Title: Accelerations and high intensity running in field and assistant football referees during match play

Running title: Accelerations and high intensity running in football referees

Amund Riiser[1], Svein Arne Pettersen[2], Vidar Andersen[1], Atle Hole Saeterbakken[1], Christian Froyd[1], Einar Ylvisåker[1], Vegard Fusche Moe[1]

1) Sogn og Fjordane University College, Faculty of Teacher Education and Sports, Norway

P.O. Box 133, N-6851 Sogndal, Norway

2) UiT, The Arctic University of Norway, Norway

Corresponding author: Amund Riiser, amund.riiser@hvl.no, +47 57676287

Svein Arne Pettersen, svein.arne.pettersen@uit.no, +4793229644

Vidar Andersen, vidar.andersen@hvl.no, +47 576761641

Atle Hole Saeterbakken, atle.saeterbakken@hvl.no, +4757676044

Christian Froyd, christian.froyd@hvl.no, +4757676382

Einar Ylvisåker, einar.ylvisaker@hvl.no, +4757676040

Vegard Fusche Moe, vegard.fusche.moe@hvl.no, +4757676037

Acknowledgements: We would like to thank Professor Jon Ingulf Medbø for statistical guidance, and Terje Ness Kjøsnes, Yngve Håkonsen, Helge Haugen and Sogndal Fotball for their help and support in the project. We sincerely thank the referees for participating and the head of referees in the Norwegian football association Terje Hauge for endorsing the project.

Funding: The project received no external funding.

Key words: Match analysis, intermittent exercise, fluctuations, soccer

Formatert: Norsk (bokmål)

Formatert: Engelsk (Storbritannia)

Formatert: Engelsk (Storbritannia)

Abstract

The aim of this study was: 1) to examine accelerations and high intensity running (HIR) in football field referees (FR) and assistant referees (AR) during football matches and 2) to evaluate fluctuations in accelerations and HIR between first and second half and in 5-min periods. All movements of the referees were measured using a radio-based tracking system during 41 matches in the Norwegian top and second league during the 2015 and the 2016 seasons. Movements were classified into accelerations (≥2 $m \cdot s^{-2}$) and HIR (≥19.8 $km \cdot h^{-1}$). AR performed 86% more accelerations than FR (158 (147-169) vs. 85 (76-94), $P<0.001$, d=1.9), and FR performed 171% longer HIR distance than AR (619 (534-703) m vs. 228 (208-248), $P<0.001$, d=2.7). When divided into 5-min periods, the number of accelerations ($P<0.001$) and acceleration distance ($P<0.001$) were reduced towards the end of both halves in AR. However, in the 5-min subsequent to the most intense 5-min period of the match, both FR and AR performed accelerations and HIR (n and m) equal to the 5-min mean ($P>0.35$). As the running performance of FR and AR are substantially different, training recommendations for AR should include more accelerations while FR should focus on HIR and endurance training.

Introduction

Football referees´ movements during matches are characterized by low intensity walking and jogging interspersed by periods with high intensity running (HIR) and accelerations with maximal or close to maximal effort, even if referees do not obtain maximal running speed in matches (Castillo, Cámara, Castellano, & Yanci, 2016). During a match, field referees (FR) and assistant referees (AR) cover 8-13 km and 5.5-7 km, respectively (Barbero-Alvarez, Boullosa, Nakamura, Andrin, & Castagna, 2012; Castagna, Abt, & D'Ottavio, 2004; Costa et al., 2013; Krustrup et al., 2009; Mallo, Navarro, Garcia Aranda, & Helsen, 2009; Weston, Castagna, Impellizzeri, Rampinini, & Abt, 2007). However, data from players show that total distance covered does not distinguish between performance levels in contrast to HIR (Stolen, Chamari, Castagna, & Wisloff, 2005). Thus, it is more relevant to examine HIR when accessing the physical performance of referees.

Sprint distances and HIR distances of football referees and players are interrelated (Weston, Drust, & Gregson, 2011) and as the amounts of HIR performed by players have increased in recent years (Bush, Barnes, Archer, Hogg, & Bradley, 2015) it is generally accepted that the running demands for referees have increased.. Nevertheless, there are limited data available on the development of referees´ running performance. However, in the 2008-2009 season in Premier League, field referees performed 716 m of HIR, which is similar to the distance performed by the players (Weston et al., 2011). Furthermore, FR perform more HIR than AR (Castillo, Weston, McLaren, Camara, & Yanci, 2016; Krustrup et al., 2009). Thus, in modern elite football referees need to have a high level of physical fitness to keep up with the players and position themselves optimally for correct decision-making during match play.

Accelerations substantially increase the metabolic demand and are of importance when quantifying high intensity activities during match play (Osgnach, Poser, Bernardini, Rinaldo, & di Prampero, 2010). They are scarcely evaluated in football referees, however FR are reported to perform less

(Castillo, Weston, et al., 2016) or equal (Barbero-Alvarez et al., 2012)amounts of accelerations, but cover greater distance during these accelerations compared with AR (Barbero-Alvarez et al., 2012).

A reduction in HIR towards the end of matches has been reported in some studies investigating referees (Krustrup & Bangsbo, 2001), but not in all (D'Ottavio & Castagna, 2001; Weston et al., 2007). More recently, Mallo et al. (2009; 2007) assessed FR during international matches and found that the 5-min period with the most HIR was followed by a 5-min period with less HIR than the match mean. The number of accelerations are also reported to decrease in the second half in FR, but not in AR (Barbero-Alvarez et al., 2012). Both FR and AR have reduced performance at physical tests after matches (Castillo, Yanci, Camara, & Weston, 2016) and the reductions in high intensity activities have been proposed as signs of fatigue (Mallo, Navarro, Aranda, et al., 2009; Mallo et al., 2007).

There are limited data published regarding acceleration and HIR in football referees (Barbero-Alvarez et al., 2012; Castagna et al., 2004; Costa et al., 2013; Krustrup et al., 2009; Mallo, Navarro, Garcia Aranda, et al., 2009; Weston et al., 2007) and fluctuations in accelerations (in periods shorter than 15 min) through the match. Thus, the aims of the study were; 1) to examine and compare the accelerations and HIR for FR and AR in the Norwegian top leagues, and 2) to evaluate fluctuations in accelerations and HIR between the halves and 5-min periods. We hypothesized that FR would perform longer HIR and acceleration distance than AR, while the AR would perform a greater number of HIR and accelerations. Our second hypothesis was that both types of referees would perform stable amounts of HIR and accelerations regardless of previous activity or time period in match.

Methods

Participants

The age, body mass, and high of the referees were 31 ± 6 years, 79 ± 7 kg, 183 ± 5 cm and they had 7 ± 5 years of experience from the two top divisions. All data were collected during 41 matches in three different arenas during the 2015 and 2016 seasons. Thirteen matches were played in the second best league in Norway in 2015. The remaining 28 matches were played in the top Norwegian league in 2016. Altogether 121 datasets from 16 FR and 33 AR was included in the analysis. The number of matches for each referee varied from one to six. The Norwegian Data Protection Official for Research (NSD) approved the study. All referees were informed orally and in writing of the procedures and provided their written consent before they were included in the study.

Data collection

The movements were captured by a fully automatic tracking system based on radio waves (ZXY Technology Ecosystem, Chyronhego, Trondheim, Norway). Transponders, weighing 21 g, were placed in light weight belts and handed out to the referees before the warm-up, giving them time to familiarize with the equipment. The belt was worn around the hip, with the transponders placed at the back close to the centre of gravity. UEFA has approved the equipment for usage in both national and international matches.

The referees´ positions were monitored by radio waves (20 times per second) from the transponders to four calibrated, stationary, sensors each mounted in one of the light masts surrounding the football field (ZXY RadioEye^{TM} Positioning Sensor, Chyronhego). By integrating information from the four receivers in an advanced vector based process, the referees position, and movement were determined. A beacon functioned as a control unit for the transponders and synchronized them, to avoid interference in the signalling process. The test – retest reliability of the system has been

assessed in a previous study reporting an interclass correlation (ICC) coefficient, of 1.0, 0.999 and 0.999 (P = 0.001) for x- and y-and total distance (Ingebrigtsen, Dalen, Hjelde, Drust, & Wisloff, 2015). Further, the data were compressed and filtrated by a Linux server using Ubuntu 14.04 before they were stored in a structured query language (SQL) database. The data were transferred from the database to a software program (Microsoft Excel 2013) for further statistical analysis. All matches were monitored live and controlled by two researchers using a software program (ZXY Sport Tracking, Chyronhego).

Criteria of data classification

Distance covered by the referees were classified into three different categories: running, HIR and sprinting, in accordance to previous, similar studies (Ingebrigtsen et al., 2015; Weston et al., 2007; Weston, Castagna, Impellizzeri, Rampinini, & Breivik, 2010). Running was defined as movement with a speed > 14.4 and ≤ 19.8 $km \cdot h^{-1}$, HIR > 19.8 $km \cdot h^{-1}$, and sprint as running above 25.2 $km \cdot h^{-1}$. Thus, HIR included sprinting. Acceleration distance was defined as the distance accumulated at an acceleration ≤ 2 $m \cdot s^{-2}$. A high intensity run was defined by four events. First, the running speed must reach 14.4 $km \cdot h^{-1}$. Secondly, the running speed must reach 19.8 $km \cdot h^{-1}$. Third, the running speed must remain above 19.8 $km \cdot h^{-1}$ for at least one second. Finally, the running speed must decrease below 14.4 $km \cdot h^{-1}$ to mark the end of a high intensity run. To be defined as an acceleration, three criteria had to be fulfilled. First, the acceleration had to reach 1 $m \cdot s^{-2}$. This marks the start of an acceleration. Secondly, the acceleration had to increase above 2 $m \cdot s^{-2}$ for at least half a second. Finally, the acceleration was defined as ended when it dropped below 1 $m \cdot s^{-2}$. The distance per acceleration and HIR was defined as distance divided by number of events. The matches were divided into two halves and 18 5-min periods.

Statistical analyses

Data are presented as mean with 95 % confidence interval or percent. Differences in running performance between FR and AR were assessed with independent sample t-test. Within FR and AR differences in running performance between halves and difference between the peak 5-min period, the following 5-min period and the mean 5-min period were assessed with paired sample t-tests. The only exception was for number of HIR between 5-min periods that was analysed by a binominal test due to the low number of HIR in each 5 min period. Effect size is reported as Cohen's d when difference is analysed by t-tests. A repeated measure ANOVA with Bonferroni post hoc corrections for repeated comparisons was used to examine the variation in accelerations and HIR between the 18 5-min periods within FR and AR. Statistical analysis were performed with SPSS version 23 (SPSS, Inc) and Microsoft Excel 2013 (Microsoft). Statistical significance was accepted at $P<0.05$.

Results

The referees' movements are presented in table 1.

Comparisons of assistant referees vs. field referees

Throughout the match AR accelerated 86 % more often (P<0.001, d=1.9) and performed 43 % (P<0.001, d=1.7) longer total acceleration distance than FR. Field referees performed 171 % longer HIR distance and 108 % higher numbers of HIR compared with AR (P<0.001, d>2.0). Number of accelerations, acceleration distance, HIR distance and number for HIR were consistent between the halves (P>0.05) for both FR and AR, while both FR (P<0.001, d= 0.6) and AR (P<0.001, d=0.3) performed more total distance in the second half. For further details, see table 1.

The acceleration distance/ number of accelerations were 4.2 (4.1-4.4) m for AR and 5.3 (5.1-5.5) m for FR (P < 0.001, d =1.8). The corresponding distance for HIR were 20.1 (18.0-22.2) m and 24.9 (22.1-27.8) m for AR and FR respectively (P = 0.01, d =0.7).

Accelerations during the matches

Acceleration distance and number of accelerations differed between the 18 5-min periods for AR (P<0.001). First, during the first half the acceleration distance decreased linearly by time during the first 20–25 min for both categories of referees. During the first 5-min period of the second half, a higher acceleration distance, not different from that of the beginning of the match, was observed, followed by a decline throughout the rest of the periods. Consequently, pairwise comparison between the first 5-min period and the other 5-min periods showed significantly lower acceleration distance in the six last 5-min periods of the first half and the eight last 5-min periods of the second half (P<0.01) (figure 1).

For FR, acceleration distance but not number of accelerations differed between 5-min periods (P=0.03, and P=0.81; figure 1). Pairwise comparison between 5-min periods showed no difference in acceleration distance or numbers of accelerations for FR (P>0.22; figure 1).

In the 5-min period following the 5-min period with the highest number of accelerations, the number of accelerations declined by 47% (P<0.001, d =1.5) in FR and 48 % (P<0.001, d =1.7) in AR. There were no difference between the number of accelerations in the latter 5-min period compared to the mean number of accelerations during 5-min periods (P>0.98; figure 2). Similarly, in the 5-min period following the period with the longest acceleration distance, acceleration distance declined by 49 % (49m (44-54) m vs. 25 (20-30) m, P<0.001, d=1.8) in FR and 50% (68 (65-78) m vs. 34 (30-37) m, P<0.001, d =1.5) in AR. However, the acceleration distance in the 5-min period following the peak 5-min was not different from the 5-min mean in either FR (25 (20-30) m vs. 24 (21-27) m, P=0.63) or AR (34 (30-37) vs. 34 (32-36) m, P=0.77).

High-intensity running during the matches

HIR distance differed between 5-min periods for AR and FR (P<0.05) while number of HIR did not differ statistically significant between 5-min periods in either group (P> 0.30). Pairwise comparison between 5-min periods showed no difference in HIR distance in AR (P>0.191) nor FR (P>0.22) (figure 3).

High intensity running distance decreased by 72% (P<0.001, d=1.7) in FR and 74% (P<0.001, d =1.6) in AR from the 5-min period with the most HIR to the next 5-min period. There were no differences between HIR in the 5-min periods following the peak 5-min periods and the 5-min period means for either FR or AR (P>0.05; figure 4). The same pattern, but not statistically significant, with "decline" from the 5-min period with the highest number of HIR to the next 5-min period was demonstrated in both FR and AR with 67% (3.93 (3.45-4.40) vs. 1.04 (0.60-1.47), P=0.19) and 54% (2.44 (2.23-2.64) vs. 1.02 (0.81-1.22), P=0.50,) respectively. The difference in number of HIR in the period following the period with most HIR compared with the 5-min mean was not statistically significant in FR (1.04 (0.60-1.47) vs. 1.51 (1.27-1.75), P=0.50) or AR (1.02 (0.81-1.22) vs. 0.71 (0.63-0.80), P=0.75).

Discussion

The present study examined accelerations and HIR in Norwegian domestic top league field and AR during official match play. AR accelerated almost twice as often and performed longer total acceleration distance compared with FR, who performed longer distance per acceleration and HIR, more HIR and longer total HIR distance. There were no difference in acceleration or HIR between the 5-min mean and the 5-min period following the 5-min period with most accelerations or HIR in neither FR nor AR. Both number of accelerations and total acceleration distance were reduced towards the end of both halves in AR, but not in FR.

Comparisons of assistant referees vs. field referees

More accelerations by AR compared with FR may be explained by the differences in referee tasks. Assistant referees are required to follow the side-line and the offside line, which may be static until the defending player defining the offside line moves, and initiates AR to accelerate. On the other hand, the running environment of FR is more open and offers multiple possible positions to obtain the best view for making correct decisions during play. Experienced FR may anticipate the ball-position and the movement of the players and thereby reduce the need for short and rapid accelerations. However, if the play changes rapidly from one field half to the other, FR is required to run over the whole pitch, which is not the case for the AR who only runs on his field-half. This may cause FR to perform longer accelerations compared with AR. In contrast to the present study Barbero-Alvarez et al. (2012) found no significant difference between the number of accelerations by FR and AR (68 vs. 49), and FR had a longer total acceleration distance (1538m vs. 715m) than the AR. In both the present study and the study by Barbero-Alvaresz et al. (2012) FR ran more meters per acceleration than the AR. However, the distances per acceleration in the present study was approximately ¼ of the distances per acceleration in the above mentioned study. Comparison between these studies should be interpreted with caution, as there are methodological differences that may affect the results. First, the present study defined an acceleration as a positive change of

speed of 2 $m \cdot s^2$ or more for at least 0.5 s while Barbero-Àlvarez et al. (2012) defined it as 1.5 $m \cdot s^2$ at a velocity of 8-18 $km \cdot h^{-1}$. The lower threshold to define accelerations in the latter study may account for the substantial differences in acceleration distance. Second, the present study used position data sampled 20 times per second to measure accelerations while Barbero-Àlvarez et al. (2012) used a 100 Hz accelerometer. Thus, the accelerometer used in the latter study may be more sensitive to register short and rapid accelerations. A 100 Hz accelerometer was also used in a recent study comparing player load (sum of accelerations recorded in the three principal axes of movement) in FR and AR reported grater player load in FR (Castillo, Weston, et al., 2016).

In the present study, FR and AR performed 6% and 5% of the total distance with HIR (619m and 228m). High intensity running may be an important contributor to perform as a high-level referee, but a modest contributor to the total load during matches. The difference in HIR between FR and AR is reported before (Barbero-Alvarez et al., 2012; Krustrup et al., 2009) and was thus expected. The HIR distance in the present study is comparable with the finding from Weston et al. (2007) and Krustrup et al. (2009), while Barbero-Àlvarez et al. (2012) reported almost four times the HIR distance in FR and twice the HIR distance in AR. Also, there are large discrepancies when the number of HIR in the present study is compared with previous literature (Krustrup et al., 2009). However, it is difficult to compare HIR, since the definition of HIR is heterogeneous (Barbero-Alvarez et al., 2012; Castagna et al., 2004; Costa et al., 2013; Krustrup & Bangsbo, 2001; Krustrup, Mohr, & Bangsbo, 2002).

The substantial difference in HIR and accelerations by referees presented in the literature may be a consequence of differences in running performance of the players in the respective leagues (Dellal et al., 2011) as the exercise intensity of the referees and players are interrelated (Weston et al., 2011). Thus, the increased HIR by players over recent years (Bush et al., 2015) has most likely increased the running demands of the referees. High intensity running during matches is also associated with the fitness level of the referees (Krustrup & Bangsbo, 2001).

Methodological considerations

Differences in running performance reported in the literature may also be related to the use of different tracking technologies. The radio based ZXY technology used in the present study is reported to have a test – retest reliability, assessed by the interclass correlation coefficient (ICC) for the x- and y-positions (from which, together with time, speed and acceleration are derivatives) and the total distance covered, of ICC <0.998, P<0.001 (Ingebrigtsen et al., 2015). The ZXY system is to our knowledge not compared with other tracking systems, but computerized semiautomatic video analysis image recognition systems compares favourably to GPS technology (Edgecomb & Norton, 2006). Different GPS and video based tracking systems have relatively large in-between-system differences when analysing the absolute distances. Thus, any comparisons of results between different movement tracking systems should be done with caution (Randers et al., 2010). Nevertheless, more studies are needed to validate the different systems used for tracking in team sports.

Differences between halves

In the present study, number of accelerations and acceleration distance were consistent between the halves in both FR and AR. According to a review about the physiology of football players (Stolen et al., 2005), analysis of differences in distance covered in the two halves is of great interest as it can reveal the occurrence of fatigue. Castillo et al. (2016) demonstrated match related fatigue in FR and AR expressed as decreased physical performance after officiating. However, changes of running performance during match play may also be related to team tactics, injuries, and substitution of players. If no reduction in running performance is evident, it is proposed that a successful pacing strategy is employed (Drust, Atkinson, & Reilly, 2007). The reason for the equal running performance in both halves in the present study is unclear, but may be related to the fitness of the referees, pacing, the demands of the match or other aspects regarding the referees or the match play. In contrast to the present study, Barbero-Àlvarez et al. (2012) reported a reduced number of

accelerations in the second half for FR, but not for AR in international matches. In our study there were no difference in HIR between the halves. This is consistent with findings in English Premier League (Weston et al., 2007), for FR in Italian Series A (D'Ottavio & Castagna, 2001) and for AR in America's cup (Barbero-Alvarez et al., 2012).

Differences between 5-min periods

Distance and number of acceleration and HIR were reduced by 45-76 % from the 5-min period with most acceleration or HIR to the following 5-min period. However, there was no differences between the 5-min period following the peak 5-min period and the 5-min mean. This may suggest that both FR and AR in the present study are able to partly recover during the matches and employ strategies to avoid impaired running performance after periods with particularly high exercise intensity. Such strategies are of great importance when refereeing at high standard competitions, where the referees may confront professional athletes who are younger and can be substituted if they become fatigued (Mallo, Navarro, Garcia Aranda, et al., 2009). Another possible explanation is that the referees have a sufficient level of fitness to cope with even the most intense periods of the match and still be well below their maximal exercise capacity. Our findings are in contrast to two studies by Mallo et al. (2009; 2007) who reported a 50% and 31% reduction in HIR after the most intense 5-min period, and this performance was significantly lower than the 5-min mean. There are no obvious reason for this discrepancy however, HIR during the 5-min periods are difficult to compare as these studies used different cut-of values to define HIR.

When evaluating running performance in 5-min periods through the match, number of accelerations and acceleration distance were lower towards the end of both halves (compared with the first 5 min) in AR, but not in FR. This reduction in accelerations is probably not caused by fatigue, but more likely AR are more alert at the start of the halves and adapts to the play during the halves. The reduction in accelerations by AR may also be a consequence of reduced number of accelerations observed in players, both the last 5- and 15- min in matches (Pettersen et al., 2014), however, as accelerations by

FR and HIR by both types of referees remains constant, this seems less likely. To our knowledge, no previous study has analysed changes in accelerations split into 5-min periods throughout the match in referees. The results are therefore difficult to compare with previous studies. However, Weston et al. (2011) compared HIR of FR and players split into 5-min periods and the pattern of HIR in players resembles the pattern of accelerations in FR, with the most HIR/accelerations in the first 5-min of each half. These patterns may be observed in accelerations (figure 1) and HIR (figure 3) in both FR and AR. However, these patterns are not always statistically significant differences in the post hoc pairwise comparisons between 5-min periods due to conservative correction for multiple testing or even in the main analysis (anova) possibly due to insufficient statistical power to detect minor differences.

Consequence for training

The different movement patterns between FR and AR should be taken into consideration when prescribing and executing training in order to prepare and perform more optimally during match play. AR performed almost twice as many accelerations as FR (158 vs. 85), but the acceleration distance in each acceleration were shorter. Specific training programs for AR should contain bouts of short powerful accelerations taxing the anaerobic energy system in addition to aerobic training. The ability to perform repeated accelerations seems vital for AR and one might speculate that an improved ability to rapidly repeat accelerations could remove or decrease the reduction in accelerations after the initial 5-min periods of each half. FR performed almost three times more HIR and sprint compared to AR indicating that these abilities must be a part of the specific training program for FR.

Strengths and limitations

The strength of the present study is a relatively large dataset and the use of radio based trakcing technology providing reliable (Ingebrigtsen et al., 2015) and valid (Stolen et al., 2005) measure of external match load (accelerations and HIR). However, there are other factors related to the total

match load for referees such as decelerations (Osgnach et al., 2010) and change of direction (Castagna, Impellizzeri, Bizzini, Weston, & Manzi, 2011) that are not included in the study. In addition, the referees performs substantial amounts of backwards and sideways running (Krustrup et al., 2009) and these locomotion's are not separated from each other or forward running in the present study. The study would have been strengthened further if had the relative intensity in addition to the absolute intensity of the accelerations and HIR.

Conclusion

This study reported that the amount of HIR and accelerations performed by FR and AR during match play are substantially different. Therefore, the training recommendations referees should be differentiated. The running performance of FR are more related to HIR, while the running performance of AR are more related to accelerations. Thus, FR may focus on training aimed at developing aerobic capacity and HIR ability, whereas the training and testing of AR may focus more on the ability to perform repeated short accelerations. The referees did not display any reduction (compared with the mean) in high intensity activities in the second half or after the most intense 5-min period. However, AR performed less accelerations towards the end of each half. The reason for this reduction is unclear. Therefore, further studies of referee running performance should adjust for the overall intensity of the match (e.g. expressed as the running performance of the players) and/or the relative intensity for each referee.

Barbero-Alvarez, J., Boullosa, D. A., Nakamura, F. Y., Andrin, G., & Castagna, C. (2012). Physical and physiological demands of field and assistant soccer referees during America's cup. *J Strength Cond Res, 26*(5), 1383-1388. doi: 10.1519/JSC.0b013e31825183c5

Bush, M., Barnes, C., Archer, D. T., Hogg, B., & Bradley, P. S. (2015). Evolution of match performance parameters for various playing positions in the English Premier League. *Hum Mov Sci, 39*, 1-11. doi: 10.1016/j.humov.2014.10.003

Castagna, C., Abt, G., & D'Ottavio, S. (2004). Activity profile of international-level soccer referees during competitive matches. *J Strength Cond Res, 18*(3), 486-490. doi: 10.1519/1533-4287(2004)18<486:apoisr>2.0.co;2

Castagna, C., Impellizzeri, F. M., Bizzini, M., Weston, M., & Manzi, V. (2011). Applicability of a change of direction ability field test in soccer assistant referees. *J Strength Cond Res, 25*(3), 860-866. doi: 10.1519/JSC.0b013e318208ae8e

Castillo, D., Cámara, J., Castellano, J., & Yanci, J. (2016). Match officials do not attain maximal sprinting speed during matches. *Kinesiology, 48*(2), 207-212

Castillo, D., Weston, M., McLaren, S. J., Camara, J., & Yanci, J. (2016). Relationships Between Internal and External Match Load Indicators in Soccer Match Officials. *Int J Sports Physiol Perform*, 1-21. doi: 10.1123/ijspp.2016-0392

Castillo, D., Yanci, J., Camara, J., & Weston, M. (2016). The influence of soccer match play on physiological and physical performance measures in soccer referees and assistant referees. *J Sports Sci, 34*(6), 557-563. doi: 10.1080/02640414.2015.1101646

Costa, E. C., Vieira, C. M. A., Moreira, A., Ugrinowitsch, C., Castagna, C., & Aoki, M. S. (2013). Monitoring External and Internal Loads of Brazilian Soccer Referees during Official Matches. *J Sports Sci Med, 12*(3), 559-564

D'Ottavio, S., & Castagna, C. (2001). Analysis of match activities in elite soccer referees during actual match play. *J Strength Cond Res, 15*(2), 167-171

Dellal, A., Chamari, K., Wong, D. P., Ahmaidi, S., Keller, D., Barros, R., . . . Carling, C. (2011). Comparison of physical and technical performance in European soccer match-play: FA Premier League and La Liga. *Eur J Sport Sci, 11*(1), 51-59. doi: 10.1080/17461391.2010.481334

Drust, B., Atkinson, G., & Reilly, T. (2007). Future perspectives in the evaluation of the physiological demands of soccer. *Sports Med, 37*(9), 783-805

Edgecomb, S. J., & Norton, K. I. (2006). Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian Football. *J Sci Med Sport, 9*(1–2), 25-32. doi: http://dx.doi.org/10.1016/j.jsams.2006.01.003

Ingebrigtsen, J., Dalen, T., Hjelde, G. H., Drust, B., & Wisloff, U. (2015). Acceleration and sprint profiles of a professional elite football team in match play. *Eur J Sport Sci, 15*(2), 101-110. doi: 10.1080/17461391.2014.933879

Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top-class soccer refereeing in relation to physical capacity: effect of intense intermittent exercise training. *J Sports Sci, 19*(11), 881-891. doi: 10.1080/026404101753113831

Krustrup, P., Helsen, W., Randers, M. B., Christensen, J. F., MacDonald, C., Rebelo, A. N., & Bangsbo, J. (2009). Activity profile and physical demands of football referees and assistant referees in international games. *J Sports Sci, 27*(11), 1167-1176. doi: 10.1080/02640410903220310

Krustrup, P., Mohr, M., & Bangsbo, J. (2002). Activity profile and physiological demands of top-class soccer assistant refereeing in relation to training status. *J Sports Sci, 20*(11), 861-871. doi: 10.1080/026404102320761778

Mallo, J., Navarro, E., Aranda, J. M., & Helsen, W. F. (2009). Activity profile of top-class association football referees in relation to fitness-test performance and match standard. *J Sports Sci, 27*(1), 9-17. doi: 10.1080/02640410802298227

Mallo, J., Navarro, E., Garcia-Aranda, J. M., Gilis, B., & Helsen, W. (2007). Activity profile of top-class association football referees in relation to performance in selected physical tests. *J Sports Sci, 25*(7), 805-813. doi: 10.1080/02640410600778602

Mallo, J., Navarro, E., Garcia Aranda, J. M., & Helsen, W. (2009). Physical demands of top-class soccer assistant refereeing during high-standard matches. *Int J Sports Med, 30*(5), 331-336. doi: 10.1055/s-0029-1202339

Osgnach, C., Poser, S., Bernardini, R., Rinaldo, R., & di Prampero, P. E. (2010). Energy cost and metabolic power in elite soccer: a new match analysis approach. *Med Sci Sports Exerc, 42*(1), 170-178. doi: 10.1249/MSS.0b013e3181ae5cfd

Pettersen, S. A., Krustrup, P., Bendiksen, M., Randers, M. B., Brito, J., Bangsbo, J., . . . Mohr, M. (2014). Caffeine supplementation does not affect match activities and fatigue resistance during match play in young football players. *J Sports Sci, 32*(20), 1958-1965. doi: 10.1080/02640414.2014.965189

Randers, M. B., Mujika, I., Hewitt, A., Santisteban, J., Bischoff, R., Solano, R., . . . Mohr, M. (2010). Application of four different football match analysis systems: a comparative study. *J Sports Sci, 28*(2), 171-182. doi: 10.1080/02640410903428525

Stolen, T., Chamari, K., Castagna, C., & Wisloff, U. (2005). Physiology of soccer: an update. *Sports Med, 35*(6), 501-536

Weston, M., Castagna, C., Impellizzeri, F. M., Rampinini, E., & Abt, G. (2007). Analysis of physical match performance in English Premier League soccer referees with particular reference to first half and player work rates. *J Sci Med Sport, 10*(6), 390-397. doi: 10.1016/j.jsams.2006.09.001

Weston, M., Castagna, C., Impellizzeri, F. M., Rampinini, E., & Breivik, S. (2010). Ageing and physical match performance in English Premier League soccer referees. *J Sci Med Sport, 13*(1), 96-100. doi: 10.1016/j.jsams.2008.07.009

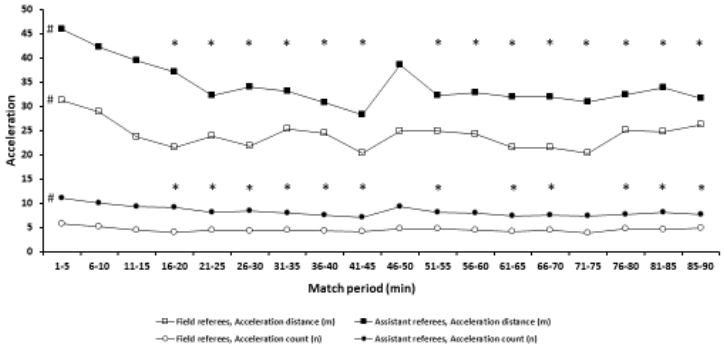
Weston, M., Drust, B., & Gregson, W. (2011). Intensities of exercise during match-play in FA Premier League referees and players. *J Sports Sci, 29*(5), 527-532. doi: 10.1080/02640414.2010.543914

Table 1: Number of accelerations, acceleration distance, number of high intensity runs, and distance covered in different speed categories for assistant and field football referees.

	Full match	1st half	2nd half
Acceleration distance (m)			
Assistant referees	652 (612-693)	329 (305-353)	323 (302-345)
Field referees	456 (401-510)	226 (198-253)	230 (199-261)
Cohen's d assistant vs. field referees	1.7	1.2	1.1
Accelerations (n)			
Assistant referees	158 (147-169)	81 (75-88)	77 (71-83)
Field referees	85 (76-94)	42 (37-46)	43 (38-49)
Cohen's d assistant vs. field referees	1.9	1.9	1.6
High intensity running distance (m)			
Assistant referees	228 (208-248)	114 (101-126)	114 (103-127)
Field referees	619 (534-703)	290 (248-332)	329 (278-380)
Cohen's d assistant vs. field referees	2.7	2.4	2.5
High intensity runs (n)			
Assistant referees	13 (11-14)	6 (5-7)	7 (6-7)
Field referees	26 (22-30)	13 (11-15)	14 (12-16)
Cohen's d assistant vs. field referees	2.0	2.0	1.9
Sprint distance (m)			
Assistant referees	21 (18-25)	12 (9-15)	9 (7-12)
Field referees	65 (47-84)	31 (20-41)	35 (24-46)
Cohen's d assistant vs. field referees	1.4	1.0	1.4
Running distance (m)			
Assistant referees	814 (775-853)	409 (387-434)	404 (381-428)
Field referees	1970 (1828-2112)	965 (891-1039)	1005 (928-1082)
Cohen's d assistant vs. field referees	4.7	4.2	4.4
Total distance (m)			
Assistant referees	7483 (7365-7601)	3690 (3623-3757)	3793 (3723-3863)
Field referees	11218 (10989-11447)	5529 (5410-5649)	5689 (5562-5816)
Cohen's d assistant vs. field referees	7.5	6.7	6.6

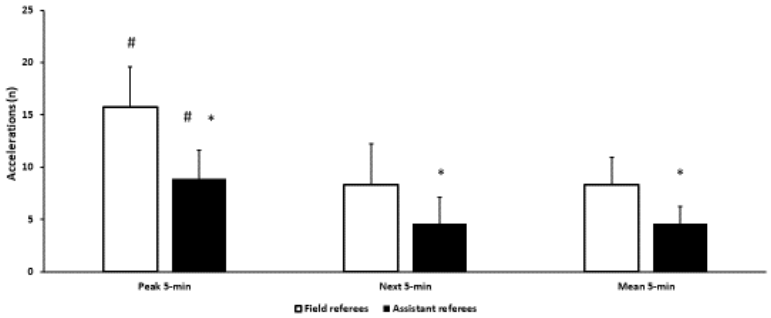
Data are reported as mean with 95 % confidence intervals. m = meter, n = number, AR = assistant referees, FR=field referees, Running: 14.4 - 19.8 km·h^{-1}, High intensity running > 19.8 km·h^{-1}, Sprint > 25.2 km·h^{-1}, Accelerations = above 2 m·s^{-2} > 0.5 second.

Figure 1



- Figure 1. Number of accelerations and acceleration distance performed by assistant and field referees every 5-min period during football matches. # = Differences between 5-min periods. * = Different from match period 1-5 min (P<0.01) (with Bonferroni correction for multiple testing).

Figure 2

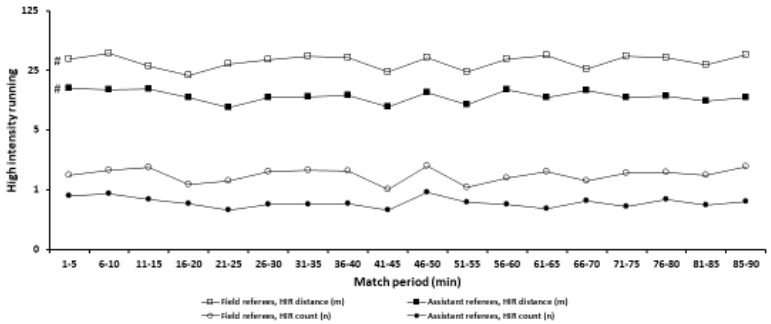


1

- Figure 2. Peak 5-min period of acceleration versus the following 5-min period and the mean 5-min value for the match in field referees and assistant referees. Data are presented as mean with standard deviation. # Different (P<0.001) from mean 5-min value. * Different (P< 0.001) from field referees.

2

Figure 3



1

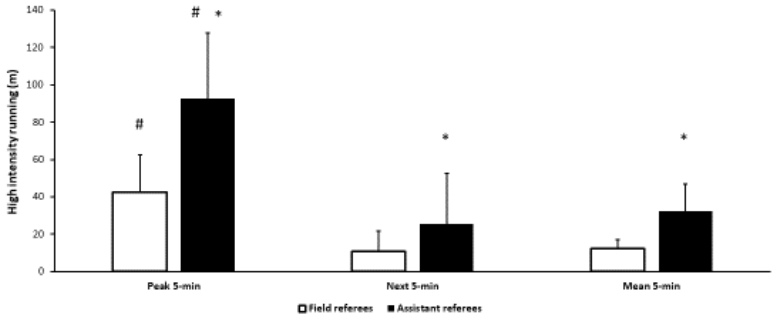
- Figure 3. Number of high intensity runs and high intensity running distance performed by assistant and field referees every 5-min period during football matches. # = Differences between 5-min periods. (But no statistically significant differences in pairwise comparison when using Bonferroni correction for multiple testing)

2

• Figure 4. Peak 5-min period of high intensity running versus the following 5-min period and the mean 5-min value for the match in field referees and assistant referees. Data are presented as mean with standard deviation. # Different (P<0.001) from mean 5-min value. * Different (P< 0.001) from field referees.

1

Figure 4



2