analyzed statistically using analysis of variances on the duration, mean step rate (intensity), maximum step rate (intensity), and minimum step rate (intensity) for work bouts and recovery bouts, with Scheffe's tests post hoc for pair-wise comparison between player positions. Significance was set at $p < 0.05$ a priori. It was hypothesized that the central midfielder would have more work bouts at moderate to high intensities compared with the other players and have shorter recovery durations. It was also hypothesized that the forward and defenders would have similar bout durations for both work and recovery. To demonstrate the usefulness of the square wave graphs

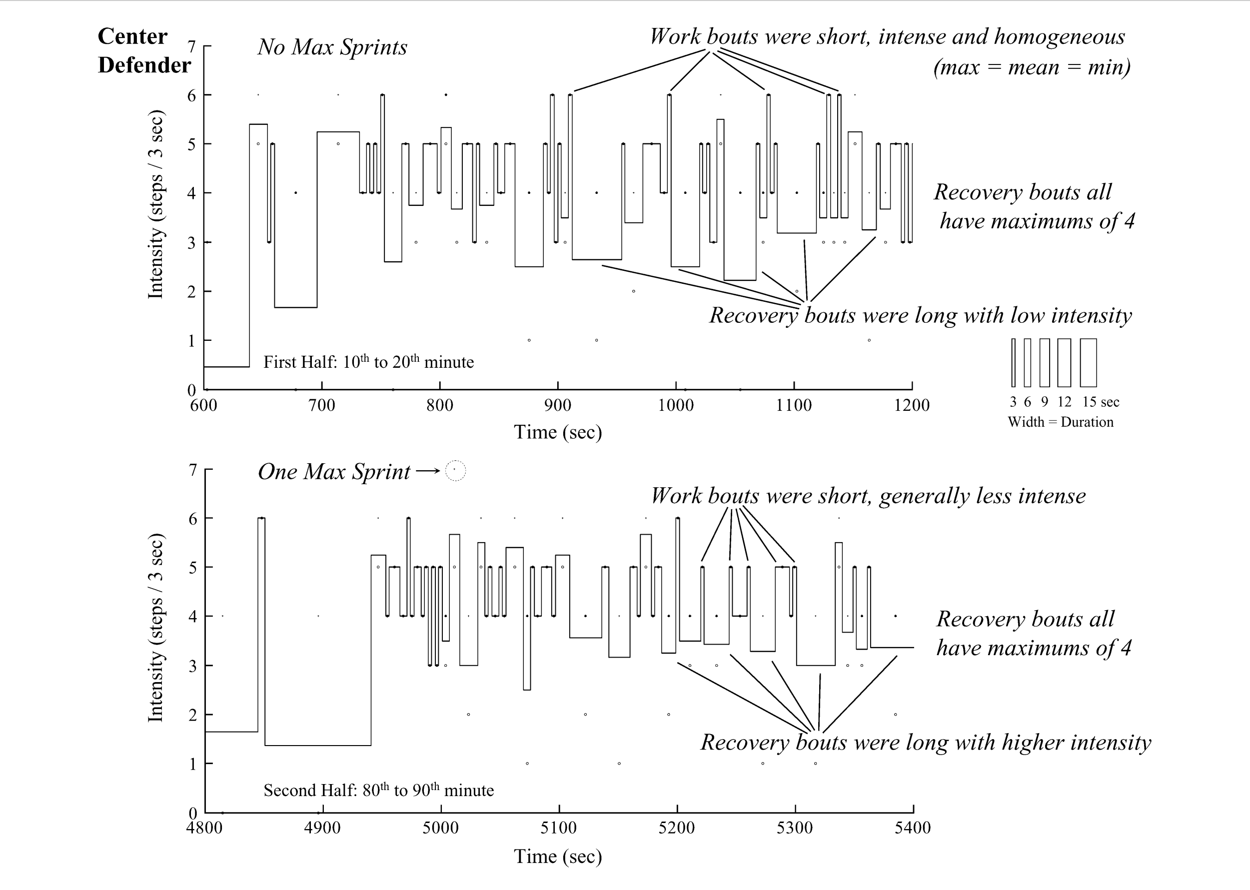

Figure 6. Square wave of running intensity for the center defender for the 10–20th minute (upper graph) and the 80–90th minute (lower graph). Note that the exertion becomes more modulated as the match progresses, with fewer extremes in work or recovery late in the match.

in characterizing fatigue that might be apparent late in the match, the central defender, center midfielder, and forward were chosen for detailed analytical evaluation of 10 minutes early in the match and 10 minutes late in the match.

Results

The running intensity distribution data showed that the majority of steps were running (42.7–23.2%) and jogging (31.4–22.0%), with some steps taken while cruising (18.8–8.4%), and very few steps shuffling (9.7–4.1%), standing (9.0–5.6%) or, at the other end of the intensity scale, in sprinting (1.5–0.0%). These data are summarized in Table 1 and presented graphically in Figures 2 and 3. This shows that players modulate their work rate to maintain moderately high movement intensity throughout the match, rarely reach a maximum sprint and rarely stand still.

Players all showed similar patterns with high-intensity bouts followed by periods of recovery at lower levels, although the specific characteristics of these bouts varied considerably. The square wave plot gave a comprehensive graphical display of the work and recovery bouts, with enough resolution to easily observe the difference between the center midfielder and the central defender (Figure 4) if plotted across a 600-second (10 minute) interval of the match.

The duration, mean intensity, minimum intensity, and maximum intensity of work bouts and recovery bouts are shown in Table 2. The duration of both work bouts and recovery bouts followed a gamma distribution with very short bouts most common and bouts becoming increasingly rare as they became longer. Statistically significant differences in the duration of work bouts were found for the 2 defenders compared with the other positions (average difference of 2.7 seconds; $p < 0.007$). Statistically significant differences were also detected between player positions for mean step rate during work bouts and maximum step rate during work bouts, but these differences were so small that they did not appear relevant (>0.21 steps·3 s^{-1}). Recovery bouts showed a statistically significant difference between the forward (9.4 ± 13.6 seconds) and the wing midfielder (5.9 ± 6.7 seconds; $p < 0.0055$) meaning the forward had longer recovery bouts. Statistically significant differences were also detected between the forward and the central defender for

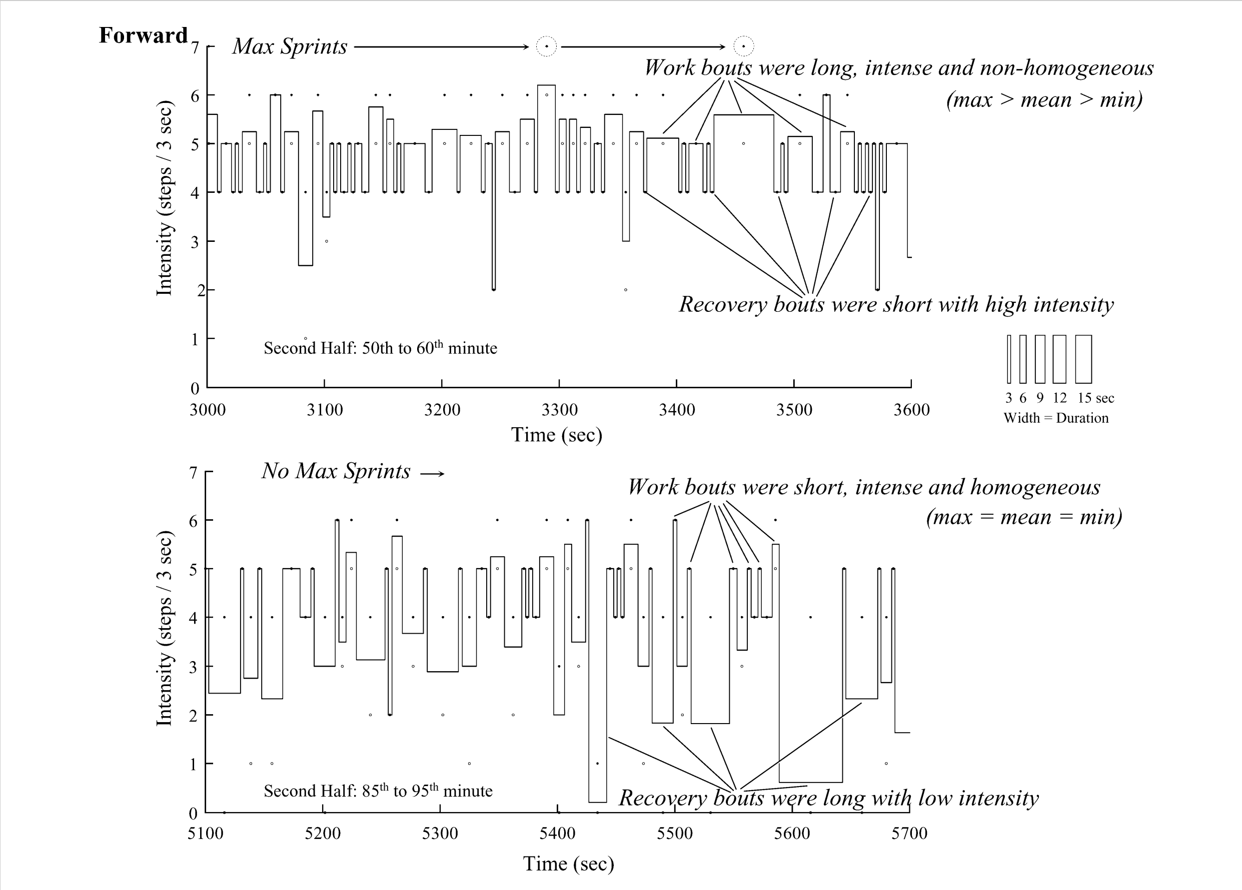

Figure 7. Square wave of running intensity for the forward for the 50–60th minute (upper graph) and the 85–95th minute (lower graph). Note that prolonged high-intensity runs separated by very short recovery periods are seen early in the second half but cannot be sustained late in the match, where recovery bouts are much longer and of much lower intensity. This is a good example of fatigue reducing the duration of high-intensity bouts. Real-time data like this might inform coaches about the timing of a substitution for this player to maintain a goal-scoring threat late into the match.

mean step rate during recovery bouts, but these differences were so small that they did not appear relevant ($>$0.22 steps·3 s^{-1}).

Work bout lengths were highly skewed toward very short periods. For these players, 43.1 ± 5.9% of all work bouts lasted $<$ 6 seconds, 22.8 ± 3.4% of all work bouts lasted between 6 and 9 seconds, 12.9 ± 4.6% of all work bouts lasted between 9 and 12 seconds, and 8.7 ± 0.7% of all work bouts lasted between 12 and 15 seconds. Combined, this accounted for 87.6% of all work bouts during the soccer match. Therefore, nearly 90% of all running lasted less than 15 seconds before a break occurred so that the player could partially recover from the effort.

Recovery bouts were highly skewed toward very short durations as well. 52.7% of all recovery bouts lasted $<$ 6 seconds, 21.7% lasted between 6 and 9 seconds, 8.6% lasted between 9 and 12 seconds, and 4.7% lasted between 12 and 15 seconds. Combined, this accounted for 87.7% of all recovery bouts during the soccer match. Therefore, nearly 90% of recovery periods lasted less than 15 seconds before another period of high-intensity running was performed.

The center midfielder (Figure 5) shows a pattern of variable (3–45 seconds), intense (step rate $>$ 5), and nonhomogeneous (maximum $>$ mean $>$ minimum) work bouts throughout the match. Work bouts often had maximum step rates of 6 early in the match but these appear less frequent late in the match. Recovery bouts were generally short (3–15 seconds) and of moderately high intensity (step rates of approximately 4) both early and late in the match. Maximum sprints (step rate = 7) were not observed early in the match, but late in the match, 3 maximum sprints were recorded for the center midfielder.

The central defender (Figure 6) shows a pattern of short (3 seconds), intense (step rate ≈ 6), and homogeneous (maximum = mean = minimum) work bouts early in the match; late in the match, the work bouts were still generally short (3 seconds) but less intense (step rate = 5) and remained homogeneous (maximum = mean = minimum). Recovery bouts for the center defender early in the match were long (15–30 seconds) and had low mean intensity (< 3); late in the match, these recovery bouts remained long (12–45 seconds) but had higher mean intensity (>3). Recovery bouts always had maximum step rates of 4 and minimums of 1 or 2, suggesting a range of jogging, walking, and strolling during the recovery bouts.

The forward had a very different pattern from the central defender or center midfielder (Figure 7). Early in the second half, the forward was able to maintain long bouts of intense work with almost all lasting 9–30 seconds. Recovery bouts during this period were very short (3–6 seconds) and did not fall below 4 very often. Late in the match, the forward's pattern was almost completely opposite: short intense work bouts lasting 3–6 seconds and recovery bouts lasting 18–48 seconds at very low-intensity levels.

Discussion

The distribution of sprinting, cruising, running, jogging, walking, shuffling, and standing in this study is similar to other work investigating the distribution of running intensity during soccer matches (8,11,14). All studies of workload intensity during matches demonstrate the tendency for soccer players to have less activity at the extreme ends of the spectrum and more activity near the moderate to moderately high intensity levels.

The current investigation adds novel components to the characterization of the HIIE observed in soccer matches by connecting each work and recovery bouts in time. The square wave graphical display preserves the temporal relationship between work and recovery bouts that is so difficult to derive from standard statistical methods. Individual square wave graphs for the different positions reveal very different patterns of exercise as the match progressed.

Although it is apparent that soccer is a HIIE activity, there has been limited information about the magnitude of "high intensity" and the definition of "intermittent." Bangsbo et al. (4) has reported that during soccer games, 70% of the activity is low intensity with approximately 150–250 brief intense actions, and the data from the current study support this assertion. This square wave method appears to characterize these "brief intense actions," which may inform the design of training activities to meet the evident demands of soccer matches.

The square wave graphs demonstrate that some players had longer periods at lower intensity to recover, presumably because of a lack of proximity to the ball for whatever reason. Other players, specifically the center midfielder, had shorter recovery bouts with less time at very low levels of activity. This suggests the need for the center midfielder to recover during movement on the ball, either in possession or defending in close proximity to an opponent in possession, and the need for the center midfielder to perform fewer sustained all-out sprints than other positions. The center midfielder demonstrated the ability to maintain their work rate late into in the match, even performing 3 maximum intensity sprints in the final minutes of the match (Figure 5). This may appear contrary to previously published literature (8,24) but consistent with others (21); Mohr et al. has suggested that a small percentage (3%) of players appear to have the fitness to continue to exhibit intense exercise behavior late in the match. The square wave can pinpoint specific high-intensity sprint bouts which may be critical to the outcome of the match.

Other positions appear to have slightly different work and recovery bout characteristics specific to their tactical responsibilities and apparent accumulated fatigue. The central defender's work and recovery bouts appear to become more attenuated as the match progressed, with both high and low intensities closer to the average and fewer bouts near the extremes. This may be an example of a pacing strategy to sustain the needed energetic reserve to respond to possible tactical situations that occur late in the game. By cutting back on the intensity and durations of each sprint, the center defender appears prepared to respond to late-match attacks by the opponent.

Late in the match, the forward shows many more long-duration recovery bouts and fewer high-intensity moderate duration work bouts, suggesting accumulated fatigue. This finding is consistent with previous research showing a decline in high-intensity exercise late in soccer matches for the majority of players (1,3,8,21,24). The fatigue pattern for the forward is interesting because the frequency of work bouts did not appear to shift appreciably–work bouts were initiated at about the same rate but sustained for shorter durations. This suggests that the forward's lack of sustained work bouts was because of fatigue and not because of some change in tactical duties in response to the opponent's less intense play. Improving the ability of the forward to maintain the duration of high-intensity bouts late in the match should be a primary training modification derived from these data.

Practical Applications

Using a square wave to assess the ability of a player to sustain the duration of high-intensity work bouts until the waning minutes of the match would give much more precise information about the success of a specific training program, especially performance in the later portions of a match. Interval training to improve match fitness falls basically into 2 categories: those designed principally to improve $\dot{V}O_2max$, for example, Helgerud et al. (15) or Hoff et al. (16), and those designed principally to increase muscle force and power output, for example, Bloomfield et al. (10) or Wisloff et al. (28), although an overlap in training outcomes is likely in both these approaches. Terms such as "high-intensity intermittent exercise" (12) or "random intermittent dynamic sports" (10) has been used to describe the exercise characteristics of many field and court sports, suggesting an acknowledgment of the balance between cardiovascular endurance, muscle strength, and repeated bout endurance needed for success in soccer (12,17,18,28–30). Understanding the deficit observed in a player during match performance may focus training programs on the specific characteristic where improvement is needed: the inability to rapidly achieve maximal sprint speed, the inability to sustain maximal sprint speed, and the inability to perform repeated sprint bouts without lengthy recovery periods.

For example, the length of the work bouts observed in this study suggests that acceleration, deceleration, and cutting are very frequent occurrences in soccer matches, and this is consistent with work by Bloomfield et al. (7,9), quantifying actions in elite soccer matches. These actions require much higher muscle forces than running at constant speed, suggesting that both overall aerobic endurance *and* muscular strength are critical for success in soccer. Helgerud et al. (15) have shown that a conventional interval training program can increase $\dot{V}O_2max$, double the *number* of sprints observed in a soccer match, and increase the number of involvements on the ball, but this publication lacks any data on increased endurance in repeated sprint bouts during the match. Bloomfield et al. (10) have shown that speed, agility, and quickness (SAQ) training dramatically lowers sprint times for 5 and 15 m distances, distances that appear highly specific to the typical demands of elite soccer. It is likely that SAQ training will improve a player's ability to rapidly achieve maximal sprint speed and that conventional interval training will increase number of sprints performed. This training strategy of "microcycle periodization" might employ traditional interval training (4×4 minutes) on some days and perform SAQ training on other days each week.

Another possibility is a *nanocycle* periodization: combining intense random 3- to 15-second SAQ training in 4-minute intervals with 3 minutes of low-intensity recovery might prove to be an ideal soccer-specific training protocol. Based on the distributions from this article, each 4 minutes of SAQ training should be composed of nanocycles with 25% sprint durations of < 3 seconds, 25% of 3–6 seconds, 25% of 6–9 seconds, and 25% of 9–15 seconds in a random pattern. Recovery periods between these sprints should follow a similar distribution: 25% < 3 seconds, 25% 3–6 seconds, 25% 6–9 seconds, and 25% 9–15 seconds. On the one hand, because $\dot{V}O_2max$ training and strength/power training might directly compete with each other from an adaptation standpoint, substantial research is needed to determine if this approach is optimal. On the other hand, this paradigm is exactly the work rate paradox of soccer, strength/power and endurance ($\dot{V}O_2max$) in repeated bouts.

Using a square wave to assess each player's work and recovery characteristics might permit player-specific training programs tailored to each individual's unique performance deficits. For example, midfielders might be trained to recover at higher intensity levels but slightly longer durations than other positions. Forwards could be trained to sustain high-intensity work rates late into the match or might be trained to develop a pacing strategy. Regardless of the training strategy chosen, the success of the particular program on repeated bout endurance during soccer matches could be accurately evaluated using this square wave method.

Improving specific characteristics of fitness needed for soccer might also be effectively accomplished with the ball during small-sided games. Mallo and Navarro (20) have shown that adding goals and goalkeepers to a 3 vs. 3 small-sided keep-away game increases the amount of time spent at the extremes: more sprinting and cruising and more time walking and standing. With detailed information about work bouts and recovery bouts, relatively small alterations in small-sided games may be able to overload a specific performance characteristic such as repeated sprint bouts interspersed with sharpening ball control skills during recovery in possession of the ball (23).

Matching work and recovery data from this square wave method with technical performance data (i.e., passing success rate) might provide salient and comprehensive information for the design of training sessions after a match. The square wave graphical display could easily be implemented using instantaneous velocity data from automatic video-based digitizing systems. If this data could be streamed real time to coaches during the match, more objective decisions about instantaneous performance and the timing of substitutions could be made.

References

1. Bangsbo, J, Norregaard, L, and Thorso, F. Activity profile of competition soccer. *Can J Sport Sci* 16: 110–116, 1991.
2. Bangsbo, J. Energy demands in competitive soccer. *J Sports Sci* 12(Spec no.): S5–S12, 1994.
3. Bangsbo, J. The physiology of soccer–with special reference to intense intermittent exercise. *Acta Physiol Scand Suppl* 619: 1–155, 1994.
4. Bangsbo, J, Mohr, M, and Krustrup, P. Physical and metabolic demands of training and match-play in the elite football player. *J Sports Sci* 24: 665–674, 2006.
5. Barros, RML, Misuta, MS, Menezes, RP, Figueroa, PJ, Moura, FA, Cunha, SA, Anido, R, and Leite, NJ. Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. *J Sports Sci Med* 6: 233–242, 2007.
6. Bloomfield, J, Polman, R, and O'Donoghue, P. The "Bloomfield movement classification": Motion analysis of individual players in dynamic movement sports. *Int J Perform Analysis Sport* 4: 20–31, 2004.
7. Bloomfield, J, Polman, R, and O'Donoghue, P. Deceleration movements performed during FA Premier League soccer matches. *J Sports Sci Med* 6(Suppl. 10): 6, 2007.
8. Bloomfield, J, Polman, R, and O'Donoghue, P. Physical demands of different positions in FA Premier League soccer. *J Sports Sci Med* 6: 63–70, 2007.
9. Bloomfield, J, Polman, R, and O'Donoghue, P. Turning movements performed during FA Premier League soccer matches. *J Sports Sci Med* 6(Suppl. 10): 9, 2007.
10. Bloomfield, J, Polman, R, O'Donoghue, P, and McNaughton, L. Effective speed and agility conditioning methodology for random intermittent dynamic type sports. *J Strength Cond Res* 21: 1093–1100, 2007.

11. Di Salvo, V, Baron, R, Tschan, H, Calderon Montero, FJ, Bachl, N, and Pigozzi, F. Performance characteristics according to playing position in elite soccer. *Int J Sports Med* 28: 222–227, 2007.

12. Ekblom, B. Applied physiology of soccer. *Sports Med* 3: 50–60, 1986.

13. Foster, RC, Lanningham-Foster, LM, Manohar, C, McCrady, SK, Nysse, LJ, Kaufman, KR, Padgett, DJ, and Levine, JA. Precision and accuracy of an ankle-worn accelerometer-based pedometer in step counting and energy expenditure. *Prev Med* 41: 778–783, 2005.

14. Gabbett, TJ and Mulvey, MJ. Time-motion analysis of small-sided training games and competition in elite women soccer players. *J Strength Cond Res* 22: 543–552, 2008.

15. Helgerud, J, Engen, LC, Wisloff, U, and Hoff, J. Aerobic endurance training improves soccer performance. *Med Sci Sports Exerc* 33: 1925–1931, 2001.

16. Hoff, J, Wisloff, U, Engen, LC, Kemi, OJ, and Helgerud, J. Soccer specific aerobic endurance training. *Br J Sports Med* 36: 218–221, 2002.

17. Hoff, J and Helgerud, J. Endurance and strength training for soccer players: Physiological considerations. *Sports Med* 34: 165–180, 2004.

18. Impellizzeri, FM, Marcora, SM, Castagna, C, Reilly, T, Sassi, A, Iaia, FM, and Rampinini, E. Physiological and performance effects of generic versus specific aerobic training in soccer players. *Int J Sports Med* 27: 483–492, 2006.

19. Macko, RF, Haeuber, E, Shaughnessy, M, Coleman, KL, Boone, DA, Smith, GV, and Silver, KH. Microprocessor-based ambulatory activity monitoring in stroke patients. *Med Sci Sports Exerc* 34: 394–399, 2002.

20. Mallo, J and Navarro, E. Physical load imposed on soccer players during small-sided training games. *J Sports Med Phys Fitness* 48: 166–171, 2008.

21. Mohr, M, Krustrup, P, and Bangsbo, J. Match performance of high-standard soccer players with special reference to development of fatigue. *J Sports Sci* 21: 519–528, 2003.

22. Rampinini, E, Bishop, D, Marcora, SM, Ferrari Bravo, D, Sassi, R, and Impellizzeri, FM. Validity of simple field tests as indicators of match-related physical performance in top-level professional soccer players. *Int J Sports Med* 28: 228–235, 2007.

23. Rampinini, E, Impellizzeri, FM, Castagna, C, Abt, G, Chamari, K, Sassi, A, and Marcora, SM. Factors influencing physiological responses to small-sided soccer games. *J Sports Sci* 25: 659–666, 2007.

24. Rampinini, E, Impellizzeri, FM, Castagna, C, Coutts, AJ, and Wisloff, U. Technical performance during soccer matches of the Italian Serie A league: Effect of fatigue and competitive level. *J Sci Med Sport* 12: 227–233, 2007.

25. Reilly, T. Energetics of high-intensity exercise (soccer) with particular reference to fatigue. *J Sports Sci* 15: 257–263, 1997.

26. Resnick, B, Nahm, ES, Orwig, D, Zimmerman, SS, and Magaziner, J. Measurement of activity in older adults: Reliability and validity of the step activity monitor. *J Nurs Meas* 9: 275–290, 2001.

27. Stroyer, J, Hansen, L, and Klausen, K. Physiological profile and activity pattern of young soccer players during match play. *Med Sci Sports Exerc* 36: 168–174, 2004.

28. Wisloff, U, Castagna, C, Helgerud, J, Jones, R, and Hoff, J. Strong correlation of maximal squat strength with sprint performance and vertical jump height in elite soccer players. *Br J Sports Med* 38: 285–288, 2004.

29. Wisloff, U, Helgerud, J, and Hoff, J. Strength and endurance of elite soccer players. *Med Sci Sports Exerc* 30: 462–467, 1998.

30. Wong, PL, Chamari, K, Dellal, A, and Wisloff, U. Relationship between anthropometric and physiological characteristics in youth soccer players. *J Strength Cond Res* 23: 1204–1210, 2009.