Title: Monitoring cardiorespiratory fitness in professional soccer players: Is it worth the prick?

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Running Head: Monitoring fitness in elite soccer players

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1. Abstract.

Purpose. The aim of the present study was to compare in soccer players between-test changes in submaximal exercise heart rate (HRex, 3 min, 12 km/h) and the speed associated with 4 mmol/L of blood lactate (V4mmol) to get insight into their level of agreement and respective sensitivity to change in player's fitness.

Methods. Nineteen elite professional players (23 ± 3 yrs) performed 2-3 graded incremental treadmill tests (3-min stages interspersed with 1 min of passive recovery, starting speed 8km/h, increment 2 km/h until exhaustion or 18 km/h if exhaustion wasn't reached before) over 1.5 seasons. The correlation between the changes in HRex and V4mmol was examined. Individual changes in the two variables were compared (> 2 x typical error considered as 'clear').

Results. The change in HRex and V4mmol were very largely correlated (r = 0.82, 90% confidence interval 0.65-0.91). In >90% of the cases, when a clear individual change in HRex was observed, it was associated with a similarly clear change in V4mmol (the same direction, improvement or impairment of fitness), and conversely.

Conclusion. When it comes to testing players sub-maximally, our results suggest that practitioners can use HRex or V4mmol interchangeably with confidence. However, in comparison with field based standardised warm-up runs (3-4 min, all players together), the value of a multi-stage incremental test with repeated blood lactate samplings is questionable for a monitoring purpose given its time labour, cost and poorer player buy-in.

Keywords: player monitoring; fitness; heart rate; lactate; cost benefit.

2. Introduction.

Monitoring players' fitness is challenging in-season for many reasons, including the need to prioritize specific (pitch) training and the lack of time/optimal moments to do so (i.e., congested matches, travel). Additionally, there is also a general reluctance to test players maximally away from the pitch environment. To overcome these limitations, submaximal field testing, such as the simple examination of the heart rate (HR) responses to a 4-min standardized warm-up run (12 km/h) has been successfully implemented in various sports.[1-6] Multiple studies have shown large correlations between the changes in exercise HR (HRex) and maximal (aerobically oriented) performance, confirming the validity and sensitivity of this simple practice.[2,6]

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.[7-9] It can also be argued that a single submaximal 4-min run may not capture the entire intensity-related fitness profile of a player, and that multiple measures (i.e., at different speeds, typically ranging from 8 to 16/18 km/h) for threshold assessment may be required for an improved examination.[9] However, since a multi-stage incremental test with repeated blood lactate ($[La^-]_b$) samplings is time consuming (likely 1 player at a time, 30 min/player = >10h to test a full team) and expensive (25 euros/players = >500 euros per team), it is important to understand its benefit (if any) over the simple 4-min run that is now widely implemented on the pitch, with all players running collectively.[1-3,5]

The aim of the present study was to compare the changes in HR and $[La^-]_b$ responses during repeated incremental treadmill tests performed over 1.5 seasons to compare their respective sensitivity to change in fitness.

3. Methods.

Participants. The data were obtained from 19 professional players (23 ± 3 yrs, 182 ± 5 cm and 74 ± 4 kg) competing in the 1st French and European Champions Leagues. These players participated on average ~8 hours of soccer-specific training and competitive play per week (~2-3 sessions + 2 game per week), alongside almost daily core and lower-body prevention work (~30 min). These data arose as a condition of player monitoring in which player activities are routinely measured over the course of the competitive season;[10] therefore, ethics committee clearance was not required. The study conformed nevertheless to the recommendations of the Declaration of Helsinki.

Design. Observational, cross-sectional.

Methodology. Players were tested at 2 or 3 occasions over 1.5 seasons. They performed a graded incremental treadmill test (3-min stages interspersed with 1 min of passive recovery, starting speed 8km/h, increment 2 km/h until exhaustion or 18 km/h max if exhaustion wasn't reached before). HR was continuously monitored (Polar H10, Polar electro, Kempele, Finland) and $[La^-]_b$ was measured immediately after each stage (finger prick, Lactate pro 2, KDK Corporation, Kyoto, Japan). For each test-retest, the between-test changes in 1) HRex at 12 km/h (average HR over the last 30 s[2]) and the speed associated with a $[La^-]_b$ of 4 $mmol.L^{-1}$ were computed. We chose the V4mmol over other $[La^-]_b$ measures (e.g., typical lactate thresholds such as the speed at the initial $[La^-]_b$ increase above resting levels or the speed corresponding to the sharp rise in $[La^-]_b$[11]) for the following reasons: 1) V4mmol is more objective and likely less observer-dependent[11] and 2) shows a better reliability (i.e., Typical Error, TE of 2.4[12] vs 3.7-5.4% for the other types of thresholds[12,13]) (Figure 1).

Statistical Analysis. Percentage changes in both HRex and V4mmol were calculated between the consecutive testing sessions (i.e., 2nd vs. 1st test for all players, and 3rd vs 2nd test for 4 of the players who were tested 3 times). The correlation between changes in HRex and V4mmol was first examined. Then, "substantial" changes in each variable were also examined at the individual level. There are many ways to assess substantial changes in physiological measures at the individual level.[14,15] The most relevant is based on the combined use of both the TE of the measure and its smallest important effect (SWC), with changes of TE + SWC generally been accepted as substantial (i.e., 'meaningful' changes with practical implications in terms of performance). While the TE for both HRex (1.2 to 3%[1,2]) and V4mmol (2.4%[12]) are known, and while the SWC for HRex has also been established,[2] there is no information today about what SWC should be used for V4mmol. For that reason, we chose another, more 'mechanistic' approach to determine a 'clear' change, such as 2 x TE.[16] We therefore used 3.5% and 5.5% as thresholds for HRex and V4mmol, respectively.

4. Results.

Of the 19 players, 4 players repeated the incremental test three times over the period, so that 23 tests/retests have been analyzed. Figure 1 shows the typical HR and $[La^{-}]_b$ patterns during two incremental tests performed at the start of two consecutive seasons in two representative players. Figure 2 shows the large correlation (r = 0.82, 90% confidence interval 0.65-0.91) between the 2 monitoring variables. Table 1 shows the % change in both HRex at 12 km/h and the speed at V4mmol for all test comparisons. Except for 2 cases when there was a clearly improved V4mmol despite an unclear change in HRex, >90% of the comparisons showed that when a clear change in HRex was observed, it was associated with a similarly clear change in V4mmol (and of the same direction, improvement or impairment of fitness), and conversely.

5. Discussion

We compared for the first time the changes in HRex at 12 km/h and the speed at V4mmol in professional players when (re)tested over 1.5 year. The results (Table 1) are straightforward and show that in >90% of the cases analyzed, when a clear change in HRex was observed, whether positive or negative, the exact same information was provided by changes in V4mmol and vice versa. The changes in the two monitoring variables were also very largely correlated (Figure 2), reflecting a logical physiological association. In fact, the fitter the player, the lower the relative cost of a given exercise, and in turn, i) the lower the HRex at a fixed running speed and ii) the faster the running speed for a given blood lactate level (V4mmol). This correlation is the first aspect of our results suggesting that practitioners can use those variables interchangeably with confidence. It remains difficult however to explain why the changes in the two monitoring variables didn't match for two of the players (Table 1), but there are numerous factors that can affect HR responses independently of fitness and lactate production (e.g., stress).[2] Interestingly, these two players were both coming back from an long injury and didn't train the day before, which can together acutely decrease plasma volume and in turn, increase HR and explain the lack of a decreased HR in relation to the increased V4mmol.[2]

While the fact that the correlation (Figure 2) wasn't perfect may suggest that both variables may still show different and complementary information, we believe that the decision process based on Table 1 is more representative of the real practices in clubs, i.e., these types of tests are more used to inform staff on whether players' fitness has improved/stagnated/deteriorated to make actions (e.g., fitness top ups, validating a return to play phase) rather than to closely look at the actual magnitude of changes. Note also that when comparing magnitudes between HRex and $[La^-]_b$ responses, the % normalization may be misleading given the large difference in the denominator values (>80% for HRex vs. 12-14 km/h for V4mmol).[17]

6. Practical applications. Unless V4mmol speed (or any other lactate threshold value[12,13]) is used for training prescription, which is not always the case in soccer/football and even less in-season, the use of multi-stage incremental tests with repeated blood lactate sampling is questionable in comparison to a simple pitch-based 4-min submaximal warm-up run[1,2] – especially with regard to its time labour (>10 hours vs 4 min to get the full squad tested), cost (>500 euros vs. 0) and players' buy-in. Also, when it comes to adjusting player's training program, frequent and repeated (e.g., weekly, bi-monthly) monitoring surely outperforms more complete but less frequent assessments.[2] It is however noting that pushing players to their max during such incremental treadmill tests may at least allow the determination of maximal aerobic speed, which can be used for training prescription.[18] But this is not without limitations either, due to different running surfaces (treadmill vs grass) and context (shoes, motivation etc) that may limit the transfer of the results from the lab to the pitch.

7. Conclusions.

Changes in HRex at 12 km/h and the speed at V4mmol during an incremental test are very largely correlated. When using only 'clear' changes in those two variables to make decisions on player's potential change in fitness, the decision would be similar for both variables >90% of time. The value of a non-maximal multi-stage incremental tests with repeated blood lactate sampling is questionable for a monitoring purpose given its time labour, cost and poorer player buy-in. The only interest of such a test may therefore be related to the possible training prescription aspect (e.g., using V4mmol or lactate thresholds), which has also to be balanced in relation to actual training practices and the number of times such training sessions may be implemented over a full season (cost/benefit approach).

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9. References

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Player	HR Test 1 (%)	HR Test 2 (%)	HR % change	V4mmol Test 1 (km/h)	V4mmol Test 2 (km/h)	V4mmol % change
1	79	83	**4**	12.7	11.2	**-12**
2	84	88	**4**	14.0	12.2	**-13**
3	88	83	**-5**	14.2	16.0	**13**
4	87	85	-2	12.2	13.1	**7**
4 (2)	85	80	**-5**	13.1	15.3	**17**
5	80	78	-2	13.8	14.1	2
6	86	83	-3	13.0	13.0	0
6 (2)	83	81	-2	13.0	13.3	2
7	88	87	-1	11.0	11.6	5
8	83	84	1	14.2	13.8	-3
8 (2)	84	81	-3	13.8	14.1	2
9	85	91	**6**	12.0	10.9	**-9**
10	84	81	-3	13.0	13.3	2
11	85	86	1	14.0	13.6	-3
12	84	87	3	13.0	13.3	2
13	79	79	0	14.6	14.9	2
14	80	80	0	12.4	13.0	5
14 (2)	80	77	-3	13.0	14.2	**9**
15	83	83	0	14.3	14.4	1
16	90	88	-2	13.8	13.5	-2
17	93	87	**-6**	12.3	13.3	**8**
18	86	85	-1	12.0	12.2	2
19	87	87	0	12.5	12.8	2

Table 1. Values for exercise HR (HRex) and the speed at 4 mmol.L^{-1} of blood lactate (V4mmol), and percentage changes between two consecutive tests in the 19 players tested (4 players tested 3 times, so n = 23). Numbers is **red** show clear impairment in fitness, while numbers in **green**, clear improvements. A decrease in HRex (-) and an increase in V4mmol (+) are representative of increased fitness. Note that all decisions about potential fitness changes are similar irrespective of the variable except for two cases.

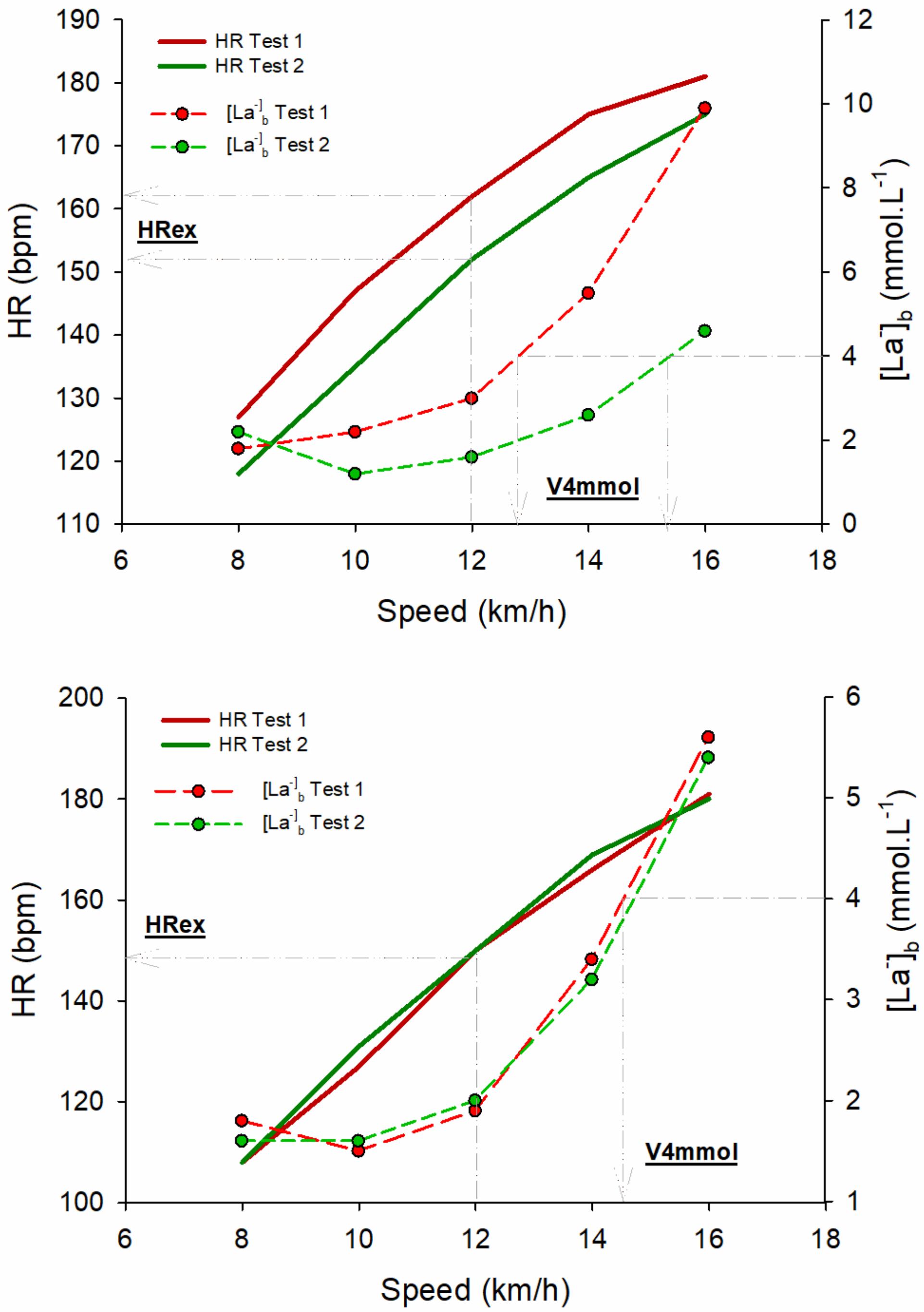

Figure 1. Typical HR and $[La^-]_b$ patterns during two incremental tests performed at the start of two consecutive seasons in two representative players. Upper panel: clear decrease in HRex of 5% and clear increase in V4mmol of 17%. Lower panel: no change in HRex and unclear increase in V4mmol of 2%. The method to derive the HR reached at 12 km/h and the speed at 4 $mmol.L^{-1}$ is also shown.

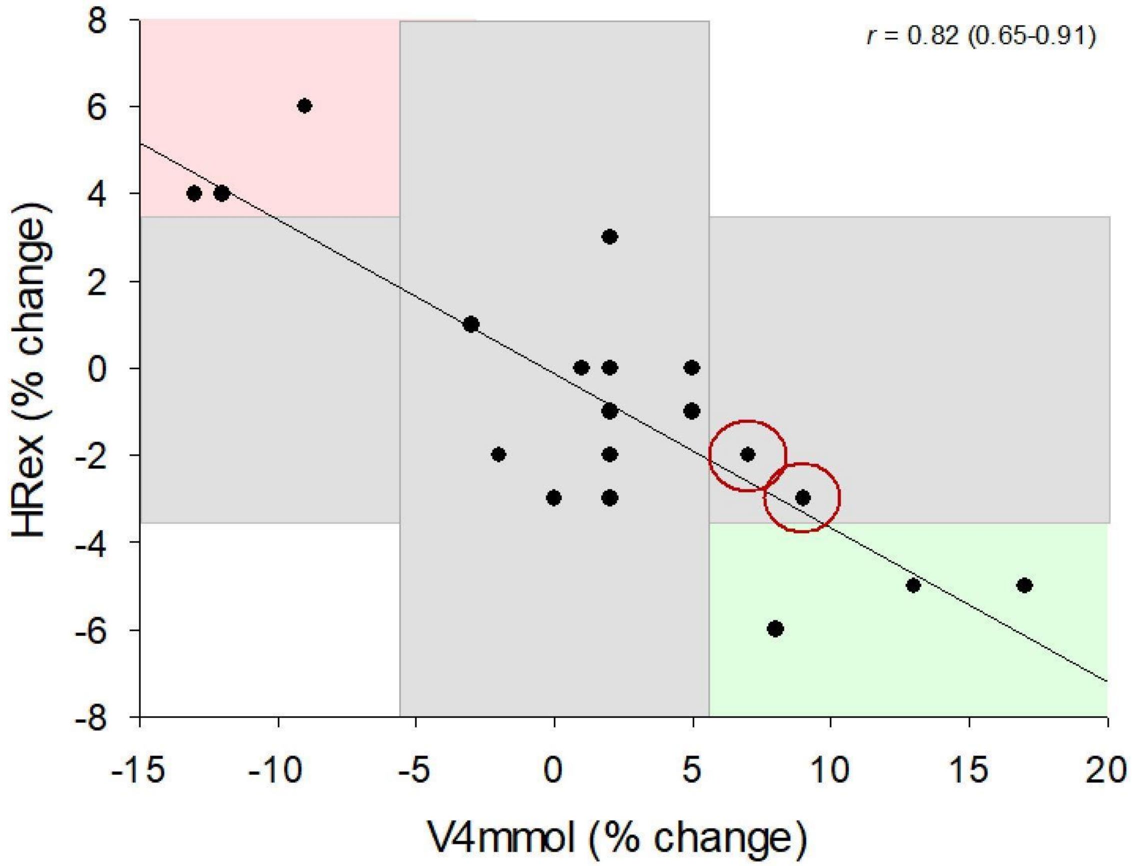

Figure 2. Percentage change in HRex at 12 km/h and the speed at V4mmol for the 22 test comparisons. Grey areas represent unclear changes (2 x TE). The red zone represents an impaired fitness, the area in green represents an improved fitness based on both variables. Note that 2 points (<10% of the observations, red circles, player 4 and 14) was suggestive of a clearly improved V4mmol despite unclear change in HRex.