Journal of Human Kinetics volume 104/2026, 245–261 DOI: 10.5114/jhk/210310

Section III – Sports and Physical Activity

Shuttle-Run Intermittent Training Prescribed from the Futsal Intermittent Endurance Test: Acute Physiological Responses from Three Different Protocols in Female and Male Futsal Players

by

Lorival José Carminatti [1], Ricardo Dantas de Lucas [2], Fernando Klitzke Borszcz [1,2], Leonardo de Lucca [1], Juliano Fernandes da Silva [2,3], Luiz Guilherme Antonacci Guglielmo [2], Anderson Santiago Teixeira [2,3,]*

This study aimed to compare the acute heart rate (HR), blood lactate concentration ([La]) and the rating of perceived exertion (RPE) responses between sexes during three different high-intensity intermittent (HIIE) shuttle-run training models prescribed from the peak speed of the Futsal Intermittent Endurance Test (PS_{FIET}). Eleven female (19.1 ± 1.7 years) and 11 male (22.1 ± 3.9 years) junior or professional futsal players firstly performed the FIET. Then, two HIIE models were performed by males and females in randomized order. Model 1 and 2 were sex-specific, while Model 3 was performed by both. HIIE models included shuttle-runs with short rest periods, followed by a 3-min rest interval between the sets. The intensity varied across models (92%, 89%, 86% PS_{FIET}). HR (expressed as the percentage of the individual maximal HR), [La], and RPE values were acquired after each set and at the end of the session. All the comparisons were performed following a Bayesian approach. At the first set, cardiovascular strain (≈93.5% HR_{max}) was similar between sexes, but higher [La] was noticed in females (7.33;7.41 mmol/L) than in males (4.96;6.42 mmol/L). Females presented larger changes in the $\%HR_{max}$ (1.25;1.29 vs. 0.41;0.58 %) and [La] (0.56;1.26 vs. −0.25;0.63 mmol/L) than males for every additional set. Also, males presented lower RPE values than females in the same HIIE format (4.9 vs. 6.0 a.u), even though they performed one more set. In conclusion, female futsal players experienced greater perceptual and metabolic responses than male players during HIIE with more directional changes, suggesting sex specific responses to the addition of COD during HIIE.

***Keywords**: change of direction; internal load; physical fitness; sex; team sport*

Introduction

Futsal is an intermittent indoor team sport characterized by stochastic activities performed at different intensities, in which players are required to perform various explosive, multidirectional, and high-intensity actions (e.g., accelerations, decelerations, and changes of direction [COD]) interspersed with recovery periods of lower intensity (Castagna et al., 2009; Chiu et al., 2024; Oliva-Lozano et al., 2023; Ribeiro et al., 2020, 2024; Serrano et al., 2020). It has been reported that during a futsal match, male and female players perform with an average heart rate (HR) close to ~86–90% and ~83% of their maximum HR (HR_{max}) during competitive and friendly games, respectively (Beato et al., 2017; Castagna et al., 2009; Rodrigues et al., 2011). Regarding the external match load, professional male players cover greater absolute (3.1 to 5.0 km vs. 2.7 to 3.2 km) and relative total distance (91 to 121 $m \cdot min^{-1}$ vs. 67 to 103 $m \cdot min^{-1}$), as well as higher total distance at a speed above 15.5 $km \cdot h^{-1}$ (~13–17% vs. ~12%) (Castagna et al., 2009; De Oliveira Bueno et al., 2014; Makaje et al., 2012; Serrano et al., 2020) than their female counterparts (Beato et al., 2017;

[1] *Human Performance Research Group, Center of Health and Sport Sciences, Santa Catarina State University, Florianópolis, Brazil.*
[2] *Physical Effort Laboratory, Sports Center, Federal University of Santa Catarina, Florianópolis, Brazil.*
[3] *Research Group for Development of Football and Futsal, Sports Center, Federal University of Santa Catarina, Florianópolis, Brazil.*
* Correspondence: anderson.santiago.teixeira@ufsc.br

Palucci Vieira et al., 2021). Furthermore, female players reduce their distances covered above 15.5 km·h^{-1} over the second half of the match (Beato et al., 2017; Oliva-Lozano et al., 2023; Palucci Vieira et al., 2021), while this was not observed for male players (Ribeiro et al., 2020; Serrano et al., 2020). Therefore, one could suppose that there are different demands between female and male futsal players, and this should be considered when designing training aimed at enhancing their physical fitness (Beato et al., 2017; Palucci Vieira et al., 2021).

The ability to perform fast change of direction (COD) has been considered a critical capacity in several court- and field-based team sports (Nygaard Falch et al., 2019). The inclusion of COD in training drills has become increasingly popular among coaches to increase training specificity to game demands (Akenhead et al., 2015; Dellal et al., 2010; Fessi et al., 2018; Ortiz et al., 2024; Teixeira et al., 2019). It has been well demonstrated that shuttle-run protocols elicit greater acute responses (i.e., physiological and perceptual) compared to straight-line running (Akenhead et al., 2015; Dellal et al., 2010; Fessi et al., 2018). Shuttle-runs with different COD frequencies could elicit different responses in the HR, blood lactate concentration ([La]), and the rating of perceived exertion (RPE) due to the volume of decelerations and accelerations (Akenhead et al., 2015; Fessi et al., 2018).

The effectiveness of high-intensity intermittent (HIIE) shuttle-run training models in female (Teixeira et al., 2018, 2019) and male (Campos et al., 2021) futsal players has been previously reported. Interestingly, those studies individualized the training intensity based on the peak speed reached during the Futsal Intermittent Endurance Test (FIET) (Castagna and Barbero Alvarez, 2010). Despite its relevance, none of those studies examined the effects of sex on acute responses to shuttle-run HIIE models prescribed from the peak speed of the FIET (PS_{FIET}) and with different COD frequency. Indeed, sex-specific differences in acute responses during HIIE have been well-documented in the literature (Coe and Astorino, 2024; Laurent et al., 2014). However, the impact of varying the number of COD on physiological responses between the sexes has not been explored well.

Of interest, female athletes can experience different physiological, perceptual and neuromuscular responses than male ones during HIIE, yet these observations have been limited to athletes from other team sports such as football and netball (Ashton and Twist, 2015; Dolci et al., 2022; Mercer et al., 2003). Assuming that training needs and adaptations may vary depending on the sport and playing standard, caution should be exercised when extrapolating these results to futsal players. Understanding sex-specific responses to shuttle-run HIIE models with different COD patterns in futsal players will allow for more precise adjustment of training stimuli to the individual athlete's needs and sport-specific demands.

The first aim of this study was to use the Bayesian approach to compare acute HR, [La], and RPE responses among three different HIIE models prescribed from the PS_{FIET}. A second aim was to compare the acute responses during the same HIIE model performed at 86% PS_{FIET} between the sexes. We hypothesized that female players would present greater physiological and perceptual responses than males during HIIE shuttle-run training sessions.

Methods

Participants

To participate in the study, athletes must have had at least three years of futsal experience and they needed to compete at the national junior or professional level. Then, 11 female (mean ± standard deviation [SD]; age: 19.1 ± 1.7 years, body mass: 58.1 ± 7.1 kg, stature: 1.60 ± 0.06 m) and 11 male (age: 22.1 ± 3.9 years, body mass: 71.6 ± 8.2 kg, stature: 1.75 ± 0.06 m) futsal players were recruited from three different teams for this study. At the time of the intervention, all players competed at the junior or the professional level in their respective teams. The current research proposal was approved by the ethics committee of the Federal University of Santa Catarina, Florianópolis, Brazil (protocol code: 19398213.3.0000.0121; approval date: 22 September 2013). The club manager and parents or legal guardians of the participants were informed about the nature of the study including objectives, protocols, and related risks, and participants provided informed written consent (≥18 years) before the commencement of this study. Participation was voluntary and players provided

assent (when they were at the age of <18 years) after being informed that they could withdraw from the study at any time.

Experimental Procedures

A randomized repeated measures design was used in this study. All players were required to complete three testing sessions on an official futsal court to compare the acute physiological responses between particular conditions. All testing sessions were carried out at the same time of the day and separated by at least 48 hours to minimize any residual fatigue. The first test consisted of performing the Futsal Intermittent Endurance Test (FIET) to determine the peak speed at the end of the test (PS_{FIET}) and the HR_{max}. The following two testing sessions were dedicated to the completion of different shuttle-run HIIE models in randomized order, in which male players performed models 1 and 3 ($M1_{M[92\% PS]}$ and $M3_{M[86\% PS]}$, respectively), while female players performed models 2 and 3 ($M2_{F[89\% PS]}$ and $M3_{F[86\% PS]}$, respectively).

Heart Rate

The beat-to-beat HR was continuously recorded during all sessions using a chest belt via short-range radio telemetry (Polar Team Sport System, Polar Electro Oy, Kempele, Finland). HR data were reduced to 15-s mean values. The highest 15-s interval during the FIET was considered the HR_{max}. During the HIIE sessions, HR data were reduced to 5-s mean values, and the HR obtained in each shuttle-running set was considered the average of the last two min of the exercise (Floriano et al., 2016). HR responses for each running set (sets 1, 2, 3, 4 and 5 [only in $M3_{M[86\% PS]}$]) were expressed as relative percentages of the HR_{max} (%HR_{max}).

Blood Lactate Concentration ([La])

Capillary blood samples (25 μL) were collected from the ear lobe. The analysis of [La] was performed using an electrochemical analyzer (YSI 2700 STAT, Yellow Springs, OH, USA). Blood samples were collected immediately after the warm-up (i.e., before the 1st set), after each running set, and in the 3rd min of recovery (after HIIE sessions).

Rating of Perceived Exertion (RPE)

The RPE of each player was assessed using the CR-10 scale adapted by Foster et al. (2001). All players were familiar with this procedure. Players reported their RPE score 30 min after the completion of the shuttle-run HIIE session.

FIET

The FIET consisted of shuttle-run bouts of 45 m (i.e., 3 × 15 m) performed at progressive speed until voluntary exhaustion (Castagna and Barbero Alvarez, 2010). Every 45 m, players were allowed to actively rest for 10 s. After each 8 × 45 m bout, players passively rested for 30 s. The initial speed was 9.0 $km \cdot h^{-1}$ with increments of 0.33 $km \cdot h^{-1}$ during the first 9 × 45 m bouts. After 9 × 45 m bouts, the increment changed to 0.20 $km \cdot h^{-1}$ every 45 m until exhaustion. The speed was controlled by prerecorded audio cues (Speaker, Satellite, Taiwan). The test was finished when participants did not reach the front line in time with the beeps for two consecutive repetitions. Then, the peak speed (i.e., PS_{FIET}) reached at the end of the test was used as the reference for the individualization of distance covered during HIIE sessions.

Shuttle-Run HIIE Protocols

Before each shuttle-run HIIE session, players completed a standardized warm-up. HIIE models named $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$ consisted of shuttle-run intervals composed of 4 sets of 6- and 4-min bouts, respectively, interspersed with 3 min of rest intervals between the sets. Model $M1_{M[92\% PS]}$ was applied for male players, while model $M2_{F[89\% PS]}$ was used for female players. Conversely, model $M3_{[86\% PS]}$ was performed by both sexes and consisted of 4 (for females) and 5 (for males) sets of 4-min bouts interspersed with 3-min rest intervals between the sets. The target intensities during HIIE model $M1_{M[92\% PS]}$, $M2_{F[89\% PS]}$, and $M3_{M/F[86\% PS]}$ were set at 92%, 89%, and 86% of PS_{FIET}, respectively. These submaximal intensity thresholds were selected to allow players to sustain the longer set duration (i.e., 4 to 6 min) used in our study, since futsal players have demonstrated reaching exhaustion in less than 3 minutes at 100% PS_{FIET} (with a time limit ranging from 1.00 to 4.42 min) during HIIE models similar to ours (Dos Santos et al., 2024). Additionally, the selection of 86% to 92% of PS_{FIET} to individualize running distance during HIIE sessions has been shown to enhance several performance outcomes in futsal players (Campos et al., 2021; Teixeira et al., 2019), highlighting the practical relevance of submaximal

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

shuttle-run intensities for HIIE programming (Akenhead et al., 2015). The 3% difference in intensity between $M1_{M[92\%\ PS]}$ and $M2_{F[89\%\ PS]}$ was designed to take into account differences between the sexes (e.g., age, anthropometric and performance features) during interval training, as previously demonstrated by Laurent et al. (2014). Finally, the intensity of $M3_{M/F[86\%\ PS]}$ was lower than of the other two sex-specific models to account for the time necessary to perform a higher number of COD (Buchheit, 2008). The average running pace performed by players between the start and return lines was dictated by a prerecorded audio cue, emitting beeps every 3.75 s. The distance covered by each player during training sessions was individualized according to their respective PS_{FIET}. $M1_{M[92\%\ PS]}$ and $M2_{F[89\%\ PS]}$ involved 7.5 s of the shuttle-run (with one direction change every 3.75 s) followed by 10 s (for $M1_{M[92\%\ PS]}$) and 7.5 s (for $M2_{F[89\%\ PS]}$) of passive rest. In contrast, model $M3_{[86\%\ PS]}$ comprised 15 s of the shuttle run (with one direction change every 3.75 s) and 15 s of passive rest. Thus, shuttle-run interval duration in $M3_{[86\%\ PS]}$ was twofold longer compared to the other models, which resulted in a greater volume of COD performed per running bout (3 vs. 1 COD). The total volume of COD performed within each model was as follows: males ($M1_{M[92\%\ PS]}$: 84 COD; $M3_{M[86\%\ PS]}$: 135 COD; ratio $M1_{M[92\%\ PS]} \div M3_{M[86\%\ PS]}$: 0.62) and females ($M2_{F[89\%\ PS]}$: 68 COD; $M3_{F[86\%\ PS]}$: 108 COD; ratio $M2_{F[89\%\ PS]} \div M3_{F[86\%\ PS]}$: 0.63).

The main differences between $M1_{M[92\%\ PS]}$ and $M2_{F[89\%\ PS]}$ in comparison to $M3_{M[86\%\ PS]}$ and $M3_{F[86\%\ PS]}$ were the intensity (i.e., $\%PS_{FIET}$) and the number of COD performed during each shuttle-running bout (1 vs. 3 COD). The HR and [La] were assessed during HIIE, while the RPE was assessed at the end of each training session.

Statistical Analysis

Analyses were carried out following established Bayesian inference methods, using statistical software R (v4.0; R Core Team [2020], Vienna, Austria) and its graphical interface RStudio (v1.2.5). The package brms (Bürkner, 2017) allowing to fit Bayesian models using Stan (Gelman et al., 2015) was applied for analysis.

Analysis of [La] and the $\%HR_{max}$ during HIIE sessions was performed using the linear multilevel modeling procedure (Equation 1). The HIIE models ($M1_{M[92\%\ PS]}$, $M2_{F[89\%\ PS]}$, $M3_{M[86\%\ PS]}$, and $M3_{F[86\%\ PS]}$), sets (as continuous 1 to 4/5 adjusted to the intercept located at the first set, i.e., each set number was subtracted by −1 [after analysis the data were readjusted]), and the interaction model × sets were included as population-level (a.k.a., fixed) effects. Group-level (a.k.a., random) effects included varying intercepts for each jth subject (i.e., the identity of each participant to deal with repeated measures in different HIIEs) and varying intercepts and slopes of all predictors (i.e., model, sets, and interaction model × sets) for each kth observation derived from the interaction subject: model (i.e., each observation of each participant). Group levels were reported as standard deviations (SD - $\sigma_{between}$), therefore, they provide the variability (spread) of between-subjects responses at the first set and the following sets in each HIIE model. The residual (unexplained) SD (σ_{within}) was modeled for each HIIE model using a distributional model via log-transformation of residual SD estimates (to ensure positive values) (Bürkner, 2017). Note, that the σ_{within} is traditionally assumed constant among all predictors in statistical models, however, Bayesian modeling allows the fitting of σ_{within} with predictors (Bürkner, 2017). Statistical modeling and the Bayesian priors utilized for [La] and $\%HR_{max}$ responses during the HIIE sessions are presented in Equation 1, as follows:

Likelihood $y_i \sim Normal(\mu, exp(\log(\sigma)))$

Variables $\mu = \alpha_{j[i],k[i]} + \beta_{1k[i]}(M2_{F[89\%\ PS]}) + \beta_{2k[i]}(M3_{M[86\%\ PS]}) + \beta_{3k[i]}(M3_{F[86\%\ PS]}) + \beta_{4k[i]}(set) + \beta_{5k[i]}(M2_{F[89\%\ PS]} \times set) + \beta_{5k[i]}(M3_{M[86\%\ PS]} \times set) + \beta_{6k[i]}(M3_{F[86\%\ PS]} \times set)$

$$\alpha_j \sim Normal(\mu_{\alpha_j}, {\sigma_{\alpha_j}}^2), for\ suject\ j = 1, \ldots, J$$

$$\begin{pmatrix} \alpha_k \\ \beta_{1k} \\ \beta_{2k} \\ \beta_{3k} \\ \beta_{4k} \\ \beta_{5k} \\ \beta_{6k} \end{pmatrix} \sim N\left(\begin{pmatrix} \mu_{\alpha_k} \\ \mu_{\beta_{1k}} \\ \mu_{\beta_{2k}} \\ \mu_{\beta_{3k}} \\ \mu_{\beta_{4k}} \\ \mu_{\beta_{5k}} \\ \mu_{\beta_{6k}} \end{pmatrix}, \begin{pmatrix} {\sigma_{\alpha_k}}^2 & \rho\alpha_k\beta_{1k} & \rho\alpha_k\beta_{2k} & \rho\alpha_k\beta_{3k} & \rho\alpha_k\beta_{4k} & \rho\alpha_k\beta_{5k} & \rho\alpha_k\beta_{6k} \\ \rho\beta_{1k}\alpha_k & {\sigma_{\beta_{1k}}}^2 & \rho\beta_{1k}\beta_{2k} & \rho\beta_{1k}\beta_{3k} & \rho\beta_{1k}\beta_{4k} & \rho\beta_{1k}\beta_{5k} & \rho\beta_{1k}\beta_{6k} \\ \rho\beta_{2k}\alpha_k & \rho\beta_{2k}\beta_{1k} & {\sigma_{\beta_{2k}}}^2 & \rho\beta_{2k}\beta_{3k} & \rho\beta_{2k}\beta_{4k} & \rho\beta_{2k}\beta_{5k} & \rho\beta_{2k}\beta_{6k} \\ \rho\beta_{3k}\alpha_k & \rho\beta_{3k}\beta_{1k} & \rho\beta_{3k}\beta_{2k} & {\sigma_{\beta_{3k}}}^2 & \rho\beta_{3k}\beta_{4k} & \rho\beta_{3k}\beta_{5k} & \rho\beta_{3k}\beta_{6k} \\ \rho\beta_{4k}\alpha_k & \rho\beta_{4k}\beta_{1k} & \rho\beta_{4k}\beta_{2k} & \rho\beta_{4k}\beta_{3k} & {\sigma_{\beta_{4k}}}^2 & \rho\beta_{4k}\beta_{5k} & \rho\beta_{4k}\beta_{6k} \\ \rho\beta_{5k}\alpha_k & \rho\beta_{5k}\beta_{1k} & \rho\beta_{5k}\beta_{2k} & \rho\beta_{5k}\beta_{3k} & \rho\beta_{5k}\beta_{4k} & {\sigma_{\beta_{5k}}}^2 & \rho\beta_{5k}\beta_{6k} \\ \rho\beta_{6k}\alpha_k & \rho\beta_{6k}\beta_{1k} & \rho\beta_{6k}\beta_{2k} & \rho\beta_{6k}\beta_{3k} & \rho\beta_{6k}\beta_{4k} & \rho\beta_{6k}\beta_{5k} & {\sigma_{\beta_{6k}}}^2 \end{pmatrix} \right),$$

$$for\ observation\ (subject{:}model)\ k = 1, \ldots, K$$

$$log(\sigma) = \eta_0 + \eta_1(M2_{F[89\%\ PS]}) + \eta_2(M3_{M[86\%\ PS]}) + \eta_3(M3_{F[86\%\ PS]})$$

Priors

$$\alpha_j \sim Normal(0, \sigma_{\alpha j})$$
$$\alpha_k \sim Normal(0, \sigma_{\alpha k})$$
$$\beta_{1k} \sim Normal(0, \sigma_{\beta 1k})$$
$$\beta_{2k} \sim Normal(0, \sigma_{\beta 2k})$$
$$\beta_{3k} \sim Normal(0, \sigma_{\beta 3k})$$
$$\beta_{4k} \sim Normal(0, \sigma_{\beta 4k})$$
$$\beta_{5k} \sim Normal(0, \sigma_{\beta 5k})$$
$$\beta_{6k} \sim Normal(0, \sigma_{\beta 6k})$$

$$\alpha, \beta_1, \beta_2, \beta_3, \beta_4, \beta_5, and\ \beta_6 \sim Student - t(\mu = 0, \sigma = 10, df = 3)$$
$$\sigma_{\alpha j}, \sigma_{\alpha k}, \sigma_{\beta 1k}, \sigma_{\beta 2k}, \sigma_{\beta 3k}, \sigma_{\beta 4k}, \sigma_{\beta 5k}, and\ \sigma_{\beta 6k} \sim Student - t^{+}(\sigma = 10, df = 3)$$
$$\rho = LKJcorr(2)$$
$$\eta_0, \eta_1, \eta_2, and\ \eta_3 \sim Normal(\mu = log(1), \sigma = 1) \quad (1)$$

For analysis of [La] and the RPE at the end of HIIE sessions, the population-level effects included HIIE models ($M1_{M[92\%\ PS]}$, $M2_{F[89\%\ PS]}$, $M3_{M[86\%\ PS]}$, and $M3_{F[86\%\ PS]}$), for both the mean (μ) and the residual SD (σ_{within}) estimates (i.e., each mean and SD of responses was modeled in each HIIE as a distributional model; Bürkner, 2017). Group levels for μ estimates included varying intercepts for each jth subject. Statistical modeling and the Bayesian priors utilized for [La] and the RPE at the end of HIIE sessions are presented in Equation 2, as follows:

Likelihood $y_i \sim Normal(\mu, exp(\log(\sigma)))$

Variables $\mu = \alpha_{j[i]} + \beta_1(M2_{F[89\%\ PS]}) + \beta_2(M3_{M[86\%\ PS]}) + \beta_3(M3_{F[86\%\ PS]})$
$$\alpha_j \sim Normal(\mu_{\alpha_j}, {\sigma_{\alpha_j}}^2), for\ suject\ j = 1, \ldots, J$$
$$log(\sigma) = \eta_0 + \eta_1(M2_{F[89\%\ PS]}) + \eta_2(M3_{M[86\%\ PS]}) + \eta_3(M3_{F[86\%\ PS]})$$

Priors $\alpha_j \sim Normal(0, \sigma_{\alpha j})$
$$\alpha, \beta_1, \beta_2, and\ \beta_3 \sim Student - t(\mu = 0, \sigma = 10, df = 3)$$
$$\sigma_{\alpha j} \sim Student - t^{+}(\sigma = 10, df = 3)$$
$$\eta_0, \eta_1, \eta_2, and\ \eta_3 \sim Normal(\mu = log(1), \sigma = 1) \quad (2)$$

For analysis of [La] before HIIE sessions, a model equal to [La] and RPE post-exercise was used, except that the data were analyzed using a log-normal likelihood model, to ensure positive values (Equation 3). After the analysis, the data were back-transformed to the original scale using an exponential function, therefore, σ_{within} was presented as times/divide form (×/÷), as presented in Equation 3:

Likelihood $y_i \sim Normal(log(\mu, \sigma))$

Variables $log(\mu) = \alpha_{j[i]} + \beta_1(M2_{F[89\%\ PS]}) + \beta_2(M3_{M[86\%\ PS]}) + \beta_3(M3_{F[86\%\ PS]})$
$$\alpha_j \sim Normal(\mu_{\alpha_j}, {\sigma_{\alpha_j}}^2), for\ suject\ j = 1, \ldots, J$$
$$log(\sigma) = \eta_0 + \eta_1(M2_{F[89\%\ PS]}) + \eta_2(M3_{M[86\%\ PS]}) + \eta_3(M3_{F[86\%\ PS]})$$

Priors $\alpha_j \sim Normal(0, \sigma_{\alpha j})$
$$\alpha, \beta_1, \beta_2, and\ \beta_3 \sim Student - t(\mu = 0, \sigma = 10, df = 3)$$
$$\sigma_{\alpha j} \sim Student - t^{+}(\sigma = 10, df = 3)$$
$$\eta_0, \eta_1, \eta_2, and\ \eta_3 \sim Normal(\mu = log(1), \sigma = 1) \quad (3)$$

Model fitting was performed using Markov chain Monte Carlo (MCMC) methods, more specifically the No-U-Turn sampler (NUTS) implemented in Stan. Priors' distributions were set to be weakly non-informative so that their influence on the estimates was relatively small (Gelman et al., 2008) (Equations 1 to 3). Unless otherwise stated all observed data are reported as means ± SD. The posterior data are presented as medians with equal-tailed 95% credible intervals (CrI), i.e., the interval that there is a probability of 95% that the true population variable is contained (Morey et al., 2016). The probabilities of the effects being lower or higher than 0 or 1 were evaluated, depending on the comparison. Specifically, the proportion (%) of the posterior distribution located below or above 0 or 1 was assessed. Results in the figures also present the prediction intervals (PredI) of 95%, which provides the range that contains 95% of future individual responses.

Results

The mean ± SD of PS_{FIET} were 16.6 ± 0.8 (males) and 15.7 ± 1.0 km·h^{-1} (females), and the HR_{max} was 191 ± 8 (males) and 197 ± 7 bpm (females). Comparisons of sex characteristics revealed that males were older (posterior median difference [95% CrI], 3.0 [0.5 to 5.0] years; probability of effect being higher than zero [$P_{>0}$] = 99.2%), heavier (13.6 [7.3 to 19.9] kg; $P_{>0}$ = 100%), taller (15 [10 to 20] cm; $P_{>0}$ = 100%), and had higher PS_{FIET} (0.9 [0.2 to 1.6] km·h^{-1}; $P_{>0}$ = 100%) than females. Conversely, females had a higher HR_{max} (6.2 [−0.2 to 12.5] bpm; $P_{>0}$ = 97.1%).

Table 1 presents the posterior estimates of the mean and SD of %HR_{max} and [La] responses at the first set and the changes in the following sets for each HIIE model, [La] responses before and after HIIE models, and the RPE after particular sessions.

Figure 2 provides the observed values for each player, the posterior median (95% CrI), and the 95% IPred of the time course %HR_{max} responses in each HIIE model. HR responses in the first set

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

were very similar across all HIIE models. Changes in the $\%HR_{max}$ with each subsequent set were clearly lower in $M1_{M[92\%\ PS]}$ than in $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$ (probability to be lower [$P_{<0}$] = 99.9% in both). The change within the sets in $M3_{F[86\%\ PS]}$ was clearly higher than in $M2_{F[89\%\ PS]}$ and $M3_{M[86\%\ PS]}$ (probability to be higher [$P_{>0}$] > 99%). In $M_{3[86\%\ PS]}$, females showed a higher increase in the HR with each following set, even though they performed one set less than males. There were no clear differences among the models in the variability of responses or residual unexplained heterogeneity (i.e., $\sigma_{between}$ and σ_{within}, respectively). The variables of comparison are detailed in Table 2.

Figure 3 depicts the observed [La] values for each player, the posterior median (95% CrI), and the 95% IPred of the time course of [La] responses related to each HIIE model. $M3_{M[86\%\ PS]}$ session elicited lower [La] in the first set compared to all other sessions ($P_{<0}$ = 99.8% for all). Changes in [La] with each subsequent set were lower in $M1_{M[92\%\ PS]}$ compared to all other models ($P_{<0}$ > 99.9%). Furthermore, the $M3_{F[86\%\ PS]}$ session induced larger increases in [La] with each following set compared to all other models. For post-exercise [La], males exhibited lower values than females regardless of models ($M1_{M[92\%\ PS]}$ and $M3_{M[86\%\ PS]}$ < $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$). Additionally, it was observed that $M1_{M[92\%\ PS]}$ also elicited lower [La] than $M3_{M[86\%\ PS]}$. Residual σ_{within} was lower in $M3_{M[92\%\ PS]}$ than $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$, indicating that men had more homogeneous [La] response (i.e., lower intra-individual variability) than women.

The post-warm-up and post-exercise [La] tended to be lower for males than females ($M1_{M[92\%\ PS]}$ and $M3_{M[86\%\ PS]}$ < $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$, $P_{>1}$ >96.6%). In addition, post-exercise [La] was higher in $M3_{M[86\%\ PS]}$ than $M1_{M[92\%\ PS]}$ and in $M3_{F[86\%\ PS]}$ than $M2_{F[89\%\ PS]}$. For post-exercise [La], the residual σ_{within} was lower in $M3_{M[86\%\ PS]}$ than in $M3_{F[86\%\ PS]}$ (Table 3).

At the individual level, the posterior median (95% CrI) and the 95% IPred of RPE responses after each HIIE model are presented in Figure 4. A unique clear difference occurred between $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$, with lower RPE values for the former.

Discussion

This study aimed to compare the acute responses of the HR, [La], and the RPE among three different HIIE models prescribed from PS_{FIET}. Additionally, the study compared the acute responses during the same HIIE protocol (i.e., $M3_{M[86\%\ PS]}$ and $M3_{F[86\%\ PS]}$) between sexes. The main finding of the present study was that female players experienced greater changes in the $\%HR_{max}$ and [La] than male players, according to the progression of sets during HIIE sessions, regardless of the number of directional changes. Furthermore, in comparison to its respective HIIE model with lower COD volume (i.e., $M1_{M[92\%\ PS]}$ and $M2_{F[89\%\ PS]}$ for males and females, respectively), female players perceived the HIIE session with more directional changes (i.e., $M_{3[86\%\ PS]}$) to be subjectively harder than male players, confirming our hypothesis.

The mean $\%HR_{max}$ derived from HIIE sessions ranged from 92% to 98% in the current study. Comparing these values to those observed during futsal matches, they were higher than those reported in friendly matches for males (Dos-Santos et al., 2020) and females (Beato et al., 2017). Regarding [La] responses, $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$ elicited much higher [La] compared to that reported previously in six Brazilian high-level female players during the first (6.3 ± 2.3 mmol/L) and the second (5.4 ± 1.3 mmol/L) half of a friendly game (Kassiano et al., 2019). In addition, [La] in $M1_{M[92\%\ PS]}$ and $M3_{M[86\%\ PS]}$ was similar to that reported by Castagna et al. (2009), but lower than that observed in another study in male futsal matches (Dos-Santos et al., 2020). These differences might be related to the fact that the intensity of effort, bout duration, and rest intervals between actions during a friendly/official futsal match may not be equivalent to those training stimuli prescribed within a standardized HIIE session.

Table 1. Posterior estimates of the mean (μ) and the between-subjects standard deviation ($\sigma_{between}$) of physiological responses in HIIE models at the first set (intercept), the change in the subsequent series sets (slopes), and the residual unexplained heterogeneity in each HIIE model (σ_{within}); the physiological and perceptual mean (μ) and standard deviation of responses (σ_{within}) during the warm-up and at post each HIIE model.

Variables and effects	Posterior median [95% CrI]		
	μ	$\sigma_{between}$	σ_{within}
	HIIE session		
	% HR$_{max}$		
$M1_{M[92\%\ PS]}$			± 1.06 [0.82, 1.40]
First set	93.6 [91.9, 95.4]	± 1.34 [0.12, 2.52]	
Each subsequent set	0.41 [0.10, 0.73]	± 0.16 [0.01, 0.43]	
$M2_{F[89\%\ PS]}$			± 0.99 [0.78, 1.31]
First set	93.5 [91.8, 95.2]	± 0.95 [0.04, 2.82]	
Each subsequent set	1.29 [0.94, 1.62]	± 0.23 [0.01, 0.65]	
$M3_{M[86\%\ PS]}$			± 0.83 [0.66, 1.10]
First set	93.2 [91.0, 95.3]	± 1.88 [0.13, 4.20]	
Each subsequent set	0.58 [0.18, 0.98]	± 0.55 [0.13, 1.03]	
$M3_{F[86\%\ PS]}$			± 1.02 [0.79, 1.37]
First set	93.5 [91.5, 95.5]	± 1.49 [0.07, 3.95]	
Each subsequent set	1.25 [0.90, 1.63]	± 0.24 [0.01, 0.73]	
	[La] (mmol/L)		
$M1_{M[92\%\ PS]}$			± 0.69 [0.53, 0.89]
First set	6.42 [5.51, 7.34]	± 0.30 [0.01, 0.84]	
Each subsequent set	−0.25 [−0.48, −0.02]	± 0.18 [0.01, 0.43]	
$M2_{F[89\%\ PS]}$			± 0.61 [0.46, 0.83]
First set	7.41 [6.46, 8.45]	± 0.47 [0.03, 1.34]	
Each subsequent set	0.56 [0.15, 0.99]	± 0.58 [0.29, 1.09]	
$M3_{M[86\%\ PS]}$			± 0.43 [0.35, 0.57]
First set	4.96 [3.81, 6.15]	± 1.17 [0.29, 2.34]	
Each subsequent set	0.63 [0.32, 0.94]	± 0.43 [0.07, 0.84]	
$M3_{F[86\%\ PS]}$			± 0.91 [0.72, 1.20]
First set	7.33 [6.37, 8.40]	± 0.41 [0.02, 1.27]	
Each subsequent set	1.26 [0.89, 1.62]	± 0.37 [0.02, 0.84]	
	Warm-up		
	[La] (mmol/L)		
$M1_{M[92\%\ PS]}$	2.18 [1.77, 2.68]		×/÷1.31 [1.13, 1.67]
$M2_{F[89\%\ PS]}$	3.02 [2.58, 3.53]		×/÷1.19 [1.07, 1.40]
$M3_{M[86\%\ PS]}$	1.90 [1.48, 2.42]		×/÷1.21 [1.08, 1.43]
$M3_{F[86\%\ PS]}$	2.77 [2.37, 3.25]		×/÷1.40 [1.21, 1.84]
	Post-exercise		
	[La] (mmol/L)		
$M1_{M[92\%\ PS]}$	5.14 [4.07, 6.35]		± 0.57 [0.19, 1.43]
$M2_{F[89\%\ PS]}$	8.04 [6.71, 9.27]		± 1.09 [0.32, 1.86]
$M3_{M[86\%\ PS]}$	6.54 [5.06, 8.05]		± 1.75 [1.07, 2.90]
$M3_{F[86\%\ PS]}$	10.10 [8.87, 11.20]		± 0.35 [0.04, 1.33]
	RPE (arbitrary units)		
$M1_{M[92\%\ PS]}$	4.93 [3.87, 6.07]		± 0.41 [0.17, 1.17]
$M2_{F[89\%\ PS]}$	5.01 [4.08, 5.86]		± 0.56 [0.07, 1.48]
$M3_{M[86\%\ PS]}$	5.17 [4.01, 6.33]		± 0.34 [0.07, 1.06]
$M3_{F[86\%\ PS]}$	5.99 [4.94, 6.93]		± 1.05 [0.25, 1.85]

All data are shown as posterior medians [equal-tailed 95% credible intervals];
** Times divide (×/÷) σ because the data were analyzed under a log-normal model to ensure positive values;*
HR$_{max}$: maximal heart rate; RPE: rating of perceived exertion; [La]: blood lactate concentration

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Table 2. Posterior estimates of the comparisons between HIIE model variables mean (μ) and the between-subjects standard deviation ($\sigma_{between}$) of physiological responses during HIIE models at the first set (intercept), the change in the subsequent series sets (slopes), and the residual unexplained heterogeneity in each HIIE model (σ_{within}).

Contrast	Comparison				
	First set		Each subsequent set		σ_{within}, × (P>1)[b]
	μ, ± (P>0)[a]	$\sigma_{between}$, × (P>1)[b]	μ, ± (P>0)[a]	$\sigma_{between}$, × (P>1)[b]	
			% HR_{max}		
$M1_{M[92\% PS]}$ – $M2_{F[89\% PS]}$	+0.15 [−2.20, 2.67] (55.1%)	×1.60 [0.14, 32.0] (69.7%)	**−0.88 [−1.32, −0.41] (0.1%)**	×0.73 [0.03, 20.2] (40.0%)	×1.07 [0.74, 1.55] (63.7%)
$M1_{M[92\% PS]}$ – $M3_{F[86\% PS]}$	+0.15 [−2.63, 2.74] (55.1%)	×0.96 [0.06, 22.5] (48.4%)	**−0.84 [−1.33, −0.37] (0.1%)**	×0.71 [0.03, 15.4] (38.7%)	×1.04 [0.71, 1.54] (58.5%)
$M1_{M[92\% PS]}$ – $M3_{M[86\% PS]}$	+0.42 [−1.47, 2.32] (69.2%)	×0.74 [0.04, 14.6] (38.3%)	−0.17 [−0.67, 0.34] (24.5%)	×0.25 [0.01, 2.46] (8.0%)	×1.27 [0.87, 1.83] (89.6%)
$M2_{F[89\% PS]}$ – $M3_{F[86\% PS]}$	−0.02 [−1.94, 1.89] (49.2%)	×0.59 [0.03, 14.3] (32.6%)	+0.03 [−0.47, 0.53] (56.1%)	×0.93 [0.03, 20.6] (48.0%)	×0.97 [0.66, 1.40] (43.8%)
$M2_{F[89\% PS]}$ – $M3_{M[86\% PS]}$	+0.25 [−2.48, 2.98] (58.6%)	×0.46 [0.02, 8.28] (23.8%)	**+0.70 [0.18, 1.24] (99.5%)**	×0.35 [0.01, 2.18] (12.1%)	×1.19 [0.82, 1.69] (81.5%)
$M3_{M[86\% PS]}$ – $M3_{F[86\% PS]}$	−0.27 [−3.36, 2.67] (42.4%)	×1.34 [0.07, 23.2] (61.9%)	**−0.67 [−1.21, −0.14] (1.0%)**	×2.61 [0.44, 46.1] (87.2%)	×0.82 [0.57, 1.19] (15.5%)
			HIIE [La] (mmol/L)		
$M1_{M[92\% PS]}$ – $M2_{F[89\% PS]}$	−1.00 [−2.44, 0.37] (7.4%)	×0.66 [0.02, 13.5] (36.2%)	**−0.81 [−1.28, −0.33] (0.1%)**	×0.28 [0.01, 2.21] (7.4%)	×1.13 [0.75, 1.66] (77.4%)
$M1_{M[92\% PS]}$ – $M3_{F[86\% PS]}$	−0.93 [−2.39, 0.49] (9.4%)	×0.75 [0.02, 17.4] (40.5%)	**−1.50 [−1.92, −1.07] (0%)**	×0.44 [0.02, 12.0] (24.6%)	×0.75 [0.52, 1.09] (6.7%)
$M1_{M[92\% PS]}$ – $M3_{M[86\% PS]}$	**+1.44 [0.55, 2.39] (99.8%)**	×0.22 [0.01, 2.29] (7.6%)	**−0.87 [−1.27, −0.49] (0%)**	×0.36 [0.02, 4.93] (15.8%)	**×1.57 [1.08, 2.24] (99.1%)**
$M2_{F[89\% PS]}$ – $M3_{F[86\% PS]}$	+0.07 [−0.73, 0.85] (57.5%)	×1.19 [0.06, 25.0] (55.2%)	**−0.70 [−1.26, −0.14] (1.0%)**	×1.60 [0.38, 26.0] (76.2%)	**×0.67 [0.46, 1.00] (2.6%)**
$M2_{F[89\% PS]}$ – $M3_{M[86\% PS]}$	**+2.46 [0.89, 4.05] (99.8%)**	×0.34 [0.02, 2.51] (11.9%)	−0.07 [−0.58, 0.45] (38.1%)	×1.30 [0.39, 6.79] (70.3%)	**×1.40 [0.94, 2.07] (99.2%)**
$M3_{M[86\% PS]}$ – $M3_{F[86\% PS]}$	**−2.39 [−4.03, −0.80] (0.2%)**	×3.39 [0.51, 73.9] (91.2%)	**−0.63 [−1.11, −0.15] (1.0%)**	×1.20 [0.20, 21.4] (59.7%)	**×0.48 [0.34, 0.68] (0%)**

*Data are shown as posterior median [equal-tailed 95% credible interval] and probabilities of the effect are higher than 0 or 1 depending on the variable. Values in **bold** indicate that the 95% CrI does not overlap 0 or 1.*
a: probability of the effect being higher than 0 (i.e., ± comparisons); b: probability of the effect being higher than 1 (i.e., × times comparisons)

Table 3. Posterior estimates of the comparisons among HIIE models of the physiological and perceptual mean (μ) and standard deviation of responses (σ_{within}) during the warm-up and at post each HIIE model.

Contrast	Comparison	
	μ, ± or × (P>0 or 1)[a]	σ_{within}, × or ± (P>1 or 0)[b]
	Warm-up [La] (mmol/L)	
$M1_{M[92\% PS]} – M2_{F[89\% PS]}$	**×0.72 [0.56, 0.93] (0.8%)**	+0.10 [−0.11, 0.35] (83.7%)
$M1_{M[92\% PS]} – M3_{F[86\% PS]}$	×0.79 [0.61, 1.02] (3.4%)	+0.09 [−0.13, 0.33] (80.1%)
$M1_{M[92\% PS]} – M3_{M[86\% PS]}$	×1.14 [0.86, 1.52] (84.8%)	−0.07 [−0.37, 0.20] (29.0%)
$M2_{F[89\% PS]} – M3_{F[86\% PS]}$	×1.09 [0.92, 1.29] (85.0%)	−0.01 [−0.22, 0.18] (43.9%)
$M2_{F[89\% PS]} – M3_{M[86\% PS]}$	**×1.59 [1.20, 2.14] (99.9%)**	−0.17 [−0.45, 0.06] (6.3%)
$M3_{M[86\% PS]} – M3_{F[86\% PS]}$	**×0.68 [0.51, 0.91] (0.6%)**	+0.15 [−0.07, 0.44] (92.1%)
	Post-exercise [La] (mmol/L)	
$M1_{M[92\% PS]} – M2_{F[89\% PS]}$	**−2.88 [−4.19, −1.09] (0.2%)**	×0.52 [0.16, 2.30] (15.0%)
$M1_{M[92\% PS]} – M3_{F[86\% PS]}$	**−4.95 [−6.44, −3.22] (0%)**	×1.69 [0.35, 10.9] (72.5%)
$M1_{M[92\% PS]} – M3_{M[86\% PS]}$	**−1.39 [−2.53, −0.21] (1.3%)**	×0.31 [0.01, 1.08] (3.1%)
$M2_{F[89\% PS]} – M3_{F[86\% PS]}$	**−2.05 [−2.84, −1.29] (0%)**	×3.39 [0.27, 27.9] (87.1%)
$M2_{F[89\% PS]} – M3_{M[86\% PS]}$	+1.48 [−0.51, 3.38] (92.9%)	×0.62 [0.18, 1.30] (9.4%)
$M3_{M[86\% PS]} – M3_{F[86\% PS]}$	**−3.55 [−5.35, −1.60] (0.1%)**	**×5.17 [1.15, 42.0] (98.5%)**
	RPE	
$M1_{M[92\% PS]} – M2_{F[89\% PS]}$	−0.07 [−1.20, 1.11] (43.4%)	×0.82 [0.21, 5.84] (40.1%)
$M1_{M[92\% PS]} – M3_{F[86\% PS]}$	−1.05 [−2.18, 0.18] (4.8%)	×0.40 [0.14, 1.92] (9.1%)
$M1_{M[92\% PS]} – M3_{M[86\% PS]}$	−0.24 [−0.77, 0.43] (18.8%)	×1.23 [0.32, 7.20] (61.2%)
$M2_{F[89\% PS]} – M3_{F[86\% PS]}$	**−0.99 [−1.74, −0.18] (1.0%)**	×0.50 [0.06, 5.03] (22.9%)
$M2_{F[89\% PS]} – M3_{M[86\% PS]}$	−0.16 [−1.41, 1.01] (40.4%)	×1.58 [0.14, 10.4] (66.7%)
$M3_{M[86\% PS]} – M3_{F[86\% PS]}$	−0.83 [−2.06, 0.46] (10.2%)	×0.34 [0.06, 1.73] (7.5%)

*Data are shown as posterior median [equal-tailed 95% credible interval] and probabilities of the effect are higher than 0 or 1 depending on the variable. Values in **bold** indicate that the 95% CrI does not overlap 0 or 1.*
a: probability of the effect being higher than 0 for post-exercise [La], and the RPE (i.e., ± comparisons), and to be higher than 1 for warm-up [La] (i.e., × times comparisons); b: probability of the effect being higher than 1 for post-exercise [La], and RPE (i.e., × times comparisons), and to be higher than 0 for warm-up [La] (i.e., ± comparisons)

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

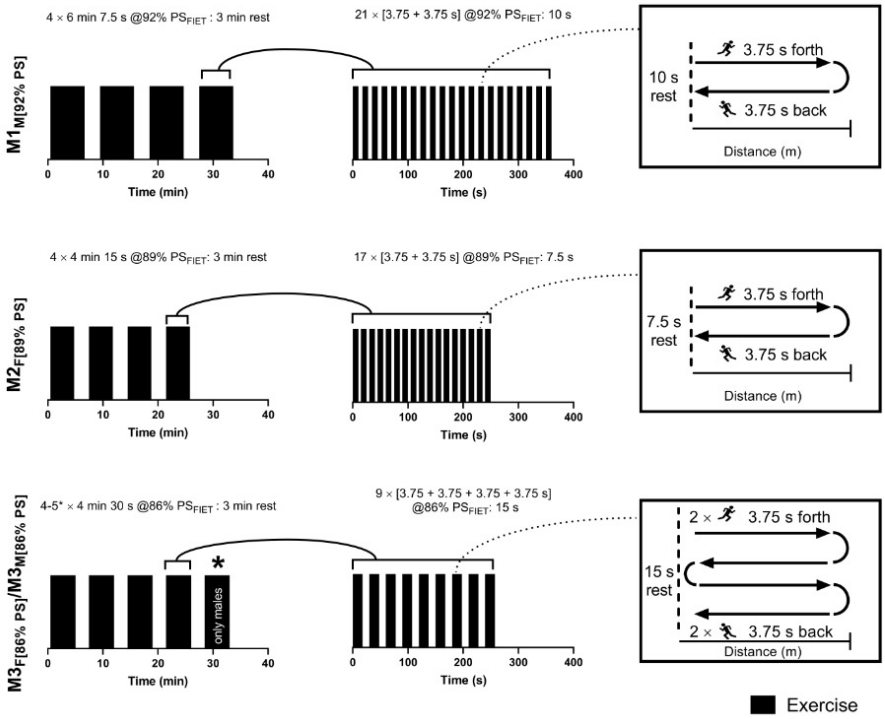

Figure 1. High intensity intermittent exercise protocol design.

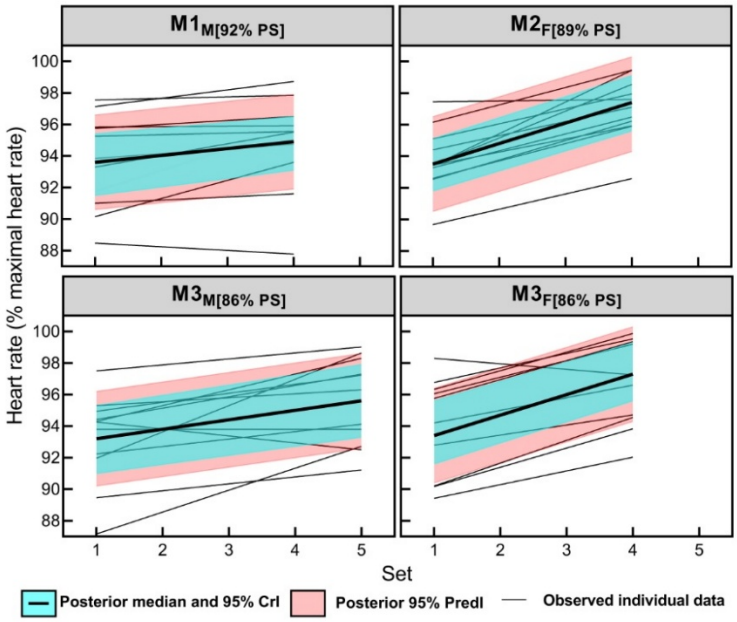

Figure 2. Heart rate (% of the maximal heart rate) responses after each exercise set during different HIIE protocols.

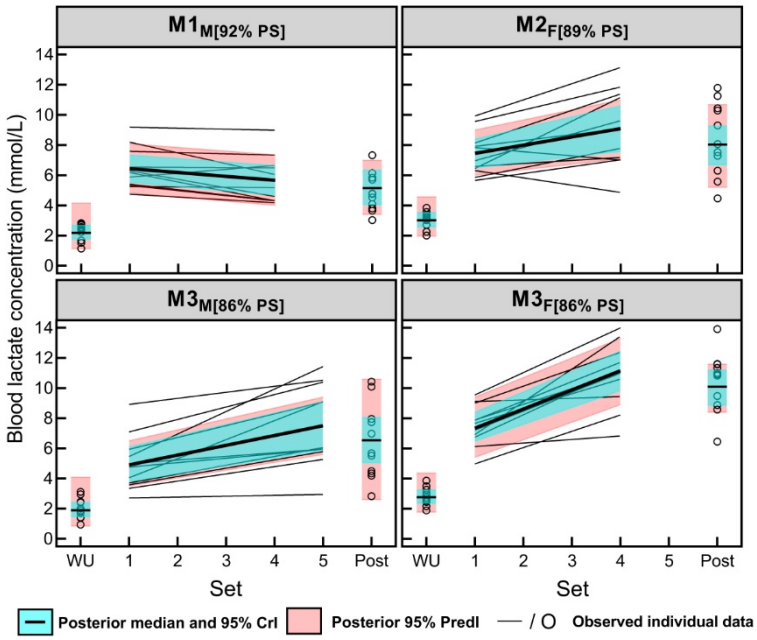

Figure 3. Blood lactate concentration responses after the warm-up, each exercise set and 3 min post exercise during different HIIE protocols.

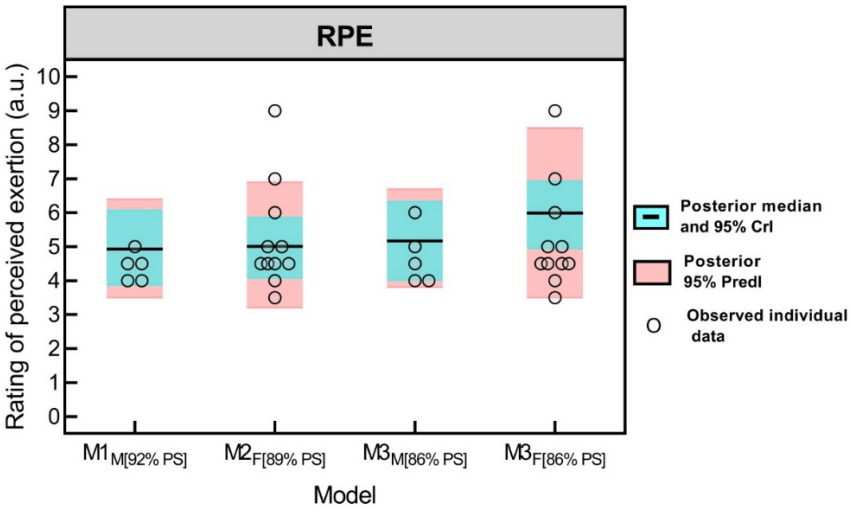

Figure 4. Rating of perceived exertion of the session following different HIIE protocols.

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

An important finding of this study was that the perceptual response in function of HIIE sets progression increased more in women (0.99 [0.18 to 1.74] a.u.) than in men (0.24 [−0.43 to 0.77] a.u.) as the COD volume increased (Table 3). The greater number of directional changes can increase the task complexity of shuttle-running (Ashton and Twist, 2015). Although a concomitant increase in perceived exertion is expected as exercise task complexity increases (De Morree et al., 2012), our data suggest that female players might respond differently than male players to more complex shuttle-running tasks. It could be partly related to differences noticed between the sexes such as the body composition profile (greater fat content in women) (Barbero-Alvarez et al., 2015; Floriano et al., 2016; Teixeira et al., 2019), the cardiovascular function (Wheatley et al., 2014) and lower-limb biomechanical features (Barnes et al., 2014) during running, as well as training and match external loads (e.g., discrepancies in acceleration and deceleration demands) (Oliva-Lozano et al., 2023; Ribeiro et al., 2020). Considering the greater fat mass observed in women (e.g., at the breast and hip) one would suppose that carrying fat as 'deadweight' could increase the muscular work during the decelerations and accelerations inherent to shuttle-run performances.

Aligned with RPE responses, changes in the $\%HR_{max}$ and [La] across the sets during HIIE models with different directional changes were also sex-dependent in the present study, with female players exhibiting larger changes in the $\%HR_{max}$ and [La] with every additional set than their male peers. This also resulted in greater post-exercise [La] in females than in males, regardless of the HIIE model ($M1_{M[92\%\ PS]}$ and $M3_{M[86\%\ PS]}$ < $M2_{F[89\%\ PS]}$ and $M3_{F[86\%\ PS]}$). Therefore, the increased perceptual response observed following $M3_{F[86\%\ PS]}$ in women can also be underlined by the greater cardiovascular and metabolic demand during this HIIE model, since RPE values are largely related with the HR and lactate response (Coutts et al., 2009).

Additionally, the larger changes in the $\%HR_{max}$ over the sets in female players may suggest that greater cardiac output is needed in women to meet the same relative physical work demand (Wheatley et al., 2014), especially due to the sex-related differences in cardiac structure and function during submaximal and maximal effort (Ogawa et al., 1992). It should also be highlighted that the greater reliance on the anaerobic energy system (inferred by the increased [La]) noticed in women may be a consequence of their lower fitness level (e.g., PS_{FIET}) in comparison to men in the current sample of futsal players. Indeed, female athletes have shown lower $\dot{V}O_{2max}$ when compared male athletes of the same performance level (Barbero-Álvarez et al., 2009; Palucci Vieira et al., 2021). It has been shown that lower levels of $\dot{V}O_{2max}$ are associated with higher energy cost of running (Bunc and Heller, 1989), which in turn, may suggest that our less physically fit female athletes (i.e., inferred from PS_{FIET}) would expend more energy than their male counterparts during shuttle-running HIIE. However, a recent study did not support this assumption (Dolci et al., 2022). Those authors (Dolci et al., 2022) showed that female soccer players had lower energetic cost than males during a 10-m shuttle-running protocol performed at average speed of 8.4 $km \cdot h^{-1}$, but similar energetic cost while performing shuttle-running over 20 m. However, it should be noted that our study employed higher absolute running speeds (13.5 to 15.0 $km \cdot h^{-1}$) than those reported by Dolci et al. (2022). Therefore, further studies investigating sex-related differences in the energetic cost of shuttle-running at higher speeds are warranted to better elucidate this topic.

For the within-sex responses, our data showed similar $\%HR_{max}$ values at the first and along the sets between the two distinct models performed in male ($M1_{M[92\%\ PS]}$ $M3_{M[86\%\ PS]}$) and female players ($M3_{F[86\%\ PS]}$ and $M2_{F[89\%\ PS]}$). It indicates that performing three CODs per running bout did not result in an increased cardiovascular response in comparison to one COD per running bout in both sexes. This finding agrees with that reported by Dellal et al. (2010) who showed similar $\%HR_{max}$ values during 15–15-s and 10–10-s intermittent exercise models performed in shuttle vs. in-line running, but it contrasts with that the finding of Da Silva et al. (2015) which showed higher $\%HR_{max}$ values in the HIIE shuttle-run model compared to in-line running. The similar HR response observed among the models within each sex could be related to the almost equal exercise volume between $M3_{M[86\%\ PS]}$ and $M1_{M[92\%\ PS]}$ (22.5 and 24.5 min), as well as $M3_{F[86\%\ PS]}$ and $M2_{F[89\%\ PS]}$ (18 and 17 min). Additionally, it may also be a consequence of a similar training stimulus evoked

by the counterbalance in the amount of COD and average running speed in $M3_{M[86\% PS]}$ and $M3_{F[86\% PS]}$ in relation to $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$. While $M3_{M[86\% PS]}$ and $M3_{F[86\% PS]}$ demanded more directional changes at a lower intensity, $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$ required less COD at a slightly higher relative intensity.

With regard to [La], our data agree with findings published elsewhere (Ashton and Twist, 2015; Dellal et al., 2010), showing greater reliance on glycolytic metabolism in HIIE models with more directional changes (i.e., $M3_{[86\% PS]}$) in comparison to those with a lesser number of turns (i.e., $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$) for both sexes. This greater metabolic demand can be potentially related to the longer time spent accelerating and decelerating during the multiple turns executed in $M3_{[86\% PS]}$ in comparison to $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$ protocols (Akenhead et al., 2015; Hatamoto et al., 2013). This implies an increased proportion of eccentric contractions during decelerations coupled with sporadic increases in running speed to offset the slowing caused by multiple COD, which in turn would elicit greater recruitment of type II fibers (Enoka, 1996) and neuromuscular overloading (Mero and Komi, 1986).

The relatively small sample size (i.e., n = 11 for males and n = 11 for females) is a limitation of this study, although it is typical for futsal teams. However, Bayesian analysis, with its reliance on MCMC methods, is less sensitive to sample size constraints compared to traditional frequentist methods (Gelman et al., 2008; Morey et al., 2016). Nevertheless, caution is needed when extrapolating the results to other team sport athletes.

Practical Implications

Current results provide guidance for strength and conditioning professionals in designing sex-specific HIIE programs for futsal settings. Regardless of the HIIE model selected by coaches and practitioners, most female and male players undergoing HIIE sessions prescribed from the FIET reached the desired target cardiovascular (> 90% HR_{max}) and metabolic (5 to 7 mmol/L) loads to elicit positive physiological and performance adaptations. During the first weeks of the pre-season phase, the application of $M1_{M[92\% PS]}$ and $M2_{F[89\% PS]}$ is recommended due to their lower perceptual and metabolic demand post-exercise. As the pre-season progresses, HIIE models with more directional changes (e.g., $M3_{M/F[86\% PS]}$) can be introduced to vary the training stimulus and increase the internal load and neuromuscular demand of HIIE training sessions in both male and female players.

Another key point of this study is the sex-specific response to the addition of COD during HIIE programming, with women perceiving their efforts as subjectively harder than men as the number of directional changes increases. It has also been demonstrated that increasing the number of turns during shuttle-run drills is likely to exacerbate the force loss in muscles around the knee joint (e.g., knee flexors) in female team sport athletes (Ashton et al., 2005). These findings together have implications for the effective conditioning and injury prevention of female futsal athletes. For example, caution is warranted when providing female players with the same training volume in terms of COD as given to men, as this may magnify the overload and, if done regularly, could lead to nonfunctional overreaching if suboptimal recovery is afforded between sessions. It might also compromise knee joint integrity and, in turn, increase the female athlete's risk of injury to this site. A practical alternative used in this study to minimize this risk was to decrease the training volume for females (four sets of 4 min) compared to males (five sets of 4 min) in $M3_{M/F[86\% PS]}$. In this sense, female athletes warrant unique considerations compared to male athletes regarding training prescription and the implementation of COD maneuvers, particularly in players returning from injury.

Conclusions

In conclusion, female futsal players performing FIET-based HIIE with more directional changes experienced greater perceptual, physiological, and metabolic responses compared to males at similar relative running intensities and the number of turns. HIIE with directional changes induces different physiological responses depending on the number of turns, sex, and relative speed. Therefore, these results are of interest for coaches and sports scientists, since it is possible to foster the common demands of futsal match play and individualize the high-intensity intermittent training models using the same audio cue for a group of athletes.

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Author Contributions: Conceptualization: L.J.C., R.D.d.L. and L.G.A.G.; methodology: L.J.C., R.D.d.L., J.F.d.S., L.G.A.G. and A.S.T.; software: L.J.C., F.K.B., L.d.L. and A.S.T.; validation: L.J.C., R.D.d.L., F.K.B., L.d.L., J.F.d.S., L.G.A.G. and A.S.T.; formal analysis: L.J.C., R.D.d.L., F.K.B., L.d.L., J.F.d.S., L.G.A.G. and A.S.T.; investigation: L.J.C., R.D.d.L., F.K.B., L.d.L., J.F.d.S., L.G.A.G. and A.S.T.; resources: L.J.C., R.D.d.L. and L.G.A.G.; data curation: L.J.C., J.F.d.S. and A.S.T.; writing—original draft preparation: L.J.C., R.D.d.L., F.K.B., L.d.L. and A.S.T.; writing—review & editing: L.J.C., R.D.d.L., F.K.B., L.d.L., J.F.d.S., L.G.A.G. and A.S.T.; visualization: L.J.C., R.D.d.L., F.K.B., L.d.L., J.F.d.S., L.G.A.G. and A.S.T.; supervision: R.D.d.L., L.G.A.G. and A.S.T.; project administration: L.J.C.; funding acquisition: L.G.A.G. and A.S.T. All authors have read and agreed to the published version of the manuscript.

ORCID ID:

Lorival José Carminatti: https://orcid.org/0000-0002-5893-109X

Ricardo Dantas de Lucas: https://orcid.org/0000-0002-8566-3086

Fernando Klitzke Borszcz: https://orcid.org/0000-0002-3773-6906

Leonardo de Lucca: https://orcid.org/0000-0003-0324-0387

Juliano Fernandes da Silva: https://orcid.org/0000-0002-6017-7145

Luiz Guilherme Antonacci Guglielmo: https://orcid.org/0000-0001-6757-5050

Anderson Santiago Teixeira: https://orcid.org/0000-0001-7508-9917

Funding Information: This study was financed in part by the Secretaria Nacional de Futebol e Defesa dos Direitos do Torcedor (SNFDT), Ministério do Esporte, Brazil (process number 71000.009871/2020-99 and TED 03/2020) and by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, Brasil (CAPES), Finance Code 001.

Institutional Review Board Statement: This study was conducted following the principles of the Declaration of Helsinki, and was approved by the ethics committee of the Federal University of Santa Catarina, Florianópolis, Brazil (protocol code: 19398213.3.0000.0121; approval date: 22 September 2013).

Informed Consent: Informed consent was obtained from all participants included in the study.

Conflict of Interest: The authors declare no conflict of interest.

Acknowledgements: We are grateful for all the support provided by the coaches, technical staff and players of the team involved in this study.

Received: 31 July 2024

Accepted: 04 September 2025

References

Akenhead, R., French, D., Thompson, K. G., & Hayes, P. R. (2015). The physiological consequences of acceleration during shuttle running. *International Journal of Sports Medicine*, *36*(4), 302–307. https://doi.org/10.1055/s-0034-1389968

Ashton, R. E. M., & Twist, C. (2015). Number of directional changes alters the physiological, perceptual, and neuromuscular responses of netball players during intermittent shuttle running. *Journal of Strength and Conditioning Research*, *29*(10), 2731–2737. https://doi.org/10.1519/JSC.0000000000000933

Barbero-Álvarez, J. C., D'Ottavio, S., Granda-Vera, J., & Castagna, C. (2009). Aerobic fitness in futsal players of different competitive level. *Journal of Strength an Conditioning Research*, *23*(7), 2163–2166.

Barbero-Alvarez, J. C., Subiela, J. V., Granda-Vera, J., Castagna, C., Gómez, M., & Del Coso, J. (2015). Aerobic fitness and performance in elite female futsal players. *Biology of Sport*, *32*(4), 339–344. https://doi.org/10.5604/20831862.1189200

Barnes, K. R., Mcguigan, M. R., & Kilding, A. E. (2014). Lower-body determinants of running economy in male and female distance runners. *Journal of Strength and Conditioning Research*, *28*(5), 1289–1297. https://doi.org/10.1519/JSC.0000000000000267

Beato, M., Coratella, G., Schena, F., & Hulton, A. T. (2017). Evaluation of the external & internal workload in female futsal players. *Biology of Sport*, *34*(3), 227–231. https://doi.org/10.5114/biolsport.2017.65998

Buchheit, M. (2008). The 30-15 intermittent fitness test: Accuracy for individualizing interval training of young intermittent sport players. *Journal of Strength and Conditioning Research*, *22*(2), 365–374. https://doi.org/10.1519/JSC.0b013e3181635b2e

Bunc, V., & Heller, J. (1989). Energy cost of running in similarly trained men and women. *European Journal of Applied Physiology and Occupational Physiology*, *59*(3), 178–183. https://doi.org/10.1007/BF02386184

Bürkner, P. C. (2017). brms: An R package for bayesian multilevel models using Stan. *Journal of Statistical Software*, *80*(1), 1–28. https://doi.org/10.18637/jss.v080.i01

Campos, F. D. S., Borszcz, F. K., Flores, L. J. F., Barazetti, L. K., Teixeira, A. S., Hartmann Nunes, R. F., & Guglielmo, L. G. A. (2021). HIIT models in addition to training load and heart rate variability are related with physiological and performance adaptations after 10-weeks of training in young futsal players. *Frontiers in Psychology*, *12*, 636153. https://doi.org/10.3389/fpsyg.2021.636153

Castagna, C., & Barbero Alvarez, J. C. (2010). Physiological demands of an intermittent futsal-oriented high-intensity test. *Journal of Strength and Conditioning Research*, *24*(9), 2322–2329. https://doi.org/10.1519/JSC.0b013e3181e347b9

Castagna, C., D'Ottavio, S., Granda Vera, J., & Barbero Alvarez, J. C. (2009). Match demands of professional Futsal: A case study. *Journal of Science and Medicine in Sport*, *12*(4), 490–494. https://doi.org/10.1016/j.jsams.2008.02.001

Chiu, Y., Silva, R. M., Ceylan, H. I., Clemente, F. M., González-Fernández, F. T., & Chen, Y. (2024). Relationships among Physical Fitness, External Loads, and Heart Rate Recovery: A Study on Futsal Players during an Overseas Congested-Weeks Training Camp. *Journal of Human Kinetics*, *92*, 73–85. https://doi.org/10.5114/jhk/176299

Coe, L. N., & Astorino, T. A. (2024). No sex differences in perceptual responses to high-intensity interval Training or sprint interval training. *Journal of Strength and Conditioning Research*, *38*(6), 1025–1032. https://doi.org/10.1519/JSC.0000000000004738

Coutts, A. J., Rampinini, E., Marcora, S. M., Castagna, C., & Impellizzeri, F. M. (2009). Heart rate and blood lactate correlates of perceived exertion during small-sided soccer games. *Journal of Science and Medicine in Sport*, *12*(1), 79–84. https://doi.org/10.1016/j.jsams.2007.08.005

Da Silva, J. F., Nakamura, F. Y., Carminatti, L. J., Dittrich, N., Cetolin, T., & Guglielmo, L. G. A. (2015). The effect of two generic aerobic interval training methods on laboratory and field test performance in soccer players. *Journal of Strength and Conditioning Research*, *29*(6), 1666–1672. https://doi.org/10.1519/JSC.0000000000000776

De Morree, H. M., Klein, C., & Marcora, S. M. (2012). Perception of effort reflects central motor command during movement execution. *Psychophysiology*, *49*(9), 1242–1253. https://doi.org/10.1111/j.1469-8986.2012.01399.x

De Oliveira Bueno, M. J., Caetano, F. G., Pereira, T. J. C., De Souza, N. M., Moreira, G. D., Nakamura, F. Y., Cunha, S. A., & Moura, F. A. (2014). Analysis of the distance covered by Brazilian professional futsal players during official matches. *Sports Biomechanics*, *13*(3), 230–240. https://doi.org/10.1080/14763141.2014.958872

Dellal, A., Keller, D., Carling, C., Chaouachi, A., Wong, D., & Chamari, K. (2010). Physiologic effects of directional changes in intermittent exercise in soccer players. *Journal of Strength and Conditioning Research*, *24*(12), 3219–3226.

Dolci, F., Kilding, A., Spiteri, T., Chivers, P., Piggott, B., Maiorana, A., & Hart, N. H. (2022). Characterising running economy and change of direction economy between soccer players of different playing positions, levels and sex. *European Journal of Sport Science*, *22*(8), 1167–1176. https://doi.org/10.1080/17461391.2021.1953151

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.

Dos-Santos, J. W., da Silva, H. S., da Silva Junior, O. T., Barbieri, R. A., Penafiel, M. L., da Silva, R. N. B., Milioni, F., Vieira, L. H. P., Coledam, D. H. C., Santiago, P. R. P., & Papoti, M. (2020). Physiology Responses and Players' Stay on the Court During a Futsal Match: A Case Study With Professional Players. *Frontiers in Psychology*, *11*, 620108. https://doi.org/10.3389/fpsyg.2020.620108

Dos Santos, J. S., Nascimento, L. L., Oneda, G., De Mattos, B. K., Rosa, C. A., Teixeira, A. S., Carminatti, L. J., & Guglielmo, L. G. A. (2024). Time limit in two interval training models derived from the futsal intermittent endurance test in Brazilian male and female futsal players. *Journal of Physical Education and Sport*, *24*(1), 211–218. https:// doi: 10.7752/jpes.2024.01026

Enoka, R. M. (1996). Eccentric contractions require unique activation strategies by the nervous system. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *81*(6), 2339–2346. https://doi.org/10.1152/jappl.1996.81.6.2339

Fessi, M. S., Farhat, F., Dellal, A., Malone, J. J., & Moalla, W. (2018). Straight-line and change-of-direction intermittent running in professional soccer players. *International Journal of Sports Physiology and Performance*, *13*(5), 562–567. https://doi.org/10.1123/ijspp.2016-0318

Floriano, L. T., Da Silva, J. F., Teixeira, A. S., Do Nascimento Salvador, P. C., Dittrich, N., Carminatti, L. J., Nascimento, L. L., & Guglielmo, L. G. A. (2016). Physiological responses during the time limit at 100% of the peak velocity in the Carminatti's test in futsal players. *Journal of Human Kinetics*, *54*(1), 91–101. https://doi.org/10.1515/hukin-2016-0038

Foster, C., Florrhaug, J. A., Franklin, J., Gottschall, L., Hrovatin, L. A., Parker, S., Doleshal, P., & Dodge, C. (2001). A New approach to monitoring exercise training. *Journal of Strength and Conditioning Research*, *15*(1), 109. https://doi.org/10.1519/1533-4287(2001)015<0109:ANATME>2.0.CO;2

Gelman, A., Jakulin, A., Pittau, M. G., & Su, Y. S. (2008). A weakly informative default prior distribution for logistic and other regression models. *Annals of Applied Statistics*, *2*(4), 1360–1383. https://doi.org/10.1214/08-AOAS191

Gelman, A., Lee, D., & Guo, J. (2015). Stan: A probabilistic programming language for Bayesian inference and optimization. *Journal of Educational and Behavioral Statistics*, *40*(5), 530–543. https://doi.org/10.3102/1076998615606113

Hatamoto, Y., Yamada, Y., Fujii, T., Higaki, Y., Kiyonaga, A., & Tanaka, H. (2013). A novel method for calculating the energy cost of turning during running. *Open Access Journal of Sports Medicine*, *4*, 117. https://doi.org/10.2147/OAJSM.S39206

Kassiano, W., Jesus, K., Assumpção, C., Lamboglia, C. G., Mendes, A., Barbosa, R., Sabóia, W., Simim, M., & Medeiros, A. I. A. (2019). Physiological and neuromuscular responses during the game in female futsal players. *Journal of Physical Education (Maringa)*, *30*(1), 4–11. https://doi.org/10.4025/jphyseduc.v30i1.3061

Laurent, C. M., Vervaecke, L. S., Kutz, M. R., & Green, J. M. (2014). Sex-specific responses to self-paced, high-intensity interval training with variable recovery periods. *Journal of Strength and Conditioning Research*, *28*(4), 920–927. https://doi.org/10.1519/JSC.0b013e3182a1f574

Makaje, N., Ruangthai, R., Arkarapanthu, A., & Yoopat, P. (2012). Physiological demands and activity profiles during futsal match play according to competitive level. *Journal of Sports Medicine and Physical Fitness*, *52*(4), 366–374.

Mercer, T. H., Gleeson, N. P., & Wren, K. (2003). Influence of prolonged intermittent high-intensity exercise on knee flexor strength in male and female soccer players. *European Journal of Applied Physiology*, *89*(5), 506–508. https://doi.org/10.1007/s00421-003-0830-6

Mero, A., & Komi, P. V. (1986). Force-, EMG-, and elasticity-velocity relationships at submaximal, maximal and supramaximal running speeds in sprinters. *European Journal of Applied Physiology and Occupational Physiology*, *55*(5), 553–561. https://doi.org/10.1007/BF00421652

Morey, R. D., Hoekstra, R., Rouder, J. N., Lee, M. D., & Wagenmakers, E. J. (2016). The fallacy of placing confidence in confidence intervals. *Psychonomic Bulletin and Review*, *23*(1), 103–123. https://doi.org/10.3758/s13423-015-0947-8

Nygaard Falch, H., Guldteig Rædergård, H., & van den Tillaar, R. (2019). Effect of different physical training forms on change of direction ability: A systematic review and meta-analysis. *Sports Medicine - Open*, *5*(1), 53. https://doi.org/10.1186/s40798-019-0223-y

Ogawa, T., Spina, R. J., Martin, W. H., Kohrt, W. M., Schechtman, K. B., Holloszy, J. O., & Ehsani, A. A. (1992). Effects of aging, sex, and physical training on cardiovascular responses to exercise. *Circulation*, *86*(2), 494–503. https://doi.org/10.1161/01.CIR.86.2.494

Oliva-Lozano, J. M., Muyor, J. M., Puche Ortuño, D., Rico-González, M., & Pino-Ortega, J. (2023). Analysis of key external and internal load variables in professional female futsal players: A longitudinal study. *Research in Sports Medicine (Print)*, *31*(4), 309–318. https://doi.org/10.1080/15438627.2021.1963728

Ortiz, J. G., De Lucas, R. D., Teixeira, A. S., Mohr, P. A., & Guglielmo, L. G. A. (2024). The Effects of a Supramaximal Intermittent Training Program on Aerobic and Anaerobic Running Measures in Junior Male Soccer Players. *Journal of Human Kinetics*, *90*, 253–267. https://doi.org/10.5114/jhk/170755

Palucci Vieira, L. H., Arins, F. B., Guglielmo, L. G. A., de Lucas, R. D., Carminatti, L. J., & Santiago, P. R. P. (2021). Game running performance and fitness in women's futsal. *International Journal of Sports Medicine*, *42*(1), 74–81. https://doi.org/10.1055/a-1202-1496

Ribeiro, J. N., Gonçalves, B., Coutinho, D., Brito, J., Sampaio, J., & Travassos, B. (2020). Activity Profile and Physical Performance of Match Play in Elite Futsal Players. *Frontiers in Psychology*, *11*, 1709. https://doi.org/10.3389/fpsyg.2020.01709

Ribeiro, J. N., Yousefian, F., Illa, J., Couceiro, M., Sampaio, J., & Travassos, B. (2024). The Effects of Players' Rotations on High-Intensity Activities in Professional Futsal Players. *Journal of Human Kinetics*, *90*, 215–226. https://doi.org/10.5114/jhk/169522

Rodrigues, V. M., Ramos, G. P., Mendes, T. T., Cabido, C. E., Melo, E. S., Condessa, L. A., Coelho, D. B., & Garcia, E. S. (2011). Intensity of official futsal matches. *Journal of Strength and Conditioning Research*, *25*(9), 2482–2487. https://doi.org/10.1519/JSC.0b013e3181fb4574

Serrano, C., Felipe, J. L., Garcia-Unanue, J., Ibañez, E., Hernando, E., Gallardo, L., & Sanchez-Sanchez, J. (2020). Local positioning system analysis of physical demands during official matches in the spanish futsal league. *Sensors (Basel, Switzerland)*, *20*(17), 4860. https://doi.org/10.3390/s20174860

Teixeira, A. S., Arins, F. B., De Lucas, R. D., Carminatti, L. J., Dittrich, N., Nakamura, F. Y., & Guglielmo, L. G. A. (2019). Comparative effects of two interval shuttle-run training modes on physiological and performance adaptations in female professional futsal players. *Journal of Strength and Conditioning Research*, *33*(5), 1416–1428. https://doi.org/10.1519/JSC.0000000000002186

Teixeira, A. S., Arins, F. B., De Lucas, R. D., Carminatti, L. J., Dittrich, N., Nakamura, F. Y., Loturco, I., & Guglielmo, L. G. A. (2018). Shuttle-run interval training with more directional changes induces superior gains in shuttle sprint performance in female professional futsal players. *Human Movement Special Issues*, *19*(5), 40–51. https://doi.org/10.5114/hm.2018.79623

Wheatley, C. M., Snyder, E. M., Johnson, B. D., & Olson, T. P. (2014). Sex differences in cardiovascular function during submaximal exercise in humans. *SpringerPlus*, *3*, 445. https://doi.org/10.1186/2193-1801-3-445

Articles published in the Journal of Human Kinetics are licensed under an open access Creative Commons CC BY 4.0 license.