THE RELATIONSHIPS BETWEEN PHYSICAL FITNESS ATTRIBUTES AND MATCH DEMANDS IN RUGBY UNION REFEREES OFFICIATING THE 2019 RUGBY WORLD CUP

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ABSTRACT

This study examined the relationships between physical fitness attributes and match demands in lead rugby union referees. Eleven referees underwent anthropometric and fitness assessments (40-m sprint, Yo-Yo Intermittent Recovery Test, 1.2-km shuttle run) prior to the 2019 Rugby World Cup. Match activities were assessed via global positioning system devices (total distance, high-speed running distance [>5 $m \cdot s^{-1}$], average speed, and peak intensities over 1-min, 5-min, and 10-min epochs) and heart rate variables were measured using chest-worn monitors (HR_{mean}, summated-heart-rate-zones, time above 90% HR_{max}). 40-m sprint time was significantly related to maximum speed (*P*=0.004; r= -0.79) and high-speed running distance (*P*=0.037, r= -0.63) during matches. Likewise, ∑7 skinfold thickness was significantly correlated with high-speed running distance (*P*=0.01, r= -0.72). Yo-Yo Intermittent Recovery Test, 1.2-km shuttle run test, age, and body mass index exhibited non-significant correlations (*P*>0.05, r= -0.58 to 0.53) with match demand variables. Results suggest it may be pertinent for referees to optimise sprint capacity and body fat composition to execute greater high-speed running volumes and reach higher peak speeds during matches. Yo-Yo Intermittent Recovery Test and 1.2-km shuttle run tests are not correlated to specific match activity variables, and thus may not be relevant for monitoring of rugby union referees.

Key words: team sport; officials; GPS; testing; elite.

INTRODUCTION

Rugby union referees are responsible for enforcing the laws of the game and inherently complete extensive physical work during matches (Blair, Cronin, et al., 2018). Recent data show referees covered 6,674 ± 566 m including 586 ± 290 m undertaking high-speed running (HSR; >5 $m \cdot s^{-1}$), and worked at mean heart rates of 146 ± 9 beats/min (79 ± 4% of maximum heart rate) during 2019 Rugby World Cup matches (Elsworthy et al., 2020). Similar findings have been reported for referees during other elite international rugby matches outside of the World Cup (total distance: 7,407 ± 949 m; HSR: 820 ± 430 m) (Blair et al., 2019). Furthermore, existing evidence indicates rugby union referees undergo high intermittent demands during matches with frequent activities performed at low and moderate intensities interspersed with brief high-intensity bouts (Blair et al., 2019).

To ensure rugby union referees can adequately cope with the demands experienced during match-play, it is important they possess requisite physical fitness attributes commensurate with those stressed during matches. In turn, regular monitoring of physical fitness attributes in referees is important for suitable selection and training prescription practices tailored to rugby union referees (Blair et al., 2019). However, to identify the most critical fitness attributes needed to meet match demands, relationships between physical fitness attributes and match demand variables must be quantified. While this type of analysis is not available for rugby union referees, previous investigations quantifying the relationships between physical fitness attributes and match demands have predominantly examined soccer referees. Specifically, 50-m sprint, 200-m sprint, and 12-min run tests were not significantly (P>0.05) correlated with total distance covered (r= -0.48 to 0.23) or time spent performing high-intensity (>3.6 $m \cdot s^{-1}$) activities (r= -0.23 to 0.54) for soccer referees during Under-17 World Cup matches (Mallo et al., 2007). Conversely, significant (P<0.05) correlations were apparent in a separate sample of soccer referees during these same fitness tests and total distance covered (r= -0.48 to 0.71) during Italian Serie A matches (Castagna et al., 2002). Likewise, using different test protocols to assess fitness attributes in soccer referees, heart rate demand during a running interval test and performance times during a 6x40-m repeat-sprint test were significantly correlated with total distance (r= -0.70 to -0.69, P <0.01) and high-intensity running (>5.5 $m \cdot s^{-1}$) distance (r= -0.77 to -0.57, P <0.05) during English Premier League matches (Weston et al., 2009), and 30-m sprint time and distance covered during the Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT1) were significantly correlated with HSR (>5 $m \cdot s^{-1}$) distance covered (r= -0.52 to 0.59, P<0.05) during Spanish national third division matches (Castillo et al., 2019). Accordingly, the collective evidence provided specific to soccer referees suggests relationships between fitness attributes and match demands may depend on the fitness test protocols adopted and the competition examined. However, given the variations in demands placed on referees during international soccer matches (Krustrup et al., 2009) compared to international rugby union matches (Blair, Elsworthy, et al., 2018; Elsworthy et al., 2020), separate analyses are essential to understand the importance and relevance of routine fitness assessments to match demands at the elite level specifically in rugby union referees.

The Rugby World Cup is the pinnacle international tournament held every 4 years. Therefore, it is important that the referees assigned to officiate matches at the Rugby World Cup have suitable physical fitness attributes to successfully endure the match demands faced. In this regard, assessing the relationships between physical fitness attributes and match demands during Rugby World Cup matches may inform: (1) the development of selection strategies to ensure referees are suitably assigned to officiate matches; (2) optimal physical preparation of referees leading into the Rugby World Cup; and (3) suitable fitness testing batteries for standardised adoption in practice. Therefore, this study examined the relationships between common physical fitness attributes and match demands in referees during the 2019 Rugby World Cup.

MATERIALS AND METHODS

Participants

Eleven male referees selected to officiate in the 2019 Rugby World Cup as lead referees voluntarily participated in this study. On average, the examined referees had officiated 34±24 international rugby union matches prior to the start of the tournament. Referees officiated 2.6±1.5 matches (range: 1-6 matches) each from 34 matches monitored during the 2019 Rugby World Cup. Study procedures were approved by the XXXXXXXXX Human Research Ethics Committee (approval number: XXXXXXX) and World Rugby, and all referees provided informed written consent prior to the commencement of the study.

Study Design

An observational study design was used to examine the relationship between fitness attributes and match demands in rugby union referees. Data were collected in two stages. Firstly, physical fitness attributes were collected in each referee's home country 4-8 weeks prior to departure for the 2019 Rugby World Cup. Dates for fitness assessment were pre-determined for each referee by World Rugby to enable them to be completed without interference from officiating duties (i.e. preparatory matches leading into the Rugby World Cup) or travel requirements. Secondly, anthropometric variables and match activities were obtained during the 2019 Rugby World Cup.

Physical Fitness Assessments

Referees refrained from strenuous physical exercise and maintained normal nutritional intake 48 hr prior to the fitness assessments. Physical fitness testing was supervised by strength and conditioning coaches as instructed by the World Rugby Athletic Performance Coordinator. Referees participating in the study and coaches administering the tests were familiar with testing protocols having delivered them consistently for at least 2 years prior to data collection. Consequently, test administrators were sufficiently experienced and skilled to coordinate all fitness assessments in a reliable manner. Upon completion of physical fitness assessments, data were entered into the FAIRPLAY Athlete Monitoring System (Fairplay AMS Pty Ltd, Brisbane, Australia) and downloaded by the World Rugby Athletic Performance Coordinator. All tests were performed in the same order as presented below. Referees were able to wear football boots during testing and all tests were performed outdoors on international standard rugby fields (natural grass).

Linear speed was assessed using a 40-m sprint test. Prior to performing the sprints, referees completed a standardised 15-min warm-up involving 5 min of low-intensity jogging, dynamic stretching, and three runs at increasing intensities (50%, 75% and 90% of maximal effort). Starting 30 cm behind the start line in a standing position, referees were instructed to sprint at maximal intensity for the entire sprint, with performance time recorded via an electronic timing light system (Fusion Sport, Coopers Plains, QLD, Australia, or Swift Performance, Wacol, QLD, Australia). Three sprints were completed each interspersed with 3 min of passive recovery. The fastest sprint time to the nearest 0.01 s was used in subsequent analyses.

1.2-km shuttle run test

For the 1.2-km shuttle run test, participants performed continuous return shuttle runs performed over increasing distances of 20 m, 40 m, and 60 m (i.e., 2x20-m runs followed by 2x40-m runs followed by 2x60-m runs). Completion of the 20-m, 40-m, and 60-m return shuttle runs was considered as one repetition with the test requiring five completed repetitions (1.2-km in total) to be completed as quickly as possible (Brew & Kelly, 2014; Deuchrass et al., 2019; Kelly et al., 2015). The test commenced via a countdown signal from the test administrator. Total shuttle time was recorded to the nearest second via a handheld stopwatch by the test administrator.

Yo-Yo Intermittent Recovery Test Level 1

The Yo-Yo IRT1 is a valid field-based assessment to estimate maximal oxygen uptake (r=0.71) (Krustrup et al., 2003) in a reliable manner (intraclass correlation coefficient = 0.78 to 0.98) (Grgic et al., 2019) amongst team sport athletes. During the Yo-Yo IRT1, referees were required to perform 2x20-m shuttles as dictated via an audio recording (Krustrup et al., 2003). A 10-s active recovery period consisting of 2x5-m jogs was provided between each shuttle. Referees were provided with one warning if they did not reach the marked line prior to the audio cue for each 20-m run. If referees failed to reach the designated marked line following another 20-m on a second non-consecutive occasion, the test was terminated. The last successfully completed level and shuttle numbers were recorded and then converted to distance (m). Referees wore a heart rate monitor (H1, Polar Electro; Kempele, Finland) during the test to determine individual maximum heart rate (HR_{max}) during the Yo-Yo IRT1.

Anthropometric testing

Anthropometric data were collected in all referees in a standardised manner by the World Rugby Athletic Performance Coordinator five days prior to the start of the 2019 Rugby World Cup. Stature was assessed using a stadiometer (MENTONE Educational S+M portable height scale, Melbourne, Australia) to the nearest 0.1 cm. Body mass was assessed using electronic scales (SECA platform medical scale, Germany) to the nearest 0.01 kg. Body mass index (BMI) was calculated using the formula: body mass (kg)/height (m)^2. A seven-site skinfold assessment (i.e., biceps, triceps, subscapular, iliac crest, supraspinale, abdominal, front thigh, and medial calf) was performed to measure skinfold thickness (mm) as a proxy for body fat using calibrated Harpenden skinfold callipers (Baty International, England) and following standard procedures set by the International Society for the Advancement of Kinanthropometry (Marfell-Jones et al., 2019). Age was recorded from birth date to the day of the first match at the tournament in decimal years for each referee.

Measurement of match demands

Match demands were assessed using global positioning system (GPS; 5 Hz; SPI HPU, Catapult Sports, Melbourne, Australia). Each device was placed into a neoprene vest and worn by referees underneath their normal uniforms during each match. Devices were turned on at least 40 min prior to the start of each match, and each referee was assigned with the same device throughout the tournament to avoid inter-device deviations (Duffield et al., 2010). Heart rate responses were recorded via heart rate monitors (H1, Polar Electro; Kempele, Finland) worn around the chest, and these data were stored within the corresponding GPS device (Elsworthy et al., 2020). Following each match, GPS and heart rate data were imported into proprietary software (Team AMS, v2019.2, Catapult Sports, Melbourne, Australia) and processed according to match halves (from kick off to the final whistle of each half). Match activity variables were determined across the entirety of each match (excluding half-time breaks) including distance (m), average speed ($m \cdot min^{-1}$), HSR distance ($\geq 5\ m \cdot s^{-1}$, m), peak speed ($m \cdot s^{-1}$), and peak intensities determined across 1-min, 5-min, and 10-min windows using rolling averages. To establish peak intensities, raw data from each match file were exported from Team AMS as a comma separated file and analysed further using customised code in R software (version 3.1.3). These analyses included the calculation of moving averages for the distance covered across 1-min, 5-min, and 10-min durations. For example, a moving average across a 1-min window was calculated for 900 data points (i.e. 15 Hz x 60 s) (Delaney et al., 2017; Whitehead et al., 2019).

Using heart rate data, average heart rate (HR_{mean}), the summated-heart-rate-zones (SHRZ) load, and time spent working >90% of maximum heart rate were calculated across matches. The SHRZ model involves calculating the total time (min) spent working in different relative intensity zones (zone 1=50.0-59.9%HR_{max}, zone 2=60-69.9%HR_{max}, zone 3=70.0-79.9%HR_{max}, zone 4=80.0-89.9%HR_{max}, and zone 5=90.0-100%HR_{max},) (Edwards, 1994). The time spent in each zone is multiplied by a given factor for each zone and then the derived values for each zone are summed together as follows: (zone 1*1) + (zone 2*2) + (zone 3*3) + (zone 4*4) + (zone 5*5), to provide an overall physiological load value in arbitrary units (AU). The HR_{max} value obtained during the Yo-Yo IR1 was used to calculate all relative heart rate data (% HR_{max}). GPS and HR data were collected as part of a larger study, some of which has previously been reported (CITATION REMOVED FOR PEER REVIEW).

Statistical analyses

All variables are presented as mean ± standard deviation (SD). To account for the differences in the number of matches officiated by each referee in the sample, the average match activity and heart rate variables were calculated for each referee (Weston et al., 2009). Relationships between physical fitness attributes and match demand variables were assessed using Pearson's product-moment correlations with 95% confidence intervals (CI). Correlation coefficients (r) were interpreted as: *trivial* (<0.10); *small* (0.10-0.29); *moderate* (0.30-0.49); *large* (0.50-0.69); *very large* (0.70-0.89); and *nearly perfect* (≥0.90) (Hopkins et al., 2009). If the 95% CI for a correlation coefficient simultaneously overlapped the threshold of ±0.1, the correlation was interpreted as *unclear*. Statistical analyses were performed using SPSS (v26, IBM Corp., Armonk, NY, USA). Statistical significance was set at an alpha level of 0.05.

RESULTS

The mean ± SD physical fitness attributes for referees are presented in Table 1. Furthermore, mean ± SD match demands experienced by referees during the 2019 Rugby World Cup are shown in Table 2.

On average, referees covered >6,500 m per match with <10% of the total distance covered performing HSR and spent ~10 min of matches working at intensities >90% HR_{max}.

TABLE 1 AROUND HERE

TABLE 2 AROUND HERE

The relationships between physical fitness attributes and match demand variables are presented in Figure 1. There was a *very large*, significant, negative correlation (P = 0.004; r = -0.79) between 40-m sprint time and maximum speed attained in matches, as well as a *large*, significant, negative correlation (P = 0.037, r = -0.63) between 40-m sprint time and HSR distance during matches. Further, a *very large*, significant, negative correlation (P = 0.013, r = -0.72) was found between ∑7 skinfold thickness and HSR distance during matches. No other significant relationships (ranged in magnitude from *unclear* to *large*) were found between physical fitness attributes and match demand variables.

FIGURE 1 AROUND HERE

DISCUSSION

This study aimed to examine relationships between physical fitness attributes and match demand variables in lead referees officiating the 2019 Rugby World Cup. Of note, 40-m sprint time was significantly correlated to the HSR distance covered and maximum speed attained during matches, while ∑7 skinfold thickness was also significantly correlated to the HSR distance covered during matches. However, no other significant relationships between physical fitness attributes and match activity variables were apparent, suggesting some common fitness testing protocols lack specificity to the physical and physiological match requirements of elite rugby union referees.

Speed (40-m sprint time) exhibited *large* and *very large* correlations with HSR distance and peak speed during matches, respectively. These relationships suggest elite rugby union referees exhibiting greater sprint speed accrue greater distances running at high speeds during matches. While these findings are the first for elite rugby union referees, conflicting relationships have been reported between speed attributes and high-intensity running demands during matches in soccer referees. Specifically, 50-m sprint times of soccer referees has been shown to be poorly correlated with distances covered performing high-intensity activity during Italian Serie A matches (Castagna et al., 2002) and Under-17 World Cup matches (Mallo et al., 2007). In contrast, the fastest time achieved during a 6 x 40-m repeated-sprint protocol has been shown to be strongly correlated with high-intensity (>5.5 $m \cdot s^{-1}$) running distance covered and peak speed attained by soccer referees during English Premier League matches (Weston et al., 2009), while 30-m sprint time has been reported to be significantly correlated with HSR (>5 $m \cdot s^{-1}$) distance covered by soccer referees during Spanish national third division matches (Castillo et al., 2019). In this regard, the ability to accomplish larger HSR distances during matches has been shown to place referees in better position to make accurate decisions in soccer (Krustrup et al., 2009). As such, the ability to run at higher speeds assessed via timed linear sprints may enable rugby union referees to sustain elevated HSR volumes and achieve higher peak speeds during matches to being optimally positioned relative to play in match scenarios requiring officiating decisions to be made. However, it is important to note that greater HSR distances performed by rugby union referees do not necessarily equate to better match performance. For example, the skill level and experience of the referee will impact their position during match sequences, with anticipatory skills being particularly important (Elsworthy et al., 2014). Consequently, superior anticipatory skills may enable referees to take more direct routes to occupy optimal positions around the play, resulting in less HSR being undertaken during some match scenarios.

Unexpectedly, performance during the 1.2-km Shuttle Run Test ($r = -0.39$ to 0.54) and Yo-Yo IRT1 ($r = 0.47$ to 0.41) was not strongly correlated with any match demand variable in referees during the 2019 Rugby World Cup. In contrast to the present findings, significant correlations have been observed between the distance travelled during the Yo-Yo IRT1 distance and HSR distance in soccer referees during elite Danish league matches (Krustrup & Bangsbo, 2001) and Spanish national third division matches (Castillo et al., 2019). Variations in findings between the previous soccer studies and our study could be underpinned by the differences in match structure between rugby union and soccer with each eliciting unique contributions of anaerobic and aerobic demands on referees. It is apparent that rugby union referees cover less distance during matches (6,608 ± 509 m in our study) compared to soccer referees (~12,000 m; Weston et al., 2012) and the lack of a significant correlation between Yo-Yo IRT1 performance and match demand variables may mean there is not as great a need for an exceptionally high aerobic capacity to accomplish match demands in rugby union referees as there is for soccer referees. While sufficient aerobic fitness is essential to successfully execute repeated HSR efforts and optimise fatigue resistance in soccer referees during matches (Krustrup & Bangsbo, 2001; Mallo et al., 2007) and the Yo-Yo IRT1 can be used to inform the development of training plans in soccer referees (Bangsbo et al., 2008), an alternative testing protocol may be better suited to measuring aerobic fitness attributes stressed during match-play in elite rugby union referees. Nonetheless, it is important to note that the purpose of such assessment is to inform individualised training sessions, rather than being directly related to the demands of a match. Both the 1.2-km Shuttle Run Test and Yo-Yo IRT1 were selected in our study given both tests form part of the regular monitoring procedures employed by World Rugby. The Yo-Yo IRT1 is performed annually, and the 1.2-km Shuttle Run Test is undertaken monthly due to its shorter duration. During testing sessions referees are instructed to perform at maximal effort, however during matches referees either self-select the required movements, or perform the activities as dictated by the movement of the ball and players throughout the field. The overall match demands imposed on rugby union referees appear substantially lower compared to other similar field-based team sports. Therefore, it is likely that the lower movement demands during matches does not require the referee to performance activities with maximal effort. Consequently, this may partially explain the lack of significant relationships between fitness testing outcomes and match demands reported in the current study. While previous studies have identified significant relationships between match demands and fitness tests in soccer referees (Castillo et al., 2019; Krustrup & Bangsbo, 2001), differences to the current study are likely due to the vastly different movement patterns between soccer and rugby referees. Nonetheless, both tests had poor relationships to the match demands experienced by referees during Rugby World Cup matches and therefore may not possess ideal levels of specificity for assessing aerobic fitness attributes specific to matches in elite rugby union referees.

Body fat represented as ∑7 skinfold thickness was significantly and negatively correlated with HSR distance during matches, indicating referees with lower body fat covered greater distances running at high intensities. While this type of analyses has only been carried out examining athletes, our finding supports previous data suggesting lower body fat is related to the ability to carry out greater HSR during matches in professional soccer players (Radzimiński et al., 2019) and rugby seven's players (Clarke et al., 2017). In this way, excessive body fat possibly limits the HSR capacities of referees similar to athletes during matches (Ross et al., 2014). Therefore, elite rugby union referees should seek to optimise body fat levels through appropriate lifestyle behaviours (e.g. training, nutrition) to best execute HSR during intense periods of play as required during matches.

While the findings of the present study are novel for elite rugby union referees, this study is not without limitations. Referees were located in different countries prior to the Rugby World Cup and it was not possible to assess all referees simultaneously by the same individual. Comprehensive fitness assessment of referees after arriving in a common location to officiate in the Rugby World Cup tournament was not permissible as it may have compromised the physical preparation of referees for the first match of the tournament, and varying travel requirements would have not enabled equitable preparation prior to testing. As such, the most recent fitness assessment leading into the Rugby World Cup was used for analysis. However, the distant locations of referees pose an obvious limitation regarding the timing and standardisation of physical assessment leading into the Rugby World Cup. While all strength and conditioning coaches acting as test administrators were experienced with all testing procedures and familiar with the set testing guidelines to best ensure assessments were completed in a consistent manner across referees, variations in some aspects of testing were not able to be controlled (i.e., weather, condition of grass surface, testing equipment). Also, it is acknowledged that a small sample ($n = 11$) was recruited; however, given the elite nature of the tournament analysed, the provided data capture almost all of the available sample representing the highest level of rugby union referees with 11 of the top 12 referees in the world being recruited.

The present study aimed to identify the relationships between physical fitness attributes and match demand variables in lead rugby union referees officiating at the 2019 Rugby World Cup. While 40-m linear sprint time was significantly correlated with HSR distance and peak speed attained during matches and ∑7 skinfold thickness was significantly correlated with HSR distance during matches, the examined physical fitness attributes derived from standardised testing protocols were mostly poorly correlated with match demands. Consequently, these findings underpin the importance of effectively developing sprint speed and optimising body fat to best endure the intense demands imposed on elite rugby union referees during matches, while also suggesting alternative testing protocols may be needed to quantify specific physical fitness attributes stressed during actual match-play to better assist in the selection and development of referees at the elite level.

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INFORMATION WITHHELD FOR PEER REVIEW PROCESS

DECLARATION OF INTEREST STATEMENT

There are no conflicts of interest.

REFERENCES

Bangsbo, J., Iaia, F. M., & Krustrup, P. (2008). The Yo-Yo intermittent recovery test. *Sports Medicine*, *38*(1), 37-51. https://doi.org/https://doi.org/10.2165/00007256-200838010-00004

Blair, M. R., Cronin, J. B., Rehrer, N. J., Button, C., & Gill, N. D. (2018). Contextual Review of Physical Requirements of Refereeing Rugby Union at an Elite Level. *Strength and Conditioning Journal*, *40*(2), 23-30. https://doi.org/https://doi.org/10.1519/ssc.0000000000000352

Blair, M. R., Elsworthy, N., Rehrer, N. J., Button, C., & Gill, N. D. (2018). Physical and Physiological Demands of Elite Rugby Union Officials. *International Journal of Sports Physiology and Performance*, *13*(9), 1199-1207. https://doi.org/10.1123/ijspp.2017-0849

Blair, M. R., Manuel-Hepi, N., Newman, L., Elsworthy, N., & Smith, T. B. (2019). Physical demands of international lead rugby union referees. *Journal of Australian Strength and Conditioning*, *27*(3), 24-31. http://search.ebscohost.com/login.aspx?direct=true&AuthType=sso&db=s3h&AN=138059715&scope=site&authtype=sso&custid=s3716178

Brew, D. J., & Kelly, V. G. (2014). The reliability of the 1.2km shuttle run test for intermittent sport athletes. *Journal of Australian Strength and Conditioning*, *22*(5), 127-131. https://www.strengthandconditioning.org/jasc-22-5/946-the-reliability-of-the-1-2km-shuttle-run-test-for-intermittent-sport-athletes

Castagna, C., Abt, G. A., & D'Ottavio, S. (2002). Relation Between Fitness Tests and Match Performance in Elite Italian Soccer Referees. *The Journal of Strength & Conditioning Research*, *16*(2), 231-235. https://doi.org/https://doi.org/10.1519/00124278-200205000-00010

Castillo, D., Cámara, J., Lozano, D., Berzosa, C., & Yanci, J. (2019). The association between physical performance and match-play activities of field and assistants soccer referees. *Research in Sports Medicine*, *27*(3), 283-297. https://doi.org/10.1080/15438627.2018.1534117

Clarke, A. C., Anson, J. M., & Pyne, D. B. (2017). Game movement demands and physical profiles of junior, senior and elite male and female rugby sevens players. *Journal of Sports Sciences*, *35*(8), 727-733. https://doi.org/https://doi.org/10.1080/02640414.2016.1186281

Delaney, J. A., Thornton, H. R., Pryor, J. F., Stewart, A. M., Dascombe, B. J., & Duthie, G. M. (2017). Peak running intensity of international rugby: implications for training prescription. *International Journal of Sports Physiology and Performance*, *12*(8), 1039-1045. https://doi.org/https://doi.org/10.1123/ijspp.2016-0469

Deuchrass, R. W., Smith, H. K., Elliott, C. E., Lizamore, C. E., & Hamlin, M. J. (2019). The 1.2 km shuttle run test: Reliability and comparison with the Yo-Yo Intermittent Recovery Level 1 Test in young elite rugby union players. *Journal of Australian Strength and Conditioning*, *27*(4), 14-20.

Duffield, R., Reid, M., Baker, J., & Spratford, W. (2010). Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *Journal of Science and Medicine in Sport*, *13*(5), 523-525. https://doi.org/https://doi.org/10.1016/j.jsams.2009.07.003

Edwards, S. (1994). *The heart rate monitor book*. Fleet Feet Press.

Elsworthy, N., Burke, D., & Dascombe, B. J. (2014). Factors relating to the decision-making performance of Australian football officials. *International Journal of Performance Analysis in Sport*, *14*, 401-410. https://doi.org/https://doi.org/10.1080/24748668.2014.11868730

Elsworthy, N., R Blair, M., & Lastella, M. (2020). On-field movements, heart rate responses and perceived exertion of lead referees in Rugby World Cup matches, 2019. *Journal of Science and Medicine in Sport*. https://doi.org/10.1016/j.jsams.2020.10.001

Grgic, J., Oppici, L., Mikulic, P., Bangsbo, J., Krustrup, P., & Pedisic, Z. (2019). Test–retest reliability of the Yo-Yo test: A systematic review. *Sports Medicine*, *49*(10), 1547-1557. https://doi.org/https://doi.org/10.1007/s40279-019-01143-4

Hopkins, W., Marshall, S., Batterham, A., & Hanin, J. (2009). Progressive statistics for studies in sports medicine and exercise science. *Medicine & Science in Sports & Exercise*, *41*(1), 3.

Kelly, V., Jackson, E., & Wood, A. (2015). Typical scores from the 1.2km shuttle run test to determine maximal aerobic speed. *Journal of Australian Strength and Conditioning*, *22*(5), 183-185.

Krustrup, P., & Bangsbo, J. (2001). Physiological demands of top-class soccer refereeing in relation to physical capacity: effect of intense intermittent exercise training. *Journal of Sports Sciences*, *19*(11), 881-891. https://doi.org/https://doi.org/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. *Journal of Sports Sciences*, *27*(11), 1167-1176. https://doi.org/https://doi.org/10.1080/02640410903220310

Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P. K., & Bangsbo, J. (2003). The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine & Science in Sports & Exercise*, *35*(4), 697-705. https://doi.org/https://doi.org/10.1249/01.mss.0000058441.94520.32

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. *Journal of Sports Sciences*, *25*(7), 805-813. https://doi.org/https://doi.org/10.1080/02640410600778602

Marfell-Jones, M., Vaquero-Cristóbal, R., & Ros, F. E. (2019). *ISAK Accreditation Handbook (2019)*. International Society for the Advancement of Kinanthropometry (ISAK).

Radzimiński, Ł., Szwarc, A., Padrón-Cabo, A., & Jastrzębski, Z. (2019). Correlations between body composition, aerobic capacity, speed and distance covered among professional soccer players during official matches. *The Journal of Sports Medicine and Physical Fitness*, *60*(2), 257-262. https://doi.org/https://doi.org/10.23736/s0022-4707.19.09979-1

Ross, A., Gill, N., & Cronin, J. (2014). Match analysis and player characteristics in rugby sevens. *Sports Medicine*, *44*(3), 357-367. https://doi.org/https://doi.org/10.1007/s40279-013-0123-0

Weston, M., Castagna, C., Helsen, W., & Impellizzeri, F. (2009). Relationships among field-test measures and physical match performance in elite-standard soccer referees. *Journal of Sports Sciences*, *27*(11), 1177-1184. https://doi.org/https://doi.org/10.1080/02640410903110982

Weston, M., Castagna, C., Impellizzeri, F. M., Bizzini, M., Williams, A. M., & Gregson, W. (2012). Science and medicine applied to soccer refereeing: an update. *Sports Medicine*, *42*(7), 615-631. https://doi.org/https://doi.org/10.2165/11632360-000000000-00000

Whitehead, S., Till, K., Weaving, D., Hunwicks, R., Pacey, R., & Jones, B. (2019). Whole, half and peak running demands during club and international youth rugby league match-play. *Science and Medicine in Football*, *3*(1), 63-69. https://doi.org/https://doi.org/10.1080/24733938.2018.1480058

TABLES

Table 1: Physical fitness attributes in referees officiating matches in the 2019 Rugby World Cup (n = 11).

Variable	Mean ± SD
Anthropometric variables	
Age (yr)	38.6 ± 5.8
Height (cm)	178 ± 6
Body mass (kg)	80.8 ± 5.1
BMI (kg/m^2)	25.4 ± 1.3
∑7 skinfolds (mm)	77.6 ± 20.6
Fitness variables	
40-m sprint time (s)	5.58 ± 0.19
Yo-Yo IRT1 distance (m)	2,367 ± 352
1.2-km Shuttle Run Test time (min:s)	5:04 ± 0:23
HR_{max} (beats·min^{-1})	185 ± 7

Note: SD: standard deviation; BMI: Body mass index; ∑7: sum of 7 skinfold sites; Yo-Yo IRT1: Yo-Yo Intermittent Recovery Test Level 1; HR_{max}: maximum heart rate.

Table 2: Match demand variables in referees officiating during the 2019 Rugby World Cup.

Variable	**Mean ± SD**
Total distance (m)	6,608 ± 509
Average speed ($m \cdot min^{-1}$)	67.9 ± 5.7
Maximum speed ($m \cdot s^{-1}$)	7.4 ± 0.6
HSR distance (m)	601 ± 273
Peak intensity 1-min epoch ($m \cdot min^{-1}$)	183 ± 13
Peak intensity 5-min epoch ($m \cdot min^{-1}$)	111 ± 8
Peak intensity 10-min epoch ($m \cdot min^{-1}$)	92 ± 6
HR_{mean} ($beats \cdot min^{-1}$)	147 ± 6
HR_{mean} (%HR_{max})	79.0 ± 2.5
SHRZ load (AU)	237 ± 26
>90% HR_{max} (min)	9.9 ± 5.4

Note: SD: standard deviation; HSR: high-speed running (>5 $m \cdot s^{-1}$); HR_{mean}: average heart rate; SHRZ: summated-heart-rate-zones; AU: arbitrary units; HR_{max}: maximum heart rate.

FIGURE CAPTIONS

Figure 1: Pearson correlation coefficients (± 95% confidence intervals) between match demand variables and a) 40-m sprint time, b) Yo-Yo Intermittent Recovery Test Level 1 (Yo-Yo IRT1) distance, c) 1.2-km Shuttle Run Test time, d) age, e) sum of 7 skinfold thickness, and f) body mass index (BMI). *Note*: HSR: high-speed running; HR_{mean}: average heart rate; SHRZ: summated-heart-rate-zones load; HR_{max}: maximum heart rate. Correlations are interpreted as unclear when they cross the entire grey area (±0.1). Dotted lines represent correlation thresholds for *small* (0.10-0.29), *moderate* (0.30-0.49), *large* (0.50-0.69), *very large* (0.70-0.89), and *almost perfect* (≥0.90) magnitudes. White markers identify significant correlation coefficients (P <0.05).