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Football Players' Physiological Responses and Rated Perceived Exertion during Running at Constant versus Varying Speeds

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Abstract

The aim of the study was to compare the oxygen uptake ($\dot{V}O_2$), heart rate (HR), rated perceived exertion (RPE), and blood-lactate concentration (BLa) in a conventional anaerobic-threshold test at constant speed intervals with running at the same mean speeds, but with speed variations similar to a football match. Nine male football players completed two test days with two treadmill running tests: a submaximal test followed by a maximal test. The submaximal tests (tests A and B) comprised five stages of five minutes each, with between 8–16 km·h^{-1} mean speeds. The speed was constant for test A, whereas in test B, the speed during the stages varied every 15 seconds. Mean values of $\dot{V}O_2$, HR, BLa, and RPE for the legs (RPElegs) and ventilation (RPEvent) were determined for each stage. No significant differences between tests A and B were found for $\dot{V}O_2$, HR, and RPElegs. The BLa was significantly higher for test B at mean speeds of 10, 14, and 16 km·h^{-1}. RPEvent did not differ between tests for any work intensity, except for a higher rating for test A at 8 km·h^{-1}. The equal HR and $\dot{V}O_2$ responses for the anaerobic-threshold tests with constant and varying speeds suggests that male football players' aerobic energy expenditure during match could be estimated based on HR recordings. The significant difference in BLa between constant and varying speeds indicates the need to use anaerobic-threshold tests with varying speeds in football.

Keywords: Soccer, oxygen uptake, heart rate, blood-lactate concentration, anaerobic threshold, rated perceived exertion.

Introduction

During a 90-minute football match, the typical distance range covered by outfield players in the highest divisions in England, Spain, Germany, and Italy (i.e., the English Premier League, La Liga, Bundesliga, and Serie A) is approximately 10–12 km (Andrzejewski et al., 2016; Bradley & Noakes, 2013; Castellano et al., 2011; Rampinini et al., 2007). Time-motion analyses reveal that football is played with large variation in intensity from standing (0–0.6 km·h^{-1}), walking (0.7–7.1 km·h^{-1}), jogging (7.2–14.3 km·h^{-1}), running (14.4–19.7 km·h^{-1}) to high-speed running (19.8–25.2 km·h^{-1}) and sprinting (> 25.2 km·h^{-1}), where the majority of the time during a match is spent walking (~ 55–62 %) or jogging (~ 25–30 %) (Rampinini et al., 2007). From a physiological perspective, the periods of relatively low work intensity are required to recover from high-intensity activities to balance the load and the most commonly observed recovery duration between consecutive high-intensity activities was more than 60 seconds (Carling et al., 2012).

The distance covered by elite male players at speeds equalling or exceeding 19.8 km·h^{-1} was found to be approximately 1,000 m (Barnes et al., 2014; Rampinini et al., 2007). Furthermore, the reported mean sprint running distance during a match ranged from 230 to 350 m (Barnes et al., 2014; Bradley & Noakes, 2013; Castellano et al., 2011), and most sprints were shorter than 10 m (Di Salvo et al., 2010). However, match analyses reveal a trend towards an increase in both high-intensity and sprint running distance across a 13-season period (from 2006/2007 to 2018/2019) in the English Premier League, whereas there was only a meagre increase in total distance covered (Allen et al., 2023; Barnes et al., 2014). In line with this trend, a recent study reported that mean sprint distance for each sprint in La Liga was 30 to 55 m depending on the tactical purpose (Oliva-Lozano et al., 2023). It has been shown that the English Premier League players make approximately 700 turns to change movement direction during a football match (Bloomfield et al., 2007), and the total number of accelerations and decelerations elite male football players perform during a match is approximately 328 and 306, respectively (Russell et al., 2016).

Thus, football can be characterised as a sport with a high degree of movement and speed variation. The high-speed and sprint intervals in a typical football match are often performed with an intensity; where the energy demand exceeds that can be delivered aerobically, causing an oxygen deficit. It is likely that during a football match, the oxygen deficit in short runs with very high intensity needs to be 'repaid' during periods with low intensity. This indicates that anaerobic metabolism can be occasionally high, but the mean oxygen uptake ($\dot{V}O_2$) will still be approximately 75 % of maximal oxygen uptake ($\dot{V}O_2$ max) undulating between 'resting values' and values up to $\dot{V}O_2$ max (Stølen et al., 2005). Hence, given the intermittent nature of the sport, rapid recovery from the repeatedly performed high-speed and sprint running bouts is required, which in turn leads to a high reliance on the aerobic energy metabolism. It has been suggested that a $\dot{V}O_2$ max of 60–62 ml·kg^{-1}·min^{-1} fulfils the demands for aerobic power in men's professional football (Tønnessen et al., 2013). However, owing to the relatively large speed variations, mean work intensity during a match corresponds to approximately 75 % of $\dot{V}O_2$ max or 85 % of the maximal heart rate (HRmax) (Stølen et al., 2005).

For the coach of a football team, it is important to evaluate the players' physiological status. The test of the anaerobic threshold has been used for decades as a test of aerobic endurance (i.e. the ability to utilise as much of the $\dot{V}O_2$ max as possible without excessive production of lactate) (Heck et al., 1985), and it has also been used to test football players (Casajus, 2001; Edwards et al., 2003; Schwesig et al., 2019; Sliwowski et al., 2013). Previously, it was shown that elite male Swedish football players had an anaerobic threshold (i.e. a blood-lactate concentration (BLa) of 4 $mmol \cdot L^{-1}$) corresponding to approximately 84 % of $\dot{V}O_2$ max (Nilsson & Cardinale, 2015), which makes the anaerobic-threshold test relevant for the evaluation of football players performance capacity. Recent studies have reported that the change in running speed corresponding to a BLa of 4 $mmol \cdot L^{-1}$ was related to changes in HR at a running speed of 12 $km \cdot h^{-1}$ among professional male football players (Altmann et al., 2021; Buchheit et al., 2020) and elite male youth football players (Altmann et al., 2023).

Anaerobic-threshold tests are often performed on a treadmill with intervals of four-to-five minutes at given constant submaximal running speeds below and above the anaerobic threshold. However, the highly intermittent character of the physical-load pattern and speed variation in football raises the question whether the role of anaerobic threshold testing at constant speeds is relevant as a test of players' performance capacity in a typical football match with a high degree of intensity variation. Hence, the constant speed during submaximal work intervals used to test the anaerobic threshold do not resemble the load pattern during a football match.

The analysis of the players' physiological load during training and matches is also crucial for the coach. The mean $\dot{V}O_2$ reflects the energy metabolism; however, but to measure $\dot{V}O_2$ directly on the pitch during match-like conditions is problematic because it necessitates carrying equipment that is cumbersome and sensitive to force impacts. Utilising heart-rate (HR) recordings and relying on the approximative linear relationship between heart rate and oxygen uptake with speed could be one solution to the problem. Previous studies have shown that HR recordings are representative of $\dot{V}O_2$ for both intermittent football exercises and treadmill running at constant speeds (Esposito et al., 2004; Hoff et al., 2002); however, a case study questions the use of HR recordings presuming work intensity in an intermittent exercise activity, such as football (Ogushi et al., 1993).

In the context of the problems regarding constant versus varying speeds presented above, the aim of the current study was to compare the $\dot{V}O_2$, HR and rated perceived exertion (RPE) as well as the BLa in a conventional anaerobic-threshold test at constant speed intervals with running at the same mean speeds but with speed variations similar to a football match. This may facilitate better understanding of different variables sensitive to speed variation, and thereby, aerobic and anaerobic metabolic responses during a football-like load and speed pattern.

Materials and methods

Nine male football players (age: 22 ± 4 years (mean ± SD); stature: 1.83 ± 0.05 m; body mass: 78.8 ± 4.8 kg), seven from the three highest Swedish divisions and two from lower divisions, volunteered to participate in the study. All subjects gave their written informed consent to participate in the study. The test procedures were performed in accordance with the World Medical Association's Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects 2008. The study was approved by the Regional Ethical Review Board, Stockholm, Sweden (Dnr 2010/1947-31/1).

To investigate the differences in physiological responses and the RPE between running at constant speed and running with speed variations, the participants completed two test days with two treadmill running tests: a submaximal test followed by a maximal test. The participants were instructed to remain in their normal training regimen during the test period with no additional training on test days. Furthermore, they were instructed to remain well-hydrated, refrain from alcohol consumption (24 h) and smoking (3 h), as well as avoid eating within two hours prior to testing. On the day of the tests, the participants completed a health-status questionnaire, and thereafter, each participant's stature and body mass were measured using medical precision scales.

After a standardised warm-up (10 min at 8 km·h^{-1} and 0° inclination) the participants completed two running tests, a submaximal test followed by a $\dot{V}O_2$ max test, on a motor-driven treadmill (Rodby RL 2000E, Rodby Innovation AB, Vänge, Sweden). The submaximal tests (tests A and B) consisted of five stages of five minutes each with mean treadmill speeds of 8, 10, 12, 14, and 16 km·h^{-1} at a treadmill belt inclination of 0°. In test A, the treadmill speed was constant for each stage, whereas in test B, the treadmill speed during the stages was manually changed every 15 seconds to mimic the speed-variation pattern specific to a given period during a football match (Figure 1).

Throughout the tests, the HR (beats·min^{-1}) was monitored using a heart-rate sensor (PE 3000, Polar Electro Oy, Kempele, Finland) and expired air was continuously analysed using a metabolic cart in mixing-chamber mode (Jaeger Oxycon Pro, Erich Jaeger Gmbh, Hoechberg, Germany). The last two minutes of each five-minute stage was used to determine the mean values of $\dot{V}O_2$ (ml·kg^{-1}·min^{-1}) and HR. During the one-minute rest period after each stage, the participants rated their perceived exertion for the legs (RPElegs) and ventilation (RPEvent) by means of a RPE-scale (Borg et al., 1985). A capillary blood sample was collected from a fingertip and the sample was analysed to determine the BLa (mmol·L^{-1}) (Biosen C-line, EKF-diagnostic GmbH, Barleben, Germany). Additionally, the differences in the blood-lactate concentration (ΔBLa) (mmol·L^{-1}) between two subsequent stages was determined.

Two minutes after the last submaximal stage, the incremental treadmill running test to determine the participants' $\dot{V}O_2$ max and HRmax was initiated. During the initial 60 seconds of the $\dot{V}O_2$ max test, the treadmill speed was 14 km·h^{-1} and the treadmill inclination was 0°. Thereafter, the speed was increased by 1 km·h^{-1} at minutes two and three (15 and 16 km·h^{-1}), from 16 to 20 km·h^{-1} the speed was increased 1 km·h^{-1} every 30 seconds. From 20 km·h^{-1} the treadmill belt inclination was increased by 0.5° every 30 seconds until volitional fatigue, and thereby, termination of the test. The $\dot{V}O_2$ max was defined as the highest mean oxygen uptake during a 60-second period, for either of the two performed $\dot{V}O_2$ max tests, when meeting the criterion of a plateau in oxygen uptake despite an increase in mean exercise intensity. For each stage during the submaximal tests, the percentual HR and $\dot{V}O_2$ were calculated by dividing the mean values with HRmax and $\dot{V}O_2$ max, respectively.

Test results are presented as the means and standard deviations (SDs). The homogeneity of the variances of the test variables was tested using Levene's test. The normality of the distributions of test variables was assessed using the Shapiro–Wilk test. For pairwise comparisons between test A and B in the HR, $\dot{V}O_2$, BLa, and ΔBLa, Student's paired samples *t*-test was applied.

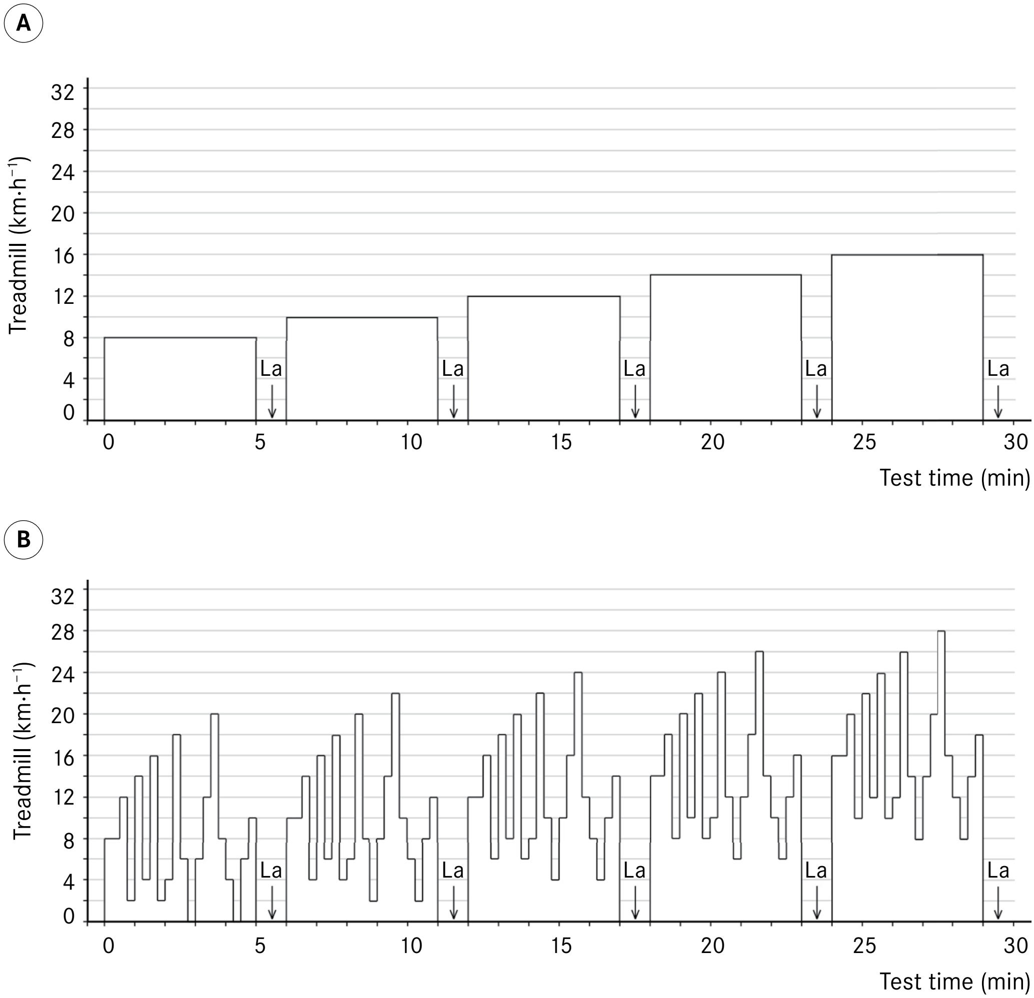

Figure 1. **Constant speed intervals on a treadmill (Test A); Variable speed intervals mimicking football-specific movement patterns (Test B)**

To analyse if the physiological response related to the relationship between percentual HR and $\dot{V}O_2$ differed between test A and B, the slopes of the regression lines were compared using Student's paired samples *t*-test. Hedges' *g*, with a correction for small sample size, was used to interpret the magnitude of the effect size (*ES*) and enable more informative inferences based on the results. Interpretations of the size of the effect were as follows: $0.2 \leq ES < 0.5$ signified a small effect, $0.5 \leq ES < 0.8$ indicated a moderate effect, and $ES \geq 0.8$ denoted a large effect (Cohen, 1988). To determine potential between-test differences in the RPE, the paired samples Wilcoxon signed-rank test was used. All statistical analyses were assumed to be significant at an alpha level of 0.05. The statistical analyses were conducted using the IBM SPSS Statistics software, Version 28 (IBM Corporation, Armonk, USA).

Results

Test results are presented in Table 1. There were no significant differences in $\dot{V}O_2$ between test A and B for any of the five mean treadmill speeds ($t = -1.94$ to -0.41; $P = 0.088$ to 0.69; $ES = -0.31$ to -0.074) (Figure 2). No between-test differences related to HR were observed for any of the work intensities ($t = 1.61$ to 0.39; $P = 0.28$ to 0.71; $ES = 0.28$ to 0.11) (Figure 3).

Table 1

Results from the two submaximal treadmill running tests

Speed	Test	$\dot{V}O_2$	HR	BLa	ΔBLa	RPElegs	RPEvent
8 km·h^{-1}	A	26.6 ± 4.7	134 ± 11	1.7 ± 1.0	N/A	8 (7:9)	8 (7:9)
	B	28.0 ± 4.0	130 ± 13	1.6 ± 0.3	N/A	7 (6:8)	7 (6:8)
10 km·h^{-1}	A	32.6 ± 4.6	147 ± 13	1.5 ± 0.5	−0.2 ± 0.7	10 (9:10.5)	10 (9:11)
	B	33.8 ± 4.4	145 ± 14	2.2 ± 0.7	0.6 ± 0.6	9 (7.5:11)	9 (7.5:10)
12 km·h^{-1}	A	38.0 ± 4.4	161 ± 12	2.5 ± 1.2	1.1 ± 0.9	13 (10:14)	13 (11:14)
	B	39.3 ± 4.2	157 ± 15	3.1 ± 0.9	0.9 ± 0.8	13 (9:13.5)	12 (10:13.5)
14 km·h^{-1}	A	44.3 ± 4.8	172 ± 13	3.8 ± 1.9	1.2 ± 1.3	15 (13.5:16)	15 (13.5:15)
	B	45.9 ± 5.8	170 ± 13	5.8 ± 2.6	2.7 ± 1.9	14 (11.5:16.5)	14 (12.5:16.5)
16 km·h^{-1}	A	49.6 ± 4.9	183 ± 10	6.7 ± 3.2	2.9 ± 1.8	17 (15:17.5)	17 (17:17.5)
	B	50.0 ± 5.7	181 ± 10	9.5 ± 3.5	3.7 ± 2.0	17 (15.5:19)	17 (15.5:19)

Test results are presented as mean ± standard deviation or as median (quartile 1 : quartile 3) for results related to rated perceived exertion.

Speed – mean treadmill speed;
Test A – five 5-min stages with constant treadmill speed (8–16 km·h^{-1});
Test B – five 5-min stages with varying treadmill speed that was changed every 15 s, but had the same mean speeds as in test A;
$\dot{V}O_2$ – oxygen uptake (ml·kg^{-1}·min^{-1});
HR – heart rate (beats·min^{-1});
BLa – blood-lactate concentration after the test (mmol·L^{-1});
ΔBLa – difference in blood-lactate concentration between the actual and the previous work intensity (mmol·L^{-1});
RPElegs – rated perceived exertion in the legs after the test;
RPEvent – rated perceived exertion for the ventilation after the test.

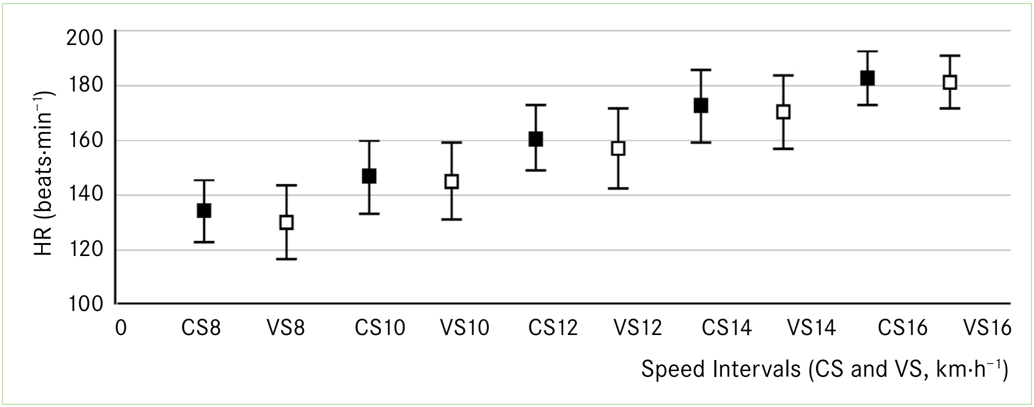

Figure 2. **Oxygen uptake ($\dot{V}O_2$) at different running speeds (8–16 km·h^{-1}) for Tests A and B**

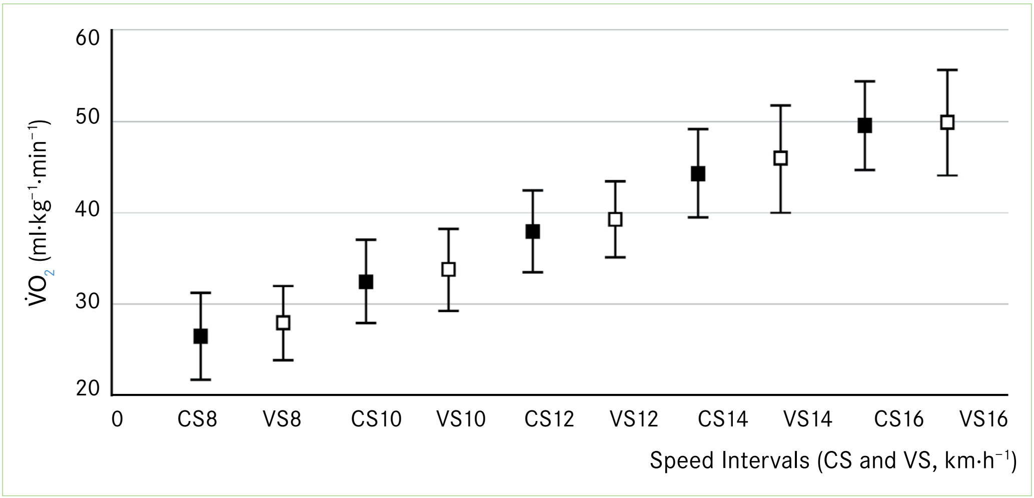

Figure 3. **Heart rate (HR) at different running speeds (8–16 km·h^{-1}) for Tests A and B**

Significant differences between test A and B were found for the BLa at treadmill speeds 10 km·h^{-1} (t = −3.22; P = 0.012; ES = −1.18), 14 km·h^{-1} (t = −3.49; P = 0.0081; ES = −0.88), and 16 km·h^{-1} (t = −5.24; P < 0.001; ES = −0.78), where test B was associated with a higher concentration. No significant between-test differences in the BLa were observed for either 8 km·h^{-1} (t = 0.13; P = 0.90; ES = 0.063) or 12 km·h^{-1} (t = −1.59; P = 0.15; ES = −0.50) (Figure 4).

For the variable ΔBLa, significant differences between tests A and B were found for the increase in work intensity between 8 and 10 km·h^{-1} (t = −2.33; P = 0.048; ES = −1.15) as well as between 12 and 14 km·h^{-1} (t = −2.99; P = 0.017; ES = −0.90) (Figure 5), where the increase in concentration was higher for test B. No significant between-test differences in the ΔBLa were found for the work-intensity increases between 10 and 12 km·h^{-1} (t = 0.40; P = 0.70; ES = 0.17) and 14 and 16 km·h^{-1} (t = −1.31; P = 0.23; ES = −0.35).

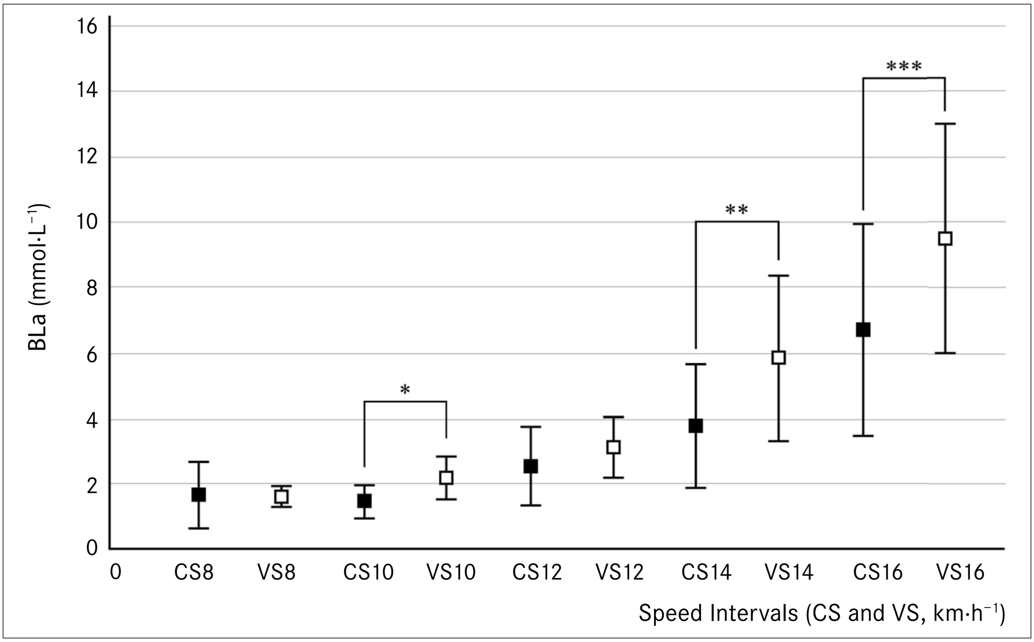

Figure 4. **Blood-lactate concentration (BLa) comparison at different running speeds for Tests A and B**

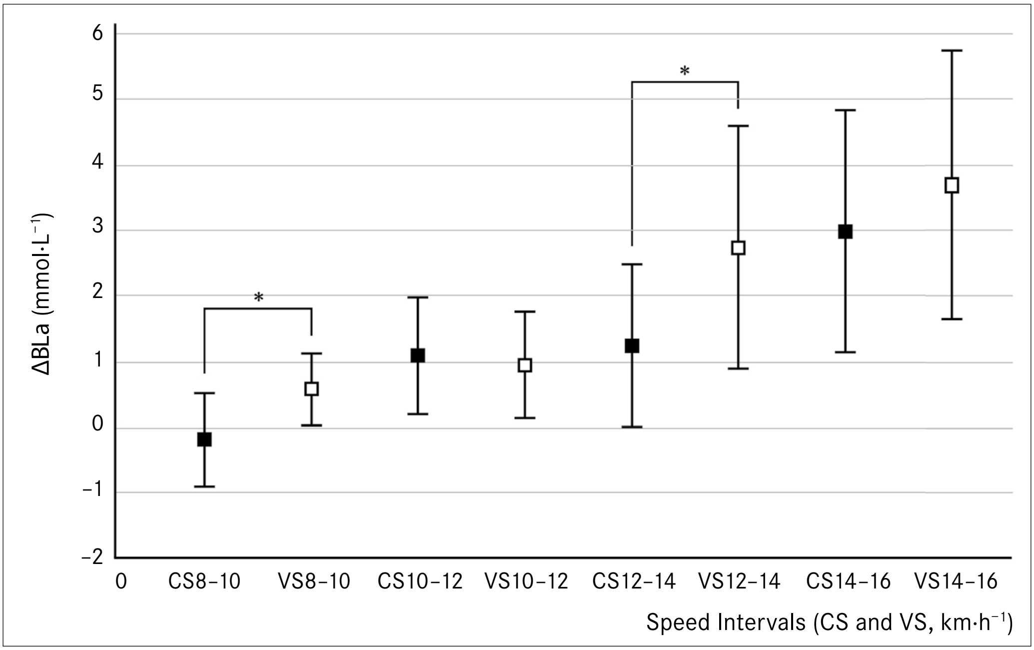

Figure 5. **Changes in blood-lactate concentration (ΔBLa) between speed intervals for Tests A and B**

For the RPE after each stage, no significant differences between test A and B were found for RPElegs at any of the work intensities (Z = −1.93 to −1.13; P = 0.053 to 0.26). A significant higher RPEvent after the 8 km·h^{-1} stage was observed for test A compared to test B (Z = −2.27; P = 0.023), but no difference in RPEvent were found for any of the four subsequent work intensities (Z = −1.91 to −0.28; P = 0.056 to 0.78).

The HRmax and $\dot{V}O_2$ max, determined during either of the $\dot{V}O_2$ max tests, were 194 ± 7 beats·min^{-1} and 57.5 ± 4.7 ml·kg^{-1}·min^{-1}, respectively. The slope for the relationship between percentual HR and $\dot{V}O_2$ was 1.64 ± 0.57 for test A and 1.56 ± 0.41 for test B. There was no significant between-test difference for the slopes (t = 0.77; P = 0.46; ES = 0.15).

Discussion

The purpose of the current study was to compare the $\dot{V}O_2$, HR and RPE as well as the BLa in a conventional anaerobic-threshold test at constant speed intervals with running at the same mean speeds but with speed variations similar to a football match. The results of this study demonstrate that $\dot{V}O_2$ and HR did not differ between constant and varying running speeds for any of the five work intensities. No differences in the RPE for the legs and ventilation were found between constant and varying running speeds, except a higher RPEvent for constant speed at the 8 km·h^{-1} stage. There was a significantly higher BLa for the test with varying running speeds at stages 8, 14, and 16 km·h^{-1}.

The current study found that the relationship between $\dot{V}O_2$ and HR in percent of maximal values was linear and the slope of the regression lines did not differ between constant and varying speed protocols. This result supports the data from previous studies, which reported that HR recordings are representative for $\dot{V}O_2$ for both intermittent football exercises and treadmill running at constant speeds (Esposito et al., 2004; Hoff et al., 2002). Together, this indicates that relative HR (% of HRmax) can be used to estimate relative $\dot{V}O_2$ (% of $\dot{V}O_2$ max) both at constant and varying speeds. Thus, HR can be used as a reasonably valid substitute during football matches and training to calculate aerobic energy expenditure (Spurr et al., 1988), if factors such as dehydration, air temperature, and ambient air humidity can be controlled or compensated for. The energy expenditure could be used to guide the player to have a sufficient energy intake (e.g., carbohydrate intake) to support the training adaptation after training and matches, because many football players experience problems balancing the energy expenditure and energy intake on a weekly basis (Briggs et al., 2015; Caccialanza et al., 2007).

Conventionally, the test variables included in the current study are measured in a laboratory using protocols with stages of four-to-five-minute duration at given constant submaximal running speeds below and above the anaerobic threshold. A football player's anaerobic threshold reflects the individual's ability to utilise as much of the $\dot{V}O_2$ max as possible without excessive production of lactate. Previously, it was found that the work intensity at the anaerobic threshold corresponds to approximately 84% of $\dot{V}O_2$ max in elite male football players (Nilsson & Cardinale, 2015). However, in football matches the work intensity has an intermittent character with a large variation in movement speed from standing to sprinting (Barnes et al., 2014; Bradley & Noakes, 2013; Castellano et al., 2011; Rampinini et al., 2007). The current study used an anaerobic-threshold test with progressively increasing speed intervals, but also with match-like speed variation at each speed-interval stage. During the test with varying speed, no between-test difference in either HR, $\dot{V}O_2$, or RPE was found with the exception of RPEvent at the 8 km·h^{-1} stage, which may be regarded as a less relevant speed in elite male football.

In contrast to the variables HR and $\dot{V}O_2$, the BLa differed between the tests especially at the two highest running speed test levels. One explanation to these differences is the inclusion of running speeds above the anaerobic threshold in the test with varying speed; in fact, the participants spent more than two minutes at a running speed above 14 km·h^{-1} including an overall duration high-speed running of 45 seconds and 60 seconds for the stages with mean running speeds of 14 km·h^{-1} and 16 km·h^{-1}, respectively. During high-speed running there is a greater force contribution from type II muscle fibres, which are more dependent on glycolytic processes. Hence, there is a higher anaerobic emphasis in the test with varying speed resulting in a higher BLa for the last two stages. Therefore, using a test protocol with varying speeds emulating the movement pattern in a football match reflects both the player's energy efficiency during high-speed running and the ability to recover during the periods with a work intensity below the anaerobic-threshold speed. Based on this reasoning, the test with speed variation during the stages should be considered as football-specific test that could provide a more nuanced view of these abilities that are important for performance in football matches.

According to several previous studies, an outfield player covers approximately 10–12 kilometers during a 90-minute football match (Andrzejewski et al. 2016; Bradley and Noakes 2013; Castellano et al. 2011; Rampinini et al. 2007). This is equivalent to a mean speed of approximately 7 km·h^{-1}. This constant work intensity corresponds to approximately 40% of $\dot{V}O_2$ max in elite male football players according to the results in the current study. However, many studies suggest that the mean $\dot{V}O_2$ during a match is approximately 75% of $\dot{V}O_2$ max (Stølen et al., 2005), which in turn corresponds to a mean speed of about 13 km·h^{-1} during treadmill running in the present population. This mean speed is considerably higher than 7 km·h^{-1} and it is not reasonable to assume that wind resistance or surface conditions can explain this difference.

Based on the above reasoning, a major part of the difference between 75% and 40% of $\dot{V}O_2$ max may be consumed by accelerations, decelerations, changes of direction, turnarounds, jumps, tackles, etc. (Buchheit et al., 2011), that are not recorded with respect to any linear displacement criteria. The majority of the maximal accelerations performed during a match do not result in a running speed that can be classified as sprint; however, these accelerations are metabolically demanding (Varley & Aughey, 2013). Therefore, traditional measurements of the running speed underestimate the energy cost (Gaudino et al., 2013). The mean relative $\dot{V}O_2$ of approximately 75% of $\dot{V}O_2$ max during matches corresponds to a work intensity below the anaerobic threshold among Swedish elite male football players (Nilsson & Cardinale 2015). Therefore, to test the physiological capacity of elite male football players, an anaerobic-threshold test using mean speeds below and slightly above the anaerobic threshold with varying speeds mimicking the running pattern during match play is recommended.

Conclusions

The results of the current study show that an anaerobic-threshold test with varying speeds during the stages have equal HR and $\dot{V}O_2$ responses as a conventional anaerobic-threshold test. This suggests that elite male players' energy expenditure during match could be estimated based on HR recordings, if certain limitation could be controlled or compensated for. However, the significant difference in the BLa between tests with constant and varying speeds indicates the need to use the anaerobic-threshold test with varying speeds in football.

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