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Human Kinetics
BRIEF REPORT

Energetics and Mechanics of Steep Treadmill Versus Overground Pole Walking: A Pilot Study

Nicola Giovanelli, Lara Mari, Asia Patini, and Stefano Lazzer

Purpose: To compare energetics and spatiotemporal parameters of steep uphill pole walking on treadmill and overground. ***Methods:*** First, the authors evaluated 6 male trail runners during an incremental graded test on a treadmill. Then, they performed a maximal overground test with poles and an overground test at 80% (OG_{80}) of vertical velocity of maximal overground test with poles on an uphill mountain path (length = 1.3 km, elevation gain = 433 m). Finally, they covered the same elevation gain using poles on a customized treadmill at the average vertical velocity of the OG_{80}. During all the tests, the authors measured oxygen uptake, carbon dioxide production, heart rate, blood lactate concentration, and rate of perceived exertion. ***Results:*** Treadmills required lower metabolic power (15.3 [1.9] vs 16.6 [2.0] W/kg, $P = .002$) and vertical cost of transport (49.6 [2.7] vs 53.7 [2.1] J/kg·m, $P < .001$) compared with OG_{80}. Also, oxygen uptake was lower on a treadmill (41.7 [5.0] vs 46.2 [5.0] mL/kg·min, $P = .001$). Conversely, respiratory quotient was higher on TR_{80} compared with OG_{80} (0.98 [0.02] vs 0.89 [0.04], $P = .032$). In addition, rate of perceived exertion was higher on a treadmill and increased with elevation ($P < .001$). The authors did not detect any differences in other physiological or in spatiotemporal parameters. ***Conclusions:*** Researchers, coaches, and athletes should be aware that steep treadmill pole walking requires lower energy consumption but same heart rate and rate of perceived exertion than overground pole walking at the same average intensity.

Keywords: steep walking, vertical km, uphill training, mountain running, trail running

The use of laboratory equipment (eg, treadmill) is considered the gold standard for exercise testing[1] and can be used for specific training in the athletic population. However, the athletic action on these devices may have different metabolic and biomechanical requirements compared with outdoor gesture. Nevertheless, the literature presents different results which may be influenced by the type and smoothness of the surface.[2–5] In fact, walking on rough terrain required higher cost of transport (CoT) than walking on smooth terrain as reported by Gast et al.[5] In addition, level treadmill and overground walking had results very similar in one group of young adults; whereas, another group reported kinematic differences between the 2 conditions.[6,7] From an energetic point of view, it is reported that walking on a treadmill required higher energy cost than overground walking[8] and similar results were reported by Parvataneni et al.[9] The latter authors concluded that treadmill walking was similar to overground walking from a kinematic point of view but different from an energetic perspective.

We found little information about the comparative use of poles during treadmill activities and overground walking. Poles are used in Nordic walking (NW), in which users adopt a specific gait pattern (diagonal stride). They are also used in competitive events, such as trail/sky running, particularly on uphill sections. Church et al[10] claimed that pole walking on a treadmill "does not accurately represent natural walking pole mechanics" and suggested that the results of previous studies of NW were not truly representative of the overground technique used by most people who engage in NW. Comparatively, Dechman et al[11] reported that NW required higher heart rate (HR), oxygen uptake ($\dot{V}O_2$), energy expenditure, and rate of perceived exertion (RPE) when it is performed overground. Because NW is typically performed on flat or slightly uphill/downhill terrain, whereas trail/sky running is performed on steep inclines, the attention of researchers, coaches, and athletes was recently directed to steeper slopes[12–16] and particularly to the use of poles on these inclines.[14] The optimal mountain trail incline to minimize the vertical CoT is ~20° to 35°[12]; and, in this range of gradients, the use of poles is recommended.[14] Consequently, the use of a treadmill at this incline could be useful for reflecting the outdoor performance and testing or training trail runners. However, there are no studies that have analyzed the metabolic and spatiotemporal characteristics of pole walking between treadmill and overground at these inclines.

This study compares the energetics and mechanics of uphill pole walking between treadmill and overground. Based on the results of Dechman et al,[11] the authors hypothesized that on a treadmill measures of CoT, HR, and RPE would be lower compared with overground. In addition, participants would use a longer stride length and lower stride frequency on a treadmill.

Methods

Based on the results of Dechman et al,[11] the authors calculated that an alpha error of .05 yielded a statistical power of 0.98 in 5 subjects (G*Power). Thus, 6 male trail runners (Table 1) participated in the study. These subjects were recruited from a group of athletes who participated in another study and offered their availability for further testing. They were recruited from a local running club and were all familiarized with the use of poles. All subjects provided informed consent. The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the institutional review board of the University of Udine (IRB 52_2020, 11/20/2020).

The authors are with the Dept of Medicine, University of Udine, Udine, Italy; and the School of Sport Science, Udine, Italy. Giovanelli (nicola.giovanelli@uniud.it) is corresponding author.

Experimental Design

For characterization, participants were first assessed during an incremental graded test on a treadmill without poles. They started at the speed of 5 km/h and a slope of 10%. Every minute, the slope was increased by 2% until 24%. Beyond 24%, the speed was increased by 0.4 km/h until volitional exhaustion. With this protocol, the vertical velocity (v_{vert}) increased linearly by ~93 m/h per minute. On the same day, participants performed pole walking on a steep treadmill. On the following days, they performed: (1) a maximal overground test with poles where the authors asked them to perform at their best throughout the entire trial and (2) an overground test at 80% (OG_{80}) of v_{vert} of maximal overground test with poles on the same uphill mountain path (length = 1.3 km, elevation gain = 433 m, average incline = 19.5°, maximum incline = 29.7°; Figure 1). The surface of the trail was a typical rough forest floor with rocks and brush, on which the participants had to be careful to place their feet and poles in the correct position. Finally, they covered the same elevation gain using poles on a customized treadmill (TR_{80}; see Giovanelli et al[14]) at the average slope of the mountain path and at the average v_{vert} of the OG_{80}. All tests were separated by at least 48 hours of rest or light exercise.

Table 1 Anthropometrics and Physiological Characteristics of the Participants (n = 6) Obtained During the Incremental Graded Test on a Treadmill Without Poles

	Mean (SD)
Age, y	37.8 (7.7)
Body mass, kg	70.2 (6.5)
Stature, m	177.5 (5.8)
ITRA performance index[a]	664.0 (89.3)
$\dot{V}O_2$max, mL/kg/min	62.2 (2.1)
v_{vert} maximum, m/h	1743 (109)
HR_{max}, bpm	175.7 (17.6)
RPE_{max}	19.3 (0.8)

Abbreviations: bpm, beats per minute; HR, heart rate; ITRA, International Trail Running Association; RPE, rate of perceived exertion; $\dot{V}O_2$max, maximal oxygen uptake; v_{vert}, vertical velocity.
[a]It is obtained from the best 5 scores achieved by a runner over the previous 3 years (see www.itra.run for details).

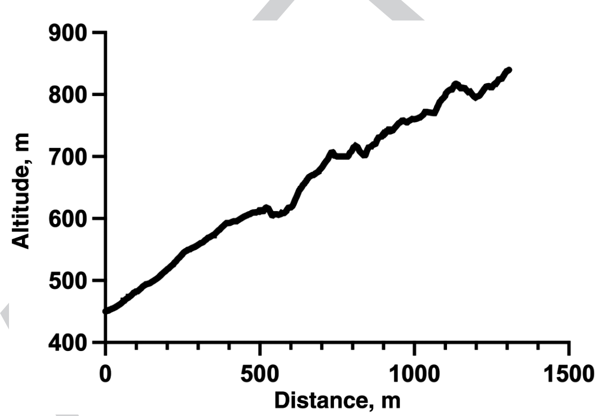

Figure 1 —

Measurements

During all the tests, $\dot{V}O_2$ and carbon dioxide production was measured using a calibrated metabolic unit (K5; Cosmed, Italy). Afterward, the authors calculated metabolic power using the formula proposed by Peronnet and Massicotte[17] and the vertical CoT (CoT_{vert}, in J/kg·m), dividing the gross metabolic power by v_{vert}. During the tests, HR was recorded with a dedicated device (Garmin HRM-run). Before the warm-up and 1 minute after the end of the test, mixed venous blood was collected at the earlobe and the blood lactate concentration was measured (Lactate Scout 4; EKF Diagnostic, United Kingdom). During OG_{80} and TR_{80}, the authors collected RPE[18] every 100 m of elevation gain. In addition, during OG_{80} and TR_{80}, the step length and step frequency were measured using the Garmin HRM-run associated to the Garmin 245 and mean values were obtained from Garmin Connect (https://connect.garmin.com/).

Statistical Analysis

The data from the entire acquisition were measured and the mean (SD) reported. The data were analyzed using GraphPad Prism (version 9.0) with alpha set to $P \le .05$. All parameters passed the Shapiro–Wilk normality test. Due to a technical problem in the metabolic unit, the authors did not analyze the carbon dioxide production for one subject, thus reporting the Also, step length and step frequency were measured in 5 participants metabolic power, CoT_{vert}, and respiratory quotient (RQ) for 5 subjects.. The authors compared average metabolic power, blood lactate concentration, CoT_{vert}, RQ, step length, and step frequency with a paired *t* test, 2 tails. RPE was analyzed using a repeated-measures 2-way analysis of variance with the Geisser–Greenhouse correction for 2 factors (surface: overground and treadmill; elevation: 100, 200, 300, and 400 m).2

Results

Table 2 reports averaged physiological and spatiotemporal parameters of the entire TR_{80} and OG_{80} trials. The TR_{80} required lower metabolic power (15.3 [1.9] vs 16.6 [2.0] W/kg, $P = .002$) and CoT_{vert} (49.6 [2.7] vs 53.7 [2.1] J/kg·m, $P < .001$) compared with OG_{80}. Also, $\dot{V}O_2$ was lower on a treadmill (41.7 [5.0] vs 46.2 [5.0] mL/kg·min, $P = .001$; Figure 2A). Conversely, RQ was higher on TR_{80} compared with OG_{80} (0.98 [0.02] vs 0.89 [0.04], $P = .032$; Figure 2B). In addition, RPE came in higher on a treadmill and increased with elevation ($P < .001$; Figure 2C). We detected no differences ($P > .05$) in HR (Figure 2D), blood lactate concentration, and spatiotemporal parameters (Table 2).

Discussion

The main results of the present study showed that metabolic power, CoT_{vert}, and $\dot{V}O_2$ were lower when subjects walked with poles on a treadmill compared with pole walking overground. The study confirmed the findings of other authors who reported −37% of $\dot{V}O_2$ during treadmill-level NW.[11] Some authors[3,5] reported that the uneven terrain produces differences in metabolic power and speed variations which accounted for the variation in CoT in a

Table 2 Mean Physiological and Spatiotemporal Parameters of the OG_{80} and TR_{80} Pole Walking (n = 6) Trials

	OG_{80}	TR_{80}	*P*
Exercise time, min:s	23:58 (02:47)	23:58 (02:47)	—
v_{vert}, m/h	1096 (127)	1096 (127)	—
$\dot{V}O_2$, mL/min	3222 (264)	2901 (199)	**.001**
$\dot{V}CO_2$,[a] mL/min	2863 (216)	2827 (229)	.561
RQ[a]	0.89 (0.04)	0.98 (0.02)	**.032**
CoT_{vert},[a] J/kg·m	53.8 (1.9)	49.6 (2.7)	**.001**
HR, bpm	143.5 (10.3)	149.8 (16.3)	.240
BLC, mmol/L	2.2 (0.6)	2.8 (1.4)	.299
Mean RPE	11.5 (1.4)	12.2 (1.0)	**.001**
Step length,[a] m	0.53 (0.06)	0.53 (0.08)	.964
Step frequency,[a] ~~step/s~~	1.63 (0.08)	1.65 (0.21)	.792

Abbreviations: BLC, blood lactate concentration; bpm, beats per minute; CoT, cost of transport; HR, heart rate; OG_{80}, overground test at 80%; TR_{80}, customized treadmill; RPE, rate of perceived exertion; RQ, respiratory quotient; $\dot{V}CO_2$, carbon dioxide production; $\dot{V}O_2$, oxygen uptake; v_{vert}, vertical velocity.
[a]Parameters refer to n = 5.

small way.[5] However, the current study found a smaller difference (−10%) in comparison with the Dechman study. This discrepancy could be related to the different experimental design (eg, type of terrain and variations in slope) and gait pattern. Specifically, the authors tested athletes on steep but not constant uphill and allowed them to use a self-selected technique (rather than forcing them to use a diagonal stride as in NW).

The study assumed that HR would be lower during TR_{80}; whereas. this parameter was unchanged between the 2 conditions, even if it was numerically higher in TR_{80} (149.8 [16.2] vs 143.5 [10.3], $P = .240$). Four out of 6 subjects had higher HR during TR_{80}, the opposite of expectation. Other authors reported that HR was lower on a treadmill when subjects used poles.[11] Contrary to this study's hypothesis, RPE was higher on a treadmill; this is in contrast to other studies that reported a lower RPE on a treadmill at the same speed.[11] The result could be influenced by the fact that on a treadmill, the speed and incline were constant (replicating the average speed and incline of the overgound course) which could lead to higher perceived fatigue. In addition, the constant speed and incline on the treadmill could have affected the RQ which was higher on a treadmill at every time point. This result is consistent with another paper[11] in which authors reported that RQ was higher during treadmill pole walking compared with overground NW. The

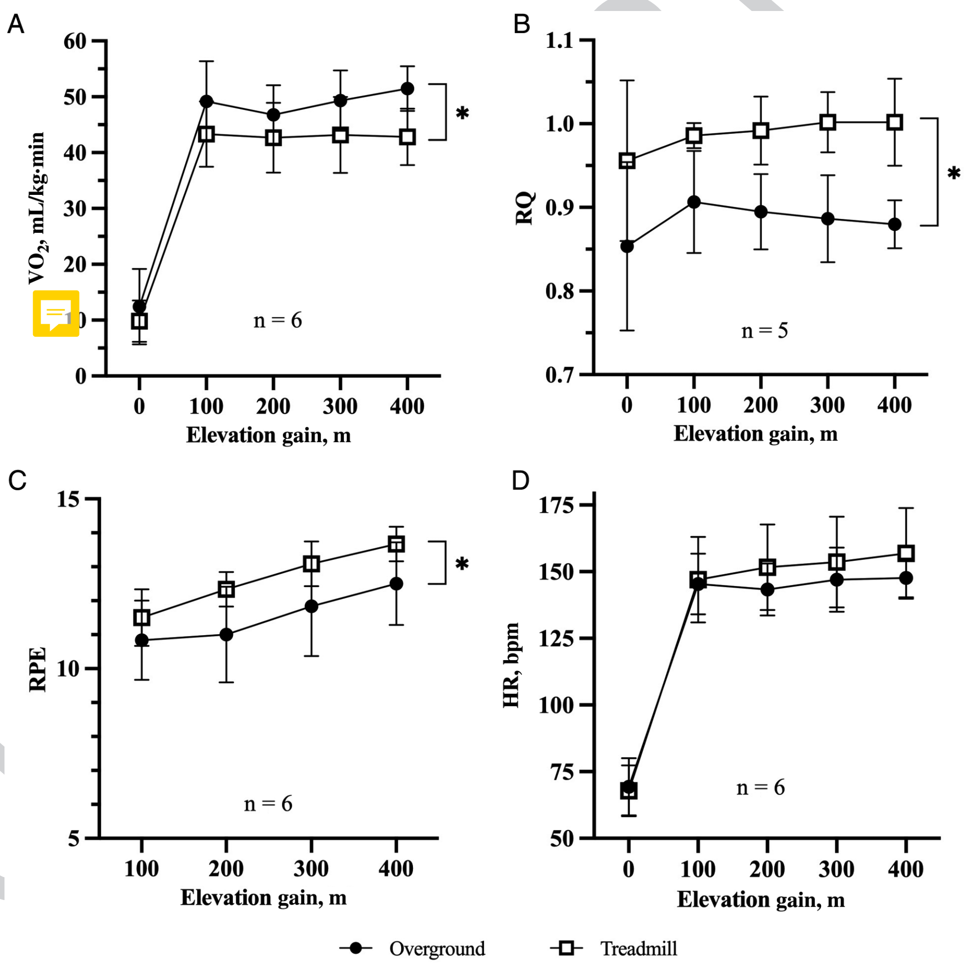

Figure 2 — (A) VO_2, (B) RQ, (C) RPE, and (D) HR as a function of elevation gain for overground (black dots) and treadmill test (white squares). *$P < .05$ between treadmill and overground pole walking. bpm indicates beats per minute; HR, heart rate; RPE, rate of perceived exertion; RQ, respiratory quotient; VO_2, oxygen consumption.

continuous variation in longitudinal speed experienced by participants during OG_{80} could explain these differences. Indeed, variations in speed/power might contribute to a lower RQ compared with a constant speed/power.[19]

Practical Applications

From the results of this pilot study, the authors hold that uphill pole walking on a treadmill is energetically less expensive than overground, but the perception and the effort required of the participants were not different. Also, contrary to the author's second hypothesis, averaged spatiotemporal parameters were not different between conditions. Therefore, researchers, coaches, and athletes using a steep treadmill as a valid device for testing or training with poles should consider that the energy demands are lower, even if other parameters are similar.

Conclusions

This is the first study in which steep pole walking is compared between overground and a treadmill. If a steep treadmill is used for testing or training, users should be aware of the difference in energy requirements between these 2 conditions. A larger sample size and more sophisticated motion analysis equipment (eg, instrumented insoles) could reveal more information about this type of exercise.

Acknowledgments

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Queries

~~Q1.~~ As per journal style, "mean ± SD" should be represented as "mean (SD)." Hence, the values are changed accordingly throughout the article. Please check and confirm.

~~Q2.~~ In the sentence beginning "The authors . . ." a word is missing after physiological. Is it measurements? Parameters?

~~Q3.~~ Please ensure author information is listed correctly here and within the byline.

~~Q4.~~ Please provide the manufacturer name and location details for "G*Power."

~~Q5.~~ Before the sentence beginning "Thus, 6 male trail runners . . ." should you explain how the calculation noted in the preceding sentence (with 5 subjects) led to 6 males participating in the study? It is not clear how this is a consequence (indicated by the word "thus") of preceding statement.

~~Q6.~~ Please provide expansion for "IRB."

~~Q7.~~ Please provide caption for Figure 1.

~~Q8.~~ In the sentence beginning "All tests . . ." can 'or' be changed to 'and light exercise'?

~~Q9.~~ Please provide city name for "EKF Diagnostic" and "Cosmed."

~~Q10.~~ Please provide the manufacturer name and location details for "GraphPad Prism."

~~Q11.~~ Please provide descriptions for bold values in Table 2.

~~Q12.~~ In the sentence beginning "However . . .", please cite the Dechman study.

~~Q13.~~ Please provide volume and page number for Ref. 15 if available.

Q1. All values are correct
Q2. Please add "measurements"
Q3. It is correct
Q4. Heinrich-Heine-Universität Düsseldorf, Düsseldorf,Germany www.psychologie.hhu.de
Q5. please change the sentence into "Due to the likelihood of drop out, we preferred to enroll 6 male trail runners (Table 1)."
Q6. Institutional Review Board
Q7. Figure 1. Course profile. See text for details.
Q8. we would prefer "or" because participants could choose between rest OR light exercise
Q9. EKF Diagnostic, Cardiff, United Kingdom)
Cosmed, Albano Laziale, Italy
Q10. GraphPad Software,San Diego, California, USA.
Q11. Please add the following sentence to the table caption: "Bold values refer to significant differences between OG^{80} and TR^{80}"
Q12. please add superscript 11 after "..with the Dechman study.[11]"
Q13. Volume 224, Issue 3,February 2021. Page number is not available