Maximal heart rate assessment in recreational football players

A study involving a multiple testing approach

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ABSTRACT

This study aimed at examining the suitability of a standard treadmill test (TT), popular intermittent field tests and small-sided recreational football matches to induce maximal heart rate (HR\textsubscript{max}) in recreational football players. Sixty-six male sedentary untrained subjects (age 39.3±5.8 years, VO\textsubscript{2\text{max}} 41.3±6.2 ml·kg\textsuperscript{-1}·min\textsuperscript{-1}, body mass 81.9±10.8 kg, height 173.2±6.4 cm) were evaluated. On separate occasions, the players were randomly submitted to a progressive VO\textsubscript{2\text{max}} TT, to the Yo-Yo intermittent endurance level 1 (YYIE1) and level 2 (YYIE2) tests, to the Yo-Yo intermittent recovery level 1 (YYIR1) test, and to 7v7 (43x27 m pitch, 83 m\textsuperscript{2}/player) football matches (45 min; 2–4 matches/player). To ensure data consistency, exercise HR was recorded using the same HR monitors in all the experimental conditions. A total of 73, 24, 18, 17 and 30% of players achieved HR\textsubscript{max} during the YYIE1, YYIE2, YYIR1, TT and the small-sided football matches, respectively. The probability of achieving HR\textsubscript{max} increased proportionally to test duration, with 7.8 min as the cut-off time. Variations in HR\textsuperscript{peak} of ±2 b·min\textsuperscript{-1} should be regarded as of practical relevance. YYIE1 HR\textsuperscript{peak} provided the most accurate estimation of a subject’s individual HR\textsubscript{max} and much higher probability of reaching HR\textsubscript{max}. Nevertheless, the results of this study suggest caution in considering a reference test for HR\textsubscript{max} assessment in this population. The use of confirmation tests is still highly advisable when the test duration is shorter than 7.8 min. In this regard, field tests seem to be suitable and accurate for individual HR\textsubscript{max} assessment in recreational football players.

Key words: association football, soccer, training monitoring, field and laboratory testing, Yo-Yo tests, endurance tests

INTRODUCTION

Heart rate (HR) assessment has been proposed as a valid procedure to estimate relative exercise intensity during cardiorespiratory exercise and, consequently, to guide the intensity of training interventions aiming to improve aerobic fitness and prevent overtraining \textsuperscript{12}. Being exercise prescription individualised as a percentage of the subject’s maximal cardiac efficiency, the direct assessment of exercise maximal HR (i.e. HR\textsubscript{max}) is of great importance to ensure the accuracy of prescription and obtain health-effective results \textsuperscript{2}.

In recreational football studies significant increments in aerobic fitness (VO\textsubscript{2\text{max}} and intermittent high-intensity performance) were reported as training effect of playing small-sided games at an average intensity of 78-85% of HR\textsubscript{max} [mode 82% HR\textsubscript{max}; \textsuperscript{3}]. It has been suggested that permanence (~20% of total match time) at intensities above 90% of individual HR\textsubscript{max} during actual match-play was probably the cause of the marked improvements observed in aerobic fitness and intermittent high-intensity performance in recreational football-based training interventions \textsuperscript{3,4}. Additionally, although the general consensus is that HR\textsubscript{max} is unaltered by training, several studies report that HR\textsubscript{max} can decrease with regular
aerobic exercise in sedentary adults and endurance athletes, and can increase upon cessation of the aerobic training or periods of tapering/detraining.

The provided evidence clearly promotes the use of HR monitoring to control and regulate aerobic training loads in both competitive and recreational football players. Technological progress favoured the economical and operational sustainability of wearable monitors for the direct assessment of exercise HR (i.e. HR monitors). Therefore, they are currently popular among fitness enthusiasts and sports professionals. Considering the interest, validity and associated popularity of HR monitoring in football for exercise prescription, monitoring and regulation, the assessment of \( HR_{\text{max}} \) requires the use of valid testing protocols that can guarantee sufficient accuracy of the attainment of individual \( HR_{\text{max}} \) values. Furthermore, they must be economically and practically feasible, yet easily replicated across time. Population-specific treadmill test protocols progressively leading subjects to exhaustion are deemed gold-standard procedures to achieve individual \( HR_{\text{max}} \). However, the limited availability of the required equipment, testing time and need for specialised personal reduces suitability of this procedure in football players either at elite or recreational levels, especially in large-scale studies. A suggested practical alternative to laboratory treadmill protocols is endurance field-testing. The Yo-Yo intermittent tests, in their different versions and levels, are proposed as feasible, valid and reliable field-testing protocols for assessing \( HR_{\text{max}} \) in football players across different competitive levels, ages and genders under field conditions, being very popular in this sport.

The Yo-Yo intermittent tests may result in different physiological demands depending on the individual’s aerobic and anaerobic fitness. Test duration may affect the extent of the aerobic pathway involvement and, consequently, of the actual achievement of \( HR_{\text{max}} \). Despite the relevance of \( HR_{\text{max}} \) for training prescription, monitoring and regulation, no systematic study has ever been performed in recreational, or even competitive, football players to evaluate the suitability of distinct field and laboratory testing protocols in evaluating individual players’ \( HR_{\text{max}} \).

The use of systematic testing protocols, either in field or laboratory conditions, requires the attainment of subjects’ maximal effort, a condition that is limited by motivation and feasibility. Recreational football playing has been reported to be an intermittent high-intensity activity with relevant cardiovascular strain. Training and descriptive studies reported that recreational players exercise at intensities above 90% of \( HR_{\text{max}} \) for 10–25% of the playing time. However, no systematic information is currently available on whether this type of exercise may also induce HRs near to individual maximum values and thus, be useful to obtain \( HR_{\text{max}} \) reference values for training normalisation.

In previous recreational football-based training interventions, several methods have been used to determine participants’ individual \( HR_{\text{max}} \). Some studies considered laboratory-based progressive tests to exhaustion, mainly in the form of treadmill running and, to lesser extent, considering cycle-ergometry. In a limited number of recreational football papers field tests (Yo-Yo intermittent tests) were used to evaluate the supposed attainment of the individual
Unfortunately, in several of the published papers no clear information is provided regarding the procedure used for HR_max assessment. The relevance of HR_max assessment for training monitoring in recreational football warrants further studies investigating the best practice for its achievement.

Therefore, the purpose of this study was to examine the suitability of popular intermittent field tests and recreational small-sided football matches to induce HR_max in sedentary untrained subjects. This with the aim to gain information useful to suggest to the practitioners (fitness trainers and sport scientists) possible alternatives to reduce the testing time and the need for specialized personal requested in HR_max laboratory assessment (standard treadmill progressive test). A working hypothesis assumed the superiority of laboratory testing in detecting individual HR_max compared to field tests and small-sided match-play.

**METHODS**

*Participants*

Sixty-six sedentary untrained adults (age 39.3±5.8 years, VO_2max 41.2±6.2 ml·kg⁻¹·min⁻¹, body mass 81.9±10.8 kg, height 173.2±6.4 cm, systolic and diastolic blood pressure 125±11 and 74±8 mmHg, respectively) volunteered to participate in this study. All the participants were familiarised with the procedures involved in this investigation during the two weeks before the commencement of the study, performing submaximal versions of the treadmill test, Yo-Yo intermittent tests and 45-min recreational small-sided football matches. The participants gave their written informed consent to participate in the study, which was conducted in accordance with the Declaration of Helsinki, and ethical approval was provided by the local Institutional Review Board before the commencement of the study data collection. All participants were informed of the risks and benefits of participating and made aware that they could withdraw from the study procedures at any time without penalty.

*Study design*

This study aimed to compare HR_peak values of recreational football players during i) an incremental continuous treadmill test for VO_2max assessment (TT), ii) three intermittent progressive field tests and iii) actual football match-play using a descriptive repeated-measurements design. The intermittent field tests were the Yo-Yo intermittent endurance tests, either level 1 (YYIE1) or level 2 (YYIE2), and the level 1 version of the Yo-Yo intermittent recovery test (YYIR1). These tests were chosen given their current popularity in recreational and competitive football and the associated validity and reliability. Recreational football matches (i.e. 2–4 per player, Match) were played as small-sided games (7v7) for 45 min on an artificial pitch (43x27 m pitch, 83m² per player). In order to ensure data consistency, exercise HR was recorded using the same HR monitors across the tests and playing conditions. To evaluate player’s general and differential fatigue (i.e. central and peripheral) the rating of perceived exertion (RPE) as global (RPE_G), cardiorespiratory (RPE_Cr) and muscular (RPE_M) scores were assessed after the Match and maximal tests, using the CR10 Börg scale.
The HR_{max} was assumed as the highest value obtained across these testing protocols and settings. For each testing procedure, players’ HR_{max} achievement was reported as the absolute and relative number of players reaching their individual HR_{max} (i.e. frequency of attainment of HR_{max}). Furthermore, to account for random measurement errors, the practical attainment of individual HR_{max} (practical HR_{max}) was considered using the smallest worthwhile change (SWC; ±2 b·min^{-1}) and reported in absolute (n) and relative (%) terms. In this paper, HR_{peak} refers to the maximal value obtained in each analysed testing and protocol setting that could overlap or not the individual HR_{max}.

**Testing procedures**

The Yo-Yo intermittent tests and the football matches were performed at the same time of day on the same artificial pitch wearing the same footwear and under neutral environmental conditions. Before the field tests, the participants performed a 10-min standardised warm-up consisting of running at different intensities and with changes of direction. The matches were preceded by a 15-min standardised warm-up consisting of running, dribbling, balance and strength exercises. The YYIE1, YYIE2, YYIR1 and the TT tests were performed in a random order with at least a 4-day recovery period in between and 2 days between matches. No vigorous physical activity was performed on the day before the testing procedures took place. The selected Yo-Yo intermittent tests differ in initial running speed, increments in running speed throughout the tests, and recovery time and distance. Their use was proposed to induce different time to exhaustion (i.e. test duration) across the field tests. The test protocols were implemented according to the procedures suggested by Krustup et al.\textsuperscript{15,16,19}.

The TT (HP Cosmos Quasar, Nussdorf, Germany) consisted of 3 min of walking at 5 km·h\(^{-1}\) and 2 min of running at 8 km·h\(^{-1}\) with 0% inclination, and then alternating between increases in speed (1 km·h\(^{-1}\)) and inclination (1%) at each 30 s until voluntary exhaustion. Expired respiratory gas fractions were measured using an open-circuit breath-by-breath automated gas analysis system (Quark CPET, Cosmed, Rome, Italy). Attainment of VO_{2max} was assumed when participants achieved plateau in VO\(_2\) despite an increase in exercise intensity and at least one of the following criteria: a respiratory exchange ratio (RER) greater than 1.10 and RPE equal to or higher than 7\textsuperscript{10,20}. The highest 15-s VO\(_2\) during the final stages of the test were considered as proof of individual VO\(_{2max}\). Data analysis was performed with manual inspection of each TT data file using an Excel file (Microsoft, Redmont, USA). All the participants in this study attained the VO\(_2\) plateau and at least one of the selected criteria for attainment of VO\(_{2max}\). This to warrant the internal validity of this study design that assumed TT as gold standard for the achievement of maximal VO\(_2\) and HR values.

All exercise HRs were recorded at 1-s intervals using HR monitors Polar Team System 2 (Polar Electro Oy, Kempele, Finland). The participants were acquainted with the use of HR monitors in advance. The players were allowed to drink water ad libitum in order to ensure
proper hydration during all the exercise conditions considered in this study. Immediately after each test and 15–20 min post-match, RPE was assessed as global and differential RPE. 

Statistical analyses

Results are expressed as means±standard deviations and 95% confidence intervals (95% CI). Normality assumption was verified using the Shapiro-Wilk W-test. A one-way repeated-measurements analysis of variance (ANOVA) with post-hoc Bonferroni test was used to compare HR\textsubscript{peak} across the considered evaluation methods (i.e. TT, YYIE1, YYE2, YYIR1 and Match). The Cohen’s d was used to evaluate the effect size, with values above 0.8, between 0.8 and 0.5, between 0.5 and 0.2 and lower than 0.2 considered as large, moderate, small and trivial, respectively. Pearson correlation (r) was used to assess the associations between variables. The magnitude of the reported effects was described using the Hopkins et al. criteria as follows: trivial, r < 0.1; small, 0.1 < r < 0.3; moderate, 0.3 < r < 0.5; large, 0.5 < r < 0.7; very large, 0.7 < r < 0.9; nearly perfect, r > 0.9; and perfect, r = 1.0. Within test condition variability was expressed as coefficient of variation (%CV). The Smallest Worthwhile Change (SWC) in measurement was considered to test the practical difference between variables and calculated as 0.2 times the variable standard deviation. Measurement agreement was assessed through the Bland and Altman approach. The ROC curve statistic was used to explore the possibility of detecting a cut-off measure for maximal testing duration to assess individual HR\textsubscript{max}. Significance was set at 5% (p< 0.05).

RESULTS

During the YYIE1, YYIE2 and YYIR1 tests, the players covered 1602±678 m (95% CI 1436–1769), 447±174 m (95% CI 405–491) and 650±286 m (95% CI 581–721), respectively. The corresponding mean times to exhaustion (i.e. test durations) were 12.0±4.7 min (95% CI 10.9–13.2), 2.9±1.1 min (95% CI 2.7–3.2) and 5.4±2.4 min (95% CI 4.4–5.7), respectively (Fig. 1). Mean TT time to exhaustion was 10.7±1.5 min (95% CI 9.8–10.7). Very large associations were found between YYIR1 and YYIE1 and YYE2 (Table 1) test duration. The TT test duration was largely associated with YYIE2 and YYIR1, and very largely associated with YYIE1.

Table 2 shows the data relative to the HR\textsubscript{peak} values achieved during the exercise protocols under consideration, including individual HR\textsubscript{max} differences between HR\textsubscript{max} and TT (9.39±6.45 b·min\textsuperscript{−1}, 95% CI 7.81–10.98; p<0.0001, d=1.56), YYIE1 (2.08±3.68 b·min\textsuperscript{−1}, 95% CI 1.17–2.98, d=0.62, p<0.0001), YYIE2 (6.24±4.74 b·min\textsuperscript{−1}, 95% CI 5.08–7.41, d=1.48, p<0.0001), YYIR1 (9.08±5.92 b·min\textsuperscript{−1}, 95% CI 7.62–10.53, d=1.59, p<0.0001) and Match (5.15±4.30 b·min\textsuperscript{−1}, 95% CI 4.05–6.24, d=1.18, p<0.0001) HR\textsubscript{peak} ranged from moderate to large. Very large to nearly perfect associations were reported between HR\textsubscript{max} and HR\textsubscript{peak} across the different conditions (p<0.0001, Table 3). SWC was the same across the testing procedures (±2 b·min\textsuperscript{−1}).

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Bland and Altman bias and LOA were: 2.08±3.69 (95% CI 1.17–2.98) and -5.15 (95% CI -6.71; -3.60) to 9.31 (95% CI 7.74–10.86), 6.24±4.73 (95% CI 5.07–7.41) and -3.05 (95% CI -5.05; -1.05) to 15.53 (95% CI 13.53–17.53), 9.08±5.92 (95% CI 7.62–10.53) and -2.53 (95% CI -5.03; -0.03) to 20.68 (95% CI 18.18–23.18), 5.14±4.30 (95% CI 4.05–6.24) and -3.29 (95% CI -5.17; -1.41) to 13.58 (95% CI 11.70–15.46) for HR$_{\text{max}}$ against TT, YYIE1, YYIE2, YYIR1 and Match HR$_{\text{peak}}$, respectively.

Players’ RPE$_G$ difference across the Yo-Yo tests were trivial ($d=0.084–0.20$, $P=0.07–0.49$) and corresponding to 7.5±1.5 (95% CI 7.1–7.9), 7.6±1.4 (95% CI 7.2–8.0) and 7.8±1.3 (95% CI 7.5–8.2) for the YYIE1, YYIE2 and YYIR1, respectively. RPE$_{\text{CR}}$ for the YYIE1, YYIE2 and YYIR1 were 8.1±1.0 (95% CI 7.6–8.5), 8.2±1.3 (95% CI 7.9–8.5) and 8.2±1.4 (95% CI 7.8–8.5), respectively. Difference between tests resulting trivial ($d=0.0–0.06$, $P=0.55–0.95$). The perception of muscle effort corresponded to 6.5±2.1 (95% CI 6.0–7.1), 6.7±2.0 (95% CI 6.2–7.2) and 6.7±2.0 (95% CI 6.2–7.2), after the YYIE1, YYIE2 and YYIR1, respectively. Between tests differences in RPE$_M$ were trivial ($d=0.0–0.12$, $P=0.41–0.88$). After the TT, players RPE$_G$, RPE$_{\text{CR}}$ and RPE$_M$ were 8.06±0.87 (95% CI 7.8–8.4), 8.60±1.03 (95% CI 8.2–9.04) and 7.29±1.15 (95% CI 6.9–7.7) respectively. Differences between TT and field tests RPE were small across the considered modalities ($d=0.26–0.49$, $P=0.55–0.93$). Across test differences in RPE modes were small to moderate (0.30–0.57), moderate (0.53–0.76) and large (0.88–1.20) for RPE$_G$ vs RPE$_{\text{CR}}$, RPE$_G$ vs RPE$_M$ and RPE$_{\text{CR}}$ vs RPE$_M$ comparisons, respectively.

The RPE$_G$, RPE$_{\text{CR}}$ and RPE$_M$ after the matches during which the players achieved their HR$_{\text{max}}$ were 5.23±1.36 (95% CI 4.41–6.05), 5.46±1.45 (95% CI 4.60–6.34) and 5.23±1.30 (95% CI 4.41–6.01), respectively (i.e. strong). Differences between RPE modes were trivial (95% CI 0.00–0.17) in the match condition. RPE$_{\text{CR}}$ for the matches when HR$_{\text{max}}$ was achieved was practically higher ($d=0.25$, small) compared with the opposite condition ($p>0.05$, 95% CI -1.61–0.75).

The ROC analyses performed using test time to exhaustion (i.e. test duration) as continuous variable and attainment or not of HR$_{\text{max}}$ as classification variable (adjusted for SWC) determined an area under the curve of 0.60±0.03 (95% CI 0.54–0.65, $p=0.005$), with a cut-off ≤7.8 min. The corresponding sensitivity and specificity were 50.4 and 69.8 s, respectively.

**DISCUSSION**

The aim of this study was to examine the capability of different field and laboratory testing protocols, as well as small-sided football games (7v7) to induce exercise HR$_{\text{max}}$ in recreational football players. A treadmill testing protocol for VO$_{2\text{max}}$ assessment and popular football-specific field tests commonly suggested as valid, reliable and feasible procedures for assessing HR$_{\text{max}}$ were considered. Additionally, exercise HR was monitored during small-sided recreational football matches in order to explore the nature of HR$_{\text{peak}}$ values.
during casual intermittent exercise. This study results showed the practical superiority of intermittent field tests longer than 7.8 min in enabling the determination of individual $HR_{\text{max}}$, with YYIE1 showing the most accurate results and much higher probability of achieving $HR_{\text{max}}$. Interestingly, 30% of the players attained their $HR_{\text{max}}$ during the recreational matches carried out between peers.

Treadmill tests for VO$_{2\text{max}}$ assessment are commonly considered as the gold standard strategy to evaluate $HR_{\text{max}}$ in different populations, given the controlled conditions and standardised procedures usually attained under laboratory settings. The present study considered a continuous progressive TT supposed to harmonically stress the players’ cardiovascular system (i.e. central) and lower-limb muscles (i.e. peripherally) with timed and alternated increments in either speed or treadmill inclination until voluntary exhaustion. The TT protocol was designed based on the assumption that, in untrained individuals, lower limb muscular fatigue occurring during constant increments or high inclinations of the treadmill running may constitute a limiting factor in the achievement of central maximal effort. A progressive alternated inclination (i.e. 1% every min) was added to limit as much as possible the attainment of speed velocities potentially unsuitable for the biomechanical structure of the participants. The reported post-tests RPE$_{\text{CR}}$ in TT were largely ($d=1.20$) higher than the correspondent RPE$_{\text{M}}$, suggesting that players’ exhaustion was mainly due to cardiorespiratory stress. This finding supports the supposed internal validity of the TT used in this study. However, only 11 out of 66 players (17%) achieved their $HR_{\text{max}}$ using the TT, which questions the validity of the TT as a reference testing protocol for $HR_{\text{max}}$ assessment, and highlights the practical usefulness of confirmatory field testing procedures for $HR_{\text{max}}$ assessment in scientific coaching and exercise. However, given the practical interest of this issue and the use of only one TT protocol in this study, further studies are warranted to explore treadmill testing protocols sensitivity and/or suitability of confirmation of testing.

Endurance-based intermittent field tests have been deemed a viable procedure for assessing individual $HR_{\text{peak}}$ across populations and for training monitoring and prescription in competitive and recreational football. The Yo-Yo intermittent tests, in their various versions and levels, are currently the most investigated endurance field tests regarding reliability and validity characteristics in football. With these sustainable procedures, sports scientists and fitness trainers routinely assess subjects’ $HR_{\text{peak}}$ on the assumption that this measure is or may result in a good estimate of subjects’ individual $HR_{\text{max}}$. Nevertheless, no structured study has been performed with the aim of evaluating, in the same population, the accuracy of $HR_{\text{max}}$ detection using different Yo-Yo intermittent test versions and levels or comparing them with TT protocols. In this study, exercise HR was monitored during the Yo-Yo intermittent tests, which were chosen for the different speed progressions used in their protocols, enabling diverse time to exhaustion, considered as a possible independent variable in $HR_{\text{max}}$ attainment. The assumed nature of the chosen Yo-Yo intermittent tests was confirmed in the present study. Large differences were reported in time to exhaustion between the considered Yo-Yo intermittent tests versions. Furthermore, the Yo-Yo tests’ times to exhaustion were very largely associated, supporting the likelihood of a common basic physiological determinant of test performance. According to the
original working hypothesis, the rate of HR\textsubscript{max} achievement with these tests was clearly different (very large), with a strong effect of test time to exhaustion on the HR\textsubscript{max} achievement rate. Plotting Yo-Yo intermittent test duration against HR\textsubscript{max} relative achievement rate revealed a nearly perfect association (r=0.99, P<0.0001). A large (r=0.67, P<0.0001) association was found when adding the TT time and relative HR\textsubscript{max} achievement rate to the above correlation. The corroboration of a time effect on HR\textsubscript{max} was provided by the ROC analysis considering test time to exhaustion and HR\textsubscript{max} achievement of each player in each performed test. Calculations provided evidence of an exhaustion time cut-off equal to or higher than 7.8 min for the progressive maximal intermittent field tests. This information is of great practical interest, suggesting that progressive intermittent field tests to exhaustion of duration equal to or longer than 7.8 min should be considered when HR\textsubscript{max} detection is of major importance in the test. The YYIE1 test, with an average duration of 12.0 min (range 1.7–13.3 min), proved to be the more convenient test for HR\textsubscript{max} determination in this population of recreational football players. The low starting speed and slow velocity progression, coupled with the intermittent nature of the test (5 s of recovery after every 40-m shuttle run) could have been the possible causes of the reported better capability of YYIE1 than the other selected tests in enabling players’ HR\textsubscript{max} achievement\textsuperscript{10}. Recreational football matches performed as a training intervention were reported to elicit HR\textsubscript{peak} in the range of 95–98% of the players’ HR\textsubscript{max}\textsuperscript{3}. The use of training activities in the evaluation of maximal physiological values, such as HR\textsubscript{max} may be of practical importance in training prescription and monitoring. In our study, the players were evaluated during 2–4 recreational small-sided football matches, using the same HR monitors as in the other testing sessions under consideration. Despite the non-exhaustive nature of recreational football matches and the stochastic occurrence of near maximal intensity activity bouts, HR\textsubscript{max} was achieved in 30% of cases. In light of this result, recreational football matches may occasionally be viewed as an alternative way of identifying individual HR\textsubscript{max} in recreational football or, at least, considered as a verification method for the accurate determination of individual HR\textsubscript{max}\textsuperscript{26}. The suggested interest in using casually intermittent high-intensity exercise, such as recreational football in the form of small-sided games is supported by the attainment of 97% of HR\textsubscript{max} during match-play, a value that was only lower (d=0.52) than that achieved during the more accurate test considered in this study, the YYIE1. Interestingly, the differential matches’ RPE values were all above 5, suggesting that, in order to have a greater chance of achieving the players’ HR\textsubscript{max}, the matches should be played, on average, at an intensity that is perceived by players as “strong” or higher. Pitch dimension and number of players per playing area (players’ density) have been reported as variables affecting match intensity. In a descriptive football recreational study using fixed pitch dimensions (40x20 m), higher average peak HR was reported when playing 3v3 (96.5±3.9 bpm) and 5v5 (96.0±3.3 bpm) compared to 7v7 (94.3±2.6 bpm). In the same study, global RPE was 6.7±2.3, 5.2±2.2 and 4.3±2.0, 0-10 range, AU) for the 3v3, 5v5 and 7v7 conditions, respectively. These results inform to the practical interest in using players’ densities equal or higher than 80 m\textsuperscript{2} per player to induce peak HRs in the range of those found in this study. Indeed, in this study the 7v7 showed to elicit peak HR that was 97.0±2.2% of the individual maximal with a global RPE of 5.23±1.36 (0-10 range, AU).
Future studies are warranted on the effect of match tempo (i.e. RPE>5) on HR$_{\text{max}}$ achievement rate by considering fast ball replacement, coach encouragements, and variations in game rules and player number. This would result as an interesting issue with great practical applications for coaching and training interventions.

Individual HR$_{\text{max}}$ was reported to be related to the subjects’ training status, with increasing aerobic fitness (VO$_{2\text{max}}$) having a large inverse association with individual HR$_{\text{max}}$. This empirical finding questioned the vision of HR$_{\text{max}}$ as a short-to-medium-term stable measure for training monitoring. The reported 2–3% HR$_{\text{max}}$ variability caused by aerobic training and detraining stresses the importance of repeated assessment of individual HR$_{\text{max}}$ during the ongoing training process. Three to six weeks was reported as the time frame of practical stability for HR$_{\text{max}}$ in a training intervention. In light of the results from this study, HR$_{\text{max}}$ should be assessed, using intermittent field tests longer than 7.8 min, to ensure the likelihood of accurate HR$_{\text{max}}$ assessment and higher probability of the subjects reaching HR$_{\text{max}}$, with complementary use of recreational football matches, as a sustainable strategy for confirming a structured assessment of HR$_{\text{max}}$. Caution should be advised when considering laboratory treadmill testing as a gold standard for the assessment of recreational football players’ HR$_{\text{max}}$. The low sensitivity of the TT in detecting HR$_{\text{max}}$, even being longer on average than the reported 7.8 min cut-off time, may have been caused by the nature of the testing protocol, including the alternation of speed and inclination increment, which may have induced premature, mainly respiratory, exhaustion. The fact that the subjects attained the currently suggested criteria for the assessment of VO$_{2\text{max}}$ warrants the internal validity of this testing protocol, but questions its suitability for HR$_{\text{max}}$ assessment, namely in recreational football players. Given the interest of this issue for physiological testing and training prescription/monitoring, further studies on the validity of various TTs are warranted.

Sports season variations in HR$_{\text{max}}$ (±4-13 b·min$^{-1}$) have been documented and are considered a consequence of training status and individual fitness level. The reported fluctuation suggested a need for accurate and repeated testing of individual HR$_{\text{max}}$ for proper monitoring of training. In this study, the SWC was the same across the testing procedures (±2 b·min$^{-1}$), meaning that only changes in HR$_{\text{max}}$ higher or lower than 2 b·min (±1-2%) should be considered of practical relevance for adjustments in training intensity. This information is of practical relevance, as using the SWC approach enabled a remarkable increase (26 to 100%, Table 2) in HR$_{\text{max}}$ achievements in this study’s subjects.

This study results questioned consideration of treadmill tests performed under controlled laboratory conditions as gold-standard for HR$_{\text{max}}$ achievement. However, the use of TT for the assessment of individual HR$_{\text{max}}$ should not be discouraged in principle. Indeed, only one TT protocol was considered in this study. This should be considered a study design limitation suggesting further confirmatory investigations using different TTs until exhaustion to appreciate possible protocol effect on HR$_{\text{max}}$ achievement when dealing with untrained recreational football players. Given the practical interest of these findings, future studies should address other populations different per age, gender, training level and health status.
PERSPECTIVES

In light of the findings of the present study, $HR_{\text{max}}$ should ideally be assessed using different procedures in recreational football, with $YYIE1$ $HR_{\text{peak}}$ providing the most accurate estimation of a subject's individual $HR_{\text{max}}$ and much higher probability of reaching $HR_{\text{max}}$. Accurate assessment of $HR_{\text{max}}$ would be critical in determining the internal load provided by a recreational football intervention, and thus, in evaluating attainment of the intensities deemed effective for providing the reported improvements in aerobic fitness $^{1,2,28}$.

According to the usual relationship between exercise HR and $VO_2$ during progressive maximal exercise, the plateauing of test HR despite a sustained increment of exercise intensity (i.e. speed) may warrant $HR_{\text{max}}$ attainment $^{9,10}$. From a practical point of view, the determination of individual $HR_{\text{max}}$ may be checked by the keen analysis of test HR profile. In the case of $HR_{\text{peak}}$ detection at test exhaustion, the use of a confirmation test, as suggested in this study, should be considered $^{26}$. When examining the cardiovascular stress imposed by recreational football, sports scientists should use multiple approach testing for individual $HR_{\text{max}}$ assessment in order to avoid biased results.

ACKNOWLEDGEMENTS

The authors do not have any conflict of interests and state that the results of the present study do not constitute endorsement by SJMSS. The authors alone are responsible for the content and writing of the manuscript.

REFERENCES


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TABLE 1.

<table>
<thead>
<tr>
<th></th>
<th>TT</th>
<th>YYIE1</th>
<th>YYIE2</th>
<th>YYIR1</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT</td>
<td>1</td>
<td>0.74 (0.60; 0.83)</td>
<td>0.67 (0.51; 0.79)</td>
<td>0.68 (0.52; 0.79)</td>
</tr>
<tr>
<td>YYIE1</td>
<td>0.74 (0.60; 0.83)</td>
<td>1</td>
<td>0.79 (0.67; 0.87)</td>
<td>0.87 (0.79; 0.92)</td>
</tr>
<tr>
<td>YYIE2</td>
<td>0.67 (0.51; 0.79)</td>
<td>0.79 (0.67; 0.87)</td>
<td>1</td>
<td>0.86 (0.78; 0.91)</td>
</tr>
<tr>
<td>YYIR1</td>
<td>0.68 (0.52; 0.79)</td>
<td>0.87 (0.79; 0.92)</td>
<td>0.86 (0.78; 0.91)</td>
<td>1</td>
</tr>
</tbody>
</table>

TT= Treadmill Test; YYIE1 = Yo-Yo Intermittent Endurance level 1 test; YYIE2 = Yo-Yo Intermittent Endurance level 2 test; YYIR1 = Yo-Yo Intermittent Recovery level 1 test.

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<table>
<thead>
<tr>
<th></th>
<th>HRmax</th>
<th>TT</th>
<th>YYIE1</th>
<th>YYIE2</th>
<th>YYIR1</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>HR&lt;sub&gt;peak&lt;/sub&gt; (b min&lt;sup&gt;-1&lt;/sup&gt;)</td>
<td>189±8 (187; 191)</td>
<td>179±11 (177; 182)</td>
<td>187±10 (184; 189)</td>
<td>183±10 (180; 185)</td>
<td>180±10 (177; 182)</td>
<td>184±8 (181; 186)</td>
</tr>
<tr>
<td>CV%</td>
<td>4.43</td>
<td>6.21</td>
<td>5.14</td>
<td>5.70</td>
<td>5.60</td>
<td>4.40</td>
</tr>
<tr>
<td>SWC</td>
<td>1.67</td>
<td>2.23</td>
<td>1.92</td>
<td>2.1</td>
<td>2.0</td>
<td>1.62</td>
</tr>
<tr>
<td>%HR&lt;sub&gt;max&lt;/sub&gt;</td>
<td>100</td>
<td>95±4</td>
<td>99±2</td>
<td>97±3</td>
<td>95±3</td>
<td>97±2</td>
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<tr>
<td>CV%</td>
<td>3.68</td>
<td>2.03</td>
<td>2.65</td>
<td>3.24</td>
<td>2.32</td>
<td></td>
</tr>
<tr>
<td>SWC</td>
<td>0.70</td>
<td>0.40</td>
<td>0.51</td>
<td>0.62</td>
<td>0.45</td>
<td></td>
</tr>
<tr>
<td>HR&lt;sub&gt;max&lt;/sub&gt; Achievement (n)</td>
<td>66</td>
<td>7</td>
<td>38</td>
<td>8</td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>HR&lt;sub&gt;max&lt;/sub&gt; Achievement (%)</td>
<td>100</td>
<td>10.6</td>
<td>57.6</td>
<td>12.1</td>
<td>9.1</td>
<td>21.2</td>
</tr>
<tr>
<td>HR&lt;sub&gt;max&lt;/sub&gt; Practically (n)</td>
<td>11</td>
<td>48</td>
<td>15</td>
<td>12</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>HR&lt;sub&gt;max&lt;/sub&gt; Practically (%)</td>
<td>17</td>
<td>73</td>
<td>24</td>
<td>18</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

HR<sub>max</sub>=Maximal Heart-Rate; TT=Treadmill Test; YYIE1= Yo-Yo intermittent Endurance Test Level 1; YYIE2= Yo-Yo intermittent Endurance Test Level 2; YYIR1= Yo-Yo intermittent Recovery Test Level 1; Match= Recreational Soccer Match.; CV%= Coefficient of Variation; SWC=Smallest Worthwhile Change; HR<sub>max</sub> Achievement= frequency of attainment of HR<sub>max</sub> in the various tests in absolute (n) and relative (%) terms; HR<sub>max</sub> Practically = Practical frequency of attainment of HR<sub>max</sub> in the various tests, in absolute (n) and relative (%) terms, using the SWC.
<table>
<thead>
<tr>
<th></th>
<th>TT</th>
<th>YYIE1</th>
<th>YYIE2</th>
<th>YYIR1</th>
<th>HRmax</th>
<th>Match</th>
</tr>
</thead>
<tbody>
<tr>
<td>TT</td>
<td>1</td>
<td>0.80 (0.69; 0.87)</td>
<td>0.80 (0.69; 0.87)</td>
<td>0.79 (0.67; 0.86)</td>
<td>0.81 (0.72; 0.88)</td>
<td>0.67 (0.50; 0.78)</td>
</tr>
<tr>
<td>YYIE1</td>
<td>0.80 (0.68; 0.87)</td>
<td>1</td>
<td>0.81 (0.70; 0.88)</td>
<td>0.81 (0.70; 0.88)</td>
<td>0.93 (0.88; 0.95)</td>
<td>0.83 (0.73; 0.89)</td>
</tr>
<tr>
<td>YYIE2</td>
<td>0.80 (0.69; 0.87)</td>
<td>0.81 (0.70; 0.88)</td>
<td>1</td>
<td>0.80 (0.68; 0.67)</td>
<td>0.90 (0.83; 0.93)</td>
<td>0.71 (0.55; 0.81)</td>
</tr>
<tr>
<td>YYIR1</td>
<td>0.79 (0.67; 0.86)</td>
<td>0.81 (0.70; 0.88)</td>
<td>0.80 (0.68; 0.87)</td>
<td>1</td>
<td>0.79 (0.71; 0.88)</td>
<td>0.72 (0.57; 0.82)</td>
</tr>
<tr>
<td>HRmax</td>
<td>0.81 (0.72; 0.88)</td>
<td>0.93 (0.88; 0.95)</td>
<td>0.90 (0.83; 0.93)</td>
<td>0.81 (0.71; 0.88)</td>
<td>1</td>
<td>0.86 (0.76; 0.91)</td>
</tr>
<tr>
<td>Match</td>
<td>0.67 (0.50; 0.78)</td>
<td>0.83 (0.73; 0.89)</td>
<td>0.71 (0.55; 0.81)</td>
<td>0.72 (0.57; 0.82)</td>
<td>0.86 (0.78; 0.91)</td>
<td>1</td>
</tr>
</tbody>
</table>

HR\textsubscript{max}= Maximal Heart Rate; TT=Treadmill Test; YYIE1= Yo-Yo intermittent Endurance Test Level 1; YYIE2= Yo-Yo intermittent Endurance Test Level 2; YYIR1= Yo-Yo intermittent Recovery Test Level 1; Match= Recreational Soccer Match.
Figure 1