Sensitivity of Monthly Heart Rate and Psychometric Measures for Monitoring Physical Performance in Highly Trained Young Handball Players

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Sensitivity of Monthly Heart Rate and Psychometric Measures for Monitoring Physical Performance in Highly Trained Young Handball Players

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Key words
- heart rate variability
- POMS
- speed tests
- counter movement jump
- 30-15 Intermittent Fitness Test
- progressive statistics

Abstract

The aim of the present study was to examine whether monthly resting heart rate (HR), HR variability (HRV) and psychometric measures can be used to monitor changes in physical performance in highly-trained adolescent handball players. Data were collected in 37 adolescent players (training $10 \pm 2.1\,h.wk^{-1}$) on 11 occasions from September to May during the in-season period, and included an estimation of training status (resting HR and HRV, the profile of mood state (POMS) questionnaire), and 3 physical performance tests (a 10-m sprint, a counter movement jump and a graded aerobic intermittent test, 30-15 Intermittent Fitness Test). The sensitivity of HR and psychometric measures to changes in physical performance was poor (<20%), irrespective of the training status markers and the performance measures. The specificity was however strong (>75%), irrespective of the markers and the performance measures. Finally, the difference in physical performance between players with better vs. worse estimated training status were all almost certainly trivial. The present results highlight the limitation of monthly measures of resting HR, HRV and perceived mood and fatigue for predicting in-season changes in physical performance in highly-trained adolescent handball players. This suggests that more frequent monitoring might be required, and/or that other markers might need to be considered.

Introduction

Team handball is a professional and Olympic sport which has received increasing popularity over the past decades [27]. Playing handball at the elite level requires, in addition to excellent technical and tactical skills, well developed physical qualities. Analyses of game demands suggest that speed, explosive strength and high-intensity intermittent running performance are the most important physical qualities for achieving success in high-level leagues [27]. To maintain team (physical) performance throughout the competitive season [7,19], the frequent monitoring of players' fatigue, fitness and performance is paramount for appropriately adjusting training load and content [5]. While the monitoring of saliva and blood variables [36] may be useful, team coaches and support staff are generally looking for time-efficient, non-invasive, non-fatiguing and cheap tools [36]. Therefore, the use of psychometric questionnaires [22,29], jump tests [36], rate of perceived exertion (RPE) responses to submaximal exercise bouts [12,14], and heart rate (HR) and HR variability measures [8,11–13,30] is becoming increasingly popular.

However, despite some of these markers during short training periods being associated with major changes in fitness, fatigue and/or performance (i.e., pre-season [13,30] or intensified training blocks [11]), it is unknown whether these markers have the same usefulness during the handball season. During the season, the ability to collect markers of training status is generally reduced from daily to fortnightly, monthly or even less frequently [7,19], which can decrease their sensitivity and usefulness. Additionally, the actual sensitivity (the ability of the marker to correctly assess changes) and specificity (the ability of the marker to correctly assess a lack of changes) [20] of these makers must still be determined.

In practice, while players generally train collectively as a team, practitioners need to monitor each athlete in isolation to accurately interpret his training status, and, in turn, make the correct decisions. To do so, W.G. Hopkins developed a specific monitoring approach which facilitates

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assessing the likelihood of the observed individual changes being 'true' [23,24]. Key to this approach is that each individual marker or performance change is considered in relation to both the smallest practical or meaningful change (the so-called smallest worthwhile change, SWC [4,25]) and the noise of the measurement of the variable of interest (i.e., the typical error arising from a test-retest study) [8,12,23,24]. Despite its attractiveness however, there is, to our knowledge, no published data in team sports using this monitoring approach over an extended period of the playing season.

Therefore, the aim of the present study was to examine, using Hopkins' monitoring approach [23,24], whether monthly measures of resting HR, resting HRV, mood and fatigue could be used to predict changes in physical performance (i.e., acceleration capacity, explosive strength and high-intensity intermittent running performance) in highly-trained adolescent handball players.

Methods

Participants

37 adolescents (girls: n=16, 15.3±0.8 years, 171.9±6.4cm, 65.5±7.2kg and 22.2±2.6% body fat, and boys: n=21, 15.8±1.0 years, 182.2±5.9cm, 73.7±10.8kg and 13.2±3.7% body fat) who trained 10±2.1 $h.wk^{-1}$ at a regional center (including 1 competitive match every weekend) were recruited to participate in the study. The training load of a typical training week was ~2800AU [26]. All players were all free of cardiovascular and pulmonary disease and were not taking any medications. The study was approved by the local research ethics committee, performed in accordance with the ethical standards of the IJSM [21] and conformed to the recommendations of the Declaration of Helsinki. Participants and their parents gave voluntary written informed consent to participate in the experiment.

Experimental overview

Data were collected on 11 occasions from September to May (i.e., every 3–4 weeks) during the 2002–2003 competitive season. During the entire season, training routines were similar week to week, and the average load remained constant (±10%). There was no specific training block, which may have specifically affected fatigue or fitness levels. All data were collected on a Monday and at the same time of the day, and included i) 3 physical performance tests (acceleration capacity with a 10-m sprint, lower limb explosive strength with a counter movement jump (CMJ) and high-intensity intermittent running performance with a graded aerobic intermittent test, 30-15 Intermittent Fitness Test), and ii) a measure of estimated training status based on resting HR and HRV, and the POMS questionnaire. The players reported to a dedicated room at 11:30a.m., sat for 10min and filed the POMS questionnaire first. They then lied supine for 10min, and HRV was measured. Physical performance tests were performed at 4:00 PM on an indoor synthetic track. Ambient temperature for all testing and training sessions ranged from 18 to 22 C°. Players were well familiar with all the testing procedures, having completed each of the test protocols at least twice during the previous season. Players were instructed to consume their last meal at least 3h before the scheduled test/measures time. Since match physical performance is largely position-dependent [27] and related more to game demands (tactics and playing roles) than physical fitness *per se* [10], assessing physical activity during matches is unlikely to provide a direct assessment of players' physical fitness and training status. Therefore, the 3 field tests described above were deemed to be appropriate to reflect any changes in players' physical performance capacity.

Resting heart rate and heart rate variability

All R–R series data were analyzed with the ProTrainer Polar 5 software (version 5.40, Polar Electro), which has been shown to provide accurate measurements. Occasional ectopic beats were automatically replaced with interpolated adjacent R-R interval values. Both resting HR and the logarithm of square root of the mean of the sum of the squares of differences between adjacent normal R-R intervals (rMSSD) were calculated during the last 5min of the 10-min period [32]. Least likely greater Ln rMSSD and lower HR were interpreted as a better training status; conversely, least likely lower Ln rMSSD and greater HR were interpreted as a worse training status.

Psychometric measures

The profile of mood state (POMS) was used. It consists of 65 items that addresses 6 components of mood: tension, depression, anger, vigor, fatigue (Fatigue), and confusion [29]. Players were asked to describe their feelings over the previous week using a 5-point response scale ranging from 0 (not at all) to 4 (extremely) for each item. An overall measure of total mood disturbance (total mood disturbance score, TMS) is calculated for all 6 subscales by combining the scores obtained on the tension, depression, anger, fatigue and confusion minus the score on the vigor scale. Based on pilot analyses, only Fatigue and TMS were used as estimates of training status. Least likely lower Fatigue and TMS were interpreted as a better training status; conversely, Least likely greater Fatigue and TMS were interpreted as a worse training status.

Speed

Acceleration capacity was evaluated by a 10-m standing-start sprint with the front foot placed 5cm before the first timing gate. Time was recorded with photoelectric cells placed 10m apart (Brower Timing System, Colorado, USA). Players started when ready, thus eliminating reaction time. Players completed three 10-m sprints with the fastest sprint time recorded. All sprints were separated by at least 45s of passive recovery.

Lower limb explosive strength

Lower limb explosive strength was assessed using a vertical countermovement jump with flight time measured by an Optojump (Microgate, Bolzano, Italy) to calculate jump height (CMJ; cm). Each trial was validated by visual inspection to ensure each landing was free of leg flexion, and participants were instructed to keep their hands on their hips during all jumps. The depth of the countermovement was self-selected. All athletes were verbally encouraged throughout the test and asked to jump as high as possible. The CMJ was performed 3 times, separated by 45s of passive recovery, and the best performance was recorded.

High-intensity intermittent running performance

The athletes performed the 30-15 Intermittent Fitness Test ($30\text{-}15_{IFT}$), with the final running speed noted as V_{IFT} [6].

Statistical analyses

Data in the text and figures are presented as means with standard deviations (SD) and 90% confidence intervals (CI), respectively. Individual changes in all variables were assessed using a specifically designed spreadsheet, [23] in which both the typical error (expressed as a CV) of each measure and the SWC were considered. The CV of all variables, assessed during a pilot study with a subsample of 22 players (11 girls, 11 boys), were 2.2% (1.5;4.6) for 10-m sprint, 4.2% (3.4;5.6) for CMJ, 1.9% (1.4;2.7) for V_{IFT}, 10.8% (8.4;14.9) for resting HR, 10.4% (8.0;14.6) for Ln rMSSD, 8.1% (6.5;11.0) for TMS and 7.1% (5.7;9.7) for Fatigue. Since there was no clear difference between boys and girls, their data were pooled together. The individual SWC was defined as 1) a small standardized effect based on Cohen's effect size principle (0.2 × between-athletes standard deviation, SD) [25] for performance, 2) ½ of the CV for TMS and Fatigue [32], and 3) the actual ΔHR (2%) and ΔLn rMSSD (3%) that generally corresponds to a small standardized (0.2 × between-athletes SD) change in performance measures [3,12]. Only individual changes rated as at least likely (>75%) were considered as substantial [12]. The value of individual ΔHR, ΔLn rMSSD, ΔTMS and ΔFatigue to predict substantial individual Δ10 m, ΔCMJ and ΔV_{IFT} was examined as true positive/(true + false positive) changes (predictive value of changes) and true negative/(true + false negative) changes (predictive value of no change) [12,20]. The sensitivity of the variables changes was assessed as true positive/(true positive + false negative) changes; the specificity of the variables changes, as true negative/(true negative + false positive) changes [12,20].

The individual changes in physical performance were then averaged for the players, showing clear changes in estimated training status (i.e., based on substantially increased vs. decreased ΔHR, ΔLn rMSSD, ΔTMS and ΔFatigue) [15]. A limitation of this approach is that repeated measures are not directly accounted for (i.e., multiple data per player can be used, depending of his estimated training status). However, this limitation is partly circumvented by the fact that i) physical performance varies consistently week-to-week at the individual level [2], ii) we adjusted all comparisons for players' fitness at the time of each measurement. Between-training status differences were standardized and expressed as a factor of the SWC for the variable of interest. Probabilities were used to make a qualitative probabilistic mechanistic inference about the true changes: if the probabilities of the effect being substantially greater and smaller than the SWC were both >5%, the effect was reported as unclear; the effect was otherwise clear and reported as the magnitude of the observed value. The scale was as follows: 25–75%, possible; 75–95%, likely; 95–99%, very likely; >99%, almost certain [25].

Results

Players were tested 9 ± 2 times on average (range: 3–11, 3 times (1 player), 4 (2), 5 (0), 6 (3), 7(1), 8 (3), 9 (16), 10 (6) and 11 (5)). The average performance values were 1.95 ± 0.14 s for 10-m time, 44.6 ± 6.2 cm for CMJ and 18.4 ± 1.5 km.h^{-1}for V_{IFT}. Resting HR was 64 ± 12 beat.min^{-1}, Ln rMSSD, 4.2 ± 0.7 ms, TMS, 151 ± 30 and Fatigue, 45.3 ± 6.9. Over the season, 17, 15 and 10% of the individual tests performance were below the individual average for 10-m, CMJ and V_{IFT}, respectively. By contrast, 18, 15 and 10% of the tests were above the average. Similarly, 10, 10, 11 and 14% of resting HR, Ln rMSSD, TMS and Fatigue were below the average, respectively (interpreted as 'feeling worse' than the average). By contrast, 7, 8, 12 and 13% of the tests were above the average (interpreted as 'feeling better' than the average). **Fig. 1** shows the different variables over the seasons in a representative player, together with the interpretation of the changes and the assessment of sensitivity and specificity.

The sensitivity and specificity of ΔHR, ΔLn rMSSD, ΔTMS and ΔFatigue to detect meaningful Δ10 m, ΔCMJ and ΔV_{IFT} is illustrated in **Fig. 2**. The value of resting HR to predict changes/no change in 10 m, CMJ and V_{IFT} was 14/55, 16/71 and 8/81%, respectively. The value of resting Ln rMMSD to predict changes/no change in 10 m, CMJ and V_{IFT} was 17/65, 13/71 and 14/82%, respectively. The value of TMS to predict changes/no change in 10 m, CMJ and V_{IFT} was 24/66, 18/70 and 6/85%, respectively.

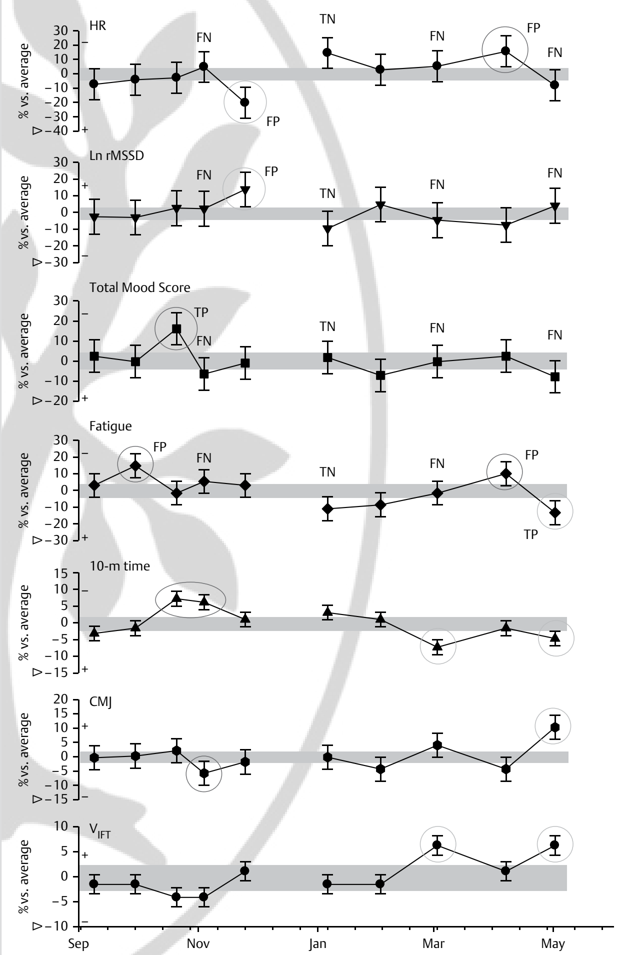

Fig. 1 Resting heart rate (HR), logarithm of square root of the mean of the sum of the squares of differences between adjacent normal R–R intervals (Ln rMSSD), total mood score (POMS TMS), fatigue score (Fatigue), 10-m sprint time (10 m), counter movement jump height (CMJ) and the maximal speed reached at the end of the 30-15 Intermittent Fitness Test (V_{IFT}) in a representative player. Error bars represent the typical error of each variable as assessed in a subsample of player prior to the study (see methods). The grey horizontal bars represent trivial changes (see methods). Circles indicate least likely better or worse estimated training status and physical performance. The value of each monitoring variables is provided at some points for illustration, i.e., TP: true positive; FP: false positive; FN: false negative; FP: false positive. Testing session #6 (end of December) was missed (school exams).

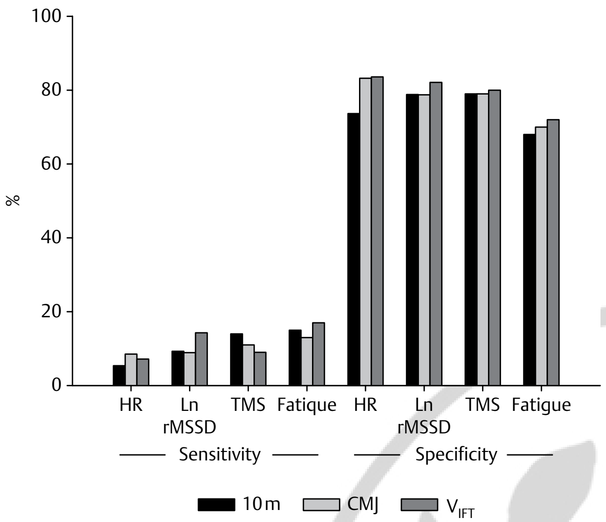

Fig. 2 Sensitivity and specificity of heart rate (HR), the logarithm of square root of the mean of the sum of the squares of differences between adjacent normal R–R intervals (Ln rMSSD), total mood score (TMS) and fatigue score (Fatigue) for predicting changes and no changes in 10-m sprint time (10 m), countermovement jump height (CMJ) and the maximal speed reached at the end of the 30-15 Intermittent Fitness Test (V_{IFT}), respectively.

Finally, the value of Fatigue to predict changes/no change in 10 m, CMJ and V_{IFT} was 16/67, 12/71 and 10/82 %, respectively.
The effect of a better, unchanged or worse estimated training status on performance is shown in **Fig. 3**. The difference in physical performance between players with better vs. worse estimated training status were all almost certainly trivial.

Discussion

We examined for the time whether monthly measures of resting HR(V), fatigue and mood could be used to monitor changes in physical performance in highly-trained adolescent handball players. The main results are as follow: 1) the sensitivity of all candidate variables to assess training status was poor (<20%), irrespective of the markers and the performance measures, 2) the specificity was however strong (>75%) irrespective of the markers and the performance measures and 3) the difference in physical performance between players with better vs. worse estimated training status were all almost certainly trivial.
In the present study, we applied for the first time in handball the monitoring approach developed by WG. Hopkins [23,24] which facilitates assessing the likelihood of the individual changes in any variable (**Fig. 1**). In the representative player examined in **Fig. 1**, all variables showed likely deviations from the mean on 2–4 occasions during the season, despite almost stable training/competitive load (not documented, which is a strong limitation of the present study). Physical performance changed sometimes according to the estimated training status (true positive cases, e.g., measure #3 in November, both PMS and 10-m sprint time were likely increased; last measure in May, Fatigue was likely decreased and all performance measures improved). In the majority of cases however, the changes in the different variables were dissociated (e.g., false negative case in October, measurement #4, when 10-m sprint time and CMJ performance were impaired despite no substantial change in all training status-related variables, or false positive case in April, measurement #10, when all performances remained stable despite the worsening in resting HR and increased Fatigue). Considering that the present statistical approach may be valid and appropriate for such monitoring [23,24], this individual example highlights the limitations of the present monthly measures of HR and mood to predict changes in physical performance, at least during an in-season period with limited variations in training load. The following sections will discuss the group results and the sensitivity and specificity of the different training status markers.
None of the monitoring variables showed sensitivity to changes in physical performance greater than 20% (**Fig. 2**). Additionally, when we compared the performance of players showing improved vs. worse estimated training status, the differences were all almost certainly trivial (**Fig. 3**). The lack of sensitivity of HR measures to changes in performance is in contrast to previous studies, where changes in both resting HR and HRV were associated with changes in aerobic-related running performance in team sport [15,30] and endurance [9,17,28,31,37] athletes. These discrepancies may be related to the fact that in the present study, HR(V) was collected on a single day, while in the some of the other studies, HR(V) was collected daily and averaged over a week [9,28,31]. Because of the important day-to-day variations [1], HR measures taken on isolated days might not reflect the actual training status of the players. It is therefore recommended to average at least 3–4 HR(V) measures per week to reach an acceptable confidence in the interpretation [34]. The differences compared with the other studies using single-day measures may also be related to both the training background of the athletes (recreational runners [37] vs. highly-trained handball players) and training phases examined (preparatory phase [17] and preseason [30] vs. in-season), which directly affects the magnitude of the changes in HR(V) and performance, and, in turn, the likelihood of observing an association between the variables. Finally, it is also worth noting that depending on the training context (e.g., cycle, load, intensity distribution), similar changes in HR(V) may have opposite outcomes [33]. Therefore, despite the tight standardization of recording procedures (e.g., stable training routines week-to-week, data collected on the same day of the week), possible variations in training/game intensity at the individual level may have confounded the expected relationship between HR(V) and players' actual training status. The lack of documentation on individual load is a limitation of the present study and should be acknowledged. Finally, whether HR(V) variables would show greater sensitivity to changes in training status and physical performance with greater variations in training/competitive load still needs to be investigated.
The lack of sensitivity of the total mood score for tracking changes in physical performance contrasts with a previous study in adolescent football players, where an impaired mood profile was associated with an increased HR response to submaximal exercise (which was interpreted as an evidence of non-functional overreaching) [35]. However, since an increased submaximal HR may actually not be a clear predictor of impaired performance [15], the results of this latter study might be flawed (the increased HR was the only diagnostic criteria for non-functional overreaching). The lack of sensitivity observed in the present study may be also explained by the fact that the POMS test was initially designed to detect heavy states of chronic fatigue such as non-functional overreaching or over-training. In the pre-

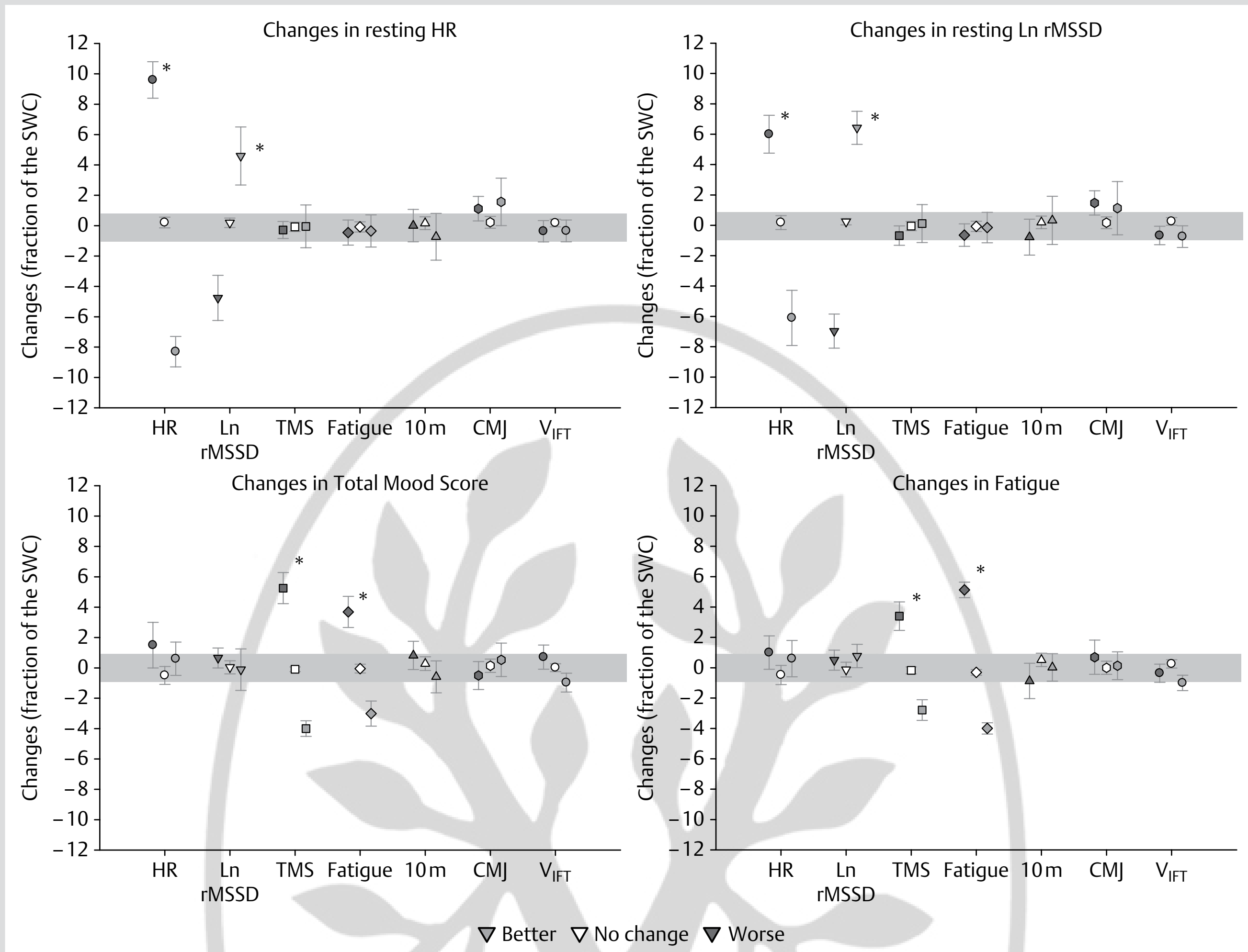

Fig. 3 Changes in heart rate (HR), the logarithm of square root of the mean of the sum of the squares of differences between adjacent normal R–R intervals (Ln rMSSD), total mood score (POMS TMS), fatigue score (Fatigue), 10-m sprint time (10 m), countermovement jump height (CMJ) and the maximal speed reached at the end of the 30-15 Intermittent Fitness Test (V_{IFT}) in players with better, unchanged or worse estimated training status. The grey horizontal bars represent trivial changes (see methods). * : almost certain difference between better and worse estimated training status.

sent study, training load was moderate for such a population (~2 800 AU [26], although not reported weekly) and remained almost constant throughout the year; none of the players presented clear non-functional overreaching or over-training symptoms. Accordingly, the average TMS was 151, which is close to the ~140 observed in 'fresh' adult football players [18]. Additionally, none of the players displayed a continued decrease in performance for more than 2 consecutive weeks (**Fig. 1**). The present changes in performance might therefore be more related to changes in acute freshness rather than non-functional overreaching. It may therefore be hypothesized that if some of the players had experienced greater fatigue levels, the performance impairments might have be greater, and the POMS score may have picked those up. The lack of the Fatigue score to predict change in (at least aerobically-related) performance contrasts also with the results of a recent study in adult Australian Football players, where individual changes in perceived wellness after a pre-season camp in the heat correlated largely with changes in high-intensity intermittent running performance [13]. As above, differences in training phases (pre- vs. in-season) might explain the present results.

Conclusion

The present data suggest that monthly measures of resting HR, HRV and perceived mood and fatigue during the season may not be sensitive enough to predict changes in physical performance in non-overreached highly-trained adolescent handball players. Whether physical performance can be accurately monitored in players showing greater changes in training status must still be examined. Additionally, the actual impact of (changes in) training load and/or training intensity distribution on the sensitivity/specificity of the different monitoring markers requires further research. In practice, sport scientists may be required to monitor these variables at a greater frequency (i.e., weekly [8]), and/or to use other variables in combination (e.g., morning wellness scores [13], flight to contraction time during CMJs and/or GPS-accelerometers measures [16]).

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Conflicts of interest: The author has no conflict of interest to declare.

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