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Comparison of a traditional graded exercise protocol and a self-paced 1-km test to assess maximal oxygen consumption

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Abstract

Purpose: To compare the assessment of the maximal oxygen consumption (VO_{2max}) in a traditional graded exercise test (GXT) and a 1-km self-paced running test on a non-motorized treadmill in men and women.

Methods: A total of 24 sports science students (12 women: 23.7±7.7 years, body height 1.68±0.02 m, body mass 66.6±4.3 kg and 12 men; 22.1±3.1 years, body height 1.82±0.06 m, body mass 75.6 ± 11.0 kg), performed a traditional GXT on a motorized treadmill and a 1-km self-paced running test on a non-motorized treadmill. VO_{2max}, blood lactate, heart rate, and rate of perceived exertion, together with running velocity and duration at each test were measured.

Results: The main findings of the study were that the 1-km test produced significantly higher VO_{2max} values (53.2±9.9 vs. 51.8±8.8 mL/kg/min) and blood lactate concentrations (11.9±1.8 vs. 11.1±2.2 mmol/L) than the GXT ($F \geq 4.8$, $P \leq .04$, $\eta^2 \geq 0.18$). However, controlling for sex, these differences were only present in men (60.6±8.1 vs. 58.1±8.0 mL/kg/min, P=.027). Peak running velocity was higher in the GXT than in the 1-km test (15.7±2.7 vs. 13.0±2.8 km/h). Men had higher VO_{2max} values and running velocities than women in both tests. However, men and women used approximately similar pacing strategies during the 1-km test.

Conclusions: Higher VO_{2max} values were observed in a 1-km self-paced test than in the GXT. This indicates that a 1-km running test performed on a non-motorized treadmill could serve as a simple and sport-specific alternative for assessment of VO_{2max}.

Keywords: aerobic capacity, pacing, treadmill, incremental, RPE

Introduction

The maximal oxygen consumption (VO_{2max}) is defined as the highest rate at which oxygen can be taken up and utilized by the body during intensive exercise.[1] The VO_{2max} test is frequently used as a measure of the cardiorespiratory fitness level of an individual or as a physiological marker for training effect in training interventions.[1] A high VO_{2max} is also known to be an important factor for performance in endurance sports,[1-3] and a strong correlation between VO_{2max} and endurance performance is reported in heterogeneous populations.[4] Accordingly, the VO_{2max} test is one of the most used exercise tests in exercise physiology and sport science.[5]

The traditional and most used protocol to measure VO_{2max} is the graded exercise test (GXT) performed as a fixed incremental stepwise test to exhaustion, typically performed on a motorized treadmill.[6] However, this traditional test protocol has received critique. For example Noakes[5] highlighted three main problems with GXT: 1) unlike most sports, the expected duration of the test is unknown for the participant, 2) the fixed incremental increase of exercise intensity during GXT is unnatural compared to exercise performed outside the laboratory, and does not allow the participants to choose an optimal pacing strategy, and 3) the end of the test is determined by the participant, making it highly dependent on psychological factors (i.e., the subject's motivation and pain tolerance). Furthermore, some studies have challenged the validity of the traditional GXT method by showing that higher VO_{2max} values can be achieved with different exercise protocols such as the "free range" test[7] and a decremental exercise test.[8]

Furthermore, the introduction of non-motorized treadmills has made it easier to conduct self-paced running tests in the laboratory. Recently, Mauger and Sculthorpe[9] designed a self-paced VO_{2max} test, consisting of 5 × 2-minute stages where the participants were allowed to vary their race speed as long as each stage matched the required rating of perceived exertion (RPE). Higher VO_{2max} values have been reported using self-paced VO_{2max} protocols compared to GXT protocols in cycling and running.[8,10-13] However, no differences between a GXT and self-paced protocols have also been reported.[14-18] These conflicting results may be due to methodological differences and the different populations used in these studies.[19]

The main critique against GXT is the fixed intensity of the test, unknown test duration, and creating a test situation unlike sporting performance.[5] It has therefore been argued that self-paced tests, offering a higher ecological validity, could represent a paradigm shift in VO_{2max} testing.[20] Furthermore, GXT protocols do not allow for the typical pacing strategy used in sports that allow for an end spurt.[21] An interesting question is therefore whether higher VO_{2max} values could be attained during a simple self-paced performance test of 1-km running, allowing for sport-specific pacing compared to a traditional GXT. Therefore, the aim of this study was to compare physiological and perceptual parameters during a traditional GXT VO_{2max} test on a motorized treadmill and a 1-km self-paced running test on a non-motorized treadmill in men and women.

Methods

Participants

A total of 24sports science students (12 women: 23.7 ± 7.7 years, body height 1.68 ± 0.02 m, body mass 66.6 ± 4.3 kg and 12 men; 22.1 ± 3.1 years, body height 1.82 ± 0.06 m, body mass 75.6 ± 11.0 kg), recruited from the local university, participated in the study. The study was approved by the Norwegian Centre for Research Data and performed according to the

Declaration of Helsinki. All the participants were fully informed of the nature of the study before providing their written consent to participate.

Design

To compare the VO_{2max} obtained in the traditional GXT protocol with a 1-km self-paced performance test, a within-subjects repeated-measures design was used. The participants were instructed to maintain similar eating and sleeping habits and avoid intensive exercise 48 hours prior to the tests.

Methodology

The GXT protocol was performed on a motorized treadmill (HP Cosmos Saturn Treadmill, HP Cosmos, Nussdorf-Traunstein, Germany), recently calibrated for speed and inclination. The 1-km performance test was performed on a non-motorized treadmill (Woodway Curve, Woodway Inc, Waukesha, USA). Since all subjects had more experience running on a motorized treadmill than a non-motorized treadmill, the warm-up procedures were performed on the non-motorized treadmill on both test days. All subjects conducted both protocols with one week in-between tests at the same time of day. Furthermore, to give the participants more familiarization time with the non-motorized treadmill, all participants performed the GXT as their first test. At the onset of each test session, all participants performed a standardized warm-up procedure consisting of 5 min running at low intensity, followed by 8 × 100 m sprints at increasing intensity (60-95% of self-perceived maximal velocity) with a 1-minute active rest period in between each sprint, as previously described.[22-24] After the standardized warm-up, all participants had a 5-min rest period before the start of the GXT or the 1-km test. During both tests, VO_2 (Oxycon Pro Erich Jaeger GmbH, Hoechberg, Germany) and heart rate (HR) (Polar E600, Polar Electro, OY Kempele, Finland) were measured continuously. Blood lactate concentration (BLa) was measured before and immediately after each test by using Lactate Pro (Arkray Lactate Pro, Shinga Japan), and the rating of perceived exertion (RPE) using the 6-20 scale, was measured directly after each test. Averaging of VO_2 was performed over 15-second time frames, with the highest measurement used for further analysis. Velocity was measured continuously during the 1-km test, and the average velocity over every 100 m was calculated and used in the analysis of the pacing strategy.

The GXT was performed at 1.75% incline to mimic air resistance from over-ground running. The test protocol consisted of a stepwise, incremental test until volitional exhaustion occurred after 4–8 minutes. The test started at submaximal speeds (8 or 9 km/h for women and 11 or 12 km/h for men), depending on the previous experience and training status of the athlete. Running velocity was increased by 1-km/h per minute, with the last velocity step maintained for at least 1 min. During each test, athletes were continuously updated with VO_2 values, time, and workload, in order to motivate for true voluntary exhaustion. After finishing the test, the participants had a 10 min resting period, before walking 5 minutes at 5 km/h on the motorized treadmill, while the VO_2 apparatus was mounted again. The verification test started with 1-min at 10 km/h for all participants, followed by continuous running to exhaustion at 1 km/h higher speed than the highest speed obtained during GXT.

Seven days after the traditional test, at the same time at the day, the 1-km self-paced performance test was performed on a non-motorized treadmill. The participants were instructed to finish the test at the shortest possible time and were motivated by the test leader counting down every 10m the final 100m of the test.

Statistical analysis

The Shapiro-Wilk test and comparison of histograms were used to assess the normality of the distribution of the variables, and all data are presented as mean ± SD. A 2-way repeated-measures analysis of variance was used for analyzing the different physiological factors (VO_2, HR, and BLa concentration) and performance (time and running velocity) between the two test protocols. To investigate if potential sex differences existed, a 2-way (sex and test protocol) analysis of variance with repeated measurements upon test protocol was used. A 2-way repeated-measures analysis of variance was also used to investigate the development of running velocity during the 1-km test (sex × mean velocity over each 100 m). A Wilcoxon signed rank test was used to analyze the RPE values between the two tests. In cases where the Mauchly test of sphericity indicated that the assumption of sphericity was violated, a Greenhouse-Geisser correction was performed. The statistical significance level was set at $p < 0.05$. Effect size was evaluated with η^2 (ETA partial squared), where $0.01 < \eta 2 < 0.06$ constitutes a small effect, $0.06 < \eta 2 < 0.14$ constitutes a medium effect, and $\eta 2 > 0.14$ constitutes a large effect. The analyses were carried out with SPPS 24 software for Windows (SPSS Inc., Chicago, IL) and Office Excel 2016 (Microsoft Corporation, Redmond, WA).

Results

No significant difference in maximal oxygen uptake was found between the GXT and the verification test (51.8 ± 8.8 vs. 51.6 ± 7.4 ml/kg/min; F = 0.9, $P = .77$, $\eta^2 = 0.05$). For the total sample, higher VO_{2max} was found in the 1-km test compared to GXT (table 1, F = 4.8, $P = .040$, $\eta^2 = 0.18$). However, a higher VO_{2max} value was only found for men ($P = .027$), while no significant differences were found for the women between the two tests (Figure 1, $P = .70$). The BLa was higher in the 1-km test than GXT (F = 7.6, $P = .023$, $\eta^2 \geq 0.46$), while average running velocity was higher in GXT (F = 198, $P < .001$, $\eta^2 = 0.9$). No differences was found for the maximal HR (F = 1.9, $P = .18$, $\eta^2 = 0.08$) and RPE ($P = .414$) between GXT and 1-km test (Table 1).

TABLE 1

FIGURE 1

Men achieved significantly higher VO_{2max} and running velocities in both tests, and higher BLa after the 1-km test compared to women (F ≥ 10.5, $P \leq .009$, $\eta^2 \geq 0.22$). No sex differences were found for heart rate and RPE (F ≤ 0.7, $P \geq .43$, $\eta^2 \leq 0.06$). For the total sample, the running time was shorter for the 1-km test than GXT (F = 29.4, $P < .001$, $\eta^2 = 0.57$). However, these differences were only found in men ($P = .027$, Figure 1). No sex differences were found in the time spent at GXT, but men performed the 1-km test at shorter times than women ($P < 0.001$, table 1).

Men achieved higher running velocities than women during each 100 m in the 1-km test (F = 61, $P < 0.001$, $\eta^2 = 0.74$, figure 2). Furthermore, men and women showed approximately similar pacing strategies (F = 3.1, $P = 0.09$, $\eta^2 = 0.13$), with a decrease in the running velocity between 300–400, 400–500 and an increase in velocity from 900–1000 m for both sexes (Figure 2, F = 198, $P < 0.001$, $\eta^2 = 0.90$). In addition, women reduced the velocity from 100–200m.

FIGURE 2

Discussion

This study compared physiological and perceptual parameters during a traditional GXT VO_{2max} test on a motorized treadmill and a 1-km self-paced running test on a non-motorized treadmill. The main findings of the study were that the 1-km test produced significantly higher VO_{2max} and blood lactate values than the GXT. However, when controlling for sex, these differences were only present in men. The peak running velocity was higher in the GXT than in the 1-km test. Furthermore, men had higher VO_{2max} values and running velocities than women in both tests. However, men and women used approximately similar pacing strategies during the 1-km test.

In total, 16 of the 24 participants in the study elicited higher VO_{2max} values during the 1-km running test than in the traditional GXT, which was also verified with an additional supramaximal stage. The mean ~3% higher VO_{2max} produced in the 1-km test is smaller than the 5 and 8% differences observed in previous studies using self-paced protocols compared to GXT.[8,10] However, this is higher than the 2% differences suggested as a minimum significant change in VO_{2max} in experimental studies.[25] Therefore, the observed difference between test protocols could be considered physiologically significant, and indicate that VO_{2max} may be underestimated using a traditional GXT.

The suggested reason for the increase in VO_{2max} found in self-paced tests is an increased oxygen extraction of the working muscles. Because no difference was found in the maximal HR elicited in the two test protocols it is likely that the higher VO_{2max} in the 1-km test occurred due to higher oxygen extraction by the working muscles. A mechanism that may influence the oxygen extraction in this case, could be the strength of each muscle contraction as well as recovery time between contractions, which can limit muscle blood flow through local occlusion.[26,27] Subsequently, this may also lead to increased blood flow velocity in the recovery phase, reducing oxygen transit time and thus extraction.[26] In the GXT, treadmill speed increases with each stage, leading to decreased recovery time between steps and increased muscle recruitment, leading to increased local occlusion. Therefore, higher VO_2 values may be limited by the muscle oxygen extraction not being optimal. Furthermore, it is likely that the relatively low submaximal running speed observed in the 1-km-test from 500–900m would reduce muscle activation and provide optimal physiological conditions that would allow for potentially higher levels of muscle oxygen extraction than the forced increased intensity during the GXT. Furthermore, the sport-specific nature of the 1-km test would allow the participants to utilize their optimal pacing strategy and spatiotemporal pattern.

An interesting finding of this study was that the observed test differences were only significant in men. Men also showed higher BLa after the 1-km test compared to women. Since small differences were found in the pacing strategies between men and women, significantly increasing the velocity during the final 100m, the reason for the higher BLa in men could be due to the shorter duration of men's test (table 1), inducing a larger anaerobic energy turnover with subsequent higher production of lactate. The resistance from the non-motorized treadmill could also be relatively larger for women than men, increasing the local occlusion of blood flow and oxygen extraction. In addition, men and women were not matched for fitness level and training status. The average VO_{2max} for women in the present study was about 39% higher than sedentary young women, while VO_{2max} in the men was 45% higher than sedentary men of similar age.[28] Furthermore, the 30% sex difference in VO_{2max} in this study was approximately twice the difference between male and female elite endurance trained athletes.[6] Therefore, it is likely that, since the men were at a higher fitness level than the women, this may have influenced the results. Future studies should investigate the influence of sex in different VO_{2max} protocols in performance-matched men and women.

Practical applications

This study indicated that a self-paced 1-km performance test could serve as an alternative to the traditional GXT protocol in the assessment of VO_{2max}. Furthermore, due to the more sports-specific nature of the 1-km test, it could provide more valuable information for the athlete and coaches related to possible running performance.

Conclusions

Significantly higher VO_{2max} was measured in a 1-km performance test on a non-motorized treadmill compared to a traditional GXT. This could be due to the more sports-specific nature of the 1-km test allowing the participants to use their preferred pacing strategy and spatiotemporal patterns. The self-paced 1-km performance test on a non-motorized treadmill could serve as an alternative in the assessment of VO_{2max}. However, since significant differences between the tests only were observed in male students, future studies should investigate the influence of sex in different VO_{2max} protocols in performance-matched men and women.

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Tables

Table 1. Maximal (Mean ± SD) Heart rate, lactate concentration (BLa), rate of perceived exertion (RPE) and oxygen uptake (VO_{2max}) at the end of the incremental VO_{2max} test and the 1-km run on the non-motorized treadmill.

	Graded exercise test			**1-km test**		
	Total (n = 24)	Men (n = 12)	Women (n = 12)	Total (n = 24)	Men (n = 12)	Women (n = 12)
VO_{2max} (mL/kg/min)	51.8 ± 8.8	58.1 ± 8.0	45.5 ± 3.4†	53.2 ± 9.9*	60.6 ± 8.1*	45.9 ± 4.7†
Heart rate (beat/min)	195 ± 10	199 ± 5	192 ± 12	193 ± 9	194 ± 6	192 ± 11
RPE (6-20)	19.4 ± 0.9	19.5 ± 0.8	19.3 ± 1.1	19.9 ± 0.3	20.0 ± 0.0	19.8 ± 0.5
BLa (mmol/L)	11.1 ± 2.2	11.9 ± 2.2	10.3 ± 2.1	11.9 ± 1.8*	13.1 ± 1.7	10.7 ± 2.1†
Running velocity (km/h)	15.7 ± 2.7	17.8 ± 2.2	13.6 ± 1.0†	13.0 ± 2.8*	15.5 ± 1.6*	10.5 ± 1.0*†
Test time (s)	352 ± 41	350 ± 43	355 ± 40	290 ± 62*	235 ± 23*	344 ± 31†

* indicates a significant difference for this parameter between the two tests on a $p<0.05$ level.
† indicates a significant difference between men and women for this parameter on a $p<0.05$ level.

Figure Legends

Figure 1. Difference in maximal oxygen uptake between the graded exercise test and the 1-km test per participant, with average change per gender indicated by a horizontal line and the 95% confidence intervals (grey lines).

Figure 2. Development of the running velocity during the 1-km test (Mean running velocity per 100m ± SD) → indicates a significant difference in running velocity from the previous 100m *(P* < .05).

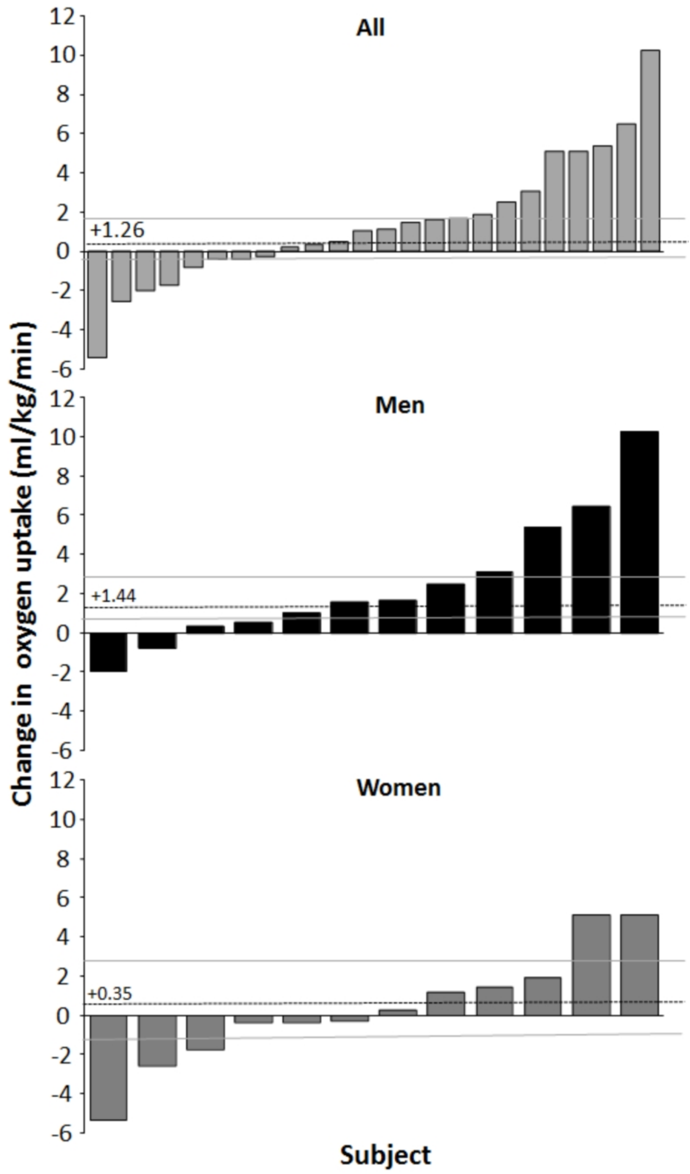

Figure 1. Difference in maximal oxygen uptake between the graded exercise test and the 1-km test per participant, with average change per gender indicated by a horizontal line and the 95% confidence intervals (grey lines).

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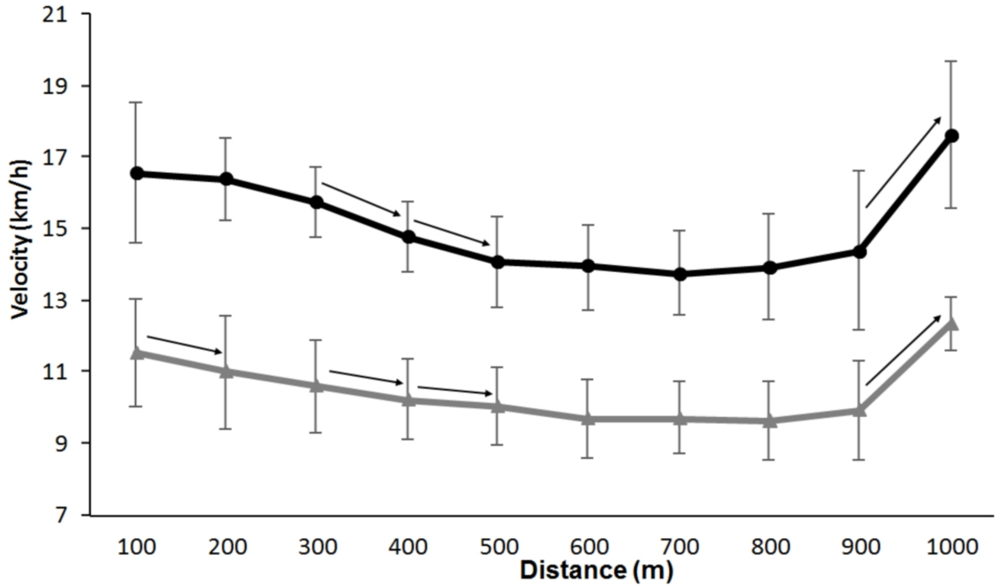

Figure 2. Development of the running velocity during the 1-km test (Mean running velocity per 100m ± SD)
→ indicates a significant difference in running velocity from the previous 100m ($P < .05$).

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