Title: The reliability, validity and sensitivity of an individualised sub-maximal fitness test in elite rugby league athletes

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Abstract

The purpose of this research was to examine the (1) reliability, (2) validity and (3) sensitivity of an individualised sub-maximal fitness test ($SMFT_{IFT60}$). Nineteen elite rugby league players (22 ± 4 y) participated in the study. *Part 1*: players performed a one-week test-retest of $SMFT_{IFT60}$. Typical Errors and ICCs were: small (<3.5%) and extremely high (>0.90) for accelerometer-derived variables; moderate (<2.5% points) and moderate to very high (0.71–0.89) for all heart rate (HR) variables. *Part 2:* $SMFT_{IFT60}$ and the 30-15 Intermittent Fitness Test (V_{IFT}) were performed prior to and following a 10-week training period. Associations with change in V_{IFT} were large for changes in heart rate during (HRex; r = -0.57) and following (HRR; 0.60) $SMFT_{IFT60}$, and very large for changes in accelerometer measures (range: -0.71 to -0.79). *Part 3*: Within-player dose-response relationships between $SMFT_{IFT60}$ heart rate measures (dependent variables) and prior accumulated internal and external training loads (independent variables) were examined. HRex relationships with acute internal and external loads (prior 3 days) were all negative and ranged from moderate (session ratings of perceived exertion, r = -0.34), to large (high-speed running distance, r = -0.51; acceleration load, r = -0.73) and very large (HR Training Impulse, r = -0.83). All other relationships were unclear or trivial to small (r= -0.24 to 0.29). The $SMFT_{IFT60}$ is reliable and valid for both physiological and accelerometer-derived measures. HRex could be the more sensitive outcome measure to acute internal and external training loads. This could therefore be useful within team sport monitoring strategies; however, a greater understanding of dose-response sensitivity and underpinning physiological mechanisms is warranted.

Key Words

Dose–response, training loads, testing, team sports, GPS

Introduction

Team sports staff aim to optimally prepare their athletes for competition while reducing their risk of injury. Training theory suggests that the internal training response is dependent on the training dose applied and its interaction with individual characteristics, environmental and lifestyle factors (1). As such, practitioners are required to use a multidimensional approach, rather than evaluate training loads in isolation, to provide a complete picture on the adaptive response to the training undertaken. Typically, practitioners may also evaluate the development of physical capacities (i.e., maximal fitness assessments), providing insights into the response of athletes, defined as the dose–response relationship (2), whilst providing information on their current performance-state (defined here as the constant and continual interaction of an individual's fitness–fatigue status) (3, 4). However, identifying an individual's performance-state in team sports is limited due to: 1) the underlying complexities of the multidimensional constructs of internal load (i.e. physiological systems, biomechanical and psychological domains (1, 5, 6)); and 2) the exposure to competition and scheduling considerations, reducing the opportunity and likelihood for maximal testing in-season (7, 8).

Sub-maximal fitness tests (SMFT) have become popular for practitioners aiming to evaluate the performance-state of their athletes in a non-exhaustive manner (9, 10). SMFT provide a practical and systematic method of observing the response to a standardised physical stimulus (dose), allowing information and interpretation on the individual's performance-state (11, 12). The most appropriate protocol to evaluate this training response is not known; with studies examining stationary cycling (13), continuous running (14, 15), intermittent shuttle running (16), modified Yo-Yo tests (10, 17), incremental running protocols (18), individualised sub-maximal shuttle runs (9, 19) and short high-intensity bursts (20, 21). Identifying and utilising specific tests with improved reliability and sensitivity is vital to practitioners given the potential for noise in field conditions (22). McLaren et al. (19) reported improved heart rate (HR) reliability (% of HRmax) during SMFT when using individually prescribed sub-maximal shuttles (57–64 m, TE = 1.3 %; $SMFT_{IFT60}$) versus continuous running (TE = 2.4%) and modified Yo-Yo (TE = 2.6%) protocols at absolute (athlete-independent) running velocities. Importantly, improved reliability of these measurement properties may lead to greater sensitivity when identifying the dose−response relationship between SMFT and training load, allowing for a 'meaningful' detection of performance-state alterations (9, 23).

The validity of SMFT remains unclear, with changes in HR recorded during SMFT (HRex) and concordant changes in maximal test performance equivocal. Some studies have suggested likely associations between HRex and maximally derived cardiorespiratory function (11, 24) while others have reported non-significant correlations (25, 26). The disparity in research suggests these tests (SMFT vs. maximal testing) may evaluate different constructs/mechanisms of the training process. Additionally, this may be reflective of the interplay between different SMFT modalities, and confounders of the multidimensional internal load construct (e.g., mood, running efficiency, surface). Hence, the identification of more sensitive measurement tools may better quantify the dose–response relationship associated with training, assisting practitioners with decision making in regard to player performance-state. Whilst the enhanced test-retest reliability of the $SMFT_{IFT60}$ may offer potential in this regard (19), its validity and sensitivity is unknown.

Typically, studies have adopted between-athlete analyses in their examinations of SMFT convergent validity. However, this is an approach does not reflect the individualised nature of monitoring used in elite sport (i.e., monitoring within-athlete change). In addition, these studies have generally examined the internal adaptive response, with consideration for only physiological (cardiorespiratory) pathways. Recently, it was suggested that physiological and biomechanical load-adaptation pathways should be considered separately due to the stress that training elicits on both systems (6). Yet little is understood on the most appropriate way to quantify this biomechanical stress in the field. Therefore, this study had 3 aims: Part 1) to re-examine the reliability of the $SMFT_{IFT60}$; Part 2) to assess the convergent validity (physiological and; mechanical, through an explorative analysis) of the $SMFT_{IFT60}$; and Part 3) determine the within-individual physiological dose−response relationship between the $SMFT_{IFT60}$ and measures of training load in elite rugby league players.

Methods

Participants

Forty-one elite rugby league players competing for a single club in the Australian-based National Rugby League (NRL), were initially eligible for participation in this study. Per specific inclusion–exclusion criteria (see *Supplementary File 1*), not all players were included in each study part. An overview of the final player samples for each part is presented in Table 1. When players participated, they were cleared of injury by the club's medical staff *a priori*. Throughout the testing periods, players adhered to their usual nutritional, hydration, and ergogenic aid strategies.

Data were collected as part of players' routine training assessments, per their contractual agreements, with no experimental manipulations. Informed consent for analysis of anonymised data was therefore not deemed necessary (27). Nonetheless, all data collection and handling conformed to recommendations of the Declaration of Helsinki and the General Data Protection Regulation (2018).

*** INSERT TABLE 1 ABOUT HERE ***

Experimental Design

All study parts followed observational, repeated-measures designs, with players tested and monitored across pre-specified periods aligned to each specific aim. All testing sessions (SMFT$_{IFT60}$ and 30-15$_{IFT}$) were performed on the same outdoor grass field at the same time of day (~0700–0900), with players wearing their own football boots. Due to the influence of external factors on HR response all players were advised to maintain their normal diet, including consuming breakfast, and to abstain from caffeine, alcohol and exercise in the 24-hours prior to testing. In an attempt to standardise player nutritional substrate status prior to all testing periods the team dietician provided nutritional and hydration strategies to all players as per club guidelines.

Part 1: Test-Retest Reliability of SMFT$_{IFT60}$ Outcome Measures

The SMFT$_{IFT60}$ was performed one week apart at the start of the pre-season phase, occurring in the morning of the first training session preceded by 24 hours of rest. Both sessions were performed under similar environmental conditions (21-23°C).

Part 2: Convergent Validity between SMFT$_{IFT60}$ Outcome Measures and Maximal Test Performance

At the beginning and following a 10- week pre-season training period, the SMFT$_{IFT60}$ was performed with the 30-15 Intermittent Fitness Test (30-15$_{IFT}$). SMFT$_{IFT60}$ was performed with near complete (30-15$_{IFT}$ performed 48-72 hours prior) rest in the 72 hours prior to completion, at the beginning and end of pre-season, respectively. Analyses were performed to evaluate the associations with observed test outcomes and pre-post change in outcomes for both tests. All testing was performed in temperatures between 21-24°C.

Part 3: Dose–Response Sensitivity of SMFT$_{IFT60}$ Heart Rate Measures to Training Load.

The SMFT$_{IFT60}$ was completed 4 times in pre-season (~every 3 weeks) and 5 times in-season (~every 4 weeks). A schematic diagram of the testing procedures is displayed in Figure 1.

Internal and external training loads were collected between every testing session and subsequently accumulated for specifically identified training 'dose' time-periods. We defined *acute* (accumulated from the previous 3-days) and *chronic* (accumulated load since the previous SMFT until the *acute* period) time-periods aligned to current tenets that these represent proposed determents of 'fatigue' and 'fitness' characteristics. While crude, the accumulated time windows were selected as they represent periods where many physiological processes are restored to baseline/homeostasis in rugby league (fatigue; ~72 hours) (28), as well as the suggested residual training effect for aerobic endurance (fitness; ~25–35 days) (29). Consequently, $SMFT_{IFT60}$ physiological (HR-derived) measures were used as measures of 'response' to this load and compared to selected internal and external measures to evaluate their sensitivity (responsiveness). Although we examined the use of $SMFT_{IFT60}$ accelerometery-based measures in Part 2 as an explorative observation (convergent validity with maximal test performance, details subsequent), we opted to omit these data from dose–response sensitivity analysis, given there is currently little scientific understanding and lack of a causal framework linking these SMFT outcome measures with prior accumulated training load. All testing was performed in temperatures between 18-24°C.

*** INSERT FIGURE 1 ABOUT HERE ***

Protocols and Outcome Measures

The 30-15 Intermittent Fitness Test (30-15$_{IFT}$)

The 40-m version of the 30-15$_{IFT}$ was conducted at the beginning and end of pre-season (prior to the $SMFT_{IFT60}$) using previously established procedures, with the final running velocity (V_{IFT}) used as our criterion measure of intermittent exercise capacity (30). Peak heart rate was recorded as the highest heart rate recorded during the final 30-s of the test and considered to be true maximum heart rate, and subsequently used to quantify all other study heart rate data as % points of maximum. Peak heart rate was modified for players if higher values were achieved during the post-test.

30-15$_{IFT}$-derived Individualised Sub-maximal Fitness Test ($SMFT_{IFT60}$)

The $SMFT_{IFT60}$ is a 4-min continuous shuttle test, designed for players to reach a steady-state (31). Testing took place on the same grass surface at the club's training facility, performed as the final stage of the warm-up (a standardised ~8-min block of drills, including running movement patterns, striding and dynamic stretching) and following a day of complete rest. During the $SMFT_{IFT60}$ players were required to complete 12, 20-second shuttles, performed together as a squad. The distance for each player was individualised, prescribed as 60% of the participant's V_{IFT} (Equation 1), with players running back and forth across their specified distance. To standardise the 'dose', this distance was determined at the beginning of pre-season and maintained throughout both the pre-season and competitive phases (i.e. it was not altered after $30\text{-}15_{IFT}$ post-test, regardless of a different result) (19).

Equation 1.

$$SMFT_{IFT60}\text{ shuttle length (m)} = [0.6 \times \left(\frac{V_{IFT}}{3.6}\right)] \times 20$$

Where: V_{IFT} is divided by 3.6 as a conversion from $km \cdot h^{-1}$ to $m \cdot s^{-1}$.

During the test, players were given a 10-s and 20-s auditory cue on each shuttle to ensure they maintained the prescribed sub-maximal running velocity. To determine individual heart rate recovery (HRR), players were required to stand with hands on their hips upon completing the test, without any movement or verbal communication, for two minutes. Findings from previous work (9) suggested that two-minute HRR is more reliable than one-minute HRR.

Heart Rate Measures

Beat-to-beat HR was recorded throughout the $30\text{-}15_{IFT,}$ $SMFT_{IFT60}$ and every session (training and competition) using a chest strap (Polar H1 sensor, Kempele, Finland), which transmitted to a microelectromechanical systems (MEMS) unit (EVO; GPSports, Canberra, Australia) at 5 Hz. Raw HR data ($beats \cdot min^{-1}$) were normalised as a percentage of each player's HR_{max} prior to analysis. The average HR during the final 60-s of the $SMFT_{IFT60}$ (HRex) was calculated in accordance with previous studies (10, 11). HRR was calculated as the percentage decrement in HRex from the end of the test up until two-minutes post-exercise, to account for potential variability in HRex across trials (11). For training sessions and matches, Edwards Training Impulse (TRIMP; summated zones) was calculated as a measure of internal load (32).

Positional and Accelerometery Measures

The MEMS unit contained a 10-Hz Global Navigation Satellite System (GNSS) and a tri-axial piezoelectric linear accelerometer (Kionix: KXP94) sampling at 100 Hz. The unit was placed in a neoprene garment supplied by the manufacturers housing the unit between the scapulae. Prior to the start of each season units were calibrated using the manufacturers jig to ensure values were within the manufacturer's guidelines. To minimise inter-unit variability, participants were fitted with the same GPS device for the entirety of the collection period (33). During pre-season $SMFT_{IFT60}$, instantaneous accelerations were recorded, and raw accelerometer data was extrapolated from the proprietary software (GPSports Console, Canberra, Australia). Vector magnitude (PL) and vertical component (PL_V) accelerometery-loads were calculated across each $SMFT_{IFT60}$ trial (expressed in arbitrary units; AU), as per the PlayerLoad algorithm (34), using Microsoft Excel (Excel 2016, Microsoft Office, Seattle, Washington, USA).

Prior to every training session and match, devices were switched on 15-mins prior to data collection to allow for the collection of erroneous data owing to poor GNSS signal quality. The mean (± SD) number of satellites and horizontal dilution of precision during the data collection period were 12.9 ± 2.8 and 0.9 ± 0.1 respectively. Data from GPS were downloaded following the completion of each training session using proprietary software (GPSports Console, Canberra, Australia) and trimmed to include only active drill or match-play time. Acceleration load (AccLoad) (35) and relative high speed running distance (HSRD) (36) were retained for analysis, as per the selection criteria (and justification) in *Supplementary File 1*. Briefly, HSRD was calculated on an athlete dependent basis (VT_{2IFT}; 87% V_{IFT} = 16.7 ± 0.7 $km \cdot h^{-1}$ or 4.6 ± 0.2 $m \cdot s^{-1}$) and updated following each $30\text{-}15_{IFT}$ assessment, as previously described (37).

Session Ratings of Perceived Exertion

Session ratings of perceived exertion (sRPE) were collected in isolation ~15–30 minutes after each training session or match. Here, numerically-blinded sRPE (using the 'centiMax' category-ratio scale; CR100) were collected using a customized application (Smartabase, Fusion, Australia) on a 7-inch tablet, as per methods previously described (32). The numeric rating was then multiplied by the duration of the session to calculate sRPE training load (sRPE-TL; AU) and retained for analysis (38).

Statistical Analysis

All raw data were approximately normally distributed and are therefore presented as the mean ± standard deviation (SD). For reliability analysis, a custom-made spreadsheet (39) was used to estimate the test-retest typical error (TE), coefficient of variation (CV; where appropriate) and intraclass correlation coefficients (2-way mixed-effects model; $ICC_{3,1}$) of each SMFT outcome measure. Additionally, the pure between-subject SD (between-player SD less the TE) was estimated (40). All estimates of reliability and variability are accompanied by the appropriate 90% confidence (compatibility) limits (CL) (40). Because TEs presented as intervals (i.e., ±) their value must be doubled to assess the entire magnitude of the limits. We performed against usual standardized thresholds for small, moderate and large effects (the pure between-subject SD multiplied by 0.2, 0.6 and 1.2, respectively) (41, 42). Intraclass correlation coefficients magnitudes were evaluated using the following thresholds: >0.99, extremely high; 0.99–0.90, very high; 0.75–0.90, high; 0.50–0.75, moderate; 0.20–0.50, low; <0.20, very low (43).

To examine convergent validity, general linear models (GLM) were used to examine the degree of association between 1) observed SMFT outcome measures and observed performance in the $30\text{-}15_{IFT}$ during pre-season, and 2) changes in SMFT outcome variables and changes in $30\text{-}15_{IFT}$ performance across pre-season. In the former analysis, the mean of pre- and post-test scores were used in replacement of the original data (44) and in the latter analysis, the paired pre–post change scores were used. Models were ran via the *stats* package in the statistical computing software R (Version 3.6.2; R Core Team, 2019). Magnitudes of Pearson's product moment correlation coefficients (*r*) were assessed, against small, moderate, large and very large thresholds (± 0.1, 0.3, 0.5 and 0.7, respectively). If the 90% CL overlapped positive and negative values, the association was interpreted as unclear (45). When associations were clear, the relationship was further described using estimates of the coefficient of determination (R^2), standard error of the estimate (SEE), intercept and slope.

Finally, for analysis of dose−response sensitivity, within-player GLMs were used to determine if changes in selected training load variables were associated with changes in $SMFT_{IFT60}$ HRex and HRR. The observed HR measures were separate dependent variables and independent variables were either acute or chronic accumulated training loads (modelled univariately due to limited degrees of freedom). The within-player correlation coefficients were calculated as per Bland & Altman (46), using the *rmcorr* package (47), with 90% CL's constructed using a bias corrected accelerated bootstrapping technique of 2000 samples with replacement from the original data. Correlation magnitudes were interpreted as previously described.

Results

Reliability

Descriptive and inferential statistics for reliability are shown in Table 2. The magnitude of TEs were small for PL and PLv, and moderate for all other variables. ICC magnitudes were high for all measures of HR and very high for PL and PL_V.

*** INSERT TABLE 2 ABOUT HERE ***

Convergent Validity

The associations between V_{IFT} and SMFT outcome measures are displayed in Figure 2. The relationships between observed test performances were all unclear, with estimated *r* values being trivial to small (Figure 2; bottom panel). The associations between changes in V_{IFT} and changes in HR measures were large (negative for HRex, positive for HRR_{120}). Very large (negative) correlations were witnessed between changes in V_{IFT} and accelerometer measures (Figure 2; top panel). Standard errors of the estimate for these relationships were all < 0.5 $km{\cdot}h^{-1}$, with coefficients of determination being 0.30–0.33 for HR measures and 0.50–0.60 for accelerometer measures (Table 3).

*** INSERT FIGURE 2 ABOUT HERE ***

*** INSERT TABLE 3 ABOUT HERE ***

Sensitivity

The within-player dose−response associations of acute and chronic training loads with SMFT heart rate outcomes are presented through Figures 3–6. HRex is presented in Figures 3 and 4, respectively. HRex relationships with acute loads were all negative and very large for TRIMP and AccLoad, large for HSRD and moderate with sRPE-TL (Figure 3). For chronic loads, all relationships with HRex were unclear, with estimated *r* values being trivial to small (Figure 4).

*** INSERT FIGURE 3 ABOUT HERE ***

*** INSERT FIGURE 4 ABOUT HERE ***

All HRR relationships with acute loads were unclear, with estimated *r* values being trivial (Figure 5). For chronic loads, HRR relationships were small and positive, with the exception of HSRD which was unclear (Figure 6).

*** INSERT FIGURE 5 ABOUT HERE ***

*** INSERT FIGURE 6 ABOUT HERE ***

Discussion

The purpose of this study was to examine the reliability, convergent validity and sensitivity of an individualised SMFT. Our findings demonstrate that both physiological and mechanical measures produced from $SMFT_{IFT60}$ have high levels of reliability and are related to changes in maximal running performance. Specifically, our findings suggest improved HRR along with decreases in HRex and accelerometry-loads are associated with improvements in maximal running performance. We also report acute and longitudinal dose−response relationships between training load measures and SMFT. Here, our results suggest that a decrease in HRex is associated to greater exposure to acute training loads, while training loads across chronic time periods present unclear to small associations; somewhat contradicting available conceptual frameworks (12).

Due to the underlying complexities of the training process and associated outcomes (1), monitoring systems that predominantly focus on the internal and external training load interaction may be limited in their evaluation of the fitness−fatigue status of athletes. In extension of previous observations (HRex TE: 1.3%; (19)), our results demonstrate that the $SMFT_{IFT60}$ has high levels of reliability across physiological measures, reinforcing the potential benefit of an individualised approach to SMFT in team sport athletes (9, 19). Moreover, the strong reliability of accelerometer-derived variables observed herein may provide practitioners with additional insights. Given the potential for extraneous noise in field conditions (22), limiting test protocol variability is vital in order to improve the sensitivity (the ability to detect small, but important changes in performance; signal > noise) of the measure. Building on past research (9, 12), our reliability data can be used to identify true within-player changes in $SMFT_{IFT60}$ by accounting for both the threshold for practical significance (e.g., 1% for HRex) and the test TE (e.g., 1.4% for HRex), rather than inappropriately interpreting the observed difference with no regard for signal or noise (48). For example, an acute, within-player change in HRex of -3.6 percentage points results in an 80% confidence interval for the true change falling entirely outside the -1% threshold, which may be considered a conservative approach to determining a ‘real’ and practically important change in elite rugby league players.

Both physiological and mechanical changes in $SMFT_{IFT60}$ related to changes in maximal running performance in the current study showing large negative associations like previous research (10, 24, 49). This is not surprising given HRex is theoretically associated with oxygen uptake (12). However, the strength of this relationship (r = -0.55; -0.82 to -0.07) offers more evidence that SMFT provides information on similar, yet divergent, constructs on the training outcome. In agreement with some endurance (50, 51) and team sport literature (10, 52), but in contrast to others (11, 49, 53), we observed a large positive relationship between HRR and changes in $30\text{-}15_{IFT}$ performance. HRR is characterised by parasympathetic reactivation and sympathetic withdrawal made in response to the cessation of exercise (54), reflective of the hemodynamic adjustments made in relation to body position (12, 50). Therefore, improvements in HRR are thought to represent improved parasympathetic activation. We offer practitioners a novel tool to practically evaluate changes in SMFT outcome measures and changes in maximal running performance (Table 3). For example, a change in HRex of -5.6% was associated with a minimally important change in $30\text{-}15_{IFT}$ performance (0.5 $km \cdot h^{-1}$; one stage). This, along with the other measures assessed, may provide practitioners with a method to describe the ‘fitness’ component of one’s performance-state using SMFT.

A reduction in PL and PL_V during $SMFT_{IFT60}$ was strongly associated with an improvement in maximal running performance. While interpretation of such measures are not yet well understood, a reduction in accelerometry-loads may be due to reduced leg stiffness (typically a measure of fatigue) (20, 55, 56), morphological adaptations (e.g. muscle architecture) (57, 58), and/or improved gait (muscle) coordination (i.e. movement efficiency) and running economy (59); aside from the former, these adaptations appear beneficial to shuttle running performance. For example, excessive changes in momentum (and increases in net and total vertical impulse) may be considered wasteful motions, requiring greater metabolic demands (59). Yet due to the complex interaction between kinetic and kinematic performance in the field (57), coupled with the lack of concurrent measures of neuromuscular performance and/or criterion measures of morphological and biomechanical functions, drawing definite conclusions may be difficult in this study. Additionally, it has been suggested that the placement of the device (between the scapulae) may be inappropriate to precisely capture true lower limb stiffness and movement given its distal location from the ground (60). As such, further research maybe warranted to identify if changes in mechanical properties (e.g., lower-limb (tendon) stiffness, ground reaction forces, running kinematics) assessed during SMFT can assist in our understanding on the performance-state of individuals.

To date, research in team sports examining the dose−response relationship between training load and SMFT response measures has primarily been conducted in training-camp environments (7-14 days) (52, 53). These studies have used between-individual analysis methods (52, 53), which differ from routine industry practice where performance staff use individual data to drive player management strategies (61). Despite these differences, the findings are concordant; observing a reduction in HRex and strong negative associations between HRex and training load (sRPE-TL; *r* = -0.85 (52), r = -0.80 (53)). On an individual level, our findings suggest an increased training load undertaken in the acute period (72 hours) prior to testing had similar moderate to strong negative associations with HRex. Contrasting previous studies (52, 53), sRPE-TL showed the poorest association (*r* = -0.34) with HRex, instead measures of TRIMP (*r* = -0.83) and external load (HSRD: *r* = -0.51; AccLoad: r = -0.73) revealed stronger relationships. Schneider and colleagues (62) observed similar, reporting HRex reduced when elite badminton players were in a strained state (following four days of training), before increasing again following two days of recovery (62). Whilst speculative, there are a few physiological mechanisms that may describe the acute changes in HRex. For example, a reduction in HRex may be associated with diminished sympathetic or increased parasympathetic nervous system activity (63, 64), decreased sensitivity to catecholamine and/or fluctuations in adrenergic receptor activity (62, 63, 65), or exercise-induced plasma expansion (53). Indeed, these acute changes in plasma volume expansion appear well associated with cardiac parasympathetic function (66). However, any proposal of the specific mechanisms that underpin the current findings are outside the scope of the current study.

It is notable that these findings are somewhat paradoxical to those observed in *Part 2*, which established large associations between decreased HRex and improved fitness. Given that this study identified decreased HRex is related to both improved fitness as well as greater acute training loads (fatigue), drawing definitive inferences may be somewhat challenging. Indeed, it appears the underpinning mechanisms related to HRex may interact across varying time scales, limiting interpretation of the outcome variable. An important note is that the current study (*Part 2*) methodology included either complete or near-complete prescribed rest in the 72-hour period prior to the criterion test measures (i.e., start and end of pre-season). As such, we may assume that the decreased HRex witnessed (in *Part 2*) is related to chronic positive adaptations in the performance-state (improved physiological function; fitness status) (10, 24, 49), rather than acute physiological impairment (fatigue status). However, in field-based settings such rest intervals may not be practical during the in-season (as in the case of Part 3). If this is the case, practitioners might consider the scheduling of SMFT given the potential impact that acute training loads may have on SMFT outcome variables, and aim to limit physical activity in the proceeding 72 hours (if feasible).

Contrary to others (52), HRR demonstrated no considerable dose−response relationship with training load measures. HRR has been suggested to improve with positive changes in high-intensity exercise performance (a notion supported by our findings in Part 2) (12), whilst remaining stable or decreasing with maintained or negative alterations in one's physical performance (fitness) (50). However, HRR is influenced by fatigue (and overreaching) (52), which may partly explain the null findings in the current study. As $SMFT_{IFT60}$ was performed throughout the pre-season and in-season phases, large variations in training loads existed. Indeed, our results demonstrate that while HRR may be used to describe positive chronic alterations in individual's performance state, it may not be sensitive enough to determine week-to-week dose-response relationships, where high variability in training loads may occur. Additionally, it could be that the defined time periods (acute and chronic) of this study dampened some of the signal of $SMFT_{IFT60}$ outcome measures. Indeed, we witnessed no substantial dose−response relationship with any $SMFT_{IFT60}$ and training load measure over the chronic period. Such findings challenge the current conceptual paradigm on changes in training load, fitness characteristics and SMFT. These largely unclear findings may also be distorted by the varying time windows (14-35 days) comprising the chronic period. This study employed a threshold of time that is suggested to be representative of the residual training effect for aerobic endurance (29), whilst ensuring no mathematical coupling occurred between the acute and chronic periods. Despite these attempts, the uncertainty associated with these (and any) chronic periods may limit current, and future, insights on individual's performance-state.

Given the exploratory nature of our study, it is important not to over-interpret the findings and acknowledge the following limitations. Firstly, the sample-sizes across the study (Part 2 and 3) delivers less confidence around point estimates. Here we traded statistical power for analysis integrity, with the application of robust exclusion criteria resulting in large amounts data loss (Supplementary File 1). The circumstances for data loss (Supplementary File 1) are the result of policies employed by the club, and therefore, likely reflect the limitations faced in the 'real' applied environment where SMFT practice may be implemented. The implementation of PL as a measure used to interpret changes in specific neuromuscular and/or musculoskeletal function also yields caution; with little evidence to suggest it has direct relations with these functions (67). Further, the time frames used to capture the acute phase (fatigue; 72 hours) and the chronic phase (fitness; day 14–35 depending on when testing occur) are arbitrary. Lastly, while strategies were employed to minimise the impact of contextual factors throughout the study period (e.g., nutrition/hydration status, ground surface, environmental conditions), the true extent of their influence in unknown. Further, some contextual factors (e.g., ground hardness, heat index) were not quantified. While we acknowledge this as a limitation of the current study, we believe our study design is representative of ecological valid conditions, allowing practitioners to interpret these findings as they would in an applied environment.

Conclusion

Our results demonstrate that the $SMFT_{IFT60}$ exhibits high levels of reliability and validity for both physiological and mechanical measures; providing information on similar, yet divergent, constructs on the training outcome as maximal fitness tests. Collectively, our findings suggest that HRex may provide a more sensitive dose−response outcome measure to monitor in team sports (particularly in an acute time period). Yet, as HRex and HRR evaluate different aspects of cardiac function (12), combined with the strong relationships witnessed between HRR and maximal running performance (fitness), we advise practitioners to monitor both. Our results also raise questions about the direct physiological mechanisms that underpin these physiological and mechanical variables. It is apparent that our conceptual understanding (12) on the function of these cardiac measures and their response to team sport training is not particularly clear. Indeed, the somewhat contrasting findings presented in *Part 2* and *Part 3* provide question over the inferences able to be made from these HR indices. As such, while we advocate the inclusion of SMFT within monitoring strategies, we suggest it is part of a multivariate approach; including multiple HR and mechanical indices from SMFT with other training load data, to assist decision-making strategies. Further, we recommend (where feasible) a standardised approach in the 72 hours prior to implementing SMFT, whereby practitioners may aim to minimise the volume and variability of training loads exposed to players.

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References

1. Impellizzeri FM, Rampinini E, Marcora SM. Physiological assessment of aerobic training in soccer. J Sports Sci. 2005;23(6):583-92.
2. Clemente FM, Clark C, Castillo D, Sarmento H, Nikolaidis PT, Rosemann T, et al. Variations of training load, monotony, and strain and dose-response relationships with maximal aerobic speed, maximal oxygen uptake, and isokinetic strength in professional soccer players. PLoS One. 2019;14(12):e0225522.
3. Thorpe RT, Atkinson G, Drust B, Gregson W. Monitoring Fatigue Status in Elite Team-Sport Athletes: Implications for Practice. Int J Sports Physiol Perform. 2017;12(Suppl 2):S227-S34.
4. Coutts AJ, Crowcroft S, Kempton T. Developing athlete monitoring systems: Theoretical basis and practical applications. In: Beckman MKJ, editor. Recovery and Performance: Interdisciplinary Insights. Abingdon: Routledge; 2018. p. 19-32.
5. Soligard T, Schwellnus M, Alonso JM, Bahr R, Clarsen B, Dijkstra HP, et al. How much is too much? (Part 1) International Olympic Committee consensus statement on load in sport and risk of injury. Br J Sports Med. 2016;50(17):1030-41.
6. Vanrenterghem J, Nedergaard NJ, Robinson MA, Drust B. Training Load Monitoring in Team Sports: A Novel Framework Separating Physiological and Biomechanical Load-Adaptation Pathways. Sports Med. 2017;47(11):2135-42.
7. Vesterinen V, Nummela A, Ayramo S, Laine T, Hynynen E, Mikkola J, et al. Monitoring Training Adaptation With a Submaximal Running Test Under Field Conditions. Int J Sports Physiol Perform. 2016;11(3):393-9.
8. Pyne DB, Spencer M, Mujika I. Improving the value of fitness testing for football. Int J Sports Physiol Perform. 2014;9(3):511-4.
9. Scott TJ, McLaren SJ, Caia J, Kelly VG. The reliability and usefulness of an individualised submaximal shuttle run test in elite rugby league players. Science and Medicine in Football. 2018;2(3):184-90.
10. Veugelers KR, Naughton GA, Duncan CS, Burgess DJ, Graham SR. Validity and Reliability of a Submaximal Intermittent Running Test in Elite Australian Football Players. J Strength Cond Res. 2016;30(12):3347-53.
11. Buchheit M, Simpson MB, Al Haddad H, Bourdon PC, Mendez-Villanueva A. Monitoring changes in physical performance with heart rate measures in young soccer players. Eur J Appl Physiol. 2012;112(2):711-23.
12. Buchheit M. Monitoring training status with HR measures: do all roads lead to Rome? Front Physiol. 2014;5:73.
13. Thorpe RT, Strudwick AJ, Buchheit M, Atkinson G, Drust B, Gregson W. The Influence of Changes in Acute Training Load on Daily Sensitivity of Morning-Measured Fatigue Variables in Elite Soccer Players. Int J Sports Physiol Perform. 2017;12(Suppl 2):S2107-S13.
14. Buchheit M, Cholley Y, Lambert P. Psychometric and Physiological Responses to a Preseason Competitive Camp in the Heat With a 6-Hour Time Difference in Elite Soccer Players. Int J Sports Physiol Perform. 2016;11(2):176-81.
15. Iaia FM, Fiorenza M, Larghi L, Alberti G, Millet GP, Girard O. Short- or long-rest intervals during repeated-sprint training in soccer? PLoS One. 2017;12(2):e0171462.
16. Fitzpatrick JF, Hicks KM, Hayes PR. Dose-Response Relationship Between Training Load and Changes in Aerobic Fitness in Professional Youth Soccer Players. Int J Sports Physiol Perform. 2018:1-6.
17. Owen C, Jones P, Comfort P. The reliability of the submaximal version of the Yo-Yo intermittent recovery test in elite youth soccer. Journal of Trainology. 2017;6:31-4.
18. Hulse MA, Morris JG, Hawkins RD, Hodson A, Nevill AM, Nevill ME. A field-test battery for elite, young soccer players. Int J Sports Med. 2013;34(4):302-11.
19. McLaren SJ, Barrett S, Scott MTU, Scott TJ, editors. Which Submaximal Fitness Test Is Most Reliable For Measuring Exercise Heart Rate? A Comparison Of Three Methods In Rugby League Players. World Congress on Science and Football; 2019; Melbourne.

20. Garrett J, Graham SR, Eston RG, Burgess DJ, Garrett LJ, Jakeman J, et al. A Novel Method of Assessment for Monitoring Neuromuscular Fatigue in Australian Rules Football Players. Int J Sports Physiol Perform. 2019;14(5):598-605.
21. Leduc C, Tee J, Lacome M, Weakley J, Cheradame J, Ramirez C, et al. Convergent validity, reliability and sensitivity of a running test to monitor neuromuscular fatigue. International Journal of Sports Physiology and Performance. 2019;In Press.
22. Currell K, Jeukendrup AE. Validity, reliability and sensitivity of measures of sporting performance. Sports Med. 2008;38(4):297-316.
23. Ryan S, Kempton T, Pacecca E, Coutts AJ. Measurement Properties of an Adductor Strength-Assessment System in Professional Australian Footballers. Int J Sports Physiol Perform. 2019;14(2):256-9.
24. Hulin BT, Gabbett TJ, Johnson RD, Jenkins DG. Sub-maximal heart rate is associated with changes in high-intensity intermittent running ability in professional rugby league players. Science and Medicine in Football. 2019;3(1):50-6.
25. Mohr M, Krustrup P. Yo-Yo intermittent recovery test performances within an entire football league during a full season. J Sports Sci. 2014;32(4):315-27.
26. Fanchini M, Castagna C, Coutts AJ, Schena F, McCall A, Impellizzeri FM. Are the Yo-Yo intermittent recovery test levels 1 and 2 both useful? Reliability, responsiveness and interchangeability in young soccer players. Journal of Sports Sciences. 2014;32(20):1950-7.
27. Winter EM, Maughan RJ. Requirements for ethics approvals. J Sports Sci. 2009;27(10):985.
28. Aben HGJ, Hills SP, Cooke CB, Davis D, Jones B, Russell M. Profiling the Post-match Recovery Response in Male Rugby: A Systematic Review. J Strength Cond Res. 2020.
29. Issurin V. Block periodization versus traditional training theory: a review. J Sports Med Phys Fitness. 2008;48(1):65-75.
30. Buchheit M. The 30-15 intermittent fitness test: accuracy for individualizing interval training of young intermittent sport players. J Strength Cond Res. 2008;22(2):365-74.
31. Cerretelli P, Di Prampero PE. Kinetics of respiratory gas exchange and cardiac output at the onset of exercise. Scand J Respir Dis Suppl. 1971;77:35a-g.
32. Lovell R, Halley S, Siegler J, Wignell T, Coutts AJ, Massard T. Use of Numerically Blinded Ratings of Perceived Exertion in Soccer: Assessing Concurrent and Construct Validity. Int J Sports Physiol Perform. 2020;15(10):1430-6.
33. Scott MT, Scott TJ, Kelly VG. The Validity and Reliability of Global Positioning Systems in Team Sport: A Brief Review. J Strength Cond Res. 2016;30(5):1470-90.
34. Boyd LJ, Ball K, Aughey RJ. The reliability of MinimaxX accelerometers for measuring physical activity in Australian football. Int J Sports Physiol Perform. 2011;6(3):311-21.
35. Delaney JA, Duthie GM, Thornton HR, Scott TJ, Gay D, Dascombe BJ. Acceleration-Based Running Intensities of Professional Rugby League Match Play. Int J Sports Physiol Perform. 2016;11(6):802-9.
36. Scott TJ, McLaren SJ, editors. The validity of relative speed thresholds derived from the 30–15 Intermittent Fitness Test to quantify external training load in rugby league 23rd Annual Congress of the European College of Sports Science; 2018 4th-7th July, 2018; Dublin, Ireland.
37. Scott TJ, Thornton HR, Scott MTU, Dascombe BJ, Duthie GM. Differences between relative and absolute speed and metabolic thresholds in rugby league. Int J Sports Physiol Perform. 2018;13(3):298-304.
38. McLaren SJ, Macpherson TW, Coutts AJ, Hurst C, Spears IR, Weston M. The Relationships Between Internal and External Measures of Training Load and Intensity in Team Sports: A Meta-Analysis. Sports Med. 2018;48(3):641-58.
39. Hopkins WG. Spreadsheets for analysis of validity and reliability. Sportscience. 2015;19:36-42 (sportsci.org/2015/ValidRely.htm).
40. Hopkins WG. Measures of Reliability in Sports Medicine and Science. Sports Med. 2000;30(1):1-15.

41. Smith TB, Hopkins WG. Variability and predictability of finals times of elite rowers. Med Sci Sports Exerc. 2011;43(11):2155-60.
42. Hopkins WG, Marshall SW, Batterham AM, Hanin J. Progressive statistics for studies in sports medicine and exercise science. Med Sci Sports Exerc. 2009;41(1):3-13.
43. Malcata RM, Vandenbogaerde TJ, Hopkins WG. Using athletes' world rankings to assess countries' performance. Int J Sports Physiol Perform. 2014;9(1):133-8.
44. Bland JM, Altman DG. Calculating correlation coefficients with repeated observations: Part 2--Correlation between subjects. Bmj. 1995;310(6980):633.
45. Hopkins WG. How to interpret changes in an athletic performance test. Sport sci. 2004;8:1-7.
46. Bland JM, Altman DG. Calculating correlation coefficients with repeated observations: Part 1--Correlation within subjects. BMJ (Clinical research ed). 1995;310(6977):446-.
47. Bakdash JZ, Marusich LR. Repeated Measures Correlation. Frontiers in Psychology. 2017;8(456).
48. Atkinson G, Batterham AM. True and false interindividual differences in the physiological response to an intervention. Exp Physiol. 2015;100(6):577-88.
49. Rabbani A, Kargarfard M, Twist C. Reliability and validity of a submaximal warm-up test for monitoring training status in professional soccer players. J Strength Cond Res. 2018;32(2):326-33.
50. Daanen HA, Lamberts RP, Kallen VL, Jin A, Van Meeteren NL. A systematic review on heart-rate recovery to monitor changes in training status in athletes. Int J Sports Physiol Perform. 2012;7(3):251-60.
51. Lamberts RP, Swart J, Noakes TD, Lambert MI. Changes in heart rate recovery after high-intensity training in well-trained cyclists. Eur J Appl Physiol. 2009;105(5):705-13.
52. Malone S, Hughes B, Roe M, Collins K, Buchheit M. Monitoring player fitness, fatigue status and running performance during an in-season training camp in elite Gaelic football. Science and Medicine in Football. 2017;1(3):229-36.
53. Buchheit M, Racinais S, Bilsborough JC, Bourdon PC, Voss SC, Hocking J, et al. Monitoring fitness, fatigue and running performance during a pre-season training camp in elite football players. Journal of Science and Medicine in Sport. 2013;16(6):550-5.
54. Bellenger CR, Fuller JT, Thomson RL, Davison K, Robertson EY, Buckley JD. Monitoring Athletic Training Status Through Autonomic Heart Rate Regulation: A Systematic Review and Meta-Analysis. Sports Med. 2016;46(10):1461-86.
55. Fitzpatrick JF, Akenhead R, Russell M, Hicks KM, Hayes PR. Sensitivity and reproducibility of a fatigue response in elite youth football players. Science and Medicine in Football. 2019;3(3):214-20.
56. Huygaerts S, Cos F, Cohen DD, Calleja-González J, Guitart M, Blazevich AJ, et al. Mechanisms of Hamstring Strain Injury: Interactions between Fatigue, Muscle Activation and Function. Sports (Basel). 2020;8(5).
57. Verheul J, Nedergaard NJ, Vanrenterghem J, Robinson MA. Measuring biomechanical loads in team sports – from lab to field. Science and Medicine in Football. 2020;4(3):246-52.
58. Nimphius S, McGuigan MR, Newton RU. Changes in muscle architecture and performance during a competitive season in female softball players. J Strength Cond Res. 2012;26(10):2655-66.
59. Heise GD, Martin PE. Are variations in running economy in humans associated with ground reaction force characteristics? European Journal of Applied Physiology. 2001;84(5):438-42.
60. Eggers TM, Massard TI, Clothier PJ, Lovell R. Measuring Vertical Stiffness in Sport With Accelerometers: Exercise Caution! J Strength Cond Res. 2018;32(7):1919-22.
61. Ward P, Coutts AJ, Pruna R, McCall A. Putting the "I" Back in Team. Int J Sports Physiol Perform. 2018;13(8):1107-11.

62. Schneider C, Wiewelhove T, McLaren SJ, Roleke L, Kasbauer H, Hecksteden A, et al. Monitoring training and recovery responses with heart rate measures during standardized warm-up in elite badminton players. PLoS One. 2020;15(12):e0244412.
63. Meeusen R, Duclos M, Foster C, Fry A, Gleeson M, Nieman D, et al. Prevention, diagnosis, and treatment of the overtraining syndrome: joint consensus statement of the European College of Sport Science and the American College of Sports Medicine. Med Sci Sports Exerc. 2013;45(1):186-205.
64. Le Meur Y, Pichon A, Schaal K, Schmitt L, Louis J, Gueneron J, et al. Evidence of parasympathetic hyperactivity in functionally overreached athletes. Med Sci Sports Exerc. 2013;45(11):2061-71.
65. Lehmann M, Foster C, Keul J. Overtraining in endurance athletes: a brief review. Med Sci Sports Exerc. 1993;25(7):854-62.
66. Buchheit M, Laursen PB, Al Haddad H, Ahmaidi S. Exercise-induced plasma volume expansion and post-exercise parasympathetic reactivation. Eur J Appl Physiol. 2009;105(3):471-81.
67. Bredt SdGT, Chagas MH, Peixoto GH, Menzel HJ, de Andrade AGP. Understanding Player Load: Meanings and Limitations. Journal of human kinetics. 2020;71:5-9.

TABLES

Table 1. Study inclusion criteria, sample size and player characteristics.

Study Part	Analysis Inclusion Criteria	Final sample	Player Characteristics (mean ± SD)		
			Age (y)	Stature (cm)	Body Mass (kg)
Part 1 (*Reliability*)	Completed $SMFT_{IFT60}$ at both the test- and re-test time points; No erroneous test data	19	22 ± 4	184.2 ± 6.1	102.4 ± 10.9
Part 2 (*Validity*)	Completed $SMFT_{IFT60}$ and $30\text{-}15_{IFT}$ at both the pre- and post-testing time points; No erroneous test data	12	24 ± 4	185.2 ± 6.7	103.9 ± 11.8
Part 3 (*Sensitivity*)	A minimum of 4 $SMFT_{IFT60}$ completed throughout the season, At least 14 and no more than 35 days between tests; No erroneous test or training load data	10	23 ± 3	183.9 ± 6.4	98.3 ± 10.3

Table 2. Descriptive statistics (group mean ± SD) and inferential statistics (90% confidence limits) for reliability of an individualised sub-maximal fitness test in elite rugby league players**.**

Testing variable		Subjects (n)	Trial 1	Trial 2	Mean Change	$ICC_{3,1}$	TE	CV (%)	Pure SD*
Exercise	HR_{ex}	17	85.6 ± 3.6	84.2 ± 4.2	-1.38	0.89 (0.75 – 0.95)	1.4 (1.0 – 2.0)		3.9 (2.3 – 5.6)
Recovery	HRR_{60}	17	22.0 ± 4.9	21.9 ± 5.0	-0.13	0.71 (0.44 – 0.87)	2.8 (2.2 – 3.9)		4.9 (2.8 – 6.9)
	HRR_{120}	17	33.4 ± 5.4	36.9 ± 6.0	3.45	0.83 (0.63 – 0.92)	2.5 (2.0 – 3.6)		5.9 (3.4 – 8.4)
PlayerLoad™	PL	19	97.7 ± 12.1	95.4 ± 11.7	-2.26	0.93 (0.86 – 0.97)	3.2 (2.0 – 3.6)	3.3	11.8 (7.1 – 16.5)
	PL_V	19	71.5 ± 10.3	71.1 ± 10.1	-0.34	0.94 (0.87 – 0.97)	2.6 (2.1 – 3.6)	3.5	10.0 (6.0 – 14.0)

All heart rate variables are expressed as a percentage of maximum heart rate.

*between-player

HR_{ex}: mean exercising heart rate recorded in the final 60 seconds of the test; HRR_{60}: 60-second heart rate recovery, expressed in percentage points as the difference between 60-second post-exercise heart rate and HR_{ex}, HRR_{120}: 120-second heart rate recovery, expressed in percentage points as the difference between 120-second post-exercise heart rate and HR_{ex}, PL: Total PlayerLoad™; PL_V: Vertical PlayerLoad™; ICC: Intraclass correlation coefficient; SD: standard deviation; TE: typical error.

Table 3. General linear models describing the associations between changes in SMFT outcome measures and the change in $30\text{-}15_{IFT}$ performance across the pre-season training phase.

$SMFT_{IFT60}$ Outcome Measure	R^2	**Intercept (km·h^{-1})**	**Slope km·h^{-1})**	**SEE (km·h^{-1})**
ΔHRex	0.30	0.13 (-0.28 to 0.53)	-0.09 (-0.17 to -0.01)	0.46
ΔHRR_{120}	0.36	0.48 (0.25 to 0.71)	0.06 (0.01 to 0.12)	0.44
ΔPL_{VM}	0.50	0.24 (0.01 to 0.49)	-0.06 (-0.09 to -0.02)	0.43
ΔPL_{V}	0.62	0.22 (0.02 to 0.42)	-0.09 (-0.13 to -0.05)	0.38

FIGURE LEGEND

Figure 1. A schematic diagram of the testing procedures implemented by this study.

: 30-15 Intermittent Fitness Test; : Sub-maximal Fitness Test ($SMFT_{IFT60}$); : Global positioning system and heart rate monitoring (collected throughout both phases); : Rating of Perceived Exertion monitoring (CR100; collected throughout both phases).

Figure 2. Pearson's correlation coefficients for changes in $30\text{-}15_{IFT}$ performance and changes in heart rate and PlayerLoad™ measures, as well as raw $30\text{-}15_{IFT}$ test performance and raw measures of heart rate and PlayerLoad™ measures with individual depiction of data. HR_{ex}: mean exercising heart rate recorded in the final 60 seconds of the test; HRR_{120}: 120-second heart rate recovery, expressed in percentage points as the difference between 120-second post-exercise heart rate and HR_{ex}, PL: Total PlayerLoad™; PL_V: Vertical PlayerLoad™

Figure 3. *Acute* (≤ 3 days) within-subject dose-response relationships between exercise heart rate (HRex) during the sub-maximal intermittent running ($SMFT_{IFT60}$) and measures of internal (a: Edwards TRIMP; and b: Session RPE-Training load) and external (c: High Speed Running Distance; and d: Acceleration Load) training load.

Figure 4. *Chronic* (between acute period and last test) within-subject dose-response relationships between exercise heart rate (HRex) during the sub-maximal intermittent running ($SMFT_{IFT60}$) and measures of internal (a: Edwards TRIMP; and b: Session RPE-Training load) and external (c: High Speed Running Distance; and d: Acceleration Load) training load.

Figure 5. *Acute* (≤ 3 days) within-subject dose-response relationships between two-minute heart rate recovery (HRR) during the sub-maximal intermittent running ($SMFT_{IFT60}$) and measures of internal (a: Edwards TRIMP; and b: Session RPE-Training load) and external (c: High Speed Running Distance; and d: Acceleration Load) training load.

Figure 6. *Chronic* (between acute period and last test) within-subject dose-response relationships between two-minute heart rate recovery (HRR) during the sub-maximal intermittent running ($SMFT_{IFT60}$) and measures of internal (a: Edwards TRIMP; and b: Session RPE-Training load) and external (c: High Speed Running Distance; and d: Acceleration Load) training load.