Peak locomotor intensity in Elite Handball players: a first insight into player position 1 differences and training practices

Article *in* The Journal of Strength and Conditioning Research · January 2022

5 authors, including:

Antoine Fleureau
French Institute of Sport (INSEP)
2 PUBLICATIONS **8** CITATIONS

Cedric Leduc
Leeds Beckett University
23 PUBLICATIONS **166** CITATIONS

Martin Buchheit
Paris Saint Germain Football Club
250 PUBLICATIONS **15,600** CITATIONS

Mathieu Lacome
Parma Calcio 1913
52 PUBLICATIONS **625** CITATIONS

Title: Peak locomotor intensity in Elite Handball players: a first insight into player position differences and training practices.

A. Fleureau[1,2], G. Rabita[2], C. Leduc[1,3], M. Buchheit[2,4,5,6], M. Lacome[1,2]
[1]*Performance Department, Paris Saint Germain, Saint-Germain-En-Laye, France.*
[2]*Research Department, Laboratory Sport, Expertise and Performance (EA 7370), French Institute of Sport (INSEP), Paris, France.*
[3]*Carnegie Applied Rugby Research (CARR) centre, Carnegie School of Sport, Leeds Beckett University, Leeds, United Kingdom*
[4]*HIITScience, Revelstoke, BC, Canada*
[5]*Institute for Health and Sport, Victoria University, Melbourne, VIC, Australia*
[6]*Kitman Labs, Performance Research Intelligence Initiative, Dublin, Ireland*

Running head: Peak locomotor intensity in Handball
Abstract count: 251
word count: 3500
Number of figures and Tables: 1 Figure and 3 Tables
Supplemental digital content: 5 Tables

Abstract:

The aims of the study were to 1) describe the peak locomotor intensity sustained during handball matches and 2) compare them with small-sided games (SSGs) programmed during training in elite handball players. SSG (n=342) and match (n=121) data were collected among 11 players (25±7y, 191±8cm, 89±12kg) belonging to an elite French Handball team. Players' locomotor activity was recorded using 20-Hz Local Positioning System. Peak total (TD[m]) and high-speed running distance (HS[m]), and mechanical load (Accel'Rate™ [a.u.]) were calculated during different time periods (1 to 15 min different rolling averages). A plot of log (locomotor variables) against log (time) allowed to obtain a straight line with a slope and an intercept for each variable. Between-position differences during matches and difference between matches and SSGs were assessed with linear mixed model and magnitude-based decisions. Almost certainly higher peak locomotor intensity (intercept) was found in Wingers (TD: 156±13; HS: 96±12; Accel'Rate™: 13±3) compared with other playing positions for TD (Back players: 127±10; Pivots: 136±13), HS (Back players: 56±9; Pivots: 57±11) and Accel'Rate™ (Back players: 11±2; Pivots: 11±2). However, no clear between-position difference was found regarding the slope. Additionally, none of the SSGs format produced an overload in peak locomotor intensity in comparison with matches (TD: 138±16; HS: 66±20; Accel'Rate™: 12±2). Since reaching the peak locomotor intensity sustained during match is not possible using SSGs, practitioners should consider using isolated conditioning drills (e.g., short or long intervals, repeated sprints, etc.). Moreover, specific attention should be paid for Winger's work supplementation, as they present the highest peak locomotor intensity in the team.

Key Words:

Match demands; team sport; small-sided games; monitoring

Introduction:

The recent development and validation of wearable local positioning system (LPS) has opened up a new area in handball players' monitoring [1]. Undeniably, the interest for this technology to describe more accurately match and training demands is growing exponentially [2].

Handball is a strenuous contact Olympic team sport that places emphasis on running, jumping, sprinting and a range of high-intensity upper-body actions over 2 halves of 30 minutes, interspersed by a 10-min half-time break [3]. Previous studies have investigated match demands (e.g., total distance, high intensity events) through time-motion analyses, over either the entire match or shorter arbitrary time periods (e.g., block of 15min) [4-8]. These demands were described both in absolute and relative to minutes played [4-8]. While those segmental approaches provide meaningful primary information for practitioners, it is likely that such methods underestimate the peak locomotor intensity fluctuations that can occurs over short periods of time (e.g., over 1-5 min) [4, 9-14]. Handball being highly intermittent in nature, with lots of interchanges, failure to consider peak activity demands may biases training prescription, which may in turn underprepare athletes to competition [15]. Moreover, consideration about the likely between-player (or position) differences in peak activity is also required [4].

One of the main applications of the analysis of peak locomotor intensity demands over shorter periods of time during matches, is their comparison with the intensities reached during specific small-sided games (SSGs) during training. While the occurrences and intensity of actions is likely time-dependent (i.e., the longer the period, the lower the average intensity), the comparison between match and training activity remains difficult [16]. Expressing whole-match running performance relative to minutes played is a first step to allow comparisons with training intensities [15], but using rolling averages have been recently suggested to be more appropriate, since it allows quantifying the peaks locomotor intensity over shorter periods of time [14, 17, 18]. While this approach has been widely investigated in outdoor team sport [19], little is known in elite handball player. With this method, locomotor intensity vs. time relationship during matches can be modelled using a power law relationship and can then be compared with SSGs activity. While some training drills have been deemed suitable to develop aerobic fitness [3, 20], SSGs prescription has always been driven by technical and tactical content [21]. Consequently, the comparison between match peak intensity and what is achieved by players during SSGs would help to optimise training prescription.

Therefore, the purpose of this study was to 1) characterise the match peak locomotor intensity demands in elite handball, with a specific reference to players' positions and 2) compare the peak intensity demands of SSGs with these reached during official matches.

Methods:

Experimental Approach to the Problem:

A retrospective observational research design was employed to characterise peak locomotor activity during both match and small-sided games. All match data were collected during official competitions (French 1st division Star League, n=19 matches and European Champion's League, n=18 matches) for a total of 121 player-match observations. Only data from players who completed the equivalent or more than one half of the match were included [6].

Regarding SSGs, data were collected in-season during typical training sessions, in the same facility as the one where matches were played, for a total of 342 player-SSGs observations. The three SSGs formats selected for the present analysis were chosen because they were very regularly used by the coaching team and therefore, remained those for which the analysis provides the greatest level of information for programming. The chosen SSGs where: 1) 4v4 played on a 12x12m surface + 1 Goalkeeper (GK), 2) 6v6 played on half field (6v6HF) + 1GK, 20×20m, half field and 3) 6v6 played on the full field (6v6FF) + 2GKs, 40×20m, full field. The details of each SSG are provided in Table 1.

To further contextualize the demands of the different SSGs and match play, the locomotor demands of a typical run-based high-intensity interval training (HIIT) drill was examined as a unique example. The running intensity of the runs was based on the velocity ($km \cdot h^{-1}$) achieved at the end of the 30-15 Intermittent Fitness Test (V_{IFT}) [22].The HIIT drill consisted of 2 sets of 6 min, with 2 min of rest between sets. Each 6 min of exercise consisted of 2 min of running, 2 min of specific high-intensity movements and another 2-min period of running. The 2-min running sequence was composed of 30-s runs at 100% V_{IFT}, interspersed with 30 s of passive recovery, 15-s runs at 110% V_{IFT}, interspersed with 15 s of passive recovery, 5-s runs at 120% V_{IFT}, interspersed with 25 s of passive recovery. The high-intensity movements sequence included throw in, short sprint, including changes of direction.

Insert Table 1 here

Subjects:

Data were collected among 11 players (25±7 years, 191±8 cm, 89±12 kg) from one French 1st division handball team during two consecutive seasons (2018-2019 and 2019-2020), including officials matches and training sessions. Only data from players who played at least 30 minutes during matches were included to limit the effect of possible performance increment according to low playing time [14, 17]. Moreover, only players who completed the whole duration of a training session were included in the analysis [17]. Players were grouped according to their playing position (Wingers [n=4], Pivots [n=3], Back players [n=4]). These data arose from the daily player monitoring in which player activities were routinely measured over the course of each season. Therefore, ethics committee clearance was not required [23]. Nevertheless, the study conformed to the recommendations of the Declaration of Helsinki.

Procedures:

For both matches and SSGs, players' activity was recorded using a 20-Hz LPS system and 100-Hz embedded accelerometer devices (Kinexon™, Kinexon GMBH, Munich, Germany) [1]. The Kinexon™ Ultrawide band (UWB) system consisted of 14 antennas, positioned around the handball playing field at three different heights, and tags worn by the players in the centre of the upper back, using the manufacturer harness. The signals were transmitted to the antennas using UWB technology in a frequency range of 4.25-7.25 GHz. The field position of the tag was calculated by a proprietary algorithm based on a combination of different methods such as Time Difference of Arrival, Two-Way Ranging and Angle of Arrival (Kinexon GmbH, Germany). Data were processed by the specific Kinexon™ software to obtained total (TD, m) and high-speed running distance (HS, distance run at a velocity above 14.5 $km \cdot h^{-1}$). The validity of the Kinexon™ LPS device have been established and showed small standardised typical error of estimate (from 0.06 to 0.48) compared with 3-dimensions motion capture (Vicon®) for sprint, lateral and specific handball movements [1, 24]. Additionally, inter-unit coefficient of variation was reported to range from 2.1 to 9.2% [24].

Data Processing. Additionally, we calculated the Accel'Rate™ (a.u.) from the raw inertial data (100-Hz) as an overall measure of mechanical load [25]. Accel'Rate™ was calculated as follow:

$$Accel'Rate = \left| \sqrt{(a_{x_i})^2 + (a_{y_i})^2 + (a_{z_i})^2} - \sqrt{(a_{x_{i-1}})^2 + (a_{y_{i-1}})^2 + (a_{z_{i-1}})^2} \right|$$

where ax is the mediolateral acceleration, ay is the anteroposterior acceleration and az is the vertical acceleration. Accel'Rate™ was processed with customised script in R Studio (Version R-4.0.2, R Foundation for Statistical Computing). These instantaneous values were summed to obtain the global workload of the players during the session analysed. For more readability, the final value obtained was divided by 100. This variable was chosen because the Accel'Rate™ was recently shown to better reflect the mechanical load than the classical PlayerLoad™. [25].

Power Law modelling. To be able to compare the data of players with different minutes of play, all the data were first reported by minutes (i.e., m·min-1 and a.u.). Peak locomotor intensities were analysed during different rolling average periods (0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 and 15 min). To estimate the decline in match and training intensity as duration increased, each measure of exercise intensity (i.e., TD, HS and Accel'Rate™) was assessed relative to the rolling average duration as a power-law relationship [14, 26, 27] for each individual observation. This analysis was not possible for HIIT training sessions as they do not follow a power-law type of relationship, due to their programming approach (i.e., prescribed intensity). A power law curve describes non-linear but clearly dependent relationships between two variables (x and y) and can be given by the equation: $y = cx^n$ where n and c are constants. A plot of log (locomotor variables) against log (time) allowed to obtain a straight line with a slope (n) and an intercept of c^e [14, 26, 27]. Linear regressions were used, to reveal the values for n and c, for each measured variable (TD, HS and Accel'Rate™) and each condition (3 SSGs and matches), The exponential of c was calculated, and therefore, a predictive equation of running intensity (i) as a function of time (t) was achieved, using the formula: $i = ct^n$. As such, running intensity was deemed to be proportionately related to the duration of the moving average window (i.e., time). Moreover, this approach has been used previously in the field of team sport, such as rugby [14, 28] and soccer [17]. While physical output in team sports will always be dependent on game context and events [29], the intercept established from the power law relationship reflects the theoretical highest intensity that occurs during match and training as time approaches 1 min [14, 17]. The slope represents the rate of decline in peak locomotor intensity as exercise duration increases. These slope and intercept values were used for the analysis.

Statistical analysis:

The Kolmogorov-Smirnov normality test was performed to verify the distribution of each variable included in the analysis. For each variable, back transformed data were used for the descriptive statistics (mean ± SD and range).

The first step of the analysis aimed to examine the overall peak locomotor intensity of different variable (TD, HS and Accel'Rate™) and assessed for potential difference between positions during competitive match-play. Slope and intercepts for each locomotor variable were first compared using linear mixed model where player positions were treated as fixed effect, while players were considered as a random factor [30]. The second set of linear mixed models aimed to investigate the difference in intercepts and slopes for each variable between matches and SSGs. Therefore, the event (matches or SSGs) was considered as fixed, while players were considered as a random factor [30].

Statistical analyses were performed using R statistical software (R. 3.1.0, R Foundation for Statistical Computing) using the *lme4* package. Each model was further investigated with standardised differences (ES), based on Cohen's effect size principle. Standardisation was performed with the estimated marginal means and associated variance provided by the generalised linear model. Threshold values for standardised differences were (trivial) <0.2 (small) <0.6 (moderate) <1.2 (large) <2 and very large (>2), as describe by Hopkins [31].

Probabilities were used to make a qualitative probabilistic mechanistic inference about the true differences in the changes, which were assessed in comparison to the smallest worthwhile change (0.2 × pooled SDs). The scale was as follows: 25-75%, possible; 75-95%, likely; 95-99%, very likely; >99%, almost certain [32].

Results:

Between-player differences in peak locomotor intensity during competitive matches

The intercepts and slopes for each locomotor variable and position are provided in Figure 1 and Table 2. All rolling average periods for each position are provided in supplemental material.

Insert Figure 1 here

Insert Table 2 here

During competitive matches, Back players sustained almost certainly higher TD intensity than Pivots (ES ± 90% Confidence Limits: 0.60 ± 0.35), while no meaningful difference was observed for HS (0.0 ± 0.03) and Accel'Rate™ (0.20 ± 0.16) intensity. Back players also presented an almost certainly lower TD (1.0 ± 0.38), HS (3.20 ± 0.38) and Accel'Rate™ (0.70 ± 0.38) intensity than Wingers. The same results were found when comparing Pivots with Wingers (TD: 1.80 ± 0.40, HS: 3.10 ± 0.40 and Accel'Rate™: 0.70 ± 0.39).

Differences between competitive matches and SSGs in peak locomotor intensity

Differences between matches and SSGs format with regard to intercepts and slopes for each locomotor variable are provided in Table 3. All rolling average periods for each SSGs, and position are provided in supplemental material (cf. Tables 1 to 5 in supplemental materials).

The comparison of HIIT and match outputs showed players to cover significantly more distance at high intensity (ES >2 for all variables). TD was 1.5 to 1.8 times greater; HSR, 2.1 to 3.4 times greater; and AR, 1.6 to 2 times greater during HIIT. The TD intensity intercept during competitive matches were *almost certainly* superior to all SSGs (6v6FF: 1.74 ± 0.20; 6v6HF: 3.56 ± 0.22; 4v4: 3.68 ± 0.21). Moreover, an *almost certainly* lower slope value was observed for 6v6FF compared with matches (-0.59 ± 0.18). Trivial differences were found regarding 6v6HF (0.17 ± 0.17) and 4v4 (-0.09 ± 0.16) for TD slope when compared with matches. Regarding HS, intercepts were *almost certainly* higher during matches than during SSGs (6v6FF: 1.33 ± 0.19; 6v6HF: 4.21 ± 0.27; 4v4: 5.94 ± 0.30). An *almost certainly* greater HS intensity slope was observed for 6v6FF (-0.76 ± 0.18) compared with that of the matches. However, *almost certainly* lower HS intensity slope were observed for 6v6HF (1.97 ± 0.20) and 4v4 (1.90 ± 0.19) when compared with matches. Lastly, competitive matches presented almost certainly higher Accel'Rate™ intensity intercept than all SSGs (6v6FF: 1.33 ± 0.19; 6v6HF: 3.31 ± 0.21; 4v4: 3.25 ± 0.20). Regarding the Accel'Rate™ slope, an *almost certainly* higher difference was observed for 6v6FF (-0.21 ± 0.18) while almost certainly to possibly lower values were found for 4v4 (0.21 ± 0.16) and 6v6HF (0.37 ± 0.16) respectively when compared with matches.

Insert Table 3 here

Discussion:

The aim of the study was to characterise the peak locomotor intensity with a specific reference to players' positions and to assess if SSGs can allow players to reach similar peak locomotor intensity than during matches in elite handball.

The main findings of the study were: 1) peak locomotor intensity during matches displayed moderate-to-large between-positions differences, with Wingers demonstrating the highest peak locomotor intensity and 2) the peak locomotor intensity during the 3 selected SSGs formats were moderately-to-largely lower than during matches.

Between-player differences in peak locomotor intensity during competitive matches

This study is the first to examine the peak locomotor intensity of elite handball players with regard to playing positions during competitive matches. Overall, Wingers demonstrated higher peak locomotor intensity during matches for all variables (i.e., TD, HS and Accel'Rate™) compared with Back and Pivots. These differences with previous studies [4, 6, 7], where Back players presented the highest TD and mechanical load (i.e., PlayerLoad™) are not surprising as they investigated overall locomotor activity - while the present study described peak intensity. This, further highlight the importance of the method employed when investigating match demands. For example, when considering the running intensity (TD) over 15-min windows, our present results were similar to those reported by Póvoas et al. for the whole match duration (81 ± 7 vs. 82 ± 15 $m \cdot min^{-1}$) [33]. However, when comparing the peak locomotor intensity (127 to 156 $m \cdot min^{-1}$), TD to was actually 1.7 to 2.4 times higher than that reported in previous studies [5, 8, 33, 34]. This seems logical as peak running intensity is influenced by the length of the rolling average window [14]. Therefore, practitioners might need to consider those shorter duration of analysis in order to provide training program matching the actual locomotor activity experienced by player during matches [6, 7, 34]. Despite the difference in methods used and focus (i.e., activity intensity vs volumes), our conclusions echo those of previous studies, where wingers presented the highest HS volumes in comparison with the other positions [4, 8, 35]. This highlights the large level of specificity of the Winger position (e.g., running back and forth over the full court length). Therefore, due to the highest TD, HS and Accel'Rate™ observed, training programs may need to be individualised for them, by including for example top-up running sequences. However, it is worth mentioning that despite the high specificity of locomotor actions for each position (e.g., holding a position in the opponent's defence for Pivots or multiple accelerations and deceleration for Back players) similar mechanical loads intensity was observed. While the calculation method is different than that of previous studies using PlayerLoad™, it is not a surprise to find similar results between Pivots and Back players regarding TD (127 ± 10 vs. 136 ± 13 respectively) and mechanical load (11 ± 2 vs. 11 ± 2 respectively) due to the multicollinearity between those two variables [36, 37]. Despite the similar observed peak locomotor intensities (at the quantitative level), the positions require different actions (qualitative analysis) [4]. For example, back players repeat more high-intensity tasks (i.e., accelerations, decelerations, changes of direction and jumps) while pivots make more high-intensity quasi-isometric actions during blocks [4, 38]. Consequently, this highlights the importance to combine LPS with accelerometer data as they both provide different information about players' locomotor activity.

Differences between match and SSGs in peak locomotor intensity

In the present study, the overall locomotor intensity (TD and HS) and mechanical load (i.e., Accel'Rate™) during typical SSGs never reached the intensity observed during matches. This is contrary to what has been shown in different team sports [17, 21, 39-41]. Indeed, in soccer, it has been shown that a 10v10 was able to reach similar or higher intensity than matches [17]. Contrary to Lacome et al. [17], the present study included only competitive matches (e.g., round 16 and quarter-final of European Champions league cup). Moreover, in elite handball, congested fixtures (e.g., a match every 3-4 day over 30 weeks) could lead to a high magnitude of neuromuscular fatigue [42] and therefore might minimise the opportunity to perform training sessions at similar intensity than matches. Consequently, the use of SSGs might be only used for technical and tactical purposes, explaining the present results. From a practical standpoint, if match intensity is difficult to reach through SSGs in-season [43], practitioners could use isolated running drills (e.g., short or long interval, repeated sprint training) in order to reach similar or higher peak locomotor intensity than matches (as shown in Figure 1) – but only if the fixtures allow it.

It is worth mentioning that several limitations remain. The present results may be exclusively representative of the players (e.g., only 11 players) and the coaching style of the team examined in the present study. Indeed, different results could have been observed with other teams using different tactical systems, which could directly influence peak locomotor intensity [44]. Consequently, caution should be taken when generalizing those results to other contexts. Additionally, only three types of SSGs were used. It is likely that other formats including different pitch size, number of players, rules, inclusion of contacts or not could lead to different results and still require further investigations. Finally, the similar Accel'Rate™ observed in both Back and Pivots, despite clearly different activity types shows the limitation of the variable that is not (yet) able to identify the nature of the movement. Consequently, future studies using recent video analysis systems for example [45, 46] may provide further insights into player's locomotor activity. Finally, characterising the difference between handball and soccer players in the external load match demands requires a deeper knowledge of the handball activity, especially regarding the evolution of internal load during competition. Indeed, previous studies have shown that handball players spend less than 10% of their playing time below 60% of their maximum heart rate and more than 50% of their playing time above 80% of their maximum heart rate [4] which is similar with results observed in soccer [47]. The analysis of heart rate through the approach of peak intensities, which has never been conducted before, could provide answers.

To conclude, the peak locomotor intensity (i.e., running activity and mechanical load) of competitive matches in elite handball players was assessed for the first time and further compared with typical SSGs. The results highlighted some differences between positions (i.e., Back, Pivots and Wingers) and variables (i.e., TD, HS, Accel'Rate™), with Wingers presenting the highest peak locomotor intensity. However, none of the SSGs examined in the study allowed players to reach the peak locomotor intensity observed during matches. This novel information can be used to individualise players physical preparation and improve the overall training load management of elite handball players. Future studies should consider the integration of contacts into the peak locomotor intensity analysis.

Practical applications:

The main practical applications of this research include the findings Wingers were shown to sustain the highest peak locomotor activity. Therefore, a specific emphasis on high intensity running may be required for this position. Moreover, any of the SSGs examined in this study allowed players to reach the peak locomotor intensities observed during matches. To prepare players adequately to match demands, practitioners may sometimes need to consider the use of isolated running drills (e.g., short intervals or repeated sprint). Finally, the use of LPSs systems allows for continuous and precise locomotor activity tracking. If such a technology is not available, data with specific reference to each playing position and SSGs are provided in the supplemental digital content of the manuscript to inform practice.

References

1. Fleureau, A., et al., *Validity of an ultra-wideband local positioning system to assess specific movements in handball.* Biology of Sport, 2020.
2. Rico-González, M., et al., *Accuracy and Reliability of Local Positioning Systems for Measuring Sport Movement Patterns in Stadium-Scale: A Systematic Review.* Applied Sciences, 2020. **10**(17): p. 5994.
3. Buchheit, M., et al., *Game-based training in young elite handball players.* Int J Sports Med, 2009. **30**(4): p. 251-8.
4. Karcher, C. and M. Buchheit, *On-court demands of elite handball, with special reference to playing positions.* Sports Med, 2014. **44**(6): p. 797-814.
5. Luig P. , C.M., M. Perše, M. Kristan, *Motion characteristics according to playing position in international men's team handball.*, in *13th Annual Congress of the European College of Sports Science.* 2008.
6. Luteberget, L.S. and M. Spencer, *High-Intensity Events in International Women's Team Handball Matches.* Int J Sports Physiol Perform, 2017. **12**(1): p. 56-61.
7. Póvoas, S.C., Ascensão, A. A., Magalhães, J., Seabra, A. F., Krustrup, P., Soares, J. M., & Rebelo, A. N. , *Physiological demands of elite team handball with special reference to playing position.* Journal of strength and conditioning research, 2014. **28**(2): p. 430–442.
8. Šibila, M.V., Dinko ; Pori, Primož, *Position-related differences in volume and intensity of large-scale cyclic movements of male players in handball.* Kinesiology : international journal of fundamental and applied kinesiology, 2004. **36**: p. 58-68.
9. Waldron, M. and J. Highton, *Fatigue and pacing in high-intensity intermittent team sport: an update.* Sports Medicine, 2014. **44**(12): p. 1645-1658.
10. Jones, M.R., et al., *Quantifying positional and temporal movement patterns in professional rugby union using global positioning system.* European Journal of Sport Science, 2015. **15**(6): p. 488-496.
11. Roberts, S.P., et al., *The physical demands of elite English rugby union.* Journal of sports sciences, 2008. **26**(8): p. 825-833.
12. Furlan, N., et al., *Running-intensity fluctuations in elite rugby sevens performance.* International Journal of Sports Physiology and Performance, 2015. **10**(6): p. 802-807.
13. Lacome, M., et al., *Fluctuations in running and skill-related performance in elite rugby union match-play.* European journal of sport science, 2017. **17**(2): p. 132-143.
14. Delaney, J.A., et al., *Modelling the decrement in running intensity within professional soccer players.* Science and Medicine in Football, 2017. **2**(2): p. 86-92.
15. Higham, D.G., et al., *Comparison of Activity Profiles and Physiological Demands Between International Rugby Sevens Matches and Training.* J Strength Cond Res, 2016. **30**(5): p. 1287-94.
16. Lacome, M., et al., *Can we use GPS for assessing sprinting performance in rugby sevens? A concurrent validity and between-device reliability study.* Biol Sport, 2019. **36**(1): p. 25-29.
17. Lacome, M., et al., *Small-Sided Games in Elite Soccer: Does One Size Fit All?* Int J Sports Physiol Perform, 2018. **13**(5): p. 568-576.

18. Varley, M.C., G.P. Elias, and R.J. Aughey, *Current match-analysis techniques' underestimation of intense periods of high-velocity running.* Int J Sports Physiol Perform, 2012. **7**(2): p. 183-5.

19. Whitehead, S., et al., *The Duration-specific Peak Average Running Speeds of European Super League Academy Rugby League Match Play.* Journal of Strength and Conditioning Research, 2019.

20. Iacono, A.D., A. Eliakim, and Y. Meckel, *Improving fitness of elite handball players: small-sided games vs. high-intensity intermittent training.* The Journal of Strength & Conditioning Research, 2015. **29**(3): p. 835-843.

21. Halouani, J., et al., *Small-sided games in team sports training: a brief review.* The journal of strength & conditioning research, 2014. **28**(12): p. 3594-3618.

22. Buchheit, M., *The 30-15 Intermittent Fitness Test: Accuracy for Individualizing Interval Training of Young Intermittent Sport Players.* The Journal of Strength & Conditioning Research, 2008. **22**(2).

23. Winter, E.M. and R.J. Maughan, *Requirements for ethics approvals.* J Sports Sci, 2009. **27**(10): p. 985.

24. Hoppe, M.W., et al., *Validity and reliability of GPS and LPS for measuring distances covered and sprint mechanical properties in team sports.* PLoS One, 2018. **13**(2): p. e0192708.

25. Hollville, E., et al., *A Novel Accelerometry-Based Metric to Improve Estimation of Whole-Body Mechanical Load.* Sensors, 2021. **21**(10): p. 3398.

26. Katz, L. and J.S. Katz, *Fractal (power law) analysis of athletic performance.* Sports Medicine, Training and Rehabilitation, 1994. **5**(2): p. 95-105.

27. Delaney, J.A., et al., *Establishing Duration-Specific Running Intensities From Match-Play Analysis in Rugby League.* Int J Sports Physiol Perform, 2015. **10**(6): p. 725-31.

28. Howe, S.T., *Quantifying & Characterising Peak Intensities of Professional Rugby using GPS & Accelerometers*. 2020, Institute for Health & Sport (IHES).

29. Mendez-Villanueva, A., et al., *Match play intensity distribution in youth soccer.* Int J Sports Med, 2013. **34**(2): p. 101-10.

30. Gilmour, A.R., R.D. Anderson, and A.L. Rae, *The analysis of binomial data by a generalized linear mixed model.* Biometrika, 1985. **72**(3): p. 593-599.

31. Hopkins, W.G., *Measures of reliability in sports medicine and science.* Sports Med, 2000. **30**(1): p. 1-15.

32. Batterham, A.M. and W.G. Hopkins, *Making meaningful inferences about magnitudes.* Int J Sports Physiol Perform, 2006. **1**(1): p. 50-7.

33. Póvoas, S.C., et al., *Physical and physiological demands of elite team handball.* J Strength Cond Res, 2012. **26**(12): p. 3365-75.

34. Michalsik, L., P. Aagaard, and K. Madsen, *Locomotion characteristics and match-induced impairments in physical performance in male elite team handball players.* International journal of sports medicine, 2013. **34**(07): p. 590-599.

35. Bilge, M., *Game Analysis of Olympic, World and European Championships in Men's Handball.* J Hum Kinet, 2012. **35**: p. 109-18.

36. David, C. and C. Julen, *The Relationship Between Intensity Indicators in Small-Sided Soccer Games.* J Hum Kinet, 2015. **46**: p. 119-28.

37. Hulin, B.T., et al., *PlayerLoad Variables: Sensitive to Changes in Direction and Not Related to Collision Workloads in Rugby League Match Play.* 2018. **13**(9): p. 1136.

38. Karcher, C. and M. Buchheit, *Competitive Demands of Elite Handball* ASPETAR Sports Medicine Journal, 2014. **3**(18): p. 112-119.

39. Clemente, F.M., et al., *Acute effects of the number of players and scoring method on physiological, physical, and technical performance in small-sided soccer games.* Res Sports Med, 2014. **22**(4): p. 380-97.

40. Kunz, P., et al., *A Meta-Comparison of the Effects of High-Intensity Interval Training to Those of Small-Sided Games and Other Training Protocols on Parameters Related to the Physiology and Performance of Youth Soccer Players.* Sports Med Open, 2019. **5**(1): p. 7.

41. Martin-Garcia, A., et al., *Positional demands for various-sided games with goalkeepers according to the most demanding passages of match play in football.* Biol Sport, 2019. **36**(2): p. 171-180.

42. Dello Iacono, A., et al., *Neuromuscular and inflammatory responses to handball small-sided games: the effects of physical contact.* Scandinavian journal of medicine & science in sports, 2017. **27**(10): p. 1122-1129.

43. Dello Iacono, A., et al., *Effect of contact and no-contact small-sided games on elite handball players.* Journal of sports sciences, 2018. **36**(1): p. 14-22.

44. Bradley, P.S., et al., *The effect of playing formation on high-intensity running and technical profiles in English FA Premier League soccer matches.* Journal of sports sciences, 2011. **29**(8): p. 821-830.

45. Johnston, R.D., et al., *Peak movement and collision demands of professional rugby league competition.* Journal of Sports Sciences, 2019. **37**(18): p. 2144-2151.

46. Weaving, D., et al., *The peak duration-specific locomotor demands and concurrent collision frequencies of European Super League rugby.* Journal of Sports Sciences, 2019. **37**(3): p. 322-330.

47. Bangsbo, J., M. Mohr, and P. Krustrup, *Physical and metabolic demands of training and match-play in the elite football player.* Journal of sports sciences, 2006. **24**(07): p. 665-674.

Tables & Figures captions:

Table 1. Description of Small-sided games used the study.

Table 2. Peak locomotor intensity per position and locomotor variables. Data are presented as mean ± SD. † Difference from Back players. ‡ Difference from Pivots. Only effect sizes > 0.6 with likely chances (>75%) that the differences are true are reported.

Table 3. Peak locomotor intensity comparisons between match and small-sided games. Intercepts and slopes are presented as mean ± SD. SEE stands for standard error of estimate.

Figure 1. Peak locomotor intensity during match, SSGs and HIIT as a function of each rolling average period for playing position.

Supplemental digital content

Table 1. Rolling Average during matches per position and locomotor variables. Data are presented as mean ± SD.

Table 2. Rolling Average during 6v6FF per position and locomotor variables. Data are presented as mean ± SD.

Table 3. Rolling Average during 6v6HF per position and locomotor variables. Data are presented as mean ± SD.

Table 4. Rolling Average during 4v4 per position and locomotor variables. Data are presented as mean ± SD.

Table 5. Rolling Average during HIIT per position and locomotor variables. Data are presented as mean ± SD.

Table 1:

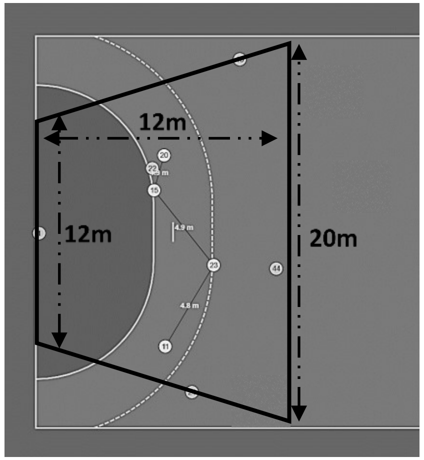
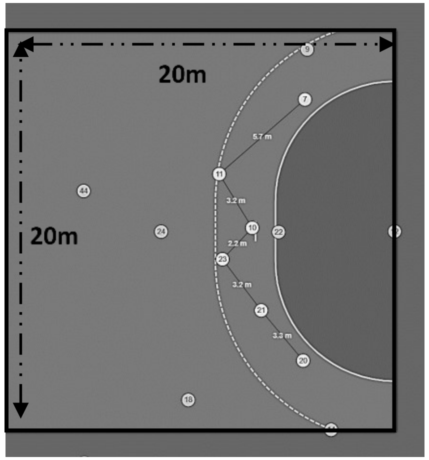
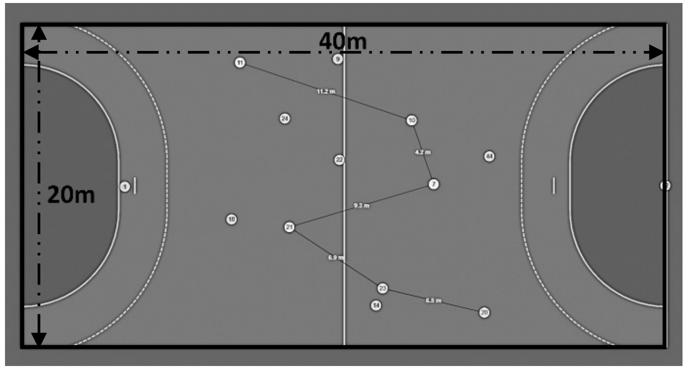
	SSG 1: 4v4 (n=136)	SSG 2: 6v6HF (n=121)	SSG 3: 6v6FF (n=85)
Players	4 attackers versus 4 defenders, 1 goalkeeper	6 attackers versus 6 defenders, 1 goalkeeper	6 attackers versus 6 defenders, 2 goalkeepers
SSGs Organisation	3 Back players and 1 Pivot as Attackers Defenders aligned at 6m 1 goalkeeper	3 Back players, 2 Wingers and 1 Pivot as attackers Defenders aligned at 6m 1 goalkeeper	3 Back players, 2 Wingers and 1 Pivot as Attackers Defenders aligned at 6m 2 goalkeepers
Rules	Typical handball rules Attackers only used tactical organisations specific to the team	Typical handball rules Attackers only used tactical organisations specific to the team	Typical handball rules Attackers only used tactical organisations specific to the team
Duration (min)	13 ± 6.5	13 ± 7	16 ± 6.5
SSGs dimension			

Table 2:

	Total distance (m·min^{-1})			High-Speed Distance (m·min^{-1})			Accel'Rate (a.u)		
	Intercept	Slope	r	Intercept	Slope	r	Intercept	Slope	r
Wingers	156 ± 13†‡	-0.27 ± 0.03	0.97	96 ± 12†‡	-0.45 ± 0.05	0.98	13 ± 3 †‡	-0.30 ± 0.03	0.97
Pivots	127 ± 10†	-0.23 ± 0.03	0.97	56 ± 9	-0.46 ± 0.06	0.98	11 ± 2	-0.26 ± 0.04	0.97
Back players	136 ± 13‡	-0.24 ± 0.03	0.98	57 ± 11	-0.49 ± 0.05	0.98	11 ± 2	-0.26 ± 0.03	0.98

Table 3:

Variable	Match Intercepts	Match Slope	SSGs format	Parameters	Value	Estimate	SEE	p.value	Effect size (±90% CI)
Total Distance (m·min^{-1})	138 ± 16	-0.24 ± 0.03	6v6FF	Intercept	110 ± 17	30	1.75	<0.001	1.74 (1.55 to 1.94)
				Slope	-0.21 ± 0.06	-0.03	0.01	0.001	-0.59 (-0.77 to -0.41)
			6v6HF	Intercept	72 ± 19	67	1.64	<0.001	3.56 (3.34 to 3.78)
				Slope	-0.26 ± 0.09	-0.02	0.01	0.08	0.17 (0.00 to 0.33)
			4v4	Intercept	77 ± 17	63	1.61	<0.001	3.68 (3.47 to 3.89)
				Slope	-0.24 ± 0.06	0	0.01	0.99	-0.09 (-0.25 to 0.07)
High-Speed Distance (m·min^{-1})	66 ± 20	-0.47 ± 0.06	6v6FF	Intercept	45 ± 14	22	1.05	<0.001	1.33 (1.14 to 1.52)
				Slope	-0.41 ± 0.09	-0.05	0.02	0.005	-0.76 (-0.94 to -0.59)
			6v6HF	Intercept	13 ± 10	55	1.04	<0.001	4.21 (3.94 to 4.48)
				Slope	-0.77 ± 0.17	-0.32	0.02	<0.001	1.97 (1.78 to 2.17)
			4v4	Intercept	10 ± 5	58	1.02	<0.001	5.94 (5.64 to 6.25)
				Slope	-0.77 ± 0.17	-0.32	0.01	<0.001	1.90 (1.71 to 2.08)
Accel'Rate (a.u)	12 ± 2	-0.27 ± 0.04	6v6FF	Intercept	8 ± 3	4	0.19	<0.001	1.33 (1.14 to 1.52)
				Slope	-0.26 ± 0.06	-0.01	0.01	0.43	-0.21 (-0.39 to -0.04)
			6v6HF	Intercept	6 ± 2	6	0.18	<0.001	3.31 (3.10 to 3.51)
				Slope	-0.3 ± 0.08	-0.03	0.01	<0.001	0.37 (0.21 to 0.53)
			4v4	Intercept	6 ± 2	6	0.17	<0.001	3.25 (3.05 to 3.44)
				Slope	-0.28 ± 0.06	-0.01	0.01	0.29	0.21 (0.05 to 0.37)

Figure 1:

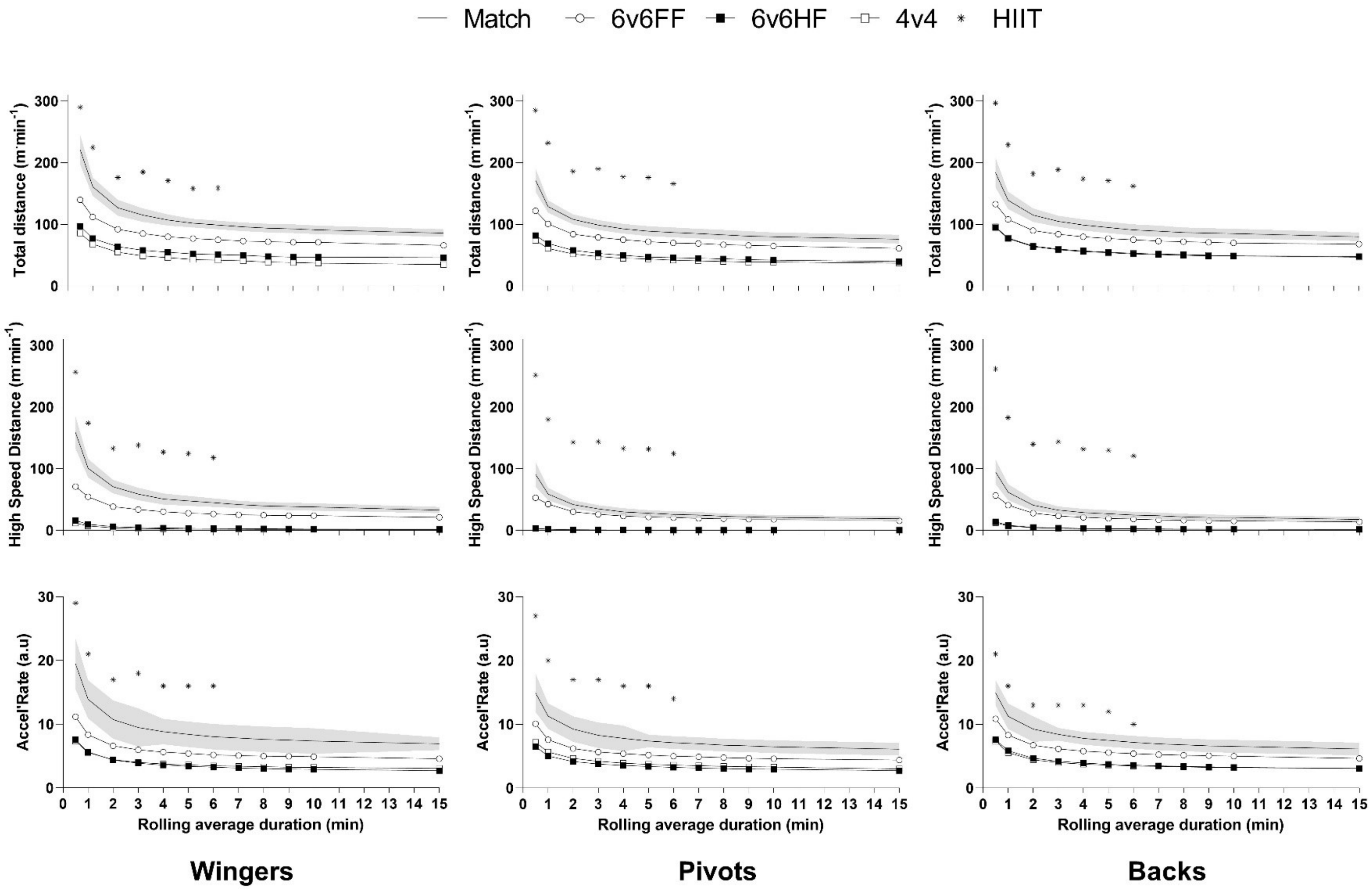

Match
6v6FF
6v6HF
4v4
HIIT
Total distance (m·min-1)
High Speed Distance (m·min-1)
Accel'Rate (a.u)
Rolling average duration (min)
Wingers
Pivots
Backs

Table Suppl 1 (Matches):

	0.5	1	2	3	4	5	6	7	8	9	10	15
Total Distance (m·min^{-1})												
Overall	192 ± 22	143 ± 13	117 ± 11	106 ± 9	100 ± 8	95 ± 8	92 ± 8	90 ± 8	88 ± 7	87 ± 7	85 ± 7	81 ± 7
Wingers	221 ± 24	161 ± 15	127 ± 13	115 ± 11	107 ± 9	102 ± 7	99 ± 7	96 ± 7	94 ± 7	93 ± 7	91 ± 7	86 ± 6
Pivots	172 ± 19	129 ± 10	108 ± 8	99 ± 8	93 ± 8	89 ± 8	87 ± 8	85 ± 7	83 ± 8	81 ± 8	80 ± 7	76 ± 7
Back players	184 ± 24	139 ± 14	115 ± 11	105 ± 9	99 ± 9	95 ± 9	91 ± 9	89 ± 9	87 ± 8	86 ± 8	85 ± 8	80 ± 7
High-Speed Distance (m·min^{-1})												
Overall	125 ± 23	80 ± 13	57 ± 9	47 ± 8	41 ± 7	38 ± 6	35 ± 6	34 ± 6	32 ± 5	31 ± 5	30 ± 5	26 ± 4
Wingers	159 ± 26	101 ± 15	71 ± 11	59 ± 10	51 ± 9	48 ± 8	45 ± 7	42 ± 6	40 ± 6	39 ± 6	38 ± 6	33 ± 5
Pivots	91 ± 20	59 ± 10	42 ± 7	35 ± 6	30 ± 6	28 ± 5	26 ± 5	25 ± 5	23 ± 4	22 ± 4	21 ± 4	19 ± 4
Back players	95 ± 20	62 ± 13	41 ± 9	33 ± 6	29 ± 6	27 ± 6	25 ± 5	24 ± 5	22 ± 5	21 ± 5	21 ± 4	18 ± 4
Accel'Rate (a.u)												
Overall	17 ± 3	13 ± 3	10 ± 2	9 ± 2	8 ± 2	8 ± 2	8 ± 2	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1
Wingers	19 ± 4	14 ± 3	11 ± 3	9 ± 2	9 ± 2	8 ± 2	8 ± 2	8 ± 2	8 ± 2	8 ± 2	7 ± 2	7 ± 1
Pivots	15 ± 3	11 ± 2	9 ± 2	8 ± 2	8 ± 2	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	6 ± 1	6 ± 1
Back players	15 ± 2	11 ± 2	9 ± 2	8 ± 1	8 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	7 ± 1	6 ± 1

Table Suppl 2 (6v6FF):

	0.5	1	2	3	4	5	6	7	8	9	10	15
Total Distance ($m \cdot min^{-1}$)												
Overall	131 ± 30	107 ± 23	89 ± 18	82 ± 16	78 ± 16	75 ± 15	74 ± 15	72 ± 15	70 ± 15	70 ± 14	69 ± 14	65 ± 14
Wingers	140 ± 34	112 ± 26	92 ± 20	85 ± 18	80 ± 17	77 ± 17	75 ± 17	73 ± 16	72 ± 16	71 ± 15	71 ± 14	66 ± 15
Pivots	122 ± 28	101 ± 22	84 ± 17	79 ± 15	75 ± 15	72 ± 15	70 ± 14	69 ± 14	67 ± 13	66 ± 13	65 ± 13	61 ± 13
Back players	133 ± 27	108 ± 20	90 ± 16	84 ± 15	80 ± 14	77 ± 14	75 ± 14	73 ± 14	72 ± 14	71 ± 14	70 ± 14	68 ± 14
High-Speed Distance ($m \cdot min^{-1}$)												
Overall	62 ± 23	49 ± 16	34 ± 11	30 ± 10	27 ± 9	25 ± 9	24 ± 8	23 ± 8	22 ± 8	21 ± 7	21 ± 7	19 ± 6
Wingers	71 ± 28	55 ± 19	39 ± 13	34 ± 11	30 ± 10	28 ± 10	27 ± 10	25 ± 9	25 ± 9	24 ± 8	24 ± 8	21 ± 7
Pivots	53 ± 19	43 ± 13	30 ± 9	26 ± 8	23 ± 8	22 ± 7	21 ± 7	20 ± 7	19 ± 6	18 ± 6	18 ± 6	16 ± 5
Back players	57 ± 18	41 ± 12	28 ± 8	24 ± 7	21 ± 6	20 ± 6	18 ± 6	17 ± 6	17 ± 5	16 ± 5	15 ± 5	14 ± 4
Accel'Rate (a.u)												
Overall	11 ± 2	8 ± 2	6 ± 1	6 ± 1	6 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1
Wingers	11 ± 3	8 ± 2	7 ± 1	6 ± 1	6 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1
Pivots	10 ± 2	8 ± 1	6 ± 1	6 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	5 ± 1	4 ± 1
Back players	11 ± 4	8 ± 4	7 ± 3	6 ± 3	6 ± 3	6 ± 3	5 ± 3	5 ± 3	5 ± 2	5 ± 2	5 ± 2	5 ± 1

Table Suppl 3 (6v6HF):

	0.5	1	2	3	4	5	6	7	8	9	10	15
Total Distance ($m \cdot min^{-1}$)												
Overall	91 ± 23	74 ± 19	62 ± 16	57 ± 14	54 ± 13	51 ± 13	50 ± 12	48 ± 12	47 ± 12	46 ± 11	46 ± 11	44 ± 9
Wingers	97 ± 26	77 ± 21	64 ± 16	58 ± 15	55 ± 14	52 ± 13	51 ± 13	50 ± 12	48 ± 12	47 ± 12	47 ± 11	46 ± 10
Pivots	82 ± 21	69 ± 18	58 ± 16	53 ± 14	50 ± 13	47 ± 12	46 ± 11	45 ± 11	44 ± 10	43 ± 10	42 ± 10	40 ± 8
Back players	95 ± 21	77 ± 18	64 ± 15	59 ± 14	56 ± 14	54 ± 13	52 ± 13	51 ± 13	50 ± 13	49 ± 13	49 ± 13	48 ± 10
High-Speed Distance ($m \cdot min^{-1}$)												
Overall	8 ± 9	5 ± 6	3 ± 3	2 ± 3	2 ± 2	1 ± 2	1 ± 2	1 ± 1	1 ± 1	1 ± 1	1 ± 1	1 ± 1
Wingers	12 ± 11	7 ± 7	4 ± 4	3 ± 3	3 ± 3	2 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 2	1 ± 1
Pivots	3 ± 7	2 ± 4	1 ± 3	1 ± 2	1 ± 1	1 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1
Back players	12 ± 9	7 ± 6	5 ± 4	3 ± 3	3 ± 3	3 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 1
Accel'Rate (a.u)												
Overall	8 ± 2	6 ± 2	5 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1
Wingers	9 ± 3	6 ± 2	5 ± 1	5 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1
Pivots	7 ± 2	6 ± 2	5 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Back players	7 ± 2	6 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1

Table Suppl 4 (4v4):

	0.5	1	2	3	4	5	6	7	8	9	10	15
Total Distance ($m \cdot min^{-1}$)												
Overall	86 ± 26	69 ± 21	57 ± 18	52 ± 16	49 ± 15	48 ± 13	46 ± 13	44 ± 13	43 ± 12	42 ± 12	42 ± 12	40 ± 10
Wingers	86 ± 30	68 ± 25	55 ± 20	49 ± 17	46 ± 16	43 ± 15	42 ± 14	41 ± 14	39 ± 14	38 ± 13	37 ± 13	35 ± 12
Pivots	74 ± 23	61 ± 19	52 ± 16	48 ± 15	45 ± 14	44 ± 12	42 ± 12	41 ± 11	40 ± 11	39 ± 11	39 ± 10	37 ± 9
Back players	96 ± 25	78 ± 20	65 ± 17	60 ± 16	57 ± 15	55 ± 13	53 ± 13	52 ± 13	51 ± 13	50 ± 13	49 ± 12	47 ± 11
High-Speed Distance ($m \cdot min^{-1}$)												
Overall	10 ± 13	6 ± 8	4 ± 6	3 ± 4	2 ± 4	2 ± 3	2 ± 3	2 ± 3	2 ± 3	1 ± 2	1 ± 2	1 ± 2
Wingers	16 ± 19	10 ± 13	6 ± 9	5 ± 7	4 ± 6	4 ± 5	3 ± 5	3 ± 5	3 ± 4	3 ± 4	2 ± 4	2 ± 3
Pivots	3 ± 7	2 ± 4	1 ± 2	1 ± 2	1 ± 1	1 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1	0 ± 1
Back players	14 ± 10	8 ± 7	5 ± 4	4 ± 3	3 ± 3	3 ± 2	3 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 2	2 ± 1
Accel'Rate (a.u)												
Overall	7 ± 2	5 ± 2	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Wingers	8 ± 3	6 ± 2	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Pivots	7 ± 2	5 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1
Back players	8 ± 2	6 ± 2	5 ± 1	4 ± 1	4 ± 1	4 ± 1	4 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1	3 ± 1

Table Suppl 5 (HIIT):

	0.5	1	2	3	4	5	6	7	8	9	10	15
Total Distance ($m \cdot min^{-1}$)												
Wingers	290 ± 5	225 ± 4	176 ± 13	185 ± 7	171 ± 10	168 ± 9	159 ± 5	-	-	-	-	-
Pivots	289 ± 6	232 ± 9	186 ± 21	190 ± 7	177 ± 14	176 ± 15	166 ± 7	-	-	-	-	-
Back players	297 ± 9	229 ± 7	182 ± 19	189 ± 9	174 ± 13	171 ± 13	162 ± 4	-	-	-	-	-
High-Speed Distance ($m \cdot min^{-1}$)												
Wingers	257 ± 6	174 ± 7	133 ± 12	138 ± 7	127 ± 8	125 ± 7	118 ± 2	-	-	-	-	-
Pivots	252 ± 10	180 ± 11	143 ± 21	144 ± 10	133 ± 15	132 ± 14	125 ± 2	-	-	-	-	-
Back players	262 ± 7	183 ± 9	140 ± 19	144 ± 11	132 ± 14	130 ± 13	121 ± 5	-	-	-	-	-
Accel'Rate (a.u)												
Wingers	29 ± 5	21 ± 3	17 ± 3	18 ± 2	16 ± 2	16 ± 2	16 ± 1	-	-	-	-	-
Pivots	27 ± 2	20 ± 2	17 ± 3	17 ± 2	16 ± 2	16 ± 2	14 ± 1	-	-	-	-	-
Back players	21 ± 2	16 ± 2	13 ± 2	13 ± 2	13 ± 2	12 ± 2	10 ± 1	-	-	-	-	-