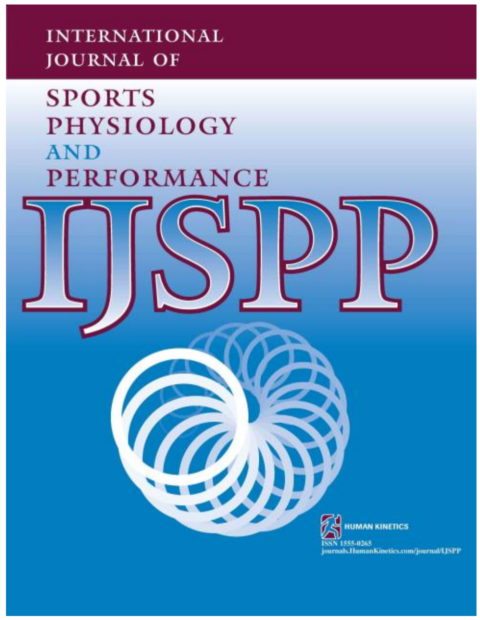
Using submaximal exercise heart rate for monitoring cardiorespiratory fitness changes in professional soccer players: A replication study



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ABSTRACT

Purpose:

To assess the value of monitoring changes in fitness in professional soccer players using changes in heart rate at submaximal intensity ($HR_{12km/h}$) over the velocity at a lactate concentration of 4 mmol/l ($v_{4mmol/l}$), we re-examined 1) a range of threshold magnitudes which may improve detecting substantial individual changes and 2) the agreement between changes in these two variables.

Methods:

On at least two occasions during different moments of the season, 97 professional soccer players from Germany (1st, 2nd, and 4th division) completed an incremental test to determine $HR_{12km/h}$ and $v_{4mmol/l}$. Optimal thresholds for changes in $HR_{12km/h}$ and $v_{4mmol/l}$ were assessed using various methods (e.g., smallest worthwhile change + typical error, successive reiterations approach). Agreement between both variables changes was examined for the whole sample (225 comparisons), four different subgroups (depending on the moment of the season), and in an individual over 6 years (n = 23 tests).

Results:

Changes of 4.5% and 6.0% for $HR_{12km/h}$ and $v_{4mmol/l}$, respectively, were rated as optimal to indicate substantial changes in fitness. Depending on the (sub-)groups analyzed, these thresholds yield 0–2% full mismatches, 22–38% partial agreements, and 60–78% full agreements in terms of fitness change interpretation between both variables.

Conclusions:

When lactate sampling during incremental tests is not possible, practitioners willing to monitor adult professional soccer players' (Germany; 1st, 2nd, and 4th division) training status can confidently implement short, 3 min submaximal runs, with 4.5% changes in $HR_{12km/h}$ being indicative of true substantial fitness changes with 60–78% accuracy. Future studies should investigate the potential role of confounding factors of $HR_{12km/h}$ to improve changes in fitness prediction.

Keywords:

soccer; replication study; player monitoring; fitness; heart rate; lactate

INTRODUCTION

Multistage incremental tests with heart rate and blood lactate sampling are considered a gold standard method for monitoring cardiorespiratory fitness in elite athletes such as professional soccer players.[1,2] However, this method has several limitations including time-labour (i.e., 20–30 min per test which may conflict with the need to prioritize specific (pitch) training and the lack of time/optimal moments to do so, i.e., congested matches, travel), poor player buy-in, and the necessity of expensive equipment for data collection and analysis. Therefore, its use for regular testing during the competitive season is somewhat limited. Consequently, the use of more rapid, convenient, and easy-to-implement methods such as the monitoring of heart rate (HR) response to a submaximal running bout in the field has gained popularity in this setting.[3] Multiple studies have shown large correlations between the changes in exercise heart rate and maximal (aerobically-oriented) performance, confirming the validity and sensitivity of this simple practice.[3–8]

Despite this evidence however, it can be argued that HR is only an indirect reflect of the aerobic metabolism contribution to the energy turnover during exercise, and that a complete fitness evaluation should also examine the response of the anaerobic (lactic) energy system.[9–11] In a recent study however, Buchheit et al.[12] showed a very large relationship (r = 0.82) between the change in HR at a running velocity of 12 km/h ($HR_{12km/h}$) and the change of the running speed at the anaerobic threshold (i.e., blood lactate concentration of 4 mmol/l; $v_{4mmol/l}$), both determined during incremental treadmill tests. Moreover, substantial individual changes in $HR_{12km/h}$ were associated with similarly substantial changes in $v_{4mmol/l}$ in more than 90% of the 23 cases investigated. This led the authors to conclude that $HR_{12km/h}$ and $v_{4mmol/l}$ can be used interchangeably, while recommending $HR_{12km/h}$ for in-season testing because of its convenient and simple application.

The abovementioned study was however limited to 1) a restricted sample size (19 players belonging to a single professional soccer team, 1st French division) and 2) between-season testing (i.e., two pre-season testing occasions compared, where players are generally all in a deconditioned state); whether these results could be generalized to larger populations and different moments of the season remains to be confirmed. Also, there remains some uncertainty around the optimal magnitude of changes in either $HR_{12km/h}$ and $v_{4mmol/l}$ to consider in order to determine substantial fitness changes at the individual level.

Therefore, the purpose of the present study was to replicate the study of Buchheit et al.[12] based on 1) a broader sample of soccer players (n = 97 players, 225 test comparisons), which were 2) tested at different moments during the competitive season. Ahead of these examinations, we first aimed to (re)define optimal thresholds for both variables: we suggested a novel approach to determine substantial changes in $v_{4mmol/l}$ at the individual level, and investigated the effect of a wide range of magnitude changes in both $HR_{12km/h}$ and $v_{4mmol/l}$ on simultaneous decisions about individual fitness status. Based on existing literature and theoretical considerations, we expected to find large agreements between changes in $HR_{12km/h}$ and $v_{4mmol/l}$. Whether the moment of the season would affect this level of agreement was, however, difficult to predict.

METHODS

Design

Observational, cross-sectional.

Subjects

Data from 97 players of four professional German soccer teams competing in the 1st, 2nd, and 4th division (age, 23.7 ± 3.9 years; height, 182.0 ± 6.8 cm; mass, 79.1 ± 7.4 kg) were used for the purpose of this study. Data were collected during the routine fitness assessments of the teams so that ethical approval was not required.[13] All players provided informed consent prior to participating in the fitness assessments.

Methodology

All players were tested on at least two occasions (i.e., beginning of pre-season in summer, end of pre-season in summer, in-season in autumn, beginning of pre-season in winter, middle of pre-season in winter, in-season in spring) during one or two consecutive seasons.
The incremental treadmill test (Woodway GmbH, Weil am Rhein, Germany) started at 6 km/h and increased by 2 km/h every 3 min until volitional exhaustion of the players. Exhaustion was determined by a combination of near-to-maximal values for HR, lactate levels, and ratings of perceived exertion. Rest between stages was passive and lasted for 30 sec. Heart rate (HR, Polar Electro Oy, Kempele, Finland) was measured during and blood lactate (capillary blood samples from the earlobe, Biosen C-Line Sport, EKF-diagnostic GmbH, Barleben, Germany) collected after each stage.[14]

Data Analysis

In addition to the velocity at the point of volitional exhaustion (v_{max}), the heart rate at a running velocity of 12 km/h (% of maximum heart rate; $HR_{12km/h}$), and the running velocity at a lactate concentration of 4 mmol/l (as an indicator of the fixed anaerobic threshold; $v_{4mmol/l}$) were used for further analysis. In case a player was not able to fully complete the last stage, v_{max} was calculated based on the time the player was able to keep up the respective velocity (e.g., if a player stopped after 1.5 min during the 18-km/h stage v_{max} was specified as 17 km/h). $V_{4mmol/l}$ was automatically determined using the Ergonizer Software (K. Roecker, Freiburg, Germany); for a graphical illustration, see Buchheit et al.[12] Regarding $HR_{12km/h}$, the average HR during the last 30 s of the 12-km/h stage was used. Between-testing session percentage changes in v_{max}, $v_{4mmol/l}$ and $HR_{12km/h}$ were calculated. As some players were tested more than twice, the whole sample included a total of 225 test comparisons.

In addition, based on the timing of testing sessions, the following subgroups were created:

- Within-season overall (n = 190): included all successive testing occasions (i.e., beginning of summer pre-season, end of summer pre-season, in-season in autumn, beginning of winter pre-season, mid of winter pre-season, in-season in spring).
- Within-season summer pre-season (n = 55): included only the comparisons from the beginning to the end of the summer pre-season.
- Between-seasons overall (n = 35): included all testing occasions from a season to the following (i.e., beginning of summer pre-season of season #1 vs. beginning of summer pre-season of season #2, end of summer pre-season of season #1 vs. end of summer pre-

season of season #2, mid of winter pre-season season #1 vs. mid of winter pre-season season #2).

- Between-seasons summer pre-season (n = 18): included only the comparisons between the beginning of the summer pre-season of season #1 vs. summer pre-season of season #2 (as previously reported).[12]

While other comparisons would have been possible (e.g., *within-season from the end of summer pre-season to in-season in autumn* or *between-seasons from the beginning of the winter pre-season*), we limited our examination to the four main subgroups described above since these latter would have included either too small sample sizes or were deemed as less important from a practical point of view.

Lastly, the changes in $HR_{12km/h}$ and $v_{4mmol/l}$ of a single player over a 6-year period (case study; n = 22) were also examined.

As information on confounding factors of $HR_{12km/h}$ and $v_{4mmol/l}$ (e.g., time of day, hydration, nutritional status, intense exercise the day before, body mass, fat percentage) were not consistently collected prior to testing, they were not included in the analysis.

Statistical Analysis

The data were analyzed using SPSS statistical software version 26.0 (SPSS, Chicago, USA) and Microsoft Excel (Microsoft, Redmond, USA).

Determining optimal thresholds for substantial changes in $HR_{12km/h}$ and $v_{4mmol/l}$

There are many ways to assess substantial changes in physiological measures at the individual level.[15,16] The most relevant is based on the combined use of both the smallest worthwhile change (SWC) of the measure and its typical error (TE), with changes of SWC + TE generally been accepted as substantial (i.e., >75% likelihood, "meaningful" changes with practical implications in terms of performance). While the TE for both $HR_{12km/h}$ (1.5 to 3.0%)[3,8] and $v_{4mmol/l}$ (2.5%)[17] are known, and while the SWC for $HR_{12km/h}$ has also been established (1.0 to 2.0%),[6] there was no information today about what SWC should be used for $v_{4mmol/l}$. For that reason, Buchheit et al.[12] chose another, more "mechanistic" approach to determine a "substantial" change, such as 2 x TE.[18] They therefore used 3.5% and 5.5% as thresholds for $HR_{12km/h}$ and $v_{4mmol/l}$, respectively.

In the present study, we aimed to offer 2 alternative solutions: 1) calculate the SWC for $v_{4mmol/l}$ as inferred from changes in v_{max} (considering that both changes would be proportional in this population, which clearly differs from endurance athletes that may target specific developments of one variable versus the other at some stages of their preparation) and 2) validate or confirm the value of these thresholds using a successive reiterations technique.

1) Determining the SWC for $v_{4mmol/l}$: we first offer a new perspective to assess the SWC for $v_{4mmol/l}$, which is based on the same approach that was used for $HR_{12km/h}$,[3] i.e., the $v_{4mmol/l}$ change corresponding to the performance (v_{max}) SWC was linearly extrapolated from the $\Delta v_{max}/\Delta v_{4mmol/l}$ relationship, and considered as the SWC for $v_{4mmol/l}$. The SWC for v_{max} is suggested to be located between 0.5 and 1.0 km/h as such values are commonly used when creating player groups for high-intensity interval training (HIIT) drills[19]. This range of values (0.5–1.0 km/h) was converted to a percentage change of v_{max} and the corresponding SWC (%) values for $v_{4mmol/l}$ were calculated by means of the regression model. For this purpose, only tests in which exhaustion criteria were clearly fulfilled were considered (n = 89). Finally, the likely optimal thresholds for substantial changes in

$v_{4mmol/l}$ were determined by adding the regression-based SWC to the TE of 2.5%.[17] Similarly for $HR_{12km/h}$ thresholds, a SWC ranging from 1.0 to 2.0% and a TE ranging from 1.5 to 3.0% were used as recommended by Buchheit et al.[12] (Table 1).

2) Confirming the optimal threshold magnitudes for both variables: we then looked at a range of magnitudes of the change in both variables that would lead to the highest possible agreement between both variables using a successive reiterations approach. All changes in $HR_{12km/h}$ and $v_{4mmol/l}$ greater than the respective thresholds obtained were rated as "substantial" (i.e., impaired or improved), while changes smaller than the thresholds were rated as "unclear". Using 0.5% step increments, all possible combinations in the changes in $HR_{12km/h}$ and $v_{4mmol/l}$ were classified in terms of full mismatches (e.g., impaired fitness inferred from $HR_{12km/h}$ / improved fitness from $v_{4mmol/l}$), partial agreements (e.g., impaired fitness from $HR_{12km/h}$ / unclear change in fitness from $v_{4mmol/l}$), and full agreements (e.g., improved fitness from $HR_{12km/h}$ / improved fitness from $v_{4mmol/l}$). The selection of optimal thresholds for $HR_{12km/h}$ and $v_{4mmol/l}$ was based not only on the greatest possible agreement between both variables, but also in relation to the practical implications when it comes to using these thresholds, i.e., allowing to detect small-to-moderate changes in fitness in practice. Indeed, while large thresholds (>2–3 x SWC) would lead to a high agreement between variables, they would only allow the monitoring of moderate changes in fitness, which may limit the value of the monitoring process.

Examining the agreement between changes in $HR_{12km/h}$ and $v_{4mmol/l}$

Consequently, the agreement of changes in $HR_{12km/h}$ and $v_{4mmol/l}$ using the optimal thresholds being specified during the successive reiterations was analyzed in-depth not only for the whole sample but also for the four abovementioned subgroups and the case study on the individual player. For that purpose, Pearson product-moment correlations with 95% confidence intervals (95% CI) were used to examine the relationships between the change in $HR_{12km/h}$ and $v_{4mmol/l}$ within each group. Moreover, the concomitant changes in both variables were classified as follows:

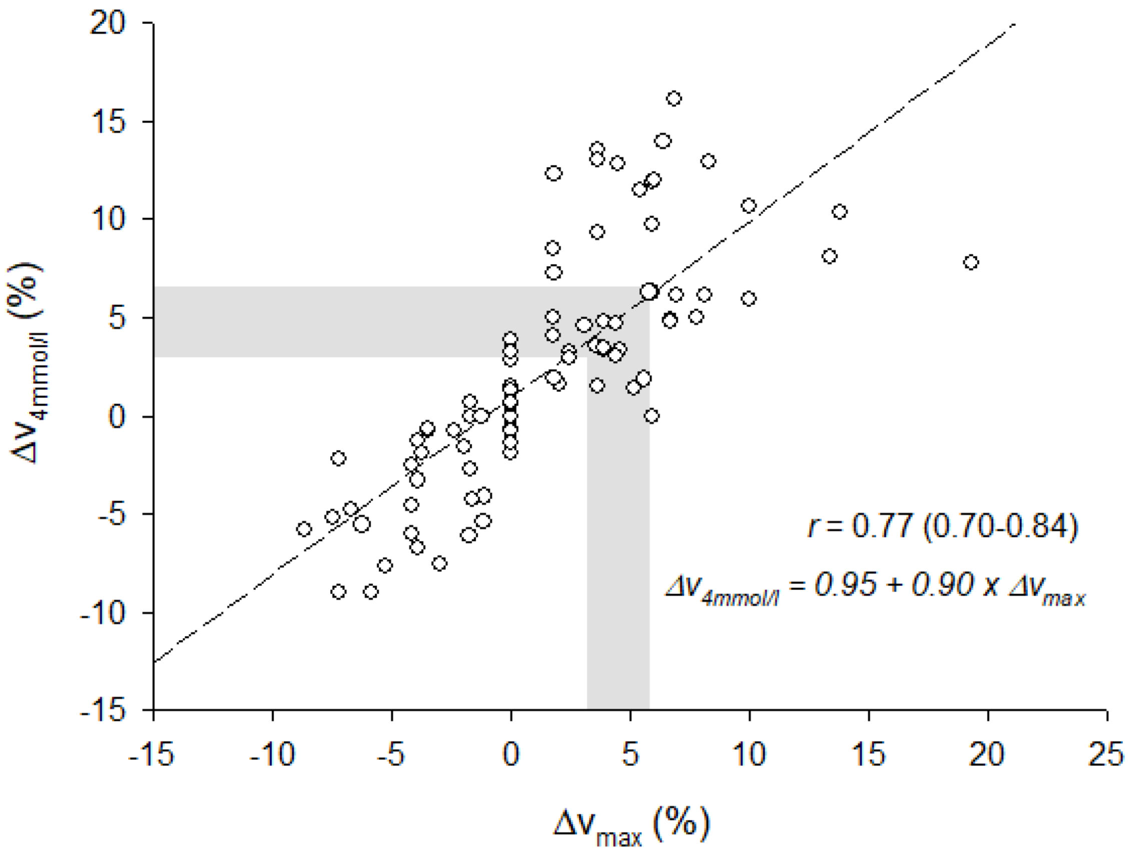
- Both variables indicating improved (↑) fitness
- Both variables showing unclear changes (↔) in fitness
- Both variables indicating impaired (↓) fitness
- Improved (↑) fitness from $HR_{12km/h}$ / unclear change (↔) in fitness from $v_{4mmol/l}$
- Unclear change (↔) in fitness from $HR_{12km/h}$ / improved (↑) fitness from $v_{4mmol/l}$
- Impaired (↓) fitness from $HR_{12km/h}$ / improved (↑) fitness from $v_{4mmol/l}$
- Improved (↑) fitness from $HR_{12km/h}$ / impaired (↓) fitness from $v_{4mmol/l}$
- Unclear change (↔) in fitness from $HR_{12km/h}$ / impaired (↓) fitness from $v_{4mmol/l}$
- Impaired (↓) fitness from $HR_{12km/h}$ / unclear change (↔) in fitness from $v_{4mmol/l}$

RESULTS

Determining substantial changes for $v_{4mmol/l}$

There was a very large correlation between changes of $v_{4mmol/l}$ and v_{max} (Figure 1).
Based on Figure 1 data, the range for the SWC of $v_{4mmol/l}$ was estimated to be between 3.5 (0.5-km/h change in v_{max}) and 6.0% (1.0-km/h change in v_{max}). Therefore, the range for substantial $v_{4mmol/l}$ changes (with TE added) was estimated to be between 6.0 and 8.5% (Table 1).

Figure 1. Regression between changes in $v_{4mmol/l}$ and v_{max} (n = 89). The grey zone indicates the smallest worthwhile change range for v_{max} (2.8–5.6%) and the corresponding smallest worthwhile change range for $v_{4mmol/l}$ (3.5–6.0%).



Confirming the optimal thresholds for substantial changes in $HR_{12km/h}$ and $v_{4mmol/l}$ together

The successive reiterations approach included the analysis of thirty-six possible threshold combinations ($HR_{12km/h}$: 2.5–5.0%; $v_{4mmol/l}$: 6.0–8.5%). Examples for this approach are illustrated in Figure 2. The threshold combination of $HR_{12km/h}$ = 4.5% and $v_{4mmol/l}$ = 6.0% was rated as optimal to indicate substantial changes (Table 1). These latter thresholds yield 0% full mismatches, 37% partial agreements, and 63% full agreements between changes in $HR_{12km/h}$ and $v_{4mmol/l}$.

Table 1. Smallest worthwhile change (SWC), Typical error (TE), Range for substantial change, "Mechanical" change, and Reiteration-based thresholds for changes in $HR_{12km/h}$ and $v_{4mmol/l}$.

Parameter	**SWC**	**TE**	**Range for sub-stantial change (SWC + TE)**	**"Mechanical" change (2 x TE)**	**Reiteration-based thresholds**
Change in $HR_{12km/h}$	1.0–2.0%[3]	1.5–3.0%[3,8]	2.5–5.0%	3.5%	4.5%
Change in $v_{4mmol/l}$	3.5–6.0%	2.5%[17]	6.0–8.5%	5.5%	6.0%

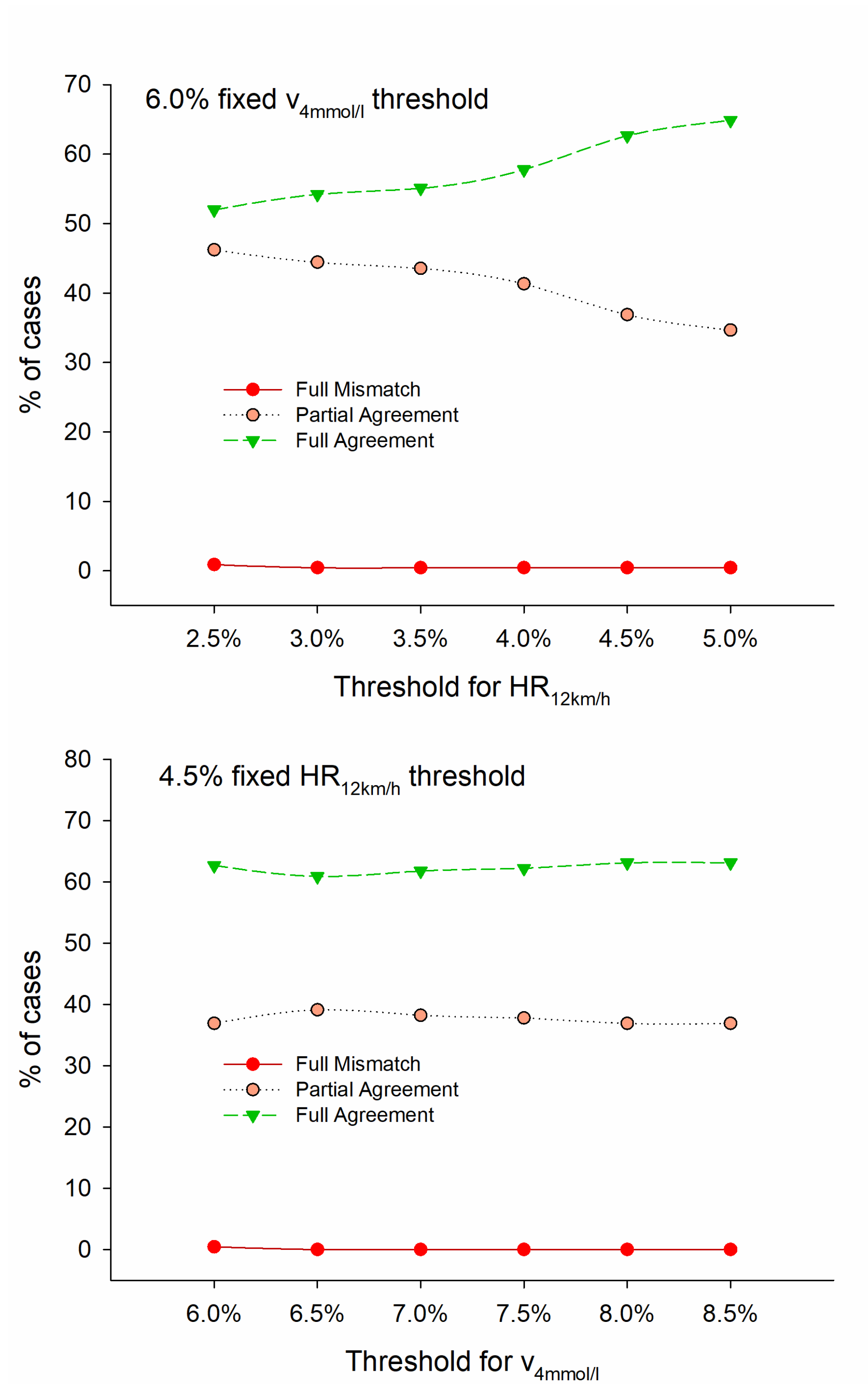


Figure 2. Results for the successive reiterations approach for a fixed $v_{4mmol/l}$ threshold of 6.0% and a range of $HR_{12km/h}$ thresholds between 2.5 and 5.0% (upper graph) as well as for a fixed $HR_{12km/h}$ threshold of 4.5% and a range of $v_{4mmol/l}$ thresholds between 6.0 and 8.5% (lower graph). The red line indicates full mismatches, the orange line indicates partial agreements, and the green line indicates full agreements.

Examining the agreement between changes in $HR_{12km/h}$ and $v_{4mmol/l}$

Pearson correlations and 95% CI between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ using the reiteration-based thresholds of $HR_{12km/h}$ = 4.5% and $v_{4mmol/l}$ = 6.0% for the whole sample, the subgroups, and the case study can be found in Table 2. All estimated combinations of changes in fitness from both variables as a function of the different groups analyzed are shown in Table 3. Absolute $HR_{12km/h}$ and $v_{4mmol/l}$ and values as well as percentage changes in $HR_{12km/h}$ and $v_{4mmol/l}$ for a single player over a 6-year period are illustrated in Figure 4.

Table 2. Pearson correlations and 95% Confidence interval (95% CI) between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ regarding the whole sample, the four subgroups, and the case study.

	Pearson's r (95% CI)
Whole sample (n = 225)	r = -0.54 (-0.45 to -0.62)
Within-season overall (n = 190)	r = -0.55 (-0.45 to -0.62)
Within-season subgroup (n = 55)	r = -0.41 (-0.19 to -0.58)
Between-seasons overall (n = 35)	r = -0.50 (-0.14 to -0.74)
Between-seasons subgroup (n = 18)	r = -0.35 (0.22 to -0.69)
Case study (n = 22)	r = -0.72 (-0.51 to -0.89)

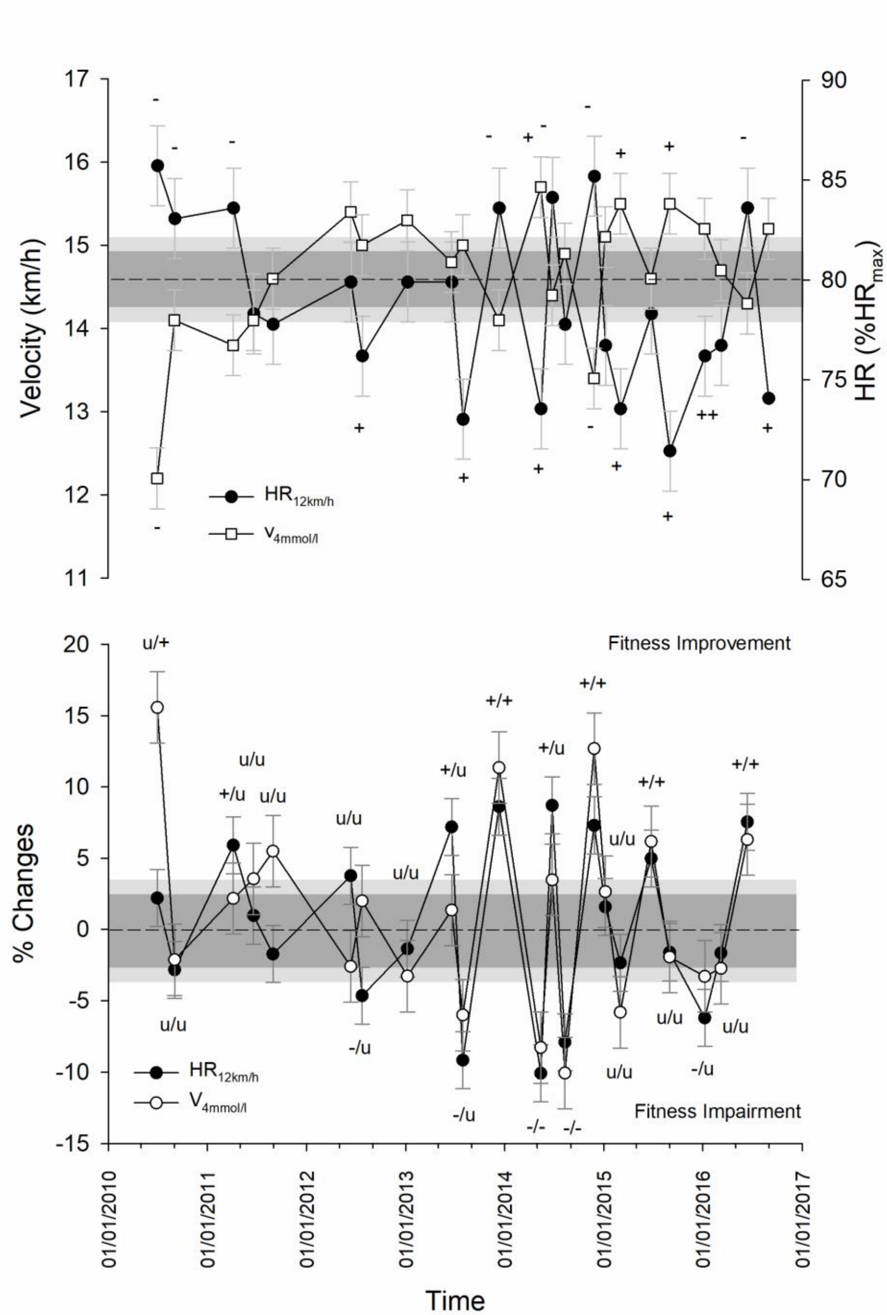


Figure 3. Absolute $HR_{12km/h}$ and $v_{4mmol/l}$ values (upper graph; n = 23) as well as percentage changes in $HR_{12km/h}$ and $v_{4mmol/l}$ (lower graph; n = 22) for a single player over a 6-year period. The smallest worthwhile changes (SWC) are shown with grey ($HR_{12km/h}$) and light grey ($v_{4mmol/l}$) areas. Error bars represent the typical errors (TE) of each variable. To be considered as substantial (i.e., positive, +, or negative, -, estimated change in fitness), changes had to be greater than the SWC + TE. Unclear changes in the lower graph are indicated with an "u". Except for a few specific dates, changes in both variables were consistent and suggested similar adaptations. Of note, changes were never suggestive of opposite changes in fitness.

Table 3. Response classifications between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ along with full mismatches, partial agreements, and full agreements regarding the whole sample, the four subgroups, and the case study.

Whole Sample (n = 225)

	↓ fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	8	23	0	Full mismatch	0%
↔ fitness from $HR_{12km/h}$	11	106	19	Partial agreement	37%
↑ fitness from $HR_{12km/h}$	1	30	27	Full agreement	63%

Within-Season Overall (n = 190)

	↓ fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	6	22	0	Full mismatch	1%
↔ fitness from $HR_{12km/h}$	9	84	16	Partial agreement	38%
↑ fitness from $HR_{12km/h}$	1	26	26	Full agreement	61%

Within-Season Summer Pre-Season Subgroup (n = 55)

	↓fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	0	1	0	Full mismatch	2%
↔ fitness from $HR_{12km/h}$	1	14	3	Partial agreement	38%
↑ fitness from $HR_{12km/h}$	1	16	19	Full agreement	60%

Between-Seasons Overall (n = 35)

	↓ fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	2	1	0	Full mismatch	0%
↔ fitness from $HR_{12km/h}$	2	22	3	Partial agreement	29%
↑ fitness from $HR_{12km/h}$	0	4	1	Full agreement	71%

Between-Seasons Summer Pre-Season Subgroup (n = 18)

	↓fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	1	1	0	Full mismatch	0%
↔ fitness from $HR_{12km/h}$	2	13	0	Partial agreement	22%
↑ fitness from $HR_{12km/h}$	0	1	0	Full agreement	78%

Case Study (n = 22)

	↓ fitness from $v_{4mmol/l}$	↔ fitness from $v_{4mmol/l}$	↑ fitness from $v_{4mmol/l}$		
↓ fitness from $HR_{12km/h}$	2	3	0	Full mismatch	0%
↔ fitness from $HR_{12km/h}$	0	9	1	Partial agreement	32%
↑ fitness from $HR_{12km/h}$	0	3	4	Full agreement	68%

DISCUSSION

The aim of the present study was to replicate the study of Buchheit et al.[12] when it comes to assessing the agreement between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ to estimate changes in fitness based on 1) a broader sample of soccer players, which were 2) tested at different moments during the competitive season. We also wished to (re)confirm the optimal threshold magnitude to assess substantial changes in fitness from those two variables.

The first main finding of this study is that thresholds of 4.5 and 6.0% are recommended when assessing substantial individual changes in fitness when using changes in $HR_{12km/h}$ and $v_{4mmol/l}$, respectively. Another important result is that, depending on the (sub-)group analyzed, these former thresholds yield 0–2% full mismatches, 22–38% partial agreements, and 60–78% full agreements between changes in $HR_{12km/h}$ and $v_{4mmol/l}$, thereby confirming the relevance of HR monitoring during short submaximal runs when lactate sampling during incremental tests is not possible.

Determining substantial changes for $HR_{12km/h}$ and $v_{4mmol/l}$

Derived from the $\Delta v_{max}/\Delta v_{4mmol/l}$ relationship, the SWC for $v_{4mmol/l}$ was deemed to be located between 3.5 and 6.0% (Figure 1). By adding its TE (2.5%),[17] the range for substantial changes was in turn determined to be between 6.0 and 8.5% (Table 1). The main advantage of this approach compared to the more “mechanistic” one (2 x TE) chosen by Buchheit et al.[12] is that it yields a >75% likelihood to obtain meaningful changes with practical implications in terms of performance.[18] Based on the SWC and TE values reported in the literature,[3,6,8] substantial changes for $HR_{12km/h}$ were (re)specified to be in the range of 2.5 to 5.0% (Table 1).

Confirming the optimal thresholds for substantial changes in $HR_{12km/h}$ and $v_{4mmol/l}$ together

Out of the ranges described above, the highest possible agreement between changes in both variables was determined using a successive reiterations approach with the threshold combination of $HR_{12km/h}$ = 4.5% and $v_{4mmol/l}$ = 6.0% rated as optimal to indicate substantial changes (Figure 2). These thresholds are slightly higher than those used by Buchheit et al.,[12] (3.5% and 5.5%, respectively), as already mentioned, due to different approaches used to determine substantial changes. Besides the level of agreement between both variables, the practical implications when it comes to using these thresholds were also considered to determine these optimal thresholds for $v_{4mmol/l}$ and $HR_{12km/h}$. In particular, while large thresholds (>2–3 x SWC) led to a high agreement between variables, they do not allow to detect small changes in fitness, thereby limiting the practical value of the monitoring process.

Examining the agreement between changes in $HR_{12km/h}$ and $v_{4mmol/l}$

In the next step, the agreement of changes in $HR_{12km/h}$ and $v_{4mmol/l}$ was examined in-depth for the whole sample, four subgroups (Table 3) as well as one case study (Figure 3). While the correlations between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ were somewhat lower (r = -0.35 to -0.72) than previously reported (r = 0.82)[12] we believe that this is not a real practical limitation since further than correlations between variables, coaches and practitioners are likely most interested in the ability of the two variables to determine substantial fitness changes at the individual level to make decisions about the training program (e.g., fitness top ups, validating a return to play phase). In this regard, the above-determined threshold combination of $HR_{12km/h}$ = 4.5% and $v_{4mmol/l}$ = 6.0% yield 0–2% full mismatches, 22–38% partial agreements, and 60–78% full agreements in terms of fitness change evaluation between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ (Table 3). Indeed, relationships or agreements, respectively, between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ seem plausible since HR is closely related to O_2 uptake during continuous exercise.[3] Therefore, when considering within-athlete changes, the lower the HR, the better the athlete's fitness. However, these relationships or agreements can never be expected to be perfect as HR is only an indirect indicator of the aerobic metabolism. Therefore, a comprehensive evaluation of the cardiorespiratory fitness should also examine the response of the anaerobic (lactic) energy system.[9–11]

The full agreements of 71–78% for between-seasons comparisons were lower than the >90% reported by Buchheit et al.[12] However, the latter study included only 19 between-seasons comparisons, while the present investigation included 35 between-seasons comparisons and a total sample of 225 comparisons and is therefore more representative for professional soccer players. Interestingly, the agreements differed in relation to the timing of testing sessions during the soccer seasons. More specifically, agreements were higher for between-seasons than with within-season comparisons (full agreement of 60–61%). The reason for the better agreement between seasons is likely twofold. First, between-seasons comparisons are possibly surrounded by rather similar conditions; e.g., in case of the between-seasons summer pre-season subgroup, players are usually tested on the first day after the off-season in summer with little or no exercise the days before. Conversely, regarding the within-season summer pre-season subgroup, where only comparisons from the beginning to the end of the summer pre-season were included, the external and internal load during the days before the test (which likely influences $HR_{12km/h}$ and $v_{4mmol/l}$ responses, e.g., acute fatigue, dehydration) might differ between test occasions and between players. Second, the proportion of unclear changes was higher for between-seasons (both $HR_{12km/h}$ and $v_{4mmol/l}$ = 77%) than for within-season comparisons ($HR_{12km/h}$ = 57%; $v_{4mmol/l}$ = 69%). Moreover, based on the whole sample, our proposed thresholds yield a higher proportion of full agreements for unclear changes in $HR_{12km/h}$ and $v_{4mmol/l}$ (56%) than for substantial changes (29%). This finding might further explain the higher agreements for between-seasons than for within-season comparisons.
It is also important to note that full mismatches were very uncommon (0–2%; 1 / 225 comparisons) for all subgroups. Therefore, based on our proposed thresholds, coaches and practitioners can be confident to at least not misinterpret changes in a player's fitness (i.e., interpreting a test result as reflective of an impaired fitness while it has actually improved, and vice versa).

Our analysis also included a case study when monitoring 23 times a single player over a 6-year period (Figure 3). The results (0% full mismatches, 32% partial agreements, and 68% full agreements) are comparable to those of the whole sample. While the changes in both variables from July 2013 to June 2016 (13 comparisons) follow a very similar pattern, the changes from June 2010 to June 2013 (9 comparisons) were less comparable (Figure 3). Influencing factors on $HR_{12km/h}$ and $v_{4mmol/l}$ such as time of day,[20] load over the previous days,[21] hydration[3] or nutritional status[22] were possibly less controlled at the start of the follow-up, but this can only remain a supposition since this was not documented. Nevertheless, the results of the case study (>2013) confirm the practical value of our proposed thresholds on an individual basis.

The main strength of this study is the large sample size (n = 97 players, 225 test comparisons), which allows for greater generalization of the findings compared to the study of Buchheit et al.[12]

Also, the agreement between changes in $HR_{12km/h}$ and $v_{4mmol/l}$ was investigated during different moments of the competitive season, which increases the practicality of our results, since in-season monitoring is also very frequent. Lastly, all tests took place in a controlled laboratory environment thereby minimizing potential sources of error.

In order to allow for a transfer of our findings to the soccer pitch, influencing factors such as environmental conditions (e.g., temperature),[23] training and competitive load across the previous days,[21] and surface (treadmill vs. grass) should be controlled for. For instance, a method for controlling for temperature has been recently proposed,[23] and allows a better estimation of real fitness changes in varying climates.

A limitation of the current investigation is that possible influencing factors of $HR_{12km/h}$ (e.g., time of day, hydration, intense exercise the day before, body mass, fat percentage)[3,21] and of $v_{4mmol/l}$ (e.g., nutritional status, intense exercise the day before)[24] were not taken into account. While the current approach has already a high practical value with respect to the monitoring of players' fitness changes (improved or impaired), further investigations of these influencing factors might help understanding of the cases in which changes in $HR_{12km/h}$ and $v_{4mmol/l}$ do not match. Moreover, the use of $HR_{12km/h}$ and $v_{4mmol/l}$ has limitations compared to individualized HR and blood lactate values (e.g., $v_{4mmol/l}$ is influenced by initial blood lactate concentrations which can differ between players). However, recent data from professional soccer players in Germany and Norway suggest that there exist only minimal differences in fitness between outfield playing positions [25,26] which might justify the use of absolute values despite their limitations. In addition, absolute values are frequently used in research and practice (e.g., Buchheit et al.[12]; Faude et al.[24]) and allow for comparisons regarding the study of Buchheit et al.[12] and were, therefore, applied in the current study.

PRACTICAL APPLICATIONS

Coaches who want to monitor substantial changes in fitness can confidently use the thresholds defined in the present study ($HR_{12km/h}$ = 4.5%; $v_{4mmol/l}$ = 6.0%). If only using changes in $HR_{12km/h}$ by means of a simple 3-min warm-up run, they can expect those measures to match changes in $v_{4mmol/l}$ in 60–78% of the time (knowing also that opposite interpretations are extremely unlikely to occur). On average, a 6.0%-change in $v_{4mmol/l}$ refers to a 1.0-km/h change in v_{max} for a given player, likely leading him to be assigned to a different player group for HIIT drills.[19] Based on a cost-benefit approach, coaches should then decide if the abovementioned level of agreement is high enough for their specific purpose. Besides professional soccer, this simple and cheap procedure might also be beneficial at an amateur level, where laboratory-based tests are less common due to financial reasons. In contrast, if coaches wish to prescribe training intensities based on lactate thresholds and are not only interested in the direction of possible changes in fitness but also in their magnitude, incremental tests with HR and blood lactate sampling together should be preferred.

CONCLUSIONS

When using submaximal exercise heart rate ($HR_{12km/h}$) response for fitness monitoring in professional soccer players (1st, 2nd, and 4th division in Germany), a threshold of 4.5% may be optimal to indicate substantial changes in fitness. Depending on the context, 4.5% changes in $HR_{12km/h}$ match changes in $v_{4mmol/l}$ in 60–78% of all cases, thereby confirming the practical value of this simple procedure. In particular, highest agreements between changes in $HR_{12km/h}$ and $v_{4mmol/l}$

can be achieved for between-seasons comparisons. Future studies should investigate possible influencing factors of $HR_{12km/h}$ and of $v_{4mmol/l}$ in order to better understand underpinning mechanisms of agreements and mismatches between changes in these two variables. In turn, such findings could ease the interpretation of changes in $HR_{12km/h}$ and $v_{4mmol/l}$, which may in turn improve decision-making when assessing fitness changes in soccer players.

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