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Abstract

Submaximal field tests are especially recommended when repeated testing is warranted. This study aimed at assessing the validity of the submaximal versions of the Yo-Yo intermittent tests in male recreational football players in untrained and trained status. The participants' (n=66; 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) heart rate after 2 min (HR_{2min}) during the level 1 ($YYIE1_{HR2min}$) and 2 ($YYIE2_{HR2min}$) versions of the Yo-Yo intermittent endurance test and the level 1 version of the Yo-Yo intermittent recovery test ($YYIR_{HR2min}$) was plotted against individual VO_{2max} values. Thirty-two participants performed all the tests after a 12-week recreational football intervention for test responsiveness. Associations between VO_{2max} and $YYIE1_{HR2min}$ were large to small (P=0.0001). Large to trivial associations were found between $YYIE2_{HR2min}$, $YYIR1_{HR2min}$ and VO_{2max} (P<0.01). Maximal Yo-Yo performances were large, significant and inversely related to HR_{2min} (-0.68 to -0.49, P<0.0001). Pre-to-post-intervention ICC values were good for $YYIE1_{HR2min}$ and $YYIE2_{HR2min}$, and excellent for $YYIR1_{HR2min}$. Post-intervention associations between HR_{2min} and Yo-Yo maximal performances were large to very large (-0.55 to -0.72; P<0.002, n=32). Training-induced changes in VO_{2max} moderately correlated with $YYR1_{HR2min}$ (-0.48; P=0.007; n=32). HR_{2min} lower than 89%, 98% and 91%HR_{max} for $YYIE1_{HR2min}$, $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$, respectively, may be considered as signs of good to excellent VO_{2max} levels. Since in the $YYIE1_{HR2min}$, the participants attained 84%HR_{max} and test specificity increased for HR_{2min} values <89%, this test may be the preferred choice when repeated assessment of aerobic fitness, using submaximal intermittent Yo-Yo tests, is considered in recreational football.

Key words: soccer, intermittent exercise, Yo-Yo tests, responsiveness, maximal oxygen uptake

INTRODUCTION

The published literature has provided convincing evidence of the wide-ranging health and physical fitness benefits of systematic recreational football practice [1-3]. Indeed, recreational football has been shown to be a motivating and enjoyable exercise mode that is effective in promoting clinically relevant improvements in body composition, aerobic fitness, physical function and metabolic health across age, gender and health status [2].

Recreational football in the form of small-sided games performed approximately 2 times per week for 12 weeks improved maximal oxygen consumption (VO_{2max}) by 8–13% [4] in healthy untrained men. The reported changes in adult men were clinically superior to those induced in a running intervention group that trained for the same amount of time [5-7]. Indeed, Milanovic et al. [4] found in their meta-analysis that recreational football practice brought about an average 3.5 $ml \cdot kg^{-1} \cdot min^{-1}$ increase in VO_{2max} compared to other non-football training protocols. Training-induced changes of the reported magnitude (i.e. 1 MET) are associated with 21 and 15% reductions in health risk for all-cause and cardiovascular mortality, respectively, promoting the interest of recreational football as a sustainable exercise mode in treating and preventing lifestyle diseases [8].

The public-health interest of aerobic fitness improvement, especially that resulting from recreational football practice, suggests the importance of training monitoring and frequent testing to evaluate the effect of this exercise mode on physiological variables associated with the aerobic metabolism. Unfortunately, direct assessment of VO_{2max} in laboratory or field conditions requires the use of standard ergometers and portable gas analysers, which may be inaccessible for most recreational football players. Maximal endurance field tests may represent a valid alternative to laboratory tests for aerobic fitness assessment [9,10]. However, since participant's effort to exhaustion is required in maximal tests, their recurrent use for health and for motivation issues may be discouraged, especially in health-related exercise interventions [11-13].

The Yo-Yo intermittent tests are the most popular field tests option for the assessment of aerobic fitness in different football competitive levels [14]. Their feasibility (capability for testing large number of participants at the same time), validity and reliability are the main reasons for their popularity [14,15].

The published research on recreational football reports widespread use of Yo-Yo tests, mainly the intermittent endurance level 1 (YYIE1) and 2 (YYIE2) versions [1,4]. Their maximal nature discourages the use of YYIE1 and 2 for repeated estimation of players' aerobic fitness in order to optimise training implementation (i.e. training intensity and or volume/density) [11]. This is in spite of the proven validity and reliability of the YYIE1 and 2 tests across different populations [9,10,16-19]. Thus, submaximal versions were proposed for estimating aerobic fitness level at baseline and during training interventions, when repeated use is required [11,17-19]. Reliability and some form of validity of Yo-Yo intermittent submaximal versions have been addressed in schoolchildren and young professional footballers [11,18,19]. Unfortunately, no study has investigated the validity and applicability of submaximal versions of the Yo-Yo intermittent tests in adult (i.e. 30–50 years) recreational football players, despite their suitability for health and motivational issues [14]. The low cost and popularity of heart monitors further promotes the interest of the Yo-Yo intermittent tests in their submaximal versions for controlling recreational football training-induced progression in aerobic fitness in untrained healthy adults [11].

The aim of this study was therefore, to assess the validity of the submaximal versions of the Yo-Yo intermittent tests in untrained healthy individuals participating in a recreational football training intervention. Given the lack of information on this relevant practical issue, the most popular Yo-Yo tests used in youth, amateur, professional and recreational football were evaluated for various levels of validity. The association between heart rate (HR) at a set time (2 min) of Yo-Yo (i.e. HR_{2min}) and maximal test performance (i.e. total distance covered at exhaustion) and participants' VO_{2max} were assumed as this study's working hypothesis.

METHODS

Participants

In this study, sixty-six untrained male adults (age 39.3±5.8 years, body mass 81.9±10.8 kg, height 173.2±6.4 cm) involved in a recreational football training intervention volunteered to participate. The untrained status was defined as participants having less than 20 min of exercise on 3 or more days a week [20]. All the participants were familiarised with the procedures used in this investigation during the two weeks before starting the study, performing submaximal versions of the treadmill test for VO_{2max} assessment and the Yo-Yo intermittent tests. 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 participation and made aware that they could withdraw from the study at any time without penalty.

Study design

In accordance with the working hypothesis under consideration, this study aimed to examine the association (i.e. validity) between the HR attained by the participants during an arbitrary submaximal chosen stage (i.e. 2 min) of the Yo-Yo intermittent tests (i.e. $Yo\text{-}Yo_{2min}$) with the total distance achieved at exhaustion in the same test to assess predictive validity [11]. Criterion validity was examined, taking into consideration the relationship between individual $Yo\text{-}Yo_{2min}$ and VO_{2max} values obtained from an incremental continuous treadmill test performed to voluntary exhaustion (TT). $Yo\text{-}Yo_{2min}$ responsiveness was tested by plotting football training-induced changes in these tests against absolute and relative changes induced in VO_{2max}[21].
Predictive and criterion validity were assessed in untrained and trained status.
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HR_{2min} consistency during the field tests was tested by comparing pre- and post-intervention values.

The field tests considered were the level 1 (YYIE1) and 2 (YYIE2) versions of the Yo-Yo intermittent endurance test and the level 1 version of the Yo-Yo intermittent recovery test (YYIR1). The current popularity of these tests in recreational and competitive football, and their associated feasibility, validity and reliability, warranted their inclusion in this study design [14,15,22].

After baseline testing (i.e. laboratory and field testing, n=66), the participants engaged in a recreational football intervention comprising 2–3 60-min training sessions per week in the form of 45-min small-sided games played on an artificial pitch (7v7; 43x27 m pitch, 83m^2 per player). The training intervention was conducted over 12 weeks, and the intensity of the sessions was monitored via HR monitors and the subjective internal load estimated by the rating of perceived exertion (RPE) method [23]. In the post-intervention retest, 32 participants repeated all the test procedures (field tests and TT).

Improvements in aerobic fitness may affect individual HR_{max} values, with lower values usually reported in the trained state [24]. The use of Yo-Yo intermittent submaximal versions assume that the variations in test peak HR refer to baseline HR_{max}, since the purpose is to avoid repeated maximal testing, namely at post-intervention. Nevertheless, as a result, post-training variations in individual HR_{max} may bias Yo-Yo intermittent submaximal version results. Hence, we evaluated the Yo-Yo_{2min} values at post-intervention in relation to untrained (baseline) and post-intervention (trained) status HR_{max}. In each occasion, the highest HR across the Yo-Yo tests and TT was considered as representative of HR_{max} according to the procedures suggested in recreational football by Póvoas et al.[25]

Testing procedures

The field tests 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 standardised warm-up consisting of 10 min of running at different intensities and with changes of direction. The YYIE1, YYIE2, YYIR1 and TT tests were performed in a random order with at least a 4-days recovery period in between. No vigorous physical activity was performed on the day before the test procedures took place. The selected field tests differ in initial running speed, increments in running speed throughout the tests, and recovery time and distance [15]. According to this study design, HR_{2min} was the Yo-Yo_{2min} outcome value. The HR_{2min} was normalised using the highest peak HR at exhaustion obtained across the Yo-Yo tests and TT, considered as the individual maximal (HR_{max})[25]. This procedure enabled the assessment of baseline and post-intervention HR_{max} and corresponding Yo-Yo_{2min} values. The test protocols were implemented according to the procedures suggested by Krustrup et al. [22,26,27].

The TT (HP Cosmos Quasar, Nussdorf, Germany) consisted of 3 min of walking at 5 $km \cdot h^{-1}$ and 2 min of running at 8 $km \cdot h^{-1}$, with 0% inclination, and then alternating between increases in speed (1 $km \cdot h^{-1}$) and inclination (1%) every 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 a 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 [28,29]. The highest 15-s VO_2 during the final stages of the test was considered as the individual VO_{2max} [28,29]. Data analysis was performed with manual inspection of each TT data file using an Excel file (Microsoft, Redmont, USA). The average TT duration was within the range suggested for VO_{2max} assessment (10.7±1.5 minutes; 95% CI: 9.8-10.7)[26,27]. Post-test verification was performed for metabolic computations to correct gas analyser drift bias [28].

All exercise HRs were recorded at 1-s intervals using Polar Team System 2 HR monitors (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.

Statistical analyses

Results are expressed as means ± standard deviations, 95% confidence intervals (95% CI) and ranges when appropriate. 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_{2min} across the evaluation methods under consideration (i.e. YYIE1, YYE2, YYIR1). The training intervention effects on the selected variables emerging from the field and laboratory tests were assessed by Student's paired t-test and practical significance (effect size) by Cohen's *d*, 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 [30]. Pearson correlation (r) was used to assess the associations between variables. The magnitude of the reported effects was described using the Hopkins et al. [31] criteria and the Cook's distance analysis was considered to detect possible influential outliers. Estimation error was reported as typical error of estimation (TEE) according to the procedures proposed by Hopkins et al. [31]. Within test conditions' absolute consistency was expressed as coefficient of variation (%CV). Relative consistency was assessed using the intraclass correlation coefficient ($ICC_{3,1}$) with 95% CI [32,33]. According to Fleiss [34], ICC values of 0.75–1.00 were considered excellent, 0.41–0.74 good and 0.00–0.40 poor.

The smallest worthwhile change (SWC) in measurements was considered to test the practical difference between variables and calculated as 0.2 times the variable standard deviation [31]. The ROC curve statistic was used to explore the possibility of detecting a cutoff measure for Yo-Yo HR_{2min} to characterise the individual level of aerobic fitness (i.e. VO_{2max}). For this purpose, VO_{2max} dichotomisation was performed using the procedures suggested by Herdy and Caixeta [35], considering the group median as reference. Values above and below the group VO_{2max} median were considered as good to excellent and fair to very poor, respectively. Significance was set at 5% ($P<0.05$) for all calculations.

RESULTS

Baseline outcomes and test reliability

The players' VO_{2max} (n=66) was 41.24±6.24 $ml·kg^{-1}·min^{-1}$ (39.71–42.78) with 41.39 $ml·kg^{-1}·min^{-1}$ (38.78–43.01) as median value. During the field tests, the players covered 1602±678 (1436–1769), 447±174 (405–491) and 650±286 m (581–721) during YYIE1, YYIE2 and YYIR1, respectively. The recreational players (n=66) achieved 84.4±6.1% (82.9–85.9, range 67.0–94.6%), 97.8±1.7% (97.3–98.2, range 92.1–100%) and 92.5±3.6% (91.6–93.4, range 83.7–98.8%) of their HR_{max} during $YYIE1_{2min}$, $YYIE2_{2min}$ and $YYIR1_{2min}$, respectively.

The ICC values were good for $YYIE1_{HR2min}$ and $YYIE2_{HR2min}$. The absolute consistency of $YYIR1_{HR2min}$ values was excellent (Table 1). SWC for $YYIE1_{HR2min}$, $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$ was 2.8, 1.8 and 2.2 b·min^{-1}, respectively.

Training intervention outcomes

The participants who repeated the entire baseline test battery post-intervention (n=32) reported a relative mean attendance of 73±15% (26±5 total training sessions out off a maximum of 36) with a weekly average of 2.2±0.5 training sessions. For the 32 players, VO_{2max}, YYIE1 (254–500m), YYE2 (140–345m) and YYIR1(126–234m) test values improved by 8±8 (range -5–30%), 25±24 (range -12.5–96.43), 44±33 (range -7.7–133.3) and 40±40% (range -14.6–123.5), respectively (P<0.001; *d*=0.90–1.28). Post-training intervention results for the $Yo\text{-}Yo_{2min}$ tests are shown in Table 1.

The pre-to-post-intervention HR_{max} values (n=32; 186±10 and 182±10 beats·min^{-1}, respectively) were significantly (P<0.0001; -5.01 to -2.19; d=1.07) different. Significant (P<0.0001) differences were observed between pre-to-post $YYIE1_{HR2min}$ (0.93–2.23; d=0.89), $YYIE2_{HR2min}$ (1.09–2.58; d=0.92) and $YYIR1_{HR2min}$ (0.88–2.23; d=0.44) values, using the baseline and post-intervention HR_{max} for data normalisation (Table 2).

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Yo-Yo$_{2min}$ criterion validity

The regression statistics for the $Yo\text{-}Yo_{2min}$ versions using the baseline HR_{max} are shown in Table 3. The magnitude of the association between VO_{2max} and $YYIE1_{HR2min}$ was large to small (P=0.0001), and for $YYIE2_{HR2min}$ large to trivial (P=0.01). The corresponding values for

$YYIR1_{HR2min}$ were large to trivial (P=0.004). TEE across the field tests was moderate (1.36–2.03 METs).

Using the baseline HRmax values for post-intervention normalisation (Table 4, n=32), the associations between $Yo\text{-}Yo_{2min}$ and VO_{2max} values were small to moderate (P<0.02). The corresponding TEE of the regression equations was moderate under the post-intervention conditions (moderate to large, 1.20–2.18 METs).

When normalizing for post-intervention HR_{max}, the $Yo\text{-}Yo_{2min}$ were moderate to large associated with post-intervention VO_{2max} values (Table 5). The TEE resulted moderate (moderate to large 1.45–1.51 METs).

Predictive validity and between tests associations

At pre-intervention, $YYIE1_{HR2min}$ expressed as $\%HR_{max}$ was large and inversely related to YYE1 maximal distance (-0.68, -0.79 to -0.52, P<0.0001, n=66). The corresponding associations between YYIE2 and YYIR1 distances at exhaustion and their HR_{2min} as $\%HR_{max}$ were large (-0.56; P<0.0001, -0.71 to -0.37, n=66) and moderate (-0.49; P<0.0001, -0.66 to -0.28, n=66), respectively. The associations between post-intervention HR_{2min} and Yo-Yo performances were large to very large, i.e. -0.55 (P=0.0016, -0.76 to -0.24, n=30), -0.64 (P=0.0001, -0.82 to -0.37, n=32) and -0.72 (P<0.0001, -0.85 to -0.49, n=30), for YYIE1, YYIE2 and YYIR1 conditions, respectively. Using the post-intervention HR_{max} the associations between post-intervention $Yo\text{-}Yo_{2min}$ and maximal tests distance were moderate for YYIE1 (-0.43, -0.69 to -0.09; P=0.16) and large for YYIE2 (-0.60, -0.80 to -0.31, P=0.0004) and YYIR1 (-0.60, -0.79 to -0.31, P=0.0004).

$YYIE1_{HR2min}$ was small (r=0.22, P=0.075, -0.023 to 0.439) and largely associated with (r=0.55, P<0.0001, 0.35 to 0.70) $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$, respectively. Moderate associations were found between $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$ (r=0.36, P=0.003, 0.13 to 0.56).

$Yo\text{-}Yo_{2min}$ responsiveness

Small associations were found between training-induced changes in $YYIE1_{HR2min}$ variables and absolute and relative changes in VO_{2max} (r=0.25; -0.12–0.56, P=0.18 and r=0.22; -0.16–0.53, P=0.25, respectively). Similarly, small associations between pre-to-post changes in $YYIE2_{HR2min}$ and VO_{2max} were found (r=0.15; -0.23–0.48, P=0.44 and r=0.11; -0.26–0.45, P=0.57 for absolute and relative changes, respectively). Training-induced variations in $YYIR1_{HR2min}$ were moderately and significantly associated with changes in VO_{2max} (r=0.48; 0.15–0.72, P=0.007 and r=0.45; 0.10–0.69, P=0.014 for absolute and relative changes, respectively).

Fitness categorisation

The ROC analyses reported a cutoff HR_{2min} as $\%HR_{max}$ of 89%, 98% and 91% for YYIE1, YYIE2 and YYIR1, respectively, with values of HR_{2min} as $\%HR_{max}$ below or equal to those thresholds indicating good to excellent VO_{2max} levels. The sensitivity and specificity for the cutoff distances of $YYIE1_{HR2min}$, $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$ were 100/45.45, 63.64/87.88 and 51.52/84.85, respectively. The area under the curve (AUC) for the Yo-Yo tests was significant and corresponded to 0.742 (0.620−0.842, P=0.0001), 0.690 (0.564−0.798, P=0.0055) and 0.681 (0.555−0.790; P=0.0067) for $YYIE1_{HR2min}$, $YYIE2_{HR2min}$ and $YYIR1_{HR2min}$, respectively.

DISCUSSION

This is the first study to examine the validity of submaximal Yo-Yo intermittent tests versions in male adult recreational football players under untrained and trained conditions. The study was devised with the aim of examining the sustainability of low-impact test procedures to evaluate the aerobic fitness status of recreational football players during the training process. This with the purpose of implementing, where necessary, training load adjustments to support clinically relevant (3.5 $ml \cdot kg^{-1} \cdot min^{-1}$) improvements in VO_{2max} [4,8]. The results of this study provided evidence of an association between Yo-Yo tests' HR_{2min} and VO_{2max} in this population of recreational players, both in the baseline criterion validity (moderate associations) and in its confirmatory evaluation in the post-intervention retest (small to moderate associations). Furthermore, there was a small to moderate association between individual training-induced improvements in VO_{2max} and Yo-Yo maximal distances, despite a large variation in HR_{2min} across these tests. Mainly large significant associations were found between HR_{2min} and distance covered in the Yo-Yo tests under both the pre- and post-intervention conditions. The resulting figures suggest that when dealing with male adult recreational football players, the predictive value of submaximal Yo-Yo versions may be considered of interest, but not to the extent of replacing the data provided by the maximal versions. However, the non-maximal nature of Yo-Yo_{2min} may favour their use as complementary tests during the training process. When repeatedly evaluations of aerobic fitness are required for male adult recreational football players, the $YYIE1_{HR2min}$ might be the most favourable option among the Yo-Yo intermittent tests.

Compared to other studies involving younger untrained healthy recreational individuals and professional football players, the duration of the Yo-Yo_{2min} versions used in this investigation was lower (2 min vs 3–9 min) [15,19,26]. This timeframe was selected with the aim of accounting for the limited test duration usually found in age- and gender-matched recreational football players, particularly when considering YYIE2 and YYIR1 protocols [15,17]. Indeed, in this study the average durations of the tests under consideration were 12.0±4.7 min (10.9–13.2), 2.9±0.5 min (2.7–3.2) and 5.4±2.4 min (4.4–5.7) for YYIE1, YYIE2 and YYIR1, respectively. Despite the reported rationale for HR_{2min} criteria, $YYIE2_{2min}$ and $YYIR1_{2min}$ elicited HR_{2min} values that were practically higher than the 90% of individual HR_{max} detected at exhaustion across the field tests and the TT. During $YYIE1_{2min}$, the participants attained 84% of their HR_{max}, suggesting that this test protocol might be preferable for implementing Yo-Yo_{2min} test procedures in recreational football players. Of the field tests performed, YYIE2 and YYIR1, with 98% and 93% HR_{max} attained after just 2 min of beginning the test, respectively, may be considered less suitable for fully satisfying the submaximal testing construct [15].

With the aim of verifying the accuracy of submaximal test versions for estimating performance to exhaustion (i.e. maximal distance covered) in the corresponding protocol, the associations between Yo-Yos' submaximal and maximal outcome variables (i.e. HR_{2min} and total distance covered, respectively) were examined [26]. The reported results mainly show large inverse associations between HR_{2min} and Yo-Yo maximal distance in the selected Yo-Yo tests when participants were in an untrained and trained status (i.e. pre- and post-intervention conditions, respectively). Similarly, the association between post-intervention Yo-Yo_{2min} and Yo-Yo_{max} ranged from moderate to large considering the post-intervention HR_{max}. Surprisingly, the almost maximal nature of $YYIE2_{2min}$ in this population, resulted in only a large (r=-0.56) association with maximal test performance. Krustrup et al. [17] found a similar magnitude of association (r=-0.53) when considering the relationship between HR_{2min} and YYIE2 maximal performance in younger untrained subjects (age 30±6 years). The reported association was lower than that found in professional football players (r=-0.73) for the same split time (2 min) [15,17].

Similar magnitudes of association were found after 12 weeks of recreational football training that elicited an 8% (range -5.3–27.2) improvement in VO_{2max}. These results are similar to those previously published for children, adolescents and adults tested with age-adapted Yo-Yo protocols [11,36].

When considering longer test split times for $YYIE2_{HR2min}$ (i.e. 4 and 6 min) in professional football players, Bradley et al. [19] found a very large association between HR at 4 and 6 min (r=-0.80 and -0.75, respectively) and test distance at exhaustion, suggesting that the chosen split time and the participants' fitness level affect the predictive potential of this demanding test. Previous studies that addressed the nature of YYIE2 in participants with different fitness levels (i.e. untrained subjects and professional football players) reported the mainly anaerobic nature of this test when performed by untrained individuals. The magnitude of YYIE2's physiological demands in untrained individuals was similar to that reported for YYIR2 when dealing with highly trained professional football players [17]. The relationship between $YYR1_{HR2min}$ and distance at exhaustion was moderate (r=-0.49) in the untrained status, though very large in the trained status. Very large (r=-0.81 and -0.75) associations were found by Krustrup et al. [26] in male subjects when considering HR at 6 and 9 min during YYIR1. In that study, the magnitude of the association was only small and not significant when cardiovascular stress was assessed at 3 min during YYIR1 [26]. These data suggest that the Yo-Yo submaximal versions have a predictive validity for the corresponding maximal version that may be considered as population and fitness level dependent. Analysis of post-training predictive validity of the tests under consideration revealed a practical increase in the magnitude of the Pearson's coefficient values for $YYIE2_{HR2min}$ (from -0.56 to -0.64) and $YYIR1_{HR2min}$ (from -0.49 to -0.72). In this regard, the resulting excellent and good relative reliability (see Table 1) of pre- to post-training $YYIR1_{2min}$ and $YYIE2_{2min}$ may partially explain the increase in the magnitude of the association. These results, together with the good ICC values reported in the other tests, may partially support the effect of fitness on $Yo\text{-}Yo_{2min}$ predictive validity.

Originally, the purpose of the Yo-Yo tests was to assess intermittent high-intensity endurance in different populations of subjects [15,26]. The validity of this assumption was tested, considering as the gold standard individual VO_{2max} values plotted against the subjects' Yo-Yo maximal test performance. A suggestion was made for submaximal versions of Yo-Yo tests to limit the physiological impact of field testing when repeated assessment was needed or during the implementation of return-to-action protocols in professional football [15,26]. The published literature examining the applicability of the Yo-Yo submaximal versions mainly focused on the association between HR at a designated split test time with Yo-Yo distance at exhaustion (predictive validity). However, given the practical interest of less impactful testing procedures, specific attention should be given to the criterion validity procedures to support the use of Yo-Yo submaximal testing in different populations, namely recreational footballers. The associations between HR_{2min} and VO_{2max} in this population were shown to be mainly moderate (from -0.47 to -0.28) under both pre- and post-training conditions, indicating a poor predictive power of HR_{2min} for VO_{2max}. Despite the suggested interest of submaximal testing, only Bendiksen et al. [36] reported data related to Yo-Yo submaximal criterion validity, in this case, for the children's version of the YYIR1. The reported association between HR_{2min} and VO_{2max} was moderate ($r=-0.42$, $P<0.05$) and similar to that reported across the Yo-Yo tests considered in this study ($r=-0.28$ to -0.47, $P<0.05$). Although studies on this aspect of test validity and differences in the addressed populations is limited, the reported data suggest the criterion, but not the predictive, validity of the Yo-Yo submaximal version.

The responsiveness of the Yo-Yo tests, or the association between test outcomes and performance changes, is an important form of validity measurement. Fanchini et al. [37] evaluated the external responsiveness (i.e. longitudinal validity) of the YYIR1 submaximal version in respect of HR_{6min} and post-training changes in match high-intensity running in male semi-professional football players, and reported a moderate ($r=-0.38$) association. Unfortunately, no data are available on the Yo-Yo submaximal versions' responsiveness in respect to post-training variation in individual VO_{2max} values. In this study, after the 12-week recreational football training intervention $YYIR1_{HR2min}$ was moderately and significantly associated with VO_{2max} post-training changes. Small and not significant associations were reported for the $YYIE1_{HR2min}$ and $YYIE2_{HR2min}$ comparisons. These data suggest that $Yo\text{-}Yo_{2min}$ should be regarded as having small to moderate responsiveness in populations of recreational football players. Practically speaking, these results indicate that HR_{2min} explains only a small amount of the changes in the variable representing aerobic fitness (i.e. VO_{2max}) that these tests are proposed to estimate. Test responsiveness is an important level of measurement validity when evaluating the interest of a protocol for inclusion in a test battery [21]. The importance of the methodological issue and the reduced number of recreational football players involved in responsiveness assessment warrant further large-scale studies involving recreational male football players.

In training practice and field testing, consideration of normative data to inform the fitness status of subjects is relevant for guiding training prescription and reinforcing participants' motivation. This is of particular interest in submaximal testing, as normalised metrics are usually considered to account for inter-subject differences. In this study, the ROC statistic was used to provide information regarding players' HR_{2min} values and individual VO_{2max} levels. According to the classification proposed by Herdy and Caixeta [35], this study indicates that HR_{2min} below or equal to 89% HR_{max} in $YYIE1_{2min}$ should be regarded as representing good to excellent VO_{2max} values. The corresponding threshold values for $YYIE2_{2min}$ and $YYIR1_{2min}$ are 98 and 91% of individual HR_{max}, indicating that these tests have lower sensitivity in detecting true positive results.

When willing to implement submaximal intermittent Yo-Yo versions, the $YYIE1_{2min}$ might be the advisable choice when considering the evaluation of aerobic fitness using submaximal versions of the intermittent Yo-Yo intermittent tests in recreational football players. Variations of 2–3 $b\cdot min^{-1}$ should be considered as representing practical variations in aerobic fitness across the Yo-Yo_{2min} considered in this study. This despite the reported pre-to-post variations in HR_{max} found in this study. Indeed, the variations in HR_{2min} across the tests and the conditions were higher than the relative SWC values.

Maximal HR assessment requires a multiple approach to obtain actual individual peak values. Furthermore, training-induced improvements in VO_{2max} reported to affect HR_{max} values. This study results reported a significant decrement of HR_{max} as result of the recreational football training intervention. The use of post-intervention HR_{max} to evaluate between variables association improved in magnitude, promoting the link between aerobic fitness and Yo-Yo_{2min} values. This finding further support the robust validity of Yo-Yo_{2min} in recreational football players.

In the present study, post-training variations in test validity levels were assessed with a reduced sample size, i.e. only close to half (32) of the 66 participants who were evaluated under baseline conditions also performed the post-intervention Yo-Yo maximal tests considered in this study. This should be regarded as a study limitation, and further studies are warranted to confirm the data reported here for post-training test validity and, particularly, test responsiveness. The mainly longitudinal descriptive design used in this study, limits understanding of the causes of the reported results. Consequently, mechanistic studies are warranted to hone knowledge of the physiological changes affecting test variability observed in this study.

PERSPECTIVES

The results of this study depict Yo-Yo intermittent submaximal tests as practically interesting testing tools when dealing with untrained or moderately trained recreational football players. Specifically, the Yo-Yo_{2min} tests considered here produced moderate to large associations with several validity constructs. Furthermore, the magnitude of the reported relationships proved to be consistent and partially related to recreational football players' aerobic fitness during the training process. Indeed, the inter-subject variability in HR_{2min} across the Yo-Yo versions was large to very largely associated with Yo-Yo maximal performance, irrespective of the testing time point considered (i.e. pre- or post-intervention). These results parallel those referring to criterion validity in both the untrained and trained status that have shown a moderate association between HR_{2min} and VO_{2max}. The recreational football training intervention implemented in this study was successful in producing large improvements in aerobic fitness, in line with previously published studies addressing different populations [1-5]. Despite the reported large (range 25–44%) decrease in HR_{2min} across the field tests, the magnitude of test changes was only small by comparison with VO_{2max} inter-individual changes. These data suggest an apparent mismatch between HR variations and aerobic fitness improvement when Yo-Yo_{2min} versions are considered. However, the reported trivial to small responsiveness of Yo-Yo_{2min} versions questions the use of these tests as sensitive markers of improvements in aerobic fitness.

With the aim of providing practitioners and sport scientists with the best option for submaximal testing, three popular versions of Yo-Yo test were examined. The inter-individual association between HR_{2min} across the tests revealed only a small to large degree of interchangeability. These results suggest that careful decisions need to be made when choosing the Yo-Yo submaximal test in recreational football interventions. According to the findings of this study, $YYIE1_{HR2min}$ seems to provide a balanced set of features that recommends it as the test of choice when repeated assessment of aerobic fitness is required in recreational football. In this regard, HR_{2min} values lower than 89% should be regarded as proof of good to excellent aerobic fitness.

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Table 1. Players' pre-to-post intervention changes in Yo-Yo submaximal heart rate (i.e. heart rate at 2 min) (n=32).

Variable	**Pre**	**Post**	**Difference**	**%Difference**	***d***	**ICC**	**TEM%CV**	**SWC**
YYIE1$_{HR2min}$ (b·min^{-1})	157±14	148±10***	9±11	6±7	0.95	0.69***	4.7	2.8
			(6; 13)			(0.44; 0.84)	(3.7; 6.3)	
YYIE2$_{HR2min}$ (b·min^{-1})	178±9	170±9***	8±7	4±4	1.15	0.70***	2.9	1.8
			(5; 10)			(0.46; 0.85)	(2.3; 4.0)	
YYIR1$_{HR2min}$ (b·min^{-1})	165±11	157±11***	8±7	5±4	1.21	0.82***	2.9	2.2
			(6; 11)			(0.67; 0.91)	(2.3; 3.9)	

ICC=Intra-class Correlation Coefficient; TEM%CV=Typical Error of Measurement as a percentage of the CV; YYIE1=Yo-Yo Intermittent Endurance Test level 1; YYIE2=Yo-Yo Intermittent Endurance Test level 2; YYIR1=Yo-Yo Intermittent Recovery Test level 1; HR2min=Heart Rate at 2 minute during the test; SWC= Smallest Worthwhile Change; ***=P<0.001; (95%CI); *d*=Cohen's *d*.

Table 2. Players' pre-to-post intervention Yo-Yo submaximal heart rate values (i.e. heart rate at 2 min) (n=32) expressed as a percentage of the baseline and the post-intervention maximal heart rates.

	$YYIE1_{HR2min}$					$YYIE2_{HR2min}$					$YYIR1_{HR2min}$				
	Pre	Post	Difference (95%CI)	P	*d*	Pre	Post	Difference (95%CI)	P	*d*	Pre	Post	Difference (95%CI)	P	*d*
$\%HR_{max}$Pre	84±5	80±5	3–7	<0.0001	0.8	95±3	92±3	2–5	<0.0001	0.86	89±4	82±16	1–14	0.02	4.24

$\%HR_{max}$Post	81±5*	1–5	0.002	0.61	94±3*	1–3	0.006	0.30	83±16*	-0.4–12	0.07	4.95

YYIE1=Yo-Yo Intermittent Endurance Test level 1; YYIE2=Yo-Yo Intermittent Endurance Test level 2; YYIR1=Yo-Yo Intermittent Recovery Test level 1; HR2min=Heart Rate at 2 minute during the test; *=different at $P<0.0001$ from Yo-Yo_{HR2min} calculated with baseline HR_{max}; 95%CI=95% Confidence Intervals; *d*=Cohen's *d*.

Table 3. Regression statistics (n=66) and associations between Yo-Yo submaximal heart rate (i.e. heart rate at 2 min) and players' VO_{2max} pre-intervention (i.e. baseline conditions).

	YYIE1$_{HR2min}$	**YYIE2**$_{HR2min}$	**YYIR1**$_{HR2min}$
Pearson r	-0.45	-0.31	-0.35
95%CI	(-0.63; -0.24)	(-0.51; -0.07)	(-0.54; -0.12)
P value	0.0001	0.012	0.004
Intercept	80.23 (61.12–99.34)	149.10 (66.07–232.14)	97.91 (59.85–135.97)
Slope	-0.46 (-0.69; -0.24)	-1.103 (-1.952; -0.254)	-0.61 (-1.02; -0.20)
TEE (ml·kg^{-1}·min^{-1})	5.60 (4.77; 6.77)	5.98 (5.10–7.23)	5.89 (5.02–7.12)
TEE (standardized)	0.90 (0.77; 1.09)	0.96 (0.82–1.16)	0.94 (0.81–1.14)
TEE as CV%	14.8 (12.5; 18.20)	16.0 (13.5–19.6)	15.6 (13.1–19.10)

TEE=Typical Error of Estimate; CV=Coefficient of Variation; YYIE1=Yo-Yo Intermittent Endurance Test level 1; YYIE2=Yo-Yo Intermittent Endurance Test level 2; YYIR1=Yo-Yo Intermittent Recovery Test level 1; HR2MIN=Heart Rate at 2 min during the field tests; 95%CI=95% Confidence Intervals.

Table 4. Regression statistics and association between submaximal Yo-Yo submaximal heart rate (i.e. heart rate at 2 min) and players' maximal oxygen uptake (VO_{2max}) post-intervention (n=32) using the baseline HR_{max} values.

	YYIE1$_{HR2min}$	**YYIE2$_{HR2min}$**	**YYIR1$_{HR2min}$**
Pearson r	-0.47	-0.43	-0.28
95%CI	(-0.70; -0.14)	(-0.68; -0.09)	(-0.57; -0.08)
P value	0.0072	0.0150	0.1229
Intercept	87.84 (57.66–118.02)	134.76 (64.06–205.43)	74.47 (36.94–112.0)
Slope	-0.52 (-0.88; -0.15)	-0.938 (-1.680; -0.197)	-0.33 (-0.75; -0.09)

TEE (ml·kg^{-1}·min^{-1})	5.26 (4.20; 7.03)	5.37 (4.29–7.18)	5.70 (4.56–7.63)
TEE (standardized)	0.90 (0.72; 1.20)	0.92 (0.73–1.23)	0.98 (0.78–1.31)
TEE as CV%	12.5 (9.9; 17. 0)	12.8 (10.1–17.5)	13.6 (10.8–18.60)

TEE=Typical Error of Estimate; CV=Coefficient of Variation; YYIE1=Yo-Yo Intermittent Endurance Test level 1; YYIE2=Yo-Yo Intermittent Endurance Test level 2; YYIR1=Yo-Yo Intermittent Recovery Test level 1; HR2min= Heart Rate at 2 min during the test; 95%CI= 95% Confidence Interval.

Table 5. Regression statistics and association between submaximal Yo-Yo submaximal heart rate (i.e. heart rate at 2 min) and players' maximal oxygen uptake (VO_{2max}) post-intervention (n=32) using the post-intervention HR_{max} values.

	YYIE1$_{\mathbf{HR}2min}$	**YYIE2**$_{\mathbf{HR}2min}$	**YYIR1**$_{\mathbf{HR}2min}$
Pearson r	-0.48	-0.50	-0.41
95%CI	(-0.71; -0.14)	(-0.73; -0.17)	(-0.67; -0.06)
P value	0.001	0.012	0.006
Intercept	91.77 (58.31–125.23)	140.52 (75.30–205.73)	89.46 (51.20–128.18)
Slope	-0.58 (-0.99; -0.17)	-1.023 (-1.72; -0.33)	-0.52 (-0.96; -0.07)
TEE ($ml \cdot kg^{-1} \cdot min^{-1}$)	5.08 (4.03; 6.87)	5.03 (3.99–6.80)	5.27 (4.18; 7.13)
TEE (standardized)	0.89 (0.71; 1.21)	0.88 (0.70–1.20)	0.93 (0.74; 1.25)
TEE as CV%	12.2 (9.6; 16.8)	12.0 (9.4–16.6)	12.7 (9.9; 17.5)

TEE=Typical Error of Estimate; CV=Coefficient of Variation; YYIE1=Yo-Yo Intermittent Endurance Test level 1; YYIE2=Yo-Yo Intermittent Endurance Test level 2; YYIR1=Yo-Yo Intermittent Recovery Test level 1; HR2min= Heart Rate at 2 min during the test; 95%CI= 95% Confidence Interval.