COMPARISON OF PHYSIOLOGICAL RESPONSES TO AN INCREMENTAL RUNNING TEST ON TREADMILL, NATURAL GRASS, AND SYNTHETIC TURF IN YOUNG SOCCER PLAYERS

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ABSTRACT

Di Michele, R, Di Renzo, AM, Ammazzalorso, S, and Merni, F. Comparison of physiological responses to an incremental running test on treadmill (Tr), natural grass (Nat), and synthetic turf (Synt). Eighteen young soccer players (mean ± SD: age, 17.4 ± 0.8 years; body mass, 66.2 ± 6.7 kg; height, 175.8 ± 5.7 cm) performed on each surface a multistage running test, including 4-minutes stages separated by a 1-minute rest, with initial speed set at 8 km·h⁻¹ and increased of 2 km·h⁻¹ after each stage. Blood lactate concentration (La) and heart rate (HR) were assessed. The test ended when La exceeded 4 mmol·L⁻¹. At each of the stages completed in the three conditions by all the subjects (8, 10, 12, and 14 km·h⁻¹), La was higher in Synt vs. both Nat and Tr with differences of at least 0.6 mmol·L⁻¹ (p < 0.05), whereas HR was higher (p < 0.05) in Synt vs. Nat with differences from 4.3 b·min⁻¹ (at 10 km·h⁻¹) to 6.4 b·min⁻¹ (at 8 km·h⁻¹). Running speed at the 4 mmol·L⁻¹ La threshold was lower (p < 0.05) in Synt (13.1 ± 1.1 km·h⁻¹) than in Nat (13.9 ± 1.2 km·h⁻¹) and Tr (14.4 ± 1.3 km·h⁻¹). The La/HR curve obtained in Synt was shifted upward compared with the Nat and Tr curves, indicating higher La values at given HRs. These results could be mostly explained by adaptations of running mechanical patterns to surface properties that affect the energy requirements of running. This study emphasized the importance of testing soccer players on the specific surface used for training activities when assessing lactate threshold indices to prescribe and monitor field training.

KEY WORDS Football, field testing, heart rate, lactate threshold, training intensity

INTRODUCTION

Endurance capacities are routinely tested in soccer players. The outcomes of these assessments, whereas evaluating the efficacy of training programs, provide indices for monitoring and prescribing training activities. To this aim, variables associated at the blood lactate concentration (La) thresholds are often used. Running speed (v) corresponding to the onset of blood lactate accumulation (OBLA), i.e., the 4 mmol·L⁻¹ La threshold, is an indicator of aerobic fitness and may be considered by coaches to determine the intensity of endurance training (3). The corresponding heart rate (HR) is a reference point to define intensity zones when assessing the internal load distribution during a training session (6,10,26). Besides the most used OBLA, other thresholds, such as 2 mmol·L⁻¹ (5,6,13) and 3 mmol·L⁻¹ (5), have been considered in literature and are routinely used by soccer coaches for monitoring and prescribing training.

Graded treadmill (Tr) tests are frequently used to assess the La thresholds, as reported in a recent review article on soccer players testing (27). However, transferring laboratory-obtained variables to the field should be inappropriate if Tr running involves physiological responses that are, to some extent, different compared with on-grass running. In this context, an important factor is the energy surplus required to overcome air resistance, eliciting a higher energy cost in over ground vs. Tr running (11,23). This phenomenon was further observed in a recent study (14), comparing the outcomes of a multistage running test performed with an identical protocol on the Tr and on synthetic turf (Synt) by young soccer players. Those investigators showed, among other things, that (a) La and HR values associated at given speeds from 12 to 18 km·h⁻¹ were higher in the field, (b) v associated...
at OBLA was higher in the Tr, and (c) the La/HR curve of the field test was shifted upward compared with that of the Tr test. Whereas these results seem to challenge the use of Tr-obtained variables for field exercise prescription, they don’t consider the possible influence of the field surface type on the physiological responses to running. Those authors only considered a Synt pitch, but there is no available evidence to assume that differences of the same magnitude would have occurred between Tr and natural grass (Nat) field running. Indeed, despite the great increase in popularity of the synthetic turfs, very little is known about the physical stress on these surfaces compared with the traditional Nat because investigators so far have turned their attention much more to comparisons of injury rates. Conversely, several studies have been conducted that support the influence of surface mechanical properties as stiffness on the kinematics and kinetics of running with potential changes of the metabolic and physiological responses (8,12,15,21,22,28).

The third-generation synthetic surfaces, accepted by the Fédération Internationale de Football Association (FIFA) (7) for official games, are made of at least 40-mm-long polypropylene fibres filled with rubber granules and/or sand. Whereas these last-generation turfs are closer to true grass than the old-generation synthetic designs, experimental data (18) and empirical evidence suggest that they show anyway some mechanical differences vs. the Nat. Furthermore, a recent study (2) reported that soccer players perceived as physically harder playing and running without the ball on the synthetic than on the Nat. It is then conjecturable that the physiological responses to running may be different on these two kinds of grass, thus also probably influencing the lactate thresholds variables. This hypothesis, whereas making it opportune to separately consider Synt and Nat when comparing field vs. laboratory assessments, challenges the interchangeability of variables between the 2 field surfaces themselves. Namely, using the outcomes of a Nat test on Synt and vice versa for training monitoring and prescribing purposes should be inappropriate, as is using Tr-obtained data in the field.

Therefore, the purpose of this study was to compare the physiological responses to a running test frequently used to assess the lactate thresholds in soccer players when performed with an identical protocol on Tr, Nat, and Synt. We hypothesized that the Nat would induce different physiological responses to running compared with the Synt because of the different surface mechanical properties and that both the field surfaces would require a higher physiological effort than the Tr because of the energy surplus required to overcome the air resistance.

METHODS

Experimental Approach to the Problem

The study was conducted on high-level, young soccer players with a repeated-measures design. Subjects performed 3 incremental running tests with an identical multi-stage protocol: a laboratory Tr test, a field test on Nat, and a field test on Synt. La and HR values obtained at any stage of the tests, i.e., at any given speed, were used to compare the physiological responses to running on the 3 different surfaces. HR and v values associated via interpolation to fixed La points, i.e., 2, 3, and 4 mmol·L⁻¹, and the overall La/HR relationship were then assessed and used to compare lactate threshold variables among the examined conditions.

Subjects

Eighteen young male soccer players were recruited. Their mean (± SD) age, body mass, height, and playing experience were 17.4 ± 0.8 years, 66.2 ± 6.7 kg, 175.8 ± 5.7 cm, and 10.2 ± 1.8 years, respectively. Players were high-level athletes belonging to the same team, which participated in the Italian Youth Championship. All playing roles, except goalkeeper, were represented. During the competitive season, they usually trained 4–6 times per week, whereas at the time this study was conducted, i.e., in May during the offseason period, they were performing only 2 or 3 light training sessions per week. They usually performed their training activities both on natural and synthetic pitches. Subjects gave written informed consent to participate in this study after being informed of the procedures and risks involved in the participation. For U-18 players, authorization to participate was given by a guardian that signed the informed consent. The protocol of this study was approved by the institutional internal review board.

Procedures

The multistage running test protocol, adapted from Heck (9), is designed for the assessment of lactate threshold variables in soccer and other team sports players and, to this aim, has been used with few variations in the literature (14,16,26). Being identical in the 3 tests, the protocol included 4-minute running stages separated by a 1-minute rest when a capillary blood sample was taken from the fingertip by an experienced operator and analyzed for La with a Lactate Pro (Arkray Inc, Kyoto, Japan) analyzer. This device has been evaluated elsewhere (24) as accurate and reliable for blood lactate measurements in the field, with a correlation of $r = 0.993$ between 2 Lactate Pro Analysers in analyzing the same blood sample over the physiological range 1–18 mmol·L⁻¹. Initial speed was set at 8 km·h⁻¹ and increased of 2 km·h⁻¹ after each stage until test termination. The test ended when La of the exercising subject exceeded 4 mmol·L⁻¹. Heart rate was recorded continuously every 5 seconds using a short-wave telemetry device (Polar Accurex Plus; Polar Electro OY, Kempele, Finland). Average HR of the last minute of each 4-minute step was considered as the player’s HR for that step. For each subject, v and HR values corresponding to 2, 3,
and 4 mmol·L⁻¹ of La were determined with a linear interpolation between consecutive points. The reliability of lactate threshold measurements obtained using a protocol similar to our own has been previously established by Pfitzinger and Freedson (20). On 3 separate days, they measured HR and La in 12 well-trained endurance runners at the completion of 5-minute running trials at several submaximal speeds. They reported intraclass correlation coefficients of 0.99 for v at OBLA and 0.92 for HR at OBLA.

**Laboratory Test.** The laboratory Tr test was performed on a Run Excite (Technogym, Gambettola, Italy) treadmill at level grade. Treadmill speed was validated for each stage using an odometer (Stanley, Milano, Italy). The temperature in the laboratory was between 21 and 24°C.

**Field Tests.** The Nat and Synt field tests were performed on 250-m oval circuits traced upon a Nat and a synthetic pitch, respectively. The Nat field was a homologated field, regularly cut, and maintained for official soccer games. The Synt, installed 3 years before the test and homologated for official games, was constituted by a third generation artificial turf (Football Green 57 SL; AK Green, Pisa, Italy), made of 55-mm-long polypropylene fibers filled with rubber and cork granules, the whole put down on a solid matrix. Meteorological conditions were stable (sunny weather with almost no wind and ambient temperature of 22–27 °C) and both the turfs were dry during the test sessions.

Reference cones were positioned every 25 m along the circuit, and the subjects followed an acoustic signal to maintain the prescribed pace. Before the test, subjects were familiarized with the procedure and instructed to adjust softly their speed when required, avoiding any abrupt acceleration or deceleration. The correspondence between the prescribed and the actual pace was checked by an operator carefully observing that the subject was in proximity to the cone at the right moment.

**Statistical Analyses**

All results are presented as mean ± SD. One-way repeated-measures analysis of variance (ANOVA), followed by post-hoc t-tests with Bonferroni correction, was used to analyze differences among Synt, Nat, and Tr for each of the dependent variables, i.e., La and HR at any given speed, as well as v and HR at any given lactate threshold. Significance was set at p < 0.05. A plot of La vs. HR at any given lactate threshold. Significance was set at p < 0.05. A plot of La vs. HR was generated for the 3 tests with all the subjects’ data, and a mathematical model was used to characterize this relationship. The best fit was a second order polynomial model for all the cases (r² = 0.63 for Synt; r² = 0.67 for Nat; r² = 0.66 for Tr).

**RESULTS**

**Blood Lactate and Heart Rate Values at Different Running Speeds**

Figure 1 displays mean La at the 4 stages completed by all the subjects in each test (8, 10, 12, and 14 km·h⁻¹).

Speeds faster than 14 km·h⁻¹ were not considered because only few subjects reached the respective stages in each condition. La values obtained during Tr and Nat were very similar at the slowest speeds, whereas at 14 km·h⁻¹, mean La tended to be lower in Tr (3.6 ± 1.1 mmol·L⁻¹) than in Nat (4.2 ± 1.7 mmol·L⁻¹), although the difference was not
significant ($p > 0.05$). In Synt, La was significantly higher ($p < 0.05$) compared with both the other conditions at all running speeds. Differences were almost constant (0.6 – 0.9 mmol L$^{-1}$) across running intensities until 12 km h$^{-1}$ but increased up to 2.4 mmol L$^{-1}$ (for Synt vs. Tr) at 14 km h$^{-1}$ (Figure 1).

Mean HR (Figure 2) showed the highest values in Synt and the lowest in Nat, whereas Tr values were intermediate.

Differences between Synt and Nat, ranging from 4.3 b min$^{-1}$ (at 10 km h$^{-1}$) to 6.4 b min$^{-1}$ (at 8 km h$^{-1}$) were significant at all running speeds ($p < 0.05$).

### Running Speed and Heart Rate at Fixed Blood Lactate Concentrations

Table 1 summarizes mean v and HR values corresponding to La levels of 2, 3, and 4 mmol L$^{-1}$.

To expand on this, individual data for v at OBLA (Figure 3) and HR at OBLA (Figure 4) are also shown.

At all the considered thresholds, running speed was significantly lower in the Synt compared with both Nat and Tr ($p < 0.05$). This is in agreement with the inverse La vs. v relationship (Figure 1) examined before.

Heart rate associated to fixed La points was the slowest in Synt, intermediate in Nat, and the fastest in Tr; mean HR values in Synt and Tr were significantly different ($p < 0.05$) at all the thresholds (Table 1). This is confirmed by the visual inspection of La vs. HR relationships modeled with second-order polynomial curves (Figure 5). The Synt curve was widely shifted upward compared with the Tr curve, whereas

### Table 1. Mean running speed and heart rate associated to lactate thresholds.

<table>
<thead>
<tr>
<th>La (mmol L$^{-1}$)</th>
<th>Synthetic turf</th>
<th>Natural grass</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11.1 ± 0.8*†</td>
<td>12.2 ± 0.9</td>
<td>12.3 ± 1.1</td>
</tr>
<tr>
<td>3</td>
<td>12.2 ± 1.1*†</td>
<td>13.1 ± 1.1</td>
<td>13.4 ± 1.2</td>
</tr>
<tr>
<td>4</td>
<td>13.1 ± 1.1*†</td>
<td>13.9 ± 1.2</td>
<td>14.4 ± 1.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Hear rate (b min$^{-1}$)</th>
<th>Synthetic turf</th>
<th>Natural grass</th>
<th>Treadmill</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 mmol L$^{-1}$ La</td>
<td>154.8 ± 7.7*</td>
<td>159.2 ± 7.1</td>
<td>162.0 ± 9.6</td>
</tr>
<tr>
<td>3 mmol L$^{-1}$ La</td>
<td>165.8 ± 6.8*</td>
<td>168.5 ± 7.7</td>
<td>172.0 ± 7.2</td>
</tr>
<tr>
<td>4 mmol L$^{-1}$ La</td>
<td>172.3 ± 7.1*</td>
<td>173.1 ± 6.5</td>
<td>177.2 ± 7.1</td>
</tr>
</tbody>
</table>

Data are presented as mean ($± SD$).

*Significant difference for synthetic turf vs. treadmill.
†Significant difference for synthetic turf vs. natural grass; $p < 0.05$. 

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the Nat curve lied in an intermediate position among the other two.

**DISCUSSION**

The purpose of the present study was to compare the physiological responses to an incremental running test used to assess the lactate threshold variables in soccer players, performed with an identical protocol on Tr and 2 field surfaces, namely, Nat and Synt. Taken together, our results showed an overall higher physiological activation on Synt compared with both the other conditions, whereas no substantial difference appeared between Nat and Tr.

In the examined test, the La response to given running speed is used to associate the running velocities to lactate thresholds, thus obtaining indices of aerobic fitness useful to determine the intensity of running training in soccer players. In the Synt test, compared with both the Nat and Tr tests, we found higher La values at any submaximal speed ranging from 8 to 14 km·h⁻¹ (Figure 1) and consequently lower velocities associated at the 2, 3, and 4 mmol·L⁻¹ thresholds (Table 1). These results are in agreement with a previous investigation comparing Tr and Synt with a procedure very similar to our own in age-matched soccer players (14), although those authors failed to find significant differences for La values at the lowest speeds (8 and 10 km·h⁻¹). This is probably because of the different aerobic fitness levels of the participants. Indeed, our subjects showed a Tr-assessed v at OBLA of 14.4 ± 1.3 km·h⁻¹; moreover, it was a value very similar to age-matched professional English players at the end of the competitive season (16), whereas players of that study showed 15.9 ± 0.9 km·h⁻¹. Evidently, for such fit soccer players, running at 8 and 10 km·h⁻¹ involved negligible La accumulation apart from the running surface, with La values close to resting baselines.

The higher La and HR values observed on Synt vs. the Nat at given speeds (Figures 1 and 2) supported our hypothesis of different physiological responses to running between the 2 field surfaces. Recently, Andersson et al. (2), using questionnaires with visual analogue scales, found that soccer players perceived playing on Synt as physically harder than on Nat, although movement patterns were not different between the 2 surfaces, as shown by motion analysis of competitive games. In that study, it was also noted that some of the players subjectively reported more difficulties in running without the ball on Synt than Nat. Therefore, although the rate of perceived exertion is not always strongly correlated with La and HR according to Chen (4), considerable consistency may be claimed between Andersson’s outcomes and the greater effort required to run on Synt vs. Nat found here.

Previous investigators assessing the physiological and metabolic responses to running on different hardness surfaces showed that the higher energy cost was associated to the more compliant surface (8,15,21,28). Mechanical factors such as reduction in recovery of elastic energy (28), decrease in muscle-tendon efficiency (15), and reduced mechanical advantage of the knee extensor caused by the greater hip and knee flexion (22) have been considered to explain why running on sand requires more energy than running at the same speed on a harder surface. It is therefore conjecturable that the higher compliance of the Synt, caused by the cushioning properties of the filling, may have been the most important reason for the higher physiological effort we observed on the artificial vs. the natural pitch. Further investigations are required to test this hypothesis and to examine which among the aforementioned or other mechanical variables may explain the different physiological requirements of running on the 2 grass surfaces.

In this study, HR and La values for running speeds from 8 to 14 km·h⁻¹ and conversely v associated to lactate thresholds showed no significant difference between Nat and Tr (Figure 1 and Table 1). These results, taken together with the great differences observed between the synthetic turf and the other conditions, allow us to infer that in our experiment, the physiological responses to running have been much more influenced by running surface properties than by overcoming air resistance. However, it remains to be explained why our results seem not to reveal the effect of air resistance for Tr vs. Nat running because it was expected. An answer to this may come from the analysis of individual response patterns. Indeed, approximately half of the players had a higher v at OBLA on the Tr as expected, whereas the other half showed a slight trend in the opposite direction (Figure 3). It is presumable that as expected, the lack of air resistance in the
laboratory lowered the physiological effort of the players, but this effect was counterbalanced, only in some of the subjects, by an additional factor. This factor may be a poor individual Tr running technique that, given the relationships between running economy and mechanics (1), increased the energy requirements. Indeed, it was shown that each athlete adapts his own running mechanics to Tr running in a proper unpredictable way (19,25). Probably, those players showing slower velocities associated at OBLA in the laboratory compared with the Nat have not been able to efficiently adapt their field running technique to the treadmill.

Heart rate values corresponding to lactate thresholds, used to define intensity zones when monitoring field training, are determined from La and HR values independently from the corresponding running speed. We found, at all the thresholds, the lowest HRs in the Synt test and the highest HRs in the Tr test, with significant differences of approximately 5 to 7 b·min⁻¹ between the 2 conditions (Table 1). Natural grass values instead were intermediate, showing no significant differences. These results are similar to the investigation of Kunduraciglu et al. (14), showing a HR at OBLA of 3 b·min⁻¹ lower in the Synt than in the Tr (190 ± 7 vs. 187 ± 7, respectively). They failed, however, to detect such differences as statistically significant at an alpha level of 0.05 in their 22-player sample. Evidently, the inherent variability of HR at OBLA, a less stable variable than v at OBLA (20), lowers the statistical power of such experiments.

For all subjects, the La/HR curve obtained on the Synt was shifted upward compared with that of the Tr (Figure 5), i.e., had higher La values for given HRs, in a very similar way to the investigation of Kunduraciglu (14). The Nat curve instead was amongst the other two, being close to the Tr values at low intensities (HR approximately 140 b·min⁻¹) and gradually going off. Therefore, with the increase of the exercise intensity, HR, and La seem to be respectively influenced in different ways according to the running condition.

Despite the wide spreading of the Synt because of its suitability and low maintenance costs, at the present, little is known on differences in the physical performance vs. the traditional Nat, because investigators so far turned their attention much more to differences in injury rates. The present study, whereas showing the influence of the field surface type on the physiological responses to an incremental running test, provides an important cue for the study of the soccer performance on the Synt. Comparison of the physiological responses during soccer games on Synt and Nat will be a matter for future studies. Furthermore, some evidence of differences in running mechanical patterns has been revealed, although without definitive conclusions, between 2 third-generation Synt filled with rubber layers of different thickness (17). Then, future research perspectives will include also the comparison of testing outcomes and soccer performance among synthetic pitches of different characteristics, especially concerning filling composition and thickness.

In conclusion, the present work showed that submaximal running induces higher La and HR values on Synt than on Nat, whereas similar mean values but individual differences appeared between Tr and Nat. This demonstrates that the physiological responses to running in young soccer players are much more influenced by the mechanical properties of the running surface and the individual adaptations to Tr running than by the effect of air resistance to overcome in outdoor conditions.

**Practical Applications**

Traditionally, the laboratory has been preferred to the field for the physiological assessment of the athletes, thanks to the more standardized conditions being not influenced by the terrain conditions, wind, or other meteorological factors. The use of laboratory-obtained indices for field exercise prescription is questionable, however, because confounding factors may interfere. Our results, comparing values of running speed corresponding to the OBLA in the Tr and Nat, showed individual response patterns (Figure 3). This is probably caused by a more or less efficient adaptation of one’s own running technique to the treadmill, a rather unpredictable factor. Apart from the physiological or biomechanical reasons of the phenomenon, an actual error of approximately 1 km·h⁻¹ seems rather noteworthy when assessing the aerobic fitness or prescribing the intensity of running repetitions. It is worth speculating also on the interchangeability of HR values at lactate thresholds, because the magnitude of the differences between the examined conditions seemed to be not much higher than that caused by the inherent intraindividual day-to-day variability. Exactly because the HR at lactate threshold is not an extremely stable variable per se (20), it seems necessary to exclude factors that may further increase the measurement error as the surface on which the assessment is performed.

Therefore, outcomes from this study emphasized the use of field tests to obtain indices for monitoring and prescribing training in soccer players. The need to program testing sessions subordinated to the weather and terrain conditions is a trouble to bear if valid variables for field exercise prescription are to be obtained. Conversely, the running speed may be easily controlled in the field with an acoustic signals system and references cones. Furthermore, the great differences observed in this study between the physiological responses to running on Nat vs. Synt challenge the interchangeability of tests results between the 2 fields surfaces themselves and lead to recommend that assessments have to be performed on the specific surface in which training activities take place.

This study, besides comparing the outcomes of a running test performed on Tr and 2 different fields, provided a physiological explanation for the higher physical effort perceived by soccer players when playing on the Synt vs. the Nat (2). While awaiting further researches comparing the 2 surfaces using more soccer-specific skills, coaches need to consider the higher physiological effort to run on Synt and...
plan opportune training interventions if their teams’ games take place on these pitches.

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References