International Journal of Kinesiology & Sports Science
ISSN: 2202-946X
www.ijkss.aiac.org.au

Investigating the Internal and External load Associated with Umpiring Semi-professional Australian Rules Football

Corey Wilson*, Mark Scanlan, Colin S. Doherty, Oliver R. Barley
School of Medical and Health Sciences, Edith Cowan University 270 Joondalup Drive, Joondalup WA 6027, Australia
Corresponding Author: Corey Wilson, E-mail: corey.wilson@ecu.edu.au

ARTICLE INFO

Article history
Received: November 25, 2024
Revised: January 13, 2025
Accepted: January 20, 2025
Published: January 30, 2025
Volume: 13 Issue: 1

Conflicts of interest: None.
Funding: None.

ABSTRACT

Background: This investigation examined internal and external load associated with umpiring semi-professional Australian Rules football, an area of limited research. **Objective:** This exploratory quantitative study recruited 39 field umpires (Age: 25.2 ± 6.8 y, Body Mass: 74.6 ± 7.9 kg, Height: 178.9 ± 7.4 cm) from the Western Australian Football League (WAFL). Each participant was assessed in one match only. **Methodology:** External measures (total distance [TD], floating distance [FSD], high-intensity running distance [HSD]) and internal measures (blood lactate [BLa], heart rate [HR], rating of perceived exertion [RPE]) were collected during 22 matches, of the 2023 WAFL season. Data collection was performed before, during, and after the match and significance was set at p = <.05. **Results:** TD (13,027.6 ± 1332.9 m) had significant reductions between Q1 and Q2 (p = 0.029), and Q4 (p = 0.003). FSD (10,411.7 ± 888.6 m) had no significant differences. HSD (1,717.8 ± 613.6 m) had significant reductions between Q1 and Q2, Q3, Q4 (p < 0.001, p = 0.003, p < 0.001). RPE (14 ± 2) had significant reductions between Q1 and Q2 (p = 0.013), Q3 (p < 0.001), and Q4 (p < 0.001). BLa was lowest in Q4 (3.3 ± 1.6 mmol/L). **Conclusion:** This study highlights significant physical demands on umpires, suggesting associations between match progression, TD, HSD, RPE, and BLa, potentially influencing training protocols and talent identification.

Key words: Football, Team Sport, Physiology, Workload

INTRODUCTION

Australian rules football (AF) is a popular national sport with the highest level of competition being the Australian Football League (AFL) (AFL, 2019; League, 2023). AF is played on a grass oval, with field dimensions between 135m to 185m long, and 110m to 155m wide. In a standard game, there are 22 players per team, with 18 on the ground, and the remaining four players being on the interchange bench, which allows rolling substitutions during match play (Hess & Stewart, 1998). Aside from the AFL, there are three state-based, semi-professional competitions, which are the main feeder talent pools for the AFL. These include the South Australian National Football League (SANFL), Victorian Football League (VFL) (includes Queensland and New South Wales AFL reserves teams), and West Australian Football League (WAFL). The state leagues are important in identifying and developing talent at the grassroots level, as well as preparing the best players for a potential career in the AFL.

As AF is a high-intensity invasion sport, it requires multiple disciplines of umpires to officiate and maintain control of the match (Gray & Jenkins, 2010; Janetzki et al., 2021). For a standard game of semi-professional AF, there are three field, three boundary, and two goal umpires on field, plus an emergency umpire on the interchange bench. The field umpires control the game and make decisions on free-kicks and other scenarios, such as restarting play after a goal has been scored (Corrigan et al., 2019). The boundary umpires' job is to judge whether the ball is out-of-bounds during play. The goal umpire's main responsibility is to judge whether the ball has crossed the goal line as a goal (kicked between the two largest posts, worth six points) or a behind (kicked between the largest posts and smaller posts, or the ball hits the largest posts, worth one point). Field umpiring has the most responsibility, and is arguably the most important, of the umpiring disciplines in AF, as they are responsible for the safety of players on the field (Coutts & Reaburn, 2000; Paradis et al., 2016).

Just as AF is a physically demanding sport, so too is the umpiring of matches (particularly field and boundary umpiring). Field umpires will typically cover a total distance (TD) between 10,000 and 15,000 m (Kittel et al., 2019; Paradis et al., 2016), which is comparable to AF players, who cover a TD of 12,939 ± 1,145 m per game (Coutts et al., 2015). Additionally, players have been reported to average 3,880 ± 633 m of high-intensity running distance (HSD) (Coutts et al., 2015), whereas field umpires cover 1,952 ± 494 m per game (Coutts & Reaburn, 2000; Elsworthy et al.,

Published by Australian International Academic Centre PTY.LTD.

http://dx.doi.org/10.7575/aiac.ijkss.v.13n.1p.80

2014; Paradis et al., 2016). External load that has been collected from global positioning systems (GPS) in AF has been relatively well documented at the highest level of competition both playing (Aughey, 2010, 2011; Coutts et al., 2015; Coutts et al., 2010; Delaney et al., 2017; Janetzki et al., 2021) and umpiring the game (Elsworthy et al., 2017; Elsworthy et al., 2014; Elsworthy & Dascombe, 2011; Larkin et al., 2014). However, external load monitoring research at a semi-professional level in AF is severely lacking. The average TD, average HSD (≥5.5m/s), and average jogging (floating) speed running (FSD: between 2.2m/s to 5.5m/s) are three specific data variables that have not been reported in semi-professional field umpires to the best of our knowledge (Coutts & Reaburn, 2000; Jessiman et al., 2020; Paradis et al., 2016). Practitioners and researchers, in turn, have little knowledge of the external loads placed on semi-professional umpires, and must rely on data acquired from the AFL and other football codes. The investigation of semi-professional AF umpires will increase the quality of the talent pools for the AFL, therefore creating umpires better equipped for the elite level. This study represents the first in-depth analysis of these variables, which has the potential to inform umpire training practices by offering insights on typical match demands, as well as improving the training protocols of field umpiring at the semi-professional level.

It is also important to develop a further understanding of internal load during umpiring, which can be assessed by evaluating variables such as blood lactate (BLa), heart rate (HR), and the rating of perceived exertion (RPE). These measures best inform researchers of the physiological exertion umpires experience during matches. While internal loads have been explored across a range of sports including soccer (Impellizzeri et al., 2005), rugby (Sant'anna et al., 2021), basketball (Garcia-Santos et al., 2019) and others (Bloß et al., 2022; Spencer et al., 2020), there is a paucity of research investigating semi-professional AF. For example, the only study on internal loads in AF umpires focuses on the premier division in Sydney (Elsworthy & Dascombe, 2011). Because this division operates as an amateur competition, the data gathered may not be applicable as a benchmark for semi-professional and professional performance. Given that quality umpiring underpins the sport of AF, an understanding of the demands specific to semi-professional (including the necessary physiological attributes), is crucial for cultivating skilled umpires at junior and community levels. Therefore, the purpose of this study was to identify and explore the physical and physiological requirements (external and internal load) of umpiring AF at a semi-professional level, as well as identify any differences in these measures across the duration of a match.

MATERIALS AND METHODS

Participants and Study Design

The exploratory, quantitative study involved one information and experimental session per participant. The experimental session involved measuring internal (HR, BLa, and RPE) and external (TD, HSD, FSD) load. Data was collected during competitive AF games in the WAFL League and Reserves competitions. Data was collected before and after the game, as well as during each break (quarter-time, half-time, three-quarter-time). The lead researcher and two research assistants collected all the data.

For this study, 39 field umpires (Age: 25.2 ± 6.8 y, Experience: 6.8 ± 4.0 y, Body Mass: 74.6 ± 7.9 kg, Height: 178.9 ± 7.4 cm), who are employed by the Western Australian Football commission (WAFC), were recruited. A priori power analysis was performed using G*Power version 3.1.9.7 (Faul et al., 2007) to calculate the minimum sample size needed to test the study hypothesis. The analysis revealed that a sample size of N = 36 was required to achieve 80% power for detecting a medium effect size, with a significance level of α =.05. Therefore, the collected sample size of N = 36 is sufficient for testing the hypothesis. Each participant was required to be over 18 years old and have at least two years' experience umpiring League and/or Reserves AF in the WAFL, or they were excluded from the study. The participants' umpiring experience level (WAFL Reserves, WAFL League, or AFL/AFLW) was recorded prior to data collection. The participants were informed of the study procedures and provided written consent during a pre-testing/information session (described below). Participants were also informed that they could withdraw from the study at any point with no penalty. This prospective cohort study was approved by the Human Research Ethics Committee of Edith Cowan University (2022-03920-WILSON).

Test Procedures

The information session provided participants an opportunity to ask any questions/voice concerns prior to data collection. Consent was also gathered during this meeting. After the study, participants received a gift card of 30AUD for a sporting goods store for their contribution. Match start times were subject to ground availabilities and AFL fixturing. The WAFL season (excluding finals) started on April 7th and finished on August 26th of 2023. During experimental sessions, participant data (height, weight, age, experience), and measurements of internal (HR, BLa, RPE; described below) and external (TD, HSD, and FSD; described below) load were collected.

Intervention Procedures

The internal load variables of HR, BLa, and RPE were collected immediately before the game started, and at the immediate conclusion of each quarter. HR was collected using a chest strap heart rate monitor (Polar H10, Polar, Kempele, Finland) (Elsworthy & Dascombe, 2011). Capillary blood samples were collected using a lancet (Unistik 3 Normal lancets, Owen Mumford, Oxfordshire, United Kingdom). The participant's earlobes were pierced using a lancet (Feliu et al., 2024) before the match started and then three minutes after the conclusion of each quarter. BLa levels were measured using a blood lactate analyser (Lactate Pro2, Arkray, Kyoto, Japan). RPE was recorded using the Borg's Scale of Perceived Exertion (Borg, 1982), which is a rating of

exertion between six (no exertion) and twenty (maximum exertion).

Time motion data (i.e., TD, HSD, and FSD) were continuously measured throughout the matches using the Catapult One (10 Hz) GPS units (Catapult Sports, Melbourne, Victoria, Australia) and analysed afterwards to calculate other variables (quarter-by-quarter TD, HSD, and FSD). The GPS units were fitted into an undergarment (Catapult Sports, Melbourne, Victoria, Australia) worn underneath the participant's normal uniform (Rampinini et al., 2015). The GPS unit continuously recorded the participant's running data, which was turned on 30 minutes prior to the commencement of the game and turned off immediately at the conclusion. The start the start and finish times of the quarters was recorded. Data between quarter breaks was not used and disregarded during data analysis.

Statistical Analysis

The descriptive statistics were reported for each quarter and the entire match to examine external and internal load experienced of the participants. Descriptive statistics was presented as mean (±SD) where applicable. Data was analysed for normality and homogeneity of variances using the Shapiro-Wilk statistic and Levene's test, respectively (Paradis et al., 2016). Continuous measures of internal (HR, BLa) and external (TD, HSD, FSD) load were analysed between quarters using a 1x4 repeated measures analysis of variance (ANOVA) or Friedman's test in the case of non-parametric data. Ordinal data (RPE) was analysed between quarters using ordinal regression. Where differences were observed, post-hoc tests with the Holm-Bonferroni sequential correction adjustment were used to determine the location. Statistical significance was set a-priori as $p<0.05$. The data analysis was performed using Jamovi (version 2.3.12; The Jamovi project, NSW, Australia).

RESULTS

External Load

For external load data, average TD covered across an entire game was 13,027.6 ± 1332.9 m, with Figure 1 displaying the quarter-by-quarter distribution. Figure 1 shows that there were significant differences in TD between Q1 and Q2 (p = 0.029), and Q1 and Q4 (p = 0.003). The Repeated Measures (RM) ANOVA was reported to be F(4, 3) = 5.37, p =.002. Total FSD across an entire game was 10,411.7 ± 888.6 m. No significant differences between quarters were found after post hoc analysis, as shown in Figure 1. The RM ANOVA was reported to be F(4, 3) = 1.15, p = 0.332. Total HSD activity throughout the matches was 1,717.8 ± 613.6 m. HSD was highest in Q1, with $Q1_{MEAN}$ being 498.4 ± 178.6 m, which was significantly greater than Q2, Q3, and Q4 (p = <0.001, p = 0.003, and p = <0.001, respectively), with no other differences between any other quarters observed (Figure 1). The RM ANOVA was reported to be F(4, 3) = 10.2, p = <.001.

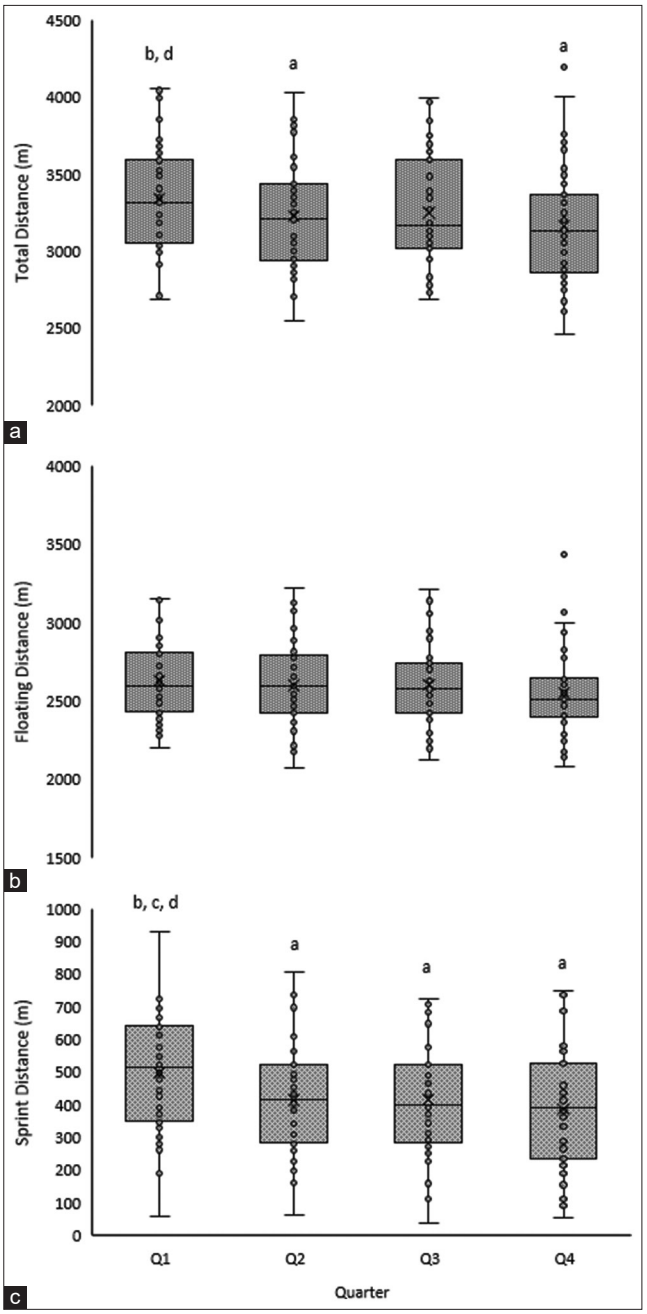

Figure 1. Quarter by quarter results of (a) total distance, (b) floating distance, (c) and sprint distance during semi-professional Australian rules football matches
[a]Significant difference compared with Q1. [b]Significant difference compared with Q2. [c]Significant difference compared with Q3. [d]Significant difference compared with Q4.

The mean distance per minute (m/min) was 120.8 ± 7.4 m/min. Significantly less distance per minute was covered in Q1 compared to Q2 (p = 0.004), Q1 and Q3 (p = <0.001), and Q1 and Q4 (p = <0.001) (Table 1). The RM ANOVA was reported to be F(4, 3) = 10.2, p = <.001. Mean top speed throughout the matches was 26.4 ± 1.8 km/h, with no significant differences observed between any of the quarters. Max deceleration was 6.2 ± 1.6 m/s/s. Max acceleration for the observed dataset was 4.5 ± 1.4 m/s/s. Both max deceleration and max acceleration had no significant differences between quarters (Table 1).

Table 1. Quarter by quarter data (mean±SD) on distance per minute, top speed, maximum deceleration, and maximum acceleration in Australian rules football field umpires (*n*=39).

SPEED	QUARTER				Total
	Q1	Q2	Q3	Q4	
Distance/minute (m/min)	127.3±9.0[b,cd]	122.2±9.5[a]	120.4±9.0[a]	119.7±10.3[a]	120.8±7.4
Top Speed (km/h)	25.2±1.7	24.7±1.6	25.3±2.1	24.7±1.8	26.4±1.8
Max Deceleration (m/s/s)	4.5±1.3	4.1±1.2	4.4±0.8	4.4±1.4	6.2±1.6
Max Acceleration (m/s/s)	4.3±1.1	4.0±0.8	4.2±0.5	4.0±1.0	4.5±1.4

[a]Significant difference compared with Q1. [b]Significant difference compared with Q2. [c]Significant difference compared with Q3. [d]Significant difference compared with Q4.

Internal Load

Average RPE was 14 ± 2. There were significant differences between RPE in Q1 and Q2 (p = 0.013), Q1 and Q3 (p = <0.001), and Q1 and Q4 (p = <0.001) (Figure 2). A Friedman's non-parametric ANOVA revealed significance (χ^2 = 109, p = <.001, df = 4, W =.285). Average BLa across entire matches was 3.91 ± 1.8 mmol/L, with BLa being the lowest in Q4 (3.3 ± 1.6 mmol/L). The RM ANOVA was reported to be F(5, 4) = 36.3, p = <.001. BLa between quarters was significantly different between Q1 and Q2 (p = 0.002), Q1 and Q3 (p = 0.039), and Q1 and Q4 (p = <0.001), as well as Q3 with Q4 (p = 0.041). Total HR mean throughout matches was 163 ± 14 bpm. The RM ANOVA was reported to be F(4, 3) = 2.83, p =.042. Q3 mean was lowest, with bpm of 161 ± 15. HR mean was not significantly different between any quarters (Figure 2).

DISCUSSION

The purpose of this study was to quantify the internal and external load of umpiring competitive semi-professional AF matches and investigate whether differences between quarters exist. There is a scarcity of research in semi-professional AF umpiring, and this is the most comprehensive study to explore and measure the external (i.e., TD, HSD, and FSD) and internal load (i.e., BLa, HR, and RPE) of field umpires during match play. The study's main findings were that external load measures decrease as match-time progresses, and that BLa decreased, RPE increased, and there was no significant difference in HR across the progression of a match.

The TD (13,028 ± 1,333 m) for the matches in this study were higher than the TD in previously reported findings in umpiring (AFL level), whereas FSD (10,412 ± 889 m) and HSD (1,718 ± 614 m) were lower (Elsworthy & Dascombe, 2011). Elsworthy et al. (2014) reported that field umpires cover 10,563 ± 608 m per match, with HSD being reported as 1,952 ± 494 m. The differences observed between previous research and the current study is that in Elsworthy et al (2014), the subject group used AFL field and boundary umpires, and repeated testing with each participant up to four times, as well as using GPS units that were 5Hz instead of 10Hz. As AFL is the highest level of competition of AF, the HSD data from match-play would plausibly be higher than semi-professional umpiring results. Identifying semi-professional external load data gives practitioners in the field a

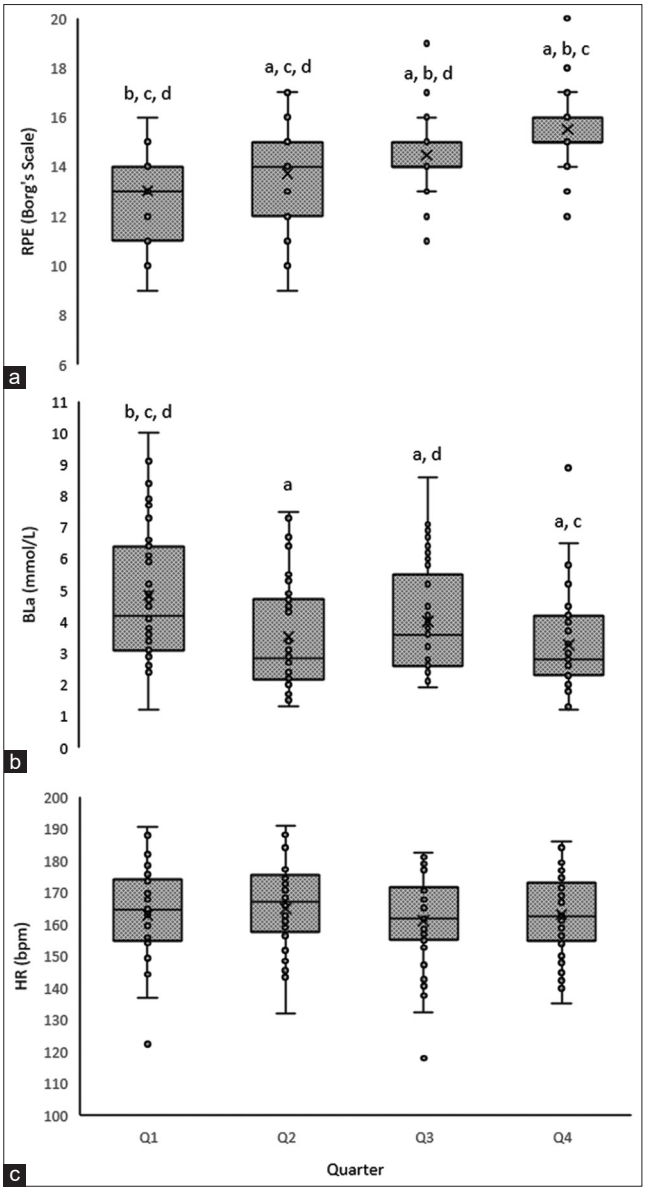

Figure 2. Quarter by Quarter (a) rating of perceived exertion (RPE), (b) blood lactate (BLa), and (c) heart rate (HR) measures during semi-professional Australian rules football matches. Note: RPE, and BLa were taken at the end of each quarter, HR was averaged across each quarter
[a]Significant difference compared with Q1. [b]Significant difference compared with Q2. [c]Significant difference compared with Q3. [d]Significant difference compared with Q4.

greater understanding of the requirements of umpiring AF, which in turn may lead to better suited training practices, hence why AFL research would not be relevant for this application. As well as this, 5Hz GPS units are not as reliable as 10Hz units, with this potentially leading to accuracy issues in HSD results (Rampinini et al., 2015). Lastly, re-measuring participants multiple times would not have produced the greatest understanding of the entire group's (WAFL field umpiring cohort) physical requirements in matches, hence why the research group measured participants once.

As mentioned, AF umpire research is scarce. However, there are countless amounts of research investigating AF players (AFL specifically) (Aughey, 2010; Brewer et al., 2010; Gray & Jenkins, 2010). When our data was compared to results from previous studies exploring running demands of AF players (AFL), HSD data was also lower, whilst TD was higher (Coutts et al., 2010; Delaney et al., 2017). The difference in running demands between AFL players and state-level AF field umpires is obvious, as umpires are only required to observe the match, not play it. Consequently, AFL players perform more HSD efforts per match than umpires. Though it is difficult to draw comparisons as they are different sides of match play, it is still relevant to compare semi-professional umpiring and AF player running data, as the results from the elite level of both playing and umpiring are quite similar due to the nature of following the play (Coutts et al., 2010; Paradis et al., 2016). Alas, the dataset collected works to fill the clear gap in literature surrounding the external load throughout a full match of semi-professional AF.

It was observed that external load measures of TD (3,340.9 ± 354.9 m), FSD (2,628.3 ± 246.5 m), and HSD (498.4 ± 178.6 m), were highest in Q1 of the match. As match progression continued, all three external load measures decreased, though not all were statistically significant. TD (3,160.7 ± 392.1 m), FSD (2,553.3 ± 287.3 m), and HSD (386.6 ± 174.2 m) were all reported as the lowest in Q4 but were not statistically different to Q2 and Q3. Previous research completed by Elsworthy and Dascombe (2011), and Coutts et al. (2010), align with the results of our research, as both studies found that umpire HSD reduced each quarter (AFL research). Reduction in external load distances over the match could be due to a wide range of physiological factors, such as a reduction of muscle glycogen stores (Lattier et al., 2004), dehydration throughout match play (Nuccio et al., 2017), thermal stress (Girard et al., 2015), and a build-up of metabolic by-products (Maclaren et al., 1989) accumulated during aerobic exercise. Within our study, other external measures such as m/min, max acceleration, and max deceleration were also the highest in the first quarter, which could be due to faster game movements completed during the first quarter of an AF match. When exploring external load data, it seems evident that the peak for the various data sets all occur in Q1 of a match whilst in Q4, the data is the lowest. This seems, in the most part, due to a reduction in player activity as games progress, and fatigue that is experienced by both players and umpires. Furthermore, it can be deduced that intensity and speed at the start of an AF match require the field umpires to perform HSD acts more frequently. Intensity and speed then decline as the match continues, as the intensity of the players reduces.

When analysing internal load data, BLa was reported to be greatest in Q1, and lowest in the last quarter (Figure 2). This was in alignment with HSD measures, as both decreased as match time progressed. A continual reduction of BLa throughout a match is not uncommon, with previous research stating that the removal of muscular blood lactate increases as match play progresses in football (Elsworthy et al., 2014; Lattier et al., 2004). There were also no significant differences in HR observed, which aligns with previous research investigating the activity profiles and physical demands of association football referees in international matches (Krustrup et al., 2009). The quarter-by-quarter HR results of the current study are difficult to compare to previous AF research, as Elsworthy and Dascombe (2011) only reported the $\%HR_{MAX}$ of the participants quarter-by-quarter, not specific HR value. As match time progressed, it was observed that RPE continually increased quarter-by-quarter and was significantly highest in Q4. The only other study to explore quarter-by-quarter RPE in a match of AF umpiring is from Elsworthy and Dascombe (2011), which found that within field umpires there is a perceived increase in match difficulty through match progression, with significant increases in RPE being observed (Elsworthy & Dascombe, 2011). Another similar study in association football, investigated the difference between first and second half RPE. The authors found an increase in RPE in field referees in the second half of LaLiga (Spanish first division) matches, from the 2014-2015 season (Castillo et al., 2018). Both studies utilised the psychophysical CR-10 scale, whereas the RPE data collected in this study was executed using the Borg's 6-20 scale. Borg et al. (2006) investigated whether the psychophysical scales such as the CR-10 and CR-100 were more accurate for determining RPE than the 6-20 scale. It was determined that the CR-10 and CR-100 scales may be a more accurate scale of determining RPE for exercise longer than approximately four to six minutes (Borg & Kaijser, 2006). Interestingly, our results (using the Borg's 6-20 RPE scale) were no different to the previously mentioned studies, with a significant increase in RPE being observed from first to second half, and also quarter-by-quarter. This may indicate that the selection of RPE scale is not an important factor. Indeed, previous research investigating field umpires perception of fatigue showed that the umpire's do not perceive themselves to be fatigued after umpiring a match of semi-professional AF (Wilson et al., 2024). However, further investigation into RPE measures in semi-professional AF field umpires using psychophysical scales should be conducted, which may present more accurate self-perceived exertion data and give researchers a clearer picture of the fatigue accumulated by umpires. Nonetheless, the RPE data further shows that a possible association between increased external load (TD, HSD, FSD) and a perceived increase in fatigue in field umpires may exist, with further research needed to identify whether there is a relationship between the two.

As with previous research, there are acknowledged limitations in the study and presented results. The study was not conducted at the same ground, with the WAFL competi-

tion utilising eight AF grounds, with each of these grounds having slightly different dimensions (all are within standard AF ground dimensions, however). As participants were only measured once, it is possible reliability issues could occur. However, this was done to gain the greatest understanding of the WAFL field umpire group's physical and physiological capacities. The WAFL League competition has moved to the four-umpire model, with there being four field umpires on ground officiating the match. At the time of data collection, the WAFL League competition utilised the three-umpire system. With the four-umpire system now in place, it would be necessary to investigate whether any differences exist between the two systems.

The implications of this study are varied, with there being multiple uses for the results investigated in this project. For instance, the addition of a fourth field umpire may be beneficial in semi-professional competitions, as this would prepare field umpires (and up and coming players) for the playing environment of the AFL. The AFL utilised a fourth field umpire as of the 2023 season, with the aim of decreasing umpire fatigue. The magnitude of match load reduction has allowed some umpires to manage multiple games over a shorter period than was previously possible. This would, in turn, further develop field umpires to advance to the professional landscape. Having four field umpires officiate semi-professional matches would likely reduce the amount of external load experienced. As well as this, implementing he four-umpire system in lower competitions (amateur, talent pathways, futures competitions) may further develop the skills of talent pathway umpires, in turn, increasing umpire performance at the highest level. However, given there is minimal research on using four field umpiring, this is an area that should be investigated.

Conclusion

In summary, the results of this study are the first of its kind to explore the physiological effects of umpiring a match of semi-professional AF. The main effects observed from the data collection an apparent trend between match progression and TD, HSD, RPE, and BLa. TD, HSD, and BLa decreased as match length progressed, whilst RPE significantly increased quarter-by-quarter. Furthermore, it was discovered that field umpires exert the highest external load in the first quarter of the match, and the least amount in the last. A potential association between HSD and BLa was observed, with both measures decreasing with one another. Future studies in the area should examine the relationship between the four-umpire system and physiological load throughout AFL umpiring and investigate as to whether there are any other internal factors contributing to a reduction of umpire running performance.

DECLARATIONS

Ethics Approval and Consent to Participate

The Human Research Ethics Committee of Edith Cowan University serves as the central institutional review board for this study (2022-03920-WILSON). Participants were also informed that they could withdraw from the study at any point with no penalty.

Consent for Publication

Not applicable.

Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author, CW. The data is not publicly available due to the conditions of ethical approval for this study.

Competing Interests

There were no competing interests in the duration of this study for any of the authors.

Funding

There was no funding for this study.

Author Contributions

OB, MS, and CW conceived of and designed the study. CW and CD collected and processed all the data. CW and CD completed the data analysis. CW, OB, CD, and MS drafted the manuscript. All authors edited and revised the manuscript before approving the final version.

Acknowledgements

The authors would like to thank the West Australian Football League field umpiring group, in particularly Duncan Bradbury, for his extensive help with the project, as well as Justin Orr, David Yole, Dean Margetts, and the members of the WANFLUA. Additionally, Cody Hoffmeister and Aidan Dallimore must be thanked for their invaluable help during the data collection period. There were no conflicts of interest for this project.

ABBREVIATIONS

AF: Australian rules football
AFL: Australian Football League
ANOVA: Analysis of variance
BLa: Blood lactate
FSD: Floating distance
GPS: Global positioning system
HR: Heart rate
HSD: High-speed running distance
Q1: First quarter
Q2: Second quarter
Q3: Third quarter
Q4: Fourth quarter
RPE: Rating of perceived exertion
TD: Total distance

WAFC: West Australian Football Commission
WAFL: West Australian Football League

REFERENCES

AFL. (2019). *History of Football*. https://www.afl.com.au/about-afl/history

Aughey, R. J. (2010). Australian football player work rate: evidence of fatigue and pacing? *International Journal of Sports Physiology and Performance*, *5*(3), 394-405. https://doi.org/10.1123/ijspp.5.3.394

Aughey, R. J. (2011). Increased high-intensity activity in elite Australian football finals matches. *International Journal of Sports Physiology and Performance*, *6*(3), 367-379. https://doi.org/10.1123/ijspp.6.3.367

Bloß, N., Loffing, F., Schorer, J., & Büsch, D. (2022). Impact of psychological and physical load on the decision-making of top-class handball referees. *International Journal of Performance Analysis in Sport*, *22*(3), 352-369. https://doi.org/https://doi.org/10.1080/24748668.2022.2061323

Borg, E., & Kaijser, L. (2006). A comparison between three rating scales for perceived exertion and two different work tests. *Scandinavian Journal of Medicine and Science in Sports*, *16*(1), 57-69. https://doi.org/10.1111/j.1600-0838.2005.00448.x

Borg, G. A. (1982). Psychophysical bases of perceived exertion. *Medicine & Science in Sports & Exercise*, *14*(5), 377-381. https://www.ncbi.nlm.nih.gov/pubmed/7154893

Brewer, C., Dawson, B., Heasman, J., Stewart, G., & Cormack, S. (2010). Movement pattern comparisons in elite (AFL) and sub-elite (WAFL) Australian football games using GPS. *Journal of Science and Medicine in Sport*, *13*(6), 618-623. https://doi.org/10.1016/j.jsams.2010.01.005

Castillo, D., Castagna, C., Camara, J., Iturricastillo, A., & Yanci, J. (2018). Influence of Team's Rank on Soccer Referees' External and Internal Match Loads During Official Matches. *The Journal of Strength & Conditioning Research*, *32*(6), 1715-1722. https://doi.org/10.1519/JSC.0000000000002040

Corrigan, S. L., Dwyer, D. B., Harvey, B., & Gastin, P. B. (2019). The influence of match characteristics and experience on decision-making performance in AFL umpires. *Journal of Science and Medicine in Sport*, *22*(1), 112-116. https://doi.org/10.1016/j.jsams.2018.06.005

Coutts, A. J., Kempton, T., Sullivan, C., Bilsborough, J., Cordy, J., & Rampinini, E. (2015). Metabolic power and energetic costs of professional Australian Football match-play. *Journal of Science and Medicine in Sport*, *18*(2), 219-224. https://doi.org/10.1016/j.jsams.2014.02.003

Coutts, A. J., Quinn, J., Hocking, J., Castagna, C., & Rampinini, E. (2010). Match running performance in elite Australian Rules Football. *Journal of Science and Medicine in Sport*, *13*(5), 543-548. https://doi.org/10.1016/j.jsams.2009.09.004

Coutts, A. J., & Reaburn, P. R. (2000). Time and motion analysis of the AFL field umpire. Australian Football League. *Journal of Science and Medicine in Sport*, *3*(2), 132-139. https://doi.org/10.1016/s1440-2440(00)80075-4

Delaney, J. A., Thornton, H. R., Burgess, D. J., Dascombe, B. J., & Duthie, G. M. (2017). Duration-specific running intensities of Australian Football match-play. *Journal of Science and Medicine in Sport*, *20*(7), 689-694. https://doi.org/10.1016/j.jsams.2016.11.009

Elsworthy, N., Burke, D., & Dascombe, J. B. (2017). Factors relating to the decision-making performance of Australian football officials. *International Journal of Performance Analysis in Sport*, *14*(2), 401-410. https://doi.org/10.1080/24748668.2014.11868730

Elsworthy, N., Burke, D., Scott, B. R., Stevens, C. J., & Dascombe, B. J. (2014). Physical and decision-making demands of Australian football umpires during competitive matches. *The Journal of Strength & Conditioning Research*, *28*(12), 3502-3507. https://doi.org/10.1519/JSC.0000000000000567

Elsworthy, N., & Dascombe, B. J. (2011). The match demands of Australian rules football umpires in a state-based competition. *International Journal of Sports Physiology and Performance*, *6*(4), 559-571. https://doi.org/10.1123/ijspp.6.4.559

Faul, F., Erdfelder, E., Lang, A.-G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods*, *39*(2), 175-191.

Feliu, J., Ventura, J. L., Segura, R., Rodas, G., Riera, J., Estruch, A., Zamora, A., & Capdevila, L. (2024). Differences between lactate concentration of samples from ear lobe and the finger tip. *Journal of Physiology and Biochemistry*, *55*(4), 333-339. https://doi.org/10.1007/bf03655586

Garcia-Santos, D., Pino-Ortega, J., Garcia-Rubio, J., Vaquera, A., & Ibanez, S. J. (2019). Internal and External Demands in Basketball Referees during the U-16 European Women's Championship. *International Journal of Environmental Research and Public Health*, *16*(18), 3421. https://doi.org/10.3390/ijerph16183421

Girard, O., Brocherie, F., & Bishop, D. J. (2015). Sprint performance under heat stress: A review. *Scandinavian Journal of Medicine and Science in Sports*, *25 Suppl 1*, 79-89. https://doi.org/10.1111/sms.12437

Gray, A. J., & Jenkins, D. G. (2010). Match analysis and the physiological demands of Australian football. *Sports Medicine*, *40*(4), 347-360. https://doi.org/10.2165/11531400-000000000-00000

Hess, R., & Stewart, B. (1998). *More than a game: The real story of Australian Rules football*. Melbourne University.

Impellizzeri, F. M., Rampinini, E., & Marcora, S. M. (2005). Physiological assessment of aerobic training in soccer. *Journal of Sports Sciences*, *23*(6), 583-592. https://doi.org/10.1080/02640410400021278

Janetzki, S. J., Bourdon, P. C., Norton, K. I., Lane, J. C., & Bellenger, C. R. (2021). Evolution of Physical Demands of Australian Football League Matches from 2005 to

2017: A Systematic Review and Meta-Regression. *Sports Medicine Open*, *7*(1), 28. https://doi.org/10.1186/s40798-021-00301-1

Jessiman, S. W., Harvey, B., Corrigan, S. L., & Gastin, P. B. (2020). Training and Competition Activity Profiles of Australian Football Field Umpires. *The Journal of Strength & Conditioning Research*, *34*(10), 2956-2964. https://doi.org/10.1519/JSC.0000000000002926

Kittel, A., Larkin, P., Elsworthy, N., & Spittle, M. (2019). Identification of key performance characteristics of elite Australian football umpires. *International Journal of Sports Science & Coaching*, *14*(4), 490-497. https://doi.org/10.1177/1747954119845071

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/10.1080/02640410903220310

Larkin, P., O'Brien, B., Mesagno, C., Berry, J., Harvey, J., & Spittle, M. (2014). Assessment of decision-making performance and in-game physical exertion of Australian football umpires. *Journal of Sports Sciences*, *32*(15), 1446-1453. https://doi.org/10.1080/02640414.2014.896998

Lattier, G., Millet, G. Y., Martin, A., & Martin, V. (2004). Fatigue and recovery after high-intensity exercise. Part II: Recovery interventions. *International Journal of Sports Medicine*, *25*(7), 509-515. https://doi.org/10.1055/s-2004-820946

Laws of Australian Football, (2023).

Maclaren, D. P., Gibson, H., Parry-Billings, M., & Edwards, R. H. (1989). A review of metabolic and physiological factors in fatigue. *Exercise and Sport Sciences Reviews*, *17*(1), 29-66. https://www.ncbi.nlm.nih.gov/pubmed/2676550

Nuccio, R. P., Barnes, K. A., Carter, J. M., & Baker, L. B. (2017). Fluid Balance in Team Sport Athletes and the Effect of Hypohydration on Cognitive, Technical, and Physical Performance. *Sports Medicine*, *47*(10), 1951-1982. https://doi.org/10.1007/s40279-017-0738-7

Paradis, K., Larkin, P., & O'Connor, D. (2016). The effects of physical exertion on decision-making performance of Australian football umpires. *Journal of Sports Sciences*, *34*(16), 1535-1541. https://doi.org/10.1080/02640414.2015.1122205

Rampinini, E., Alberti, G., Fiorenza, M., Riggio, M., Sassi, R., Borges, T. O., & Coutts, A. J. (2015). Accuracy of GPS devices for measuring high-intensity running in field-based team sports. *International Journal of Sports Medicine*, *36*(1), 49-53. https://doi.org/10.1055/s-0034-1385866

Sant'anna, R. T., Roberts, S. P., Moore, L. J., Reid, A., & Stokes, K. A. (2021). Rugby union referees' physical and physiological demands across different competitive levels. *Journal of Sports Medicine and Physical Finess*, *61*(6), 788-796. https://doi.org/10.23736/S0022-4707.20.11447-6

Spencer, K., Paget, N., Farley, O. R. L., & Kilding, A. E. (2020). Activity Profile of Elite Netball Umpires During Match Play. *The Journal of Strength & Conditioning Research*, *34*(10), 2832-2839. https://doi.org/10.1519/JSC.0000000000003248

Wilson, C., Scanlan, M., Bradbury, D. G., & Barley, O. R. (2024). Intervention Accuracy and Perception of Fatigue in State-Level Australian Football Umpires. *International Journal of Sports Science & Coaching*, 17479541241289077. https://doi.org/10.1177/17479541241289077