Better economy in field running than on the treadmill: evidence from high-level distance runners

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ABSTRACT: Given the ongoing interest in ways to improve the specificity of testing elite athletes in their natural environment, portable metabolic systems provide an opportunity to assess metabolic demand of exercise in sport-specific settings. Running economy (RE) and maximal oxygen uptake ($\dot{V}O_2$max) were compared between track and treadmill (1% inclination) conditions in competitive level European distance runners who were fully habituated to treadmill running (n = 13). All runners performed an exercise test on running track and on treadmill. While $\dot{V}O_2$max was similar on the track and on the treadmill (68.5 ± 5.3 vs. 71.4 ± 6.4 $ml \cdot kg^{-1} \cdot min^{-1}$, p = 0.105, respectively), superior RE was found on the track compared to the treadmill (215.4 ± 12.4 vs. 236.8 ± 18.0 O_2 $ml \cdot kg^{-1} \cdot km^{-1}$, $p < 0.001$). RE on the track was strongly correlated with RE on the treadmill (r = 0.719, p = 0.006). The present findings indicate that high-level distance runners have significantly better RE but not $\dot{V}O_2$max on the track compared to treadmill. This difference may be due to biomechanical adjustments. As RE is strongly correlated between the two conditions, it would be reasonable to assume that interventions affecting RE on the treadmill will also affect RE on the track.

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INTRODUCTION

Treadmill running is widely used to assess maximal oxygen uptake ($\dot{V}O_2$ max) and to determine aerobic and anaerobic thresholds by measuring gas exchange during stepwise incremental tests in distance runners. Furthermore, running economy (RE) has been traditionally measured by running on a treadmill in standard laboratory settings. Although running on a treadmill is not the same as running on a track, it gives an indication of how economical a runner is and how RE can change over time [1]. In response to the growing interest in ways to improve the specificity of physiological testing for elite athletes in their natural environment, portable metabolic systems which enable the assessment of the metabolic demand of exercise in a sport-specific field environment (e.g. running on a track) have been developed [2].

Running on a treadmill is influenced by the lack of air resistance that results in lower energy cost and therefore better RE compared with running on an outdoor track at the same velocity [1,3]. In 1996, Jones and Doust [3] showed that the reason for the difference between treadmill and outdoor running is the extra work required to move through the air rather than mechanical factors. They introduced a 1% incline of the treadmill gradient to increase the energy cost in compensation. Other possible reasons for differences between the two running conditions, such as (i) the runner may gain energy from the motor-driven treadmill belt and (ii) biomechanical changes in running technique due to different surfaces or to the instability caused by visual cues from static rather than moving surroundings, have been discussed [3,4].

The habituation of running on the treadmill can also significantly influence differences in RE between track and treadmill conditions [5], except for athletes who are fully habituated to treadmill running [3], as in the present study. Furthermore, from our personal contact with recreational up to international level runners, we have observed lower values on the rating of perceived exertion (RPE) scale in track running compared to treadmill running at the same velocity. It has also been shown that higher velocities on the track compared to the treadmill were attained when athletes were asked to maintain the same relative effort (RPE score) during both running conditions [6]. The aim of the present study was to compare RE and $\dot{V}O_2$max values between running on a treadmill and on a track in high competitive level habitual treadmill runners using portable metabolic systems. It was hypothesised that (i) at the speed of 16 $km \cdot h^{-1}$ high-level distance runners have better RE on the track compared to the treadmill; (ii) $\dot{V}O_2max$ values on the track are not different from those on the treadmill.

MATERIALS AND METHODS

Subjects. A total of 13 European distance runners were recruited for this study. The best performance of the athletes was established using the International Association of Athletics Federations (IAAF) Scoring Tables [7,8,9]. These tables assign a definite score to each performance, enabling comparison between different events [8]. Study procedures and protocols were approved by the Ethics Committee of the University of Tartu (Tartu, Estonia) and conformed to the Declaration of Helsinki. All testing procedures and related risks were described before providing written informed consent to participate in the study.

Study design

A cross-sectional analysis of 13 distance runners was performed. On the first visit to the laboratory, the main anthropometric parameters were measured. Runners performed the first test on an outdoor track and the second one on a treadmill (see specific protocols below). Track and treadmill tests were separated by at least 48 h. Athletes were requested to maintain their usual dietary intake and to refrain from alcohol throughout the study period [10]. They were also asked to abstain from hard training and/or competition for at least 24 h before testing. Athletes wore the same shoes and running clothes for both of the tests.

Exercise testing

A maximal running test on a 400 m outdoor track was performed. The athlete ran next to a cyclist who set a speed for each stage using a speedometer (Cateye Velo 05, Osaka, Japan). The bicycle speedometer was calibrated according to the instructions of the manufacturer and checked using the treadmill (HP Cosmos Quasar, Nussdorf-Traunstein, Germany) speed and 12-channel GPS (Garmin eTrex, Garmin Ltd, Kansas, USA). Two additional recording GPS devices (Polar RS800cx G5, Polar Electro Oy, Kempele, Finland and Garmin Forerunner 405 Garmin Ltd, Kansas, USA) were attached to the runner to calculate the average running speed of each running stage. Before commencement of the exercise test, each athlete remained stationary on the track for three minutes and pre-test cardio-respiratory data were collected. Initial running speed was set at 8 $km \cdot h^{-1}$ and then increased by 2 $km \cdot h^{-1}$ every three minutes up to 20 $km \cdot h^{-1}$. The speed at 20 and 22 $km \cdot h^{-1}$ was maintained for two minutes. From that point on, the speed was increased by 1 $km \cdot h^{-1}$ after every two minutes until voluntary exhaustion.

Following familiarisation with the treadmill, participants performed an incremental running test on a motorized treadmill (HP Cosmos Quasar, Nussdorf-Traunstein, Germany) until voluntary exhaustion. Before commencement of the exercise test, each athlete remained stationary on the treadmill for three minutes and cardio-respiratory data were collected. The initial running speed was set at 8 $km \cdot h^{-1}$ with a gradient of 1% [3,11] and then increased by 2 $km \cdot h^{-1}$ every three minutes until 14 $km \cdot h^{-1}$. The speed of the 16 $km \cdot h^{-1}$ stage on the treadmill was replaced by the speed measured during the track test calculated from the average of the values of the two GPS devices rounded to the nearest decimal point (i.e. if the average speed on the track was 15.7 $km \cdot h^{-1}$, then the treadmill speed was set to 15.7 $km \cdot h^{-1}$ instead of 16 $km \cdot h^{-1}$). Following the 3 min 17 $km \cdot h^{-1}$ stage, the speed remained constant and elevation increased 1% after every one minute until voluntary exhaustion [12].

During track and treadmill tests, expired gases and heart rate (HR) were measured using the same Metamax 3B device (Cortex Biophysik GmbH, Leipzig, Germany), which was calibrated before each test according to instructions of the manufacturer. $\dot{V}O_{2max}$ was defined as the highest average $\dot{V}O_2$ during a 30 s period and a failure to increase $\dot{V}O_2$ further despite an increase in work rate [13]. RE was measured during the last two minutes of the speed during the 16 $km \cdot h^{-1}$ stage. RE was expressed as oxygen cost (O_2 $ml \cdot kg^{-1} \cdot km^{-1}$) and was calculated as follows:

$$RE = \frac{1000 \cdot VO_2}{v},$$

where $\dot{V}O_2$ is steady-state oxygen uptake ($ml \cdot kg^{-1} \cdot min^{-1}$) and v is running velocity ($m \cdot min^{-1}$) [14]. Steady state was defined as an increase of less than 100 ml O_2 over the final two minutes of the respective running stage [15]. During the treadmill test, ambient temperature and relative humidity in the laboratory were regulated with an air conditioning device to correspond to conditions on the outdoor track.

Statistical analysis

Treadmill and track conditions within the group were compared with the paired t-test or Wilcoxon signed-rank test. Linear relationships between the two conditions were assessed with Pearson's correlation coefficient. Calculations were performed using IBM SPSS v.20 software for Windows (SPSS Inc, Chicago, IL, USA). Effect size was calculated with G*Power v.3.1.7 (University of Düsseldorf, Düsseldorf, Germany). Cohen's *d* [16] was calculated to indicate effect size and practical meaningfulness. The effect size was evaluated using Lipsey's criteria and considered medium when d was between 0.45 and 0.89, and large when *d* was higher than 0.90 [17]. The level of significance was set at $p < 0.05$.

RESULTS

The main characteristics of the runners are presented in table 1. While $\dot{V}O_{2max}$ was similar between track and treadmill conditions (68.5 ± 5.3 vs. 71.4 ± 6.4 $ml \cdot kg^{-1} \cdot min^{-1}$, $p = 0.105$, $d = 0.49$ respectively), superior RE was found on the track compared to the treadmill (215.4 ± 12.4 vs. 236.8 ± 18.0 O_2 $ml \cdot kg^{-1} \cdot km^{-1}$, $p < 0.001$, $d = 1.72$) (Figure 1). In other words, runners were 8.8% more economical on the track than on the treadmill. RE on the track was strongly correlated with RE on the treadmill ($r = 0.719$,

TABLE 1. Characteristics of participants (mean ± SD).

	Europeans (N = 13)
Age (years)	25.4 ± 4.4
Mass (kg)	69.0 ± 5.9
Height (m)	1.81 ± 0.05
BMI (kg·m^{-2})	21.0 ± 1.2
IAAF (p)	786 ± 111
Regular training (years)	8.3 ± 5.3

Note: BMI – body mass index; IAAF (p) – International Amateur Athletic Federation scoring table points.

$p = 0.006$). Runners presented significantly lower VE (102.3 ± 16.6 vs. 115.5 ± 19.2 l·min^{-1}, $p < 0.001$, $d = 2.19$) but not HR (169 ± 10 vs. 171 ± 8 bpm, $p = 0.269$, $d = 0.32$) on the track compared with the treadmill during the 16 km·h^{-1} stage. VE on the treadmill was 11.2% higher than that on the track.

DISCUSSION

The novel finding of the present study was that high-level distance runners have significantly better RE on the track compared to the treadmill with the widely used 1% inclination. The treadmill is not only a popular research instrument in studying human locomotion and exercise capacity, but has also been used for training and conditioning purposes for a long time [18,19]. At the same time, as there is a growing interest in the use of treadmill running as part of regular training for high-level distance runners, it has been debated whether the changes observed in laboratory-based $\dot{V}O_{2max}$ and RE tests would automatically translate into actual changes in running performance in the field. Coaches are looking for reliable sport-specific tests, which reflect the real status of their athletes. Therefore, assessment of the differences between treadmill and track running using a modern, portable metabolic system would give the necessary insight before generalizing the results of treadmill studies to outdoor running. This is the first study to use a modern, portable metabolic measurement system to compare track and treadmill running in high competitive level distance runners in their everyday training conditions.

Several studies have concluded that air resistance is the only cause of the observed differences between track and treadmill locomotion [3,4]. However, Pugh [20] designed a wind screen to alleviate air resistance and still observed higher energy cost in track running than on the treadmill. This indicated that other factors might be responsible for the differences in RE between the two running conditions, such as biomechanical adjustments [19]. Running in a more “natural” environment on a track compared to a more “artificial” environment on a treadmill led to a better RE of 8.8%. This better RE may be partly explained by the significantly lower VE on the track compared to the treadmill. As ventilatory work accounts for 7–8% of the overall energy cost of exercise [21], a decrease in VE leads to a decrease in $\dot{V}O_2$ (i.e. better RE) [22,23,24]. The technique of running on a treadmill is different to that running over ground where the hamstrings are used to a greater extent to produce propulsive forces [1]. The slightly different muscle recruitment patterns on the treadmill can then lead to an increase in ventilation, especially at submaximal stages on a treadmill [25]. The findings of the present study are in agreement with the significantly higher energy expenditure observed during treadmill running at submaximal stages compared to track running [25]. On the other hand, contradictory results showing no significant differences or impairment in RE between track and treadmill conditions have previously been reported [3,20,26,27]. However, these studies were conducted with the Douglas bag method for field measurements, which likely interfered with running movements and thus limited the submaximal values [25]. While it seems that there is a consensus that biomechanical adjustments occur between treadmill and track conditions and can consequently alter

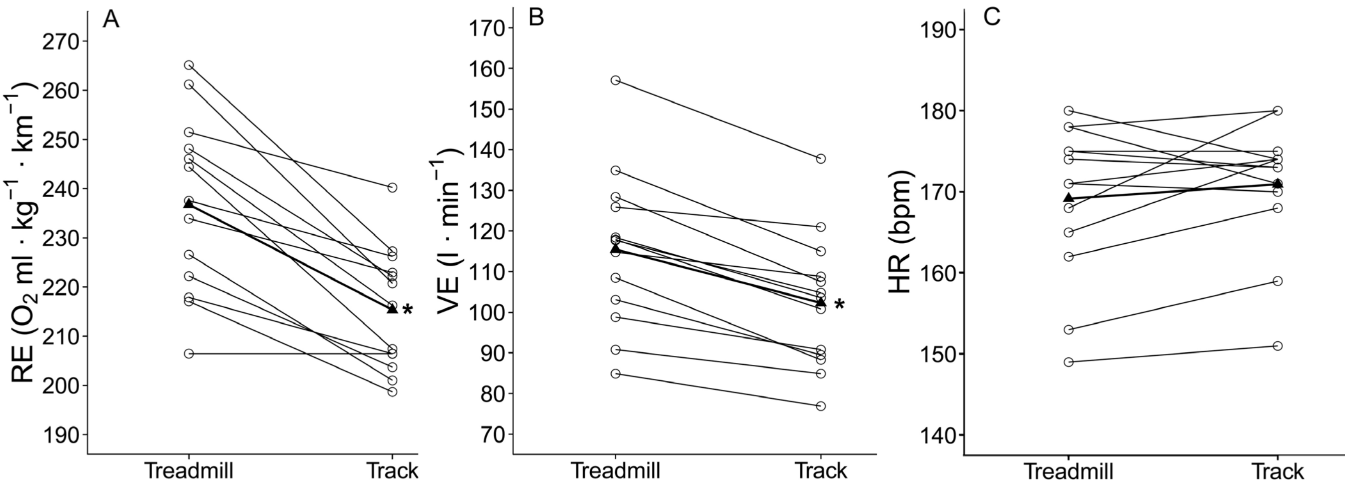

FIG. 1. Mean (thick lines with triangles) and individual results for running economy (A), ventilation (B) and heart rate (C).
Note: * – significant difference between track and treadmill.

energy expenditure, the conclusion on whether these biomechanical adjustments are advantageous on the treadmill or on the track may differ due to the characteristics of the group studied (e.g. sprinters vs. endurance runners) [19]. The slightly higher RE values at the speed of 16 km·h^{-1} reported in the present study compared to previously published data [11,28,29,30] are most likely due to the portable device MetaMax 3B used to measure $\dot{V}O_2$. However, and importantly, although the MetaMax 3B has been shown to overestimate $\dot{V}O_2$ by up to 10% when compared to the primary criterion Douglas bag method [2,31] and secondary criterion Jaeger Oxycon Pro system [31], it has excellent reproducibility, with a typical error of 2–3% for $\dot{V}O_2$, $\dot{V}CO_2$ and VE [2].

Using a modern portable metabolic system, the present study also confirmed that identical $\dot{V}O_{2max}$ results are obtained during tests conducted in both treadmill and track running conditions. This indicates that $\dot{V}O_{2max}$ in running is independent of the execution of the test whether on the track or on the treadmill, if an equal amount of effort is spent [25]. Finally, the practical implications of the findings of the present study give confidence for running coaches that training methods resulting in an improvement in RE and $\dot{V}O_{2max}$ in treadmill tests would lead to a similar improvement in running on the track in high-level distance runners. However, the 1% inclination on the treadmill is likely to be too high to reproduce similar efforts to those in track running.

CONCLUSIONS

In the present study we demonstrated in high-level distance runners that (i) RE is significantly better on the track compared to the treadmill, and (ii) $\dot{V}O_{2max}$ values do not depend on whether the test was conducted on a treadmill or on a track. Finally, as RE was strongly correlated between conditions, it is reasonable to assume that interventions affecting RE on the treadmill will also affect RE on the track.

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