Title: Assessing climatic, travel, and methodological influences on whole-match and worst-case scenario locomotor demands of international men's rugby sevens match-play

Running head: Demands of rugby sevens

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Abstract

This study assessed the influence of environmental factors, air travel, and epoch estimation method on locomotor demands of international men's rugby sevens match-play. Eighteen men's rugby sevens players wore 10 Hz Global Positioning Systems (STATsport) during 52 international matches over nine global tournaments (418 observations). Whole-match average speed was recorded, whilst average speed and relative high-speed distance (>5.0 $m \cdot s^{-1}$) were quantified using FIXED and ROLL methods over 60-420 s epochs (60 s increments) to establish worst-case scenario demands. Linear mixed models compared FIXED versus ROLL estimation methods and assessed whether temperature, humidity, travel duration, number of time-zones crossed, and travel direction were associated with locomotor responses. Temperature and humidity were positively associated with overall and worst-case scenario average speed (effect estimates; *b:* 0.18 to 0.54), whilst worst-case scenario high-speed distance at 300 s was also related to temperature (*b*: 0.19). Easterly air travel compromised overall and 180 and 300 s worst-case scenario average speed (*b:* -8.31 to-7.39), alongside high-speed distance over 300 s *(b:* -4.54). For worst-case scenario average speed and high-speed distance, FIXED underestimated ROLL at all epoch lengths (~9.9 to 18.4%, $p \leq 0.001$). This study indicated that international rugby sevens match-play locomotor responses were greater as air temperature increased but reduced following eastward air travel. Underestimation of demands in FIXED vs ROLL over 60-420 s epochs was confirmed. Such climatic and travel influences warrant the adoption of strategies targeted at maximising performance and safety according to the tournament conditions. Knowing the most demanding periods of match-play facilitates training specificity.

Key words: Team sport; Temperature; Monitoring; Environment; Activity profiles; Time-zone

Highlights

- Selected locomotor responses were reduced following eastward air travel, potentially suggesting interventions to mitigate these effects are warranted.
- Match-play running responses were greater as air temperature increased. Strategies targeted at optimising body temperature in both warm and cool conditions warrant consideration to promote performance and maintain player safety.
- Fixed epochs underestimated worst-case scenario average speed (9.9-11.7%) and high-speed distance (11.4-18.4%). Rolling averages may thus be more appropriate for detecting the most intense periods, while duration-specific data provide training targets.

Introduction

Rugby sevens is a version of rugby union, involving two teams of seven players competing in matches consisting of seven min halves, separated by a two min half-time. International men's rugby sevens players achieve average speeds of ~91-120 $m \cdot min^{-1}$ across a whole-match,[1-3] with ~17-19 % of total distance covered being at speeds >5 $m \cdot s^{-1}$ (high-speed running; HSR).[1, 4] Rugby sevens tournaments typically require each team to complete five to six matches within a two or three day period and the World Rugby Sevens Series (WRSS) involves international teams playing in multiple tournaments around the world, often in different countries on consecutive weekends. For example, the 2018-2019 WRSS included tournaments in United Arab Emirates, South Africa, Australia, New Zealand, United States of America, Canada, Hong Kong, Singapore, England, and France within an eight-month period. Such schedules mean that international rugby sevens players are required to travel extensively and play multiple matches within a relatively short period of time.

Long-haul travel across time-zones can contribute to jet lag and/or travel fatigue.[5] Whilst these are distinct phenomena, each is characterised by disruptions to a player's circadian rhythm which could negatively influence mood, cognitive capacity, and/or indices of physical performance for up to 96 h post-travel.[5] Such effects may be particularly pronounced following eastward versus westward travel[5] and have the potential to influence a player or team's performance responses, especially when competition takes place within four days of arrival. Mitchell et al.[6] reported reductions in countermovement jump power in international rugby sevens players following long-haul (over five hours) and short-haul (under five hours) travel, with the largest decrements observed after long-haul flights. However, as only trivial differences in average speed (i.e., $m \cdot min^{-1}$) were evident in matches played following long-haul versus short-haul travel, the broader influence of pre-tournament travel on the match-play responses of rugby sevens players remains unclear.[2, 6]

The likely varied climatic conditions experienced during WRSS tournaments contested in different locations worldwide could potentially influence rugby sevens performance, particularly for unacclimatised players competing in hot or humid conditions. Notably, in tournaments played in London, Singapore, and Fiji, some individuals reached peak core temperature values that were capable of impairing repeated sprint performance (>39 °C)[7] and approached thresholds associated with exertional heat illness (~40 °C).[8, 9] However, such responses were not universal and were influenced by an individual's playing time and running distance.[8, 9] Conversely, physical performance can also be negatively affected in cool conditions, which can accelerate losses in body temperature.[10] As global travel likely exposes rugby sevens players to a range of climatic conditions during competition, profiling climatic and travel influences on match-play responses could help identify areas in which strategies may be developed to maximise performance and safety in international rugby sevens players.

Whilst whole-match activity profiles provide insight into the overall physical loads experienced during match-play, the intermittent nature of rugby sevens means that such data may not elucidate the heightened demands associated with certain phases within a match.[11, 12] Quantifying the most intense periods of play ('worst-case scenario'; WCS) can help to design tailored training programmes that better prepare players for these potentially decisive moments of competition. Due to a potential loss of sampling resolution and thus underestimation of WCS when match-play data are divided into time-periods that are fixed relative to the time of kick-off (FIXED),[11, 13, 14] recent team sports research has assessed WCS using rolling averages (ROLL).[11, 12, 14] In this method, if 10 Hz Global Positioning

Systems (GPS) are used to establish 60 s epochs (600 samples·min^{-1}), each rolling epoch would be calculated using the current and 599 preceding samples. FIXED, whereby epochs do not overlap (i.e., epochs would represent samples 1–600, 601–1200, 1201–1800, etc), is commonly used due to its ease of implementation. However, researchers and practitioners are increasingly recognising the potential limitations of this approach in terms of underestimation of WCS. Duration-specific WCS running demands may be quantified over different epoch lengths. For example, it is possible to quantify the most intense 60 s, 120 s, or any other duration during a match. Whilst WCS average speeds of ~176-184 and ~130 m·min^{-1} have been reported over 60 and 120 s, respectively, when using the ROLL method in international men's rugby sevens,[15-17] direct comparison between FIXED and ROLL is currently lacking in international rugby sevens. Investigating this relationship in rugby sevens would provide valuable information for practitioners seeking to profile WCS in this population. Moreover, examining average speed and HSR responses over longer epochs (i.e., over two min) could further inform physical preparation programmes and technical-tactical training that are targeted at the varied demands of match-play. This study aimed to evaluate the influence of travel schedules and climatic conditions on the whole-match and WCS demands of international rugby sevens match-play, while assessing duration-specific WCS locomotor responses over fixed and rolling epochs ranging from 60-420 s.

Materials and methods

Participants

Following ethics approval from the Swansea University Ethics Committee, 18 players (age: 25 ± 4 years; stature: 1.84 ± 0.07 m; body mass: 91.5 ± 8.8 kg) from an international men's rugby sevens squad were monitored during the 2018-2019 WRSS. From 52 matches across nine tournaments, 418 individual player observations were yielded (6-46 observations·player^{-1}).

Activity monitoring

Players were monitored via Global Positioning Systems (GPS; 10 Hz; STATSports Apex, Northern Ireland), worn between the scapulae, and contained within their playing jersey in a pocket designed to minimise movement artifact. This technology is sufficiently reliable (coefficients of variation of 0.3% and 1.3% for assessment of total distance and HSR, respectively)[18] and compares closely (mean bias: $<2.5\%$) to measured distances during team sports-specific movements.[19] Players were familiar with this form of activity profiling and each individual wore the same unit throughout the study to avoid the influence of inter-unit variation.

The devices were activated at least 15 min before the pre-match warm-up to achieve satellite lock according to the manufacturer’s guidelines, while data were downloaded after each match using proprietary software (Apex Rugby, Team Series, STATSports). Mean values for Horizontal Dilution of Position and number of satellite connections during data collection were 0.7 ± 0.3 and 18.7 ± 0.8, respectively. Raw instantaneous speed data files were exported to a bespoke analysis programme which was later used to quantify duration-specific WCS. Epochs were specified in increments of 60 s in duration, as per previous studies,[11, 14] to produce fixed and rolling periods ranging from 60-420 s in length. The locomotor variables profiled for this analysis were average speed and HSR (distance covered at speeds $>5\ m \cdot s^{-1}$).[1, 4, 13] These variables were chosen as metrics that were of particular interest to performance staff working with the team and also reflect previous studies.[1, 4, 13] To allow comparison between playing periods of differing duration, absolute outcome variables were expressed relative to epoch length (i.e., $m \cdot min^{-1}$). Only data from players who completed at least five min of playing time in a given match were included, while only completed epochs were considered for WCS analysis (e.g., a player who played for between six and seven min, would only provide data for the 60-360 s epochs).

Climatic and travel conditions

A travel itinerary was maintained for each tournament destination to document the number of time-zones crossed, whether travel was eastward or westward across the meridian, and total time spent traveling. All air travel was via commercial flights with players seated in economy class. Climatic data for the weather station closest to the specific location of each match were obtained from the Virtual Crossing website (https://www.visualcrossing.com). Air temperature and relative humidity were recorded at 30-180 min intervals, and the measurement taken closest to the match kick-off time was used as the value for that fixture. Pre-match warm-ups began with a 10 min individual preparation time before an 18 min rugby-specific warm-up. This included running of increasing intensity, change of direction preparation and at least one run at 85-90% maximum velocity. Chilled isotonic drinks and water were provided *ab libitum* to aid with pre-cooling. Some players also chose to apply ice towels to the neck and back.

Statistical analyses

To account for the non-independence of data obtained via repeated measurement of players over multiple matches, linear mixed models were used with “player” and “match” specified as random effects in all models. For analysing WCS estimation methods, separate models were built for each dependent variable (average speed, HSR), with “epoch duration” (60-420 s) and “method” (‘FIXED’, ‘ROLL’) entered as categorical fixed effects. To assess the influence of climatic and travel-related variables on locomotor responses over a range of timeframes, further models were constructed in relation to overall average speed, as well as rolling average-derived WCS average speed and HSR over 60, 180, and 300 s. As per the research question, air temperature, relative humidity, number of time-zones crossed, travel direction (‘no change’, ‘eastward’, ‘westward’), and travel duration represented fixed effects. Residual plots were inspected and Bonferroni-adjusted pairwise comparisons were conducted using least squares means tests to assess differences between each level of categorical fixed effects. Standardised effect sizes (ES) were calculated for significant comparisons, which were interpreted as <0.20 trivial; 0.20 – 0.49 small; 0.50 – 0.79 moderate; ≥0.80 large.[20] Analyses were performed using Jamovi (The Jamovi Project, 2021) and significant effects were indicated when $p < 0.05$. Data are presented as mean ± standard deviation, whereas effect estimates (*b*) from the linear mixed models are presented with 95% confidence intervals (CI).

Results

Table 1 provides climatic and travel data for each tournament location, while Table 2 shows locomotor outputs for the whole sample and at each tournament.

****INSERT TABLE 1 HERE****

****INSERT TABLE 2 HERE****

Air temperature was positively associated with overall average speed (*b*: 0.50, [CI: 0.20, 0.79], p = 0.002), alongside WCS average speed over 60 (*b*: 0.54 [0.09, 1.00], p = 0.025) and 300 s (*b*: 0.36 [0.13, 0.60], p = 0.004). The effect estimates (*b*) can be interpreted as the change (positive or negative) in $m{\cdot}min^{-1}$ over the relevant timeframe for each 1 °C increase in air temperature. Temperature was also positively associated with WCS HSR at 300 s (*b*: 0.19 [0.04, 0.34], p = 0.016). Relative humidity demonstrated positive coefficients for overall average speed (*b*: 0.18 [0.07, 0.30], p = 0.002), as well as WCS average speed over 60 (*b*: 0.26 [0.08, 0.43], p = 0.008), 180 (*b*: 0.18 [0.06, 0.29], p = 0.003), and 300 s (*b*: 0.18 [0.09, 0.27], p ≤0.001).

Eastward travel compromised average speed and HSR. After traveling eastward, overall average speed (*b*: -7.39 [-14.29, -0.49], p = 0.041, ES: 0.08, *trivial*), WCS average speed over 180 (*b*: -8.31 [-15.28, -1.34], p = 0.023, ES: 0.26, *small*) and 300 s (*b* = -7.56, CI: -13.26, -1.85, p = 0.012, ES: 0.85, *large*), and WCS HSR over 300 s (*b*: -4.64 [-8.29, -0.99], p = 0.016, ES: 0.39, *small*) were lower than when no air travel preceded a tournament. Neither total travel duration nor the number of time-zones crossed influenced either dependent variable over any time duration.

Estimation method influenced WCS, with FIXED underestimating ROLL (all p ≤0.001) for average speed (~9.9-11.7%, ES: 0.85-105, *all large*) and HSR (11.4-18.4%, ES: 0.32-0.93, *small to large*) at all epoch lengths (Table 3).

****INSERT TABLE 3 HERE****

Discussion

This study aimed to investigate the influence of travel schedules and climatic conditions on whole-match and WCS movement demands across an international season, while assessing the duration-specific WCS locomotor demands of international rugby sevens match-play over fixed and rolling epochs ranging from 60-420 s. Locomotor responses were positively associated with air temperature and humidity but reduced following eastward travel. Moreover, FIXED underestimated ROLL for quantifying WCS demands in international men's rugby sevens. This study provides valuable information to inform training and preparation strategies to maximise performance and safety for international players traveling to compete worldwide.

Players covered ~99 $m\cdot min^{-1}$ across their playing period, values that fall within ranges previously observed in international men's rugby sevens.[1-3] Despite rugby sevens matches being considerably shorter than many other team sports, FIXED underestimated WCS for all epochs compared with ROLL for WCS average speed and HSR by ~10-12% and ~11-18% respectively. These underestimations reflect values that have been reported in international rugby union over 60-300 s and provide valuable information for practitioners profiling the demands of international sevens players.[11, 13] Such findings highlight that rolling averages may be a more appropriate method of quantifying duration-specific WCS to inform training prescription in international men's rugby sevens, compared with fixed epochs.

Existing research has reported that international men's rugby sevens players covered ~176-184 $m\cdot min^{-1}$ and ~130 $m\cdot min^{-1}$ during their "peak" 60 and 120 s of match-play, respectively.[15-17] Such values broadly correspond to the ~173 $m\cdot min^{-1}$ (60 s) and ~136 $m\cdot min^{-1}$ (120 s) recorded in the current study for WCS average speed in ROLL. However, this study also profiled WCS HSR and average speed over longer epochs up to 420 s, providing additional duration-specific data that may help to design or evaluate training drills of differing lengths. For example, the data in Table 3 suggest that ~173 $m\cdot min^{-1}$

would be an appropriate target for a one min training drill if the intention is to reflect WCS average speed in this population, whereas ~109 m·min^{-1} may be appropriate for a five min activity.

Compared with matches played following no air travel, traveling eastward was associated with reductions in the overall and WCS responses profiled, with effect sizes ranging from trivial (overall average speed) to large (WCS average speed over 300 s). Decrements in physical performance have been observed in athletic individuals following transmeridian travel,[5, 21] responses that have been attributed to alterations in circadian rhythms and misalignment with external cues such as sunlight at the new destination.[5, 21, 22] Notably, jet lag symptoms may be most severe following eastward travel.[21, 22] Whilst it is not possible to conclusively determine, and it remains unclear whether reductions in average speed adversely affected overall match-play performance, the greater magnitude of circadian rhythm disruption associated with traveling eastward could have contributed to the marked reduction in locomotor responses in matches following eastward flights in the current study; either directly via impairment of physical abilities or increased cognitive fatigue influencing playing style. Although practical and/or logistical constrains may prevent international rugby sevens teams from arriving at tournament destinations early enough to allow circadian rhythm adjustment (a minimum of 96 h before competition is recommended[5]), practitioners may consider implementing strategies to reduce the negative effects of transmeridian travel,[22] particularly when traveling east.

Reductions in countermovement jump performance have been observed in international rugby sevens players when assessed following long-haul (over five hours) and short-haul (less than five hours) travel, with the largest decrements manifesting following long-haul flights.[6] Although this suggests the presence of neuromuscular fatigue, only trivial changes in average speed were reported in matches played five to six days following long-haul travel.[6] These findings appear to align with the results of the current study, in which relative locomotor outputs were not influenced by travel duration and only trivial reductions in whole-match average speed were observed following eastward travel. Whilst the reasons for such responses remain unclear, it has been suggested that team sports players suffering from neuromuscular fatigue may alter their running mechanics, yet maintain average speed and HSR via an increased proportion of running at speeds slightly above the HSR threshold.[6, 23] Notwithstanding, travelinduced neuromuscular fatigue could reduce a player's ability to execute the explosive or very high-speed activities that often determine success in team sports match-play.[6] Given the nature of international rugby sevens schedules, further research is needed to explore the likely complex relationship between travel demands and match-play performance.

Excessive elevation in core temperature is indicative of whole-body thermal strain, which can impair physical performance in the repeated high-intensity activities that characterise rugby sevens match-play.[7] Indeed, heat-induced fatigue can occur in response to high-intensity exercise in hot and humid conditions, which can be explained by a combination of physiological factors.[24] However, the fact that air temperature was positively associated with WCS and overall relative locomotor outputs suggests that hotter conditions within the range recorded in this study were not sufficient to substantially impair players' physical responses during the matches observed. Notwithstanding, it has previously been reported that several rugby sevens players reached peak core temperatures >39 °C during two-day tournaments held in London, Singapore, and Fiji, with core temperature tending to increase on a match-by-match basis during each day of these tournaments.[8, 9] The role of match-play activities in elevating core temperature was highlighted by the fact that both total playing time and average speed were positively related to an individual's core temperature response.[8, 9] Although neither core temperature nor heat illness were directly assessed in the current study, the finding that players may be willing to perform at higher relative running intensities in warmer and/or more humid environments may potentially highlight the importance of interventions designed to mitigate the risk of heat illness in rugby sevens players competing in warm conditions even if physical outputs are not impaired.[8, 9] For example, particularly if players perform more activity during matches in warmer conditions, there may be an opportunity to implement between-match cooling strategies or to limit between-match activities to avoid threats to player safety due to excessive core temperature increases throughout a tournament.[9]

The current results indicate that lower average speeds occurred in cooler temperatures. This is consistent with the understanding that reductions in body temperature can impair muscular power in team sports players.[25, 26] Cool conditions could accelerate thermal energy transfer during periods of inactivity before and in-between matches if moderating strategies are not employed.[10] Reduced neuromuscular force production has been observed following 60 min air exposures in 10-20 °C compared to 27 °C, with performance decreasing in an air temperature-dependent manner.[10] Although not measured, the relationship between temperature and locomotor responses in the current study could potentially reflect enhanced body temperature maintenance in warmer conditions. If so, players in warmer temperatures may have been physically or psychologically better prepared to perform. Similarly, lower humidity may increase body heat loss through evaporation, potentially exacerbating the rate of cooling.[24] The relationships observed in this study could also highlight an opportunity to modify the acute preparatory strategies employed in cool conditions (e.g., increasing the volume and/or intensity of pre-match activity[27]). Matches in locations with warmer climates may also have been played on firmer pitches, which could have contributed to a faster pace of play relative to cooler or wetter conditions.[28]

Although valuable information is presented that may help to inform preparatory practices in international men's rugby sevens, these data relate only to independent analyses of average speed and HSR. These variables were chosen to represent the primary locomotor variables typically used in monitoring rugby sevens players. It is acknowledged that this univariate approach to WCS estimation is somewhat limited, and further research investigating WCS and climatic and/or travel influences on additional or multiple variables, such as collision and/or acceleration-based metrics alongside internal load variables such as heart rate responses would provide valuable insight. Rugby sevens success is also determined largely by cognitive, technical, and tactical performance, and other situational factors influence responses.[29, 30] Whilst these aspects are beyond the scope of the current study, travel demands and/or climatic conditions could profoundly affect some or all of these components of rugby sevens performance. This will be an important avenue for further exploration to help improve preparations for international tournaments, especially given the likely interrelationship between technical, tactical, and physical responses.

This study reported overall average speed and profiled WCS average speed and HSR during international rugby sevens match-play, while assessing the influence of climatic and travel-related factors. Players covered ~99 $m \cdot min \cdot match^{-1}$, with rolling average-derived WCS average speed and HSR ranging from ~102-173 $m \cdot min^{-1}$ and ~20-64 $m \cdot min^{-1}$, respectively, depending upon epoch length (60-

420 s). Locomotor demands were greater as air temperature and relative humidity increased but were reduced following eastward travel, while FIXED underestimated ROLL. These climatic and travel influences indicate the importance of bespoke preparation strategies for each tournament to promote performance and player safety, whereas duration-specific locomotor profiles may be useful to aid training prescription based on WCS demands

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Legends

Table 1. Whole sample and per tournament profile for climatic conditions, travel demands, and number of observations

Table 2. Whole sample and per tournament locomotor demands of international men's sevens match-play

Table 3. Duration-specific worst-case scenario average speed and HSR when estimated using FIXED and ROLL methods

Table 2. Whole sample and per tournament profile for climatic conditions, travel demands, and number of observations

Tournament	Air temperature (°C)	Relative humidity (%)	Travel duration (h)	Travel direction	Number of matches (count)	Individual player observations (count)
Whole sample	21.0 ± 6.8	58.1 ± 17.4	8.3 ± 7.0	NA	52	418
Dubai	26.8 ± 2.6	44.8 ± 10.9	6.8 ± 0.0	Eastward	6	53
Cape Town	21.1 ± 0.8	56.2 ± 2.9	9.7 ± 0.0	Westward	6	51
Hamilton	19.1 ± 0.7	81.7 ± 12.6	23.6 ± 0.0	Eastward	6	53
Sydney	27.4 ± 3.0	62.3 ± 15.0	3.7 ± 0.0	Westward	6	56
Las Vegas	20.0 ± 1.3	32.0 ± 10.7	10.8 ± 0.0	Westward	6	49
Vancouver	6.0 ± 1.0	65.8 ± 2.9	2.8 ± 0.0	Westward	6	52
Hong Kong	27.4 ± 1.1	66.8 ± 2.9	11.7 ± 0.0	Eastward	5	38
London	20.0 ± 1.8	57.9 ± 14.5	0.0 ± 0.0	NA	6	52
Paris	27.4 ± 2.3	45.3 ± 6.8	2.3 ± 0.0	Eastward	5	14

NA: Not applicable (no air travel). Data are presented as mean ± standard deviation or counts

Table 2. Whole sample and per tournament locomotor demands of international men's sevens match-play

	Overall average speed (m.min^{-1})	WCS average speed (m.min^{-1})							WCS HSR (m.min^{-1})						
Tournament	Overall	60 s	120 s	180 s	240 s	300 s	360 s	420 s	60 s	120 s	180 s	240 s	300 s	360 s	420 s
Whole sample	99.2 ± 12.6	173.1 ± 21.0	136.2 ± 14.8	122.9 ± 13.8	114.7 ± 12.8	109.4 ± 12.2	105.4 ± 12.4	101.9 ± 12.1	63.8 ± 23.4	40.5 ± 13.9	31.4 ± 10.6	26.7 ± 9.0	23.7 ± 7.9	21.6 ± 7.5	19.9 ± 7.0
Dubai	99.0 ± 10.8	173.6 ± 19.3	135.1 ± 14.0	120.5 ± 14.1	113.0 ± 13.0	107.4 ± 12.0	103.9 ± 12.6	99.8 ± 11.2	60.6 ± 19.2	40.1 ± 13.4	30.9 ± 11.1	26.5 ± 9.3	23.1 ± 7.5	21.5 ± 7.3	20.0 ± 6.8
Cape Town	99.0 ± 13.2	172.4 ± 18.4	138.4 ± 14.4	124.5 ± 15.2	115.2 ± 13.0	109.9 ± 12.2	107.4 ± 12.9	104.4 ± 12.3	65.8 ± 20.2	44.2 ± 13.5	34.4 ± 9.6	29.8 ± 8.5	26.1 ± 7.3	24.1 ± 6.6	22.3 ± 6.3
Hamilton	106.0 ± 12.7	180.0 ± 20.2	140.9 ± 14.1	128.3 ± 13.6	120.5 ± 13.0	115.2 ± 12.6	111.7 ± 13.0	107.5 ± 13.2	66.2 ± 26.2	41.2 ± 14.2	32.5 ± 10.3	26.7 ± 8.6	24.3 ± 8.1	22.5 ± 8.0	20.9 ± 7.3
Sydney	105.7 ± 9.3	179.5 ± 19.2	141.4 ± 14.8	127.0 ± 12.5	120.6 ± 12.1	114.5 ± 9.7	110.2 ± 10.6	106.5 ± 10.2	64.8 ± 21.5	41.1 ± 12.8	32.6 ± 10.1	28.0 ± 8.8	25.2 ± 7.4	22.7 ± 7.2	21.2 ± 7.1
Las Vegas	95.8 ± 11.2	163.5 ± 17.4	130.9 ± 15.2	117.9 ± 13.2	109.8 ± 12.1	105.5 ± 11.5	101.3 ± 11.5	98.8 ± 11.5	54.6 ± 16.4	36.3 ± 12.5	28.1 ± 9.9	24.1 ± 8.3	21.2 ± 6.9	19.4 ± 6.9	17.7 ± 6.4
Vancouver	92.3 ± 9.6	166.5 ± 26.0	129.5 ± 12.0	119.8 ± 14.2	109.9 ± 12.4	104.4 ± 11.7	99.8 ± 10.8	96.1 ± 10.9	68.4 ± 36.6	38.6 ± 18.0	29.5 ± 12.3	24.3 ± 10.4	21.3 ± 9.0	19.4 ± 8.0	17.6 ± 7.4
Hong Kong	94.2 ± 11.7	171.9 ± 20.5	136.3 ± 17.1	119.9 ± 12.6	112.2 ± 11.4	105.7 ± 11.3	101.0 ± 11.1	98.8 ± 11.5	60.4 ± 20.2	37.7 ± 12.5	27.9 ± 8.9	24.7 ± 7.6	21.1 ± 6.8	18.9 ± 6.4	17.4 ± 6.0
London	100.8 ± 15.3	177.9 ± 21.5	137.5 ± 14.5	126.1 ± 12.3	116.5 ± 11.2	111.9 ± 12.2	107.3 ± 12.0	103.7 ± 12.0	66.8 ± 18.5	43.4 ± 13.2	34.0 ± 10.9	28.7 ± 9.5	26.1 ± 8.4	23.7 ± 8.1	21.4 ± 7.3
Paris	94.1 ± 7.6	165.7 ± 16.8	132.5 ± 11.0	116.3 ± 9.6	109.2 ± 9.0	105.4 ± 8.2	100.6 ± 7.5	96.8 ± 7.1	69.3 ± 21.4	42.9 ± 11.2	32.4 ± 8.4	26.4 ± 6.7	23.7 ± 6.6	21.9 ± 6.4	19.6 ± 6.5

HSR: Relative high-speed running distance, WCS: Worst-case scenario. WCS data are derived via rolling averages and data are presented as mean ± standard deviation

Table 3. Duration-specific worst-case scenario average speed and HSR when estimated using FIXED and ROLL methods

	WCS HSR (m.min^{-1})		
Epoch length	FIXED	ROLL	Difference (FIXED – ROLL) %
60 s	56.5 ± 22.5	63.8 ± 23.4 *	-11.4
120 s	34.2 ± 12.9	40.53 ± 13.9 *	-15.6
180 s	26.2 ± 9.5	31.4 ± 10.6 *	-16.5
240 s	22.2 ± 8.2	26.7 ± 9.0 *	-15.4
300 s	19.9 ± 7.3	23.7 ± 7.9 *	-15.9
360 s	17.7 ± 6.6	21.6 ± 7.5 *	-18.4
420 s	16.6 ± 6.5	19.9 ± 7.0 *	-16.7
	WCS average speed (m.min^{-1})		
60 s	153.7 ± 20.9	173.1 ± 21.0 *	-11.2
120 s	121.4 ± 15.7	136.2 ± 14.8 *	-10.9
180 s	108.5 ± 13.7	123.0 ± 13.8 *	-11.7
240 s	103.4 ± 13.6	114.7 ± 12.8 *	-9.9
300 s	98.0 ± 12.4	109.4 ± 12.2 *	-10.4
360 s	94.2 ± 12.9	105.4 ± 12.4 *	-10.6
420 s	90.9 ± 12.9	101.9 ± 12.1 *	-10.8

FIXED: Fixed average method, HSR: Relative high-speed running distance, ROLL: Rolling average method, WCS: Worst-case scenario, *: Significantly different from FIXED ($p \leq 0.001$). Data are presented as mean ± standard deviation or % change values