International Journal of Sports Physiology and Performance, (Ahead of Print)
https://doi.org/10.1123/ijspp.2021-0274

First Published Online: Mar. 22, 2022

Human Kinetics
ORIGINAL INVESTIGATION

Pole Walking Is Faster but Not Cheaper During Steep Uphill Walking

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***Purpose**:* The aim of this study was to compare pole walking (PW) and walking without poles (W) on a steep uphill mountain path (1.3 km, 433 m of elevation gain) at 2 different intensities: a maximal effort that would simulate a vertical kilometer intensity and a lower intensity (80% of maximal) simulating an ultratrail race. ***Methods**:* On the first day, we tested the participants in the laboratory to determine their maximal physiological parameters, respiratory compensation point, and gas exchange threshold. Then, they completed 4 uphill tests along a mountain path on 4 separate days, 2 at their maximum effort (PW_{max} and W_{max}, randomized order) and 2 at 80% of the mean vertical velocity maintained during the first 2 trials (PW_{80} and W_{80}, randomized order). We collected metabolic data, heart rate, blood lactate concentration, and rating of perceived exertion at the end of each trial. We also collected rating of perceived exertion at every 100 m of elevation gain during PW_{80} and W_{80}. ***Results**:* Participants completed the maximal effort faster with poles versus without poles (18:51 [03:12] vs 19:19 [03:01] in min:s, $P = .013$, $d = 0.08$, *small*). Twelve of the 15 participants (80%) improved their performance when they used poles. During PW_{80} and W_{80}, none of the physiological or biomechanical parameters were different. ***Conclusion**:* In the examined condition, athletes should use poles during steep uphill maximal efforts to obtain the best performance. Conversely, during submaximal effort, the use of poles does not provide advantages in uphill PW.

***Keywords**:* energetics, uphill locomotion, uphill performance, vertical km, trail running, incline, skyrunning

Recently, it was reported that the use of poles during walking (PW) on a steeply inclined treadmill (>15°) is metabolically advantageous compared with walking without poles (W).[1] That study explored inclines that had not been previously studied during PW, and the data suggested that athletes who compete in mountain trail/sky running, and particularly in vertical kilometer (VK) races, should use poles to optimize their performance (ie, finish the race in shorter time).

However, a few criticisms may be made about that study. First, laboratory treadmill conditions might not reflect the real-life outdoor situation. In fact, the energetics and mechanics of locomotion on rough terrain are different than on a smooth treadmill.[2,3] Furthermore, Church et al[4] reported that the poling technique on a moving treadmill belt does not mimic the natural poling technique used overground. Such differences may be especially pronounced when subjects walk on mountain paths, that present uneven surfaces. More specifically, Dechman et al[5] reported that overground Nordic walking required higher $\dot{V}O_2$ (~37%), energy expenditure (~33%), and heart rate (HR; ~22%) than Nordic walking on a treadmill. Second, many authors[1,6,7] adopted a protocol comprising short 4- to 5-minute trials that may not reflect the demands of a "real" uphill training or competition that has much longer durations and in which the pace may change during the trial depending on various factors (eg, trail surface and incline). Indeed, the metabolic and mechanical changes that occur during a prolonged uphill competition may not be revealed during a 5-minute experimental trial (at constant speed and incline), making such experimental results irrelevant for athletes.[8,9] It should be noted that the VK world records are 28 minutes and 53 seconds for men and 34 minutes and 44 seconds for women; much longer than 5 minutes. Third, and maybe most important, none of the published research to date has compared PW and W at maximum intensities, thus there is no scientific evidence as to whether PW allows athletes to move faster than W or not.

Only a few studies on the use of poles have been conducted in an outdoor environment,[4,10,11] and we have found no studies that analyzed the performance with and without poles in mountain trail running/skyrunning events (for an explanation of these disciplines, see Scheer et al[12]). Grainer et al[11] analyzed the use of poles in a natural mountain environment and found that PW elicited both higher HR and energy expenditure than W, whereas the rate of perceived exertion (RPE) were similar. Furthermore, step frequency was slower and step length was longer when subjects used poles. These results agree with most other studies that reported higher energy expenditure (ie, cost of transport, CoT) and/or oxygen consumption when participants used poles, as reviewed by Hawke and Jensen.[13] However, in the Grainer et al study, participants self-selected speed in both conditions and when they walked with poles the speed was faster, so it is not clear if the kinematic changes were due to poles or speed. Furthermore, the energy expenditure was only estimated from an armband, and the uphill slope was only moderate (~5.7°). Although the technique used during Nordic walking is well defined (diagonal stride), during trail and sky running events, athletes do not use one specific technique. The focus of competitors is on performance not "proper" pole technique and so the poling technique varies with the terrain.

Overall, the scientific literature does not yet provide answers to 2 questions important to competitive mountain trail/sky runners: (1) Is it beneficial to use poles during a short maximal effort (eg, 20–30 min) in which the aim is to achieve the shortest time? and (2) Is it beneficial to use poles during long-duration events at submaximal intensities used during ultramarathon trail races in

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which the aim is to minimize energy consumption, perceived effort, and muscle damage?

The aim of this study was to compare PW and W on a steep uphill mountain path at 2 different intensities: a maximal effort for ~400 m of elevation gain that would simulate the effort maintained during a VK, and a lower intensity simulating an ultra-trail race. Although Grainer et al[11] reported higher energy consumption during PW, based on our previous research on steep incline locomotion,[1] we hypothesized that PW would be less metabolically demanding than W. By reducing metabolic cost, PW should enhance performance during the maximum effort.

Methods

Participants

Based on Grainer et al,[11] we estimated that the smallest sample size for having a statistical power of 80% with an alpha error of .05 and a beta error of 0.20 using paired *t* tests (PW vs W) would be 12 subjects. Thus, we enrolled 15 mountain running male athletes, all experienced with the use of poles (Table 1). They provided informed consent 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).

Table 1 Anthropometrical and Physiological Parameters of the Participants (N = 15)

	Mean (SD)
Age, y	32.0 (8.1)
Body mass, kg	68.6 (5.3)
Stature, m	1.75 (0.05)
ITRA points	638.0 (118.2)
$\dot{V}O_2$, mL·kg^{-1}·min^{-1}	67.6 (8.0)
v_{vert} max, m/h	1827 (233)
HR_{max}, beats·min^{-1}	184.6 (10.7)
RPE max	19.5 (0.9)
Respiratory compensation point	
$\dot{V}O_2$, mL·kg^{-1}·min^{-1}	56.9 (7.8)
$\dot{V}O_2$, %max	84.1% (3.1%)
HR, beats·min^{-1}	173.9 (12.5)
HR, %max	94.2% (2.3%)
v_{vert}, m/h	1509 (205)
v_{vert}, %max mL·kg^{-1}·min^{-1}	82.6% (3.2%)
RPE	16.9 (1.4)
Gas exchange threshold	
$\dot{V}O_2$, mL·kg^{-1}·min^{-1}	46.6 (6.1)
$\dot{V}O_2$, %max	69.0% (4.0%)
HR, beats·min^{-1}	157.3 (14.7)
HR, %max	85.2% (4.9%)
v_{vert}, m/h	1217 (157)
v_{vert}, %max	62.8% (3.3%)
RPE	14.4 (1.5)

Abbreviations: HR, heart rate; ITRA, International Trail Running Association; RPE, rating of perceive exertion; $\dot{V}O_2$, oxygen consumption; v_{vert}, vertical velocity. Note: The parameters obtained during the incremental test corresponding to the maximum respiratory compensation point and GET are presented.

Experimental Design

Participants performed 5 test sessions separated by at least 2 days of rest or active recovery. The first day we tested them in the laboratory to determine their maximal physiological parameters, the respiratory compensation point (RCP), and gas exchange threshold.[14] Then, they completed 4 uphill tests along a mountain path in 4 separated days. They performed 2 of these trials at their maximum effort (PW_{max} and W_{max}, randomized order), whereas the other 2 at 80% of the mean vertical velocity (v_{vert}) maintained during the first 2 trials (PW_{80} and W_{80}, randomized order).

Incremental Uphill Test

We determined maximal oxygen uptake ($\dot{V}O_2$max), maximal heart rate (HR_{max}), and maximal v_{vert} (v_{vert}max) during a graded exercise test on a treadmill (Skillrun, Technogym) under medical supervision. Participants performed this test without poles and could walk or run as they liked. We determined the RCP and gas exchange threshold with the *V*-slope method.[14] After a 5-minute warm-up at a self-selected speed and slope, athletes started the test at the speed of 5 km/h and a slope of 10%. Every minute, the slope increased by 2% until 24%. Beyond 24%, the speed increased by 0.4 km/h until volitional exhaustion of the subject. We choose this protocol because it allowed to increase the vertical velocity linearly by ~93 m/h every minute. During this test, we measured the rates of oxygen uptake ($\dot{V}O_2$) and carbon dioxide production ($\dot{V}CO_2$) using a wearable metabolic unit (K5; Cosmed). We calibrated the volume and gas analyzers before every test using a 3-L calibration syringe and calibration gas (16.00% O_2 and 5.00% CO_2), respectively. In addition, we recorded HR with a dedicated device (Garmin HRM-run). Before the warm-up and 1 minute after the end of the test, we collected mixed venous blood at the earlobe and measured the blood lactate concentration (BLC; Lactate Scout 4; EKF Diagnostic).

Outdoor Tests

During all trials, athletes wore the same metabolic unit and HR belt as above, together with a sport watch (Garmin 245). All the tests were separated at least by 2 days of active recovery (1 h <70% of HR_{max}) or rest. All the tests were performed on the same mountain path (length: 1.3 km, elevation gain: 433 m, average incline: 19.5°, and max 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. We tested the participants in stable weather conditions (10.3°C [6.1°C], 51.3% [9.8%] relative humidity). Before PW_{max} and W_{max}, we instructed the participants to perform their best. At the end of each test, we measured total time and RPE (see below).

After the 2 maximum tests, we calculated the 80% of the mean v_{vert} maintained in the PW_{max} and W_{max} for each participant. Then, they performed PW_{80} and W_{80} at this v_{vert}. To maintain the target v_{vert}, we marked the trail every 25 m of elevation gain and an experienced investigator (who is also an athlete) walked ahead of each subject to pace them. The investigator asked the participants to rate their perceived exertion every 100 m of elevation gain.

Before and after all 4 trials, we measured BLC. In addition, during all 4 trials, we measured the step length, step frequency, and contact time via the Garmin HRM-run associated to the Garmin 245 and the mean values were obtained from Garmin Connect (https://connect.garmin.com/).

Pole Length and PW Technique

Participants were free to use their own poles adjusted to their preferred pole length. However, we suggested that they adopt a pole length previously recommended for steep uphill walking (ie, ~58% of height's subjects[1]). Nevertheless, we did not force them to change pole length and the average pole length used corresponded to 67.3% (4.6%) of individual height. Subjects self-selected their PW technique to better cope with variations in terrain.

Metabolic and Biomechanical Analysis

For all trials, we averaged the data of the entire duration of the trial, and we used mean values for the statistical analysis. We calculated gross metabolic power (in W/kg) using the equation proposed by Peronnet and Massicotte.[15] Afterward, we calculated the vertical cost of transport (CoT_{vert}, in J/kg·m) with and without poles by dividing the gross metabolic power by v_{vert}. Also, we calculated the diagonal cost of transport (CoT_{diag}, in J/kg·m) with and without poles by dividing the gross metabolic power by average diagonal velocity.

Perceived Exertion

During the incremental test, we asked the subjects to rate their overall perceived exertion every minute by using the Borg 6 to 20 Scale.[16]

During PW_{max} and W_{max}, we asked the subjects to evaluate their RPE at the end of each trial, whereas during PW_{80} and W_{80}, we collected the RPE every 100 m of elevation gain. In all occasions, an investigator showed a printout of the Borg scale to the participant who expressed his rating.

Statistical Analysis

We analyzed the data using GraphPad Prism (version 9.0; GraphPad Software) with alpha set to $P \le .05$. We performed the ROUT method (Regression and OUTlier removal) with a $Q = 1\%$ to detect any outliers in all parameters.[17] All parameters passed the Shapiro–Wilk normality test, thus for PW_{max} and W_{max} we compared the exercise time, RPE, BLC, and CoT_{vert} with and without poles with 2-tailed paired *t* tests. Also, we calculated the effect sizes using the Cohen *d* ($0 < d < 0.20$, *small*; $0.20 < d < 0.50$, *medium*; and $0.50 < d$, *large*).

Due to a technical problem with the Cosmed K-5 device, we only obtained metabolic data for 13 subjects for the PW_{80} and W_{80} trials. We compared the averaged values for BLC, CoT_{vert}, and biomechanical parameters with a 2-tailed paired *t* test. RPE was analyzed using a repeated-measures 2-way analysis of variance with the Geisser–Greenhouse correction for 2 factors (gait: PW_{80} and W_{80}; elevation: 100, 200, 300, and 400 m). Also, CoT_{vert} of all 4 trials was compared with a mixed-effects model with 2 factors (gait: PW and W; intensity: max and 80%). Finally, the PW_{max} and W_{max} results were compared with those of the incremental test using a repeated-measures 1-way analysis of variance analysis, with the Geisser–Greenhouse correction.

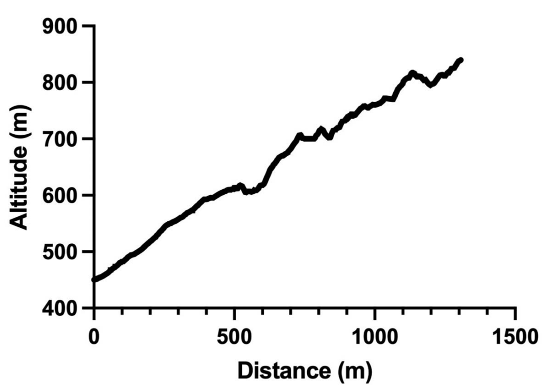

Figure 1 — Course profile. See text for details.

Results

PW_{max} and W_{max}

Subjects completed the 1.3-km uphill course faster with poles versus without poles (18:51 [03:12] vs 19:19 [03:01] in min:s, $P = .013$, $d = 0.08$, *small*). Twelve of the 15 participants (80%) improved their performance when they used poles (Figure 2A and 2B). Consequently, the v_{vert} during PW_{max} was faster (1409.5 [210.3] vs 1375.5 [212.3] m/h, $P = .014$, $d = 0.08$, *small*). However, no other parameters were different between the 2 conditions ($P > .05$) (Table 2).

PW_{80} and W_{80}

The average times was 23:56 (03:43) and 23:57 (03:45) minutes: seconds for PW_{80} and W_{80}, respectively ($P = .540$) corresponding to a v_{vert} of 1109.7 (173.4) and 1109.5 (174.5) m/h for PW and W ($P = .760$) (81.4% [1.7%] and 82.4% [1.8%] of the mean v_{vert} maintained during PW_{max} and W_{max}, respectively). None of the physiological or biomechanical parameters were different between PW and W conditions during the submaximal trials (Table 2).

Vertical Cost of Transport

Although the metabolic power consumption was of course grater in the maximal trials, the mixed-effects model revealed that the CoT_{vert} was not different between intensities (max vs 80%, $P = .128$) or gaits (PW vs W, $P = .426$) (Figure 3 and Table 2).

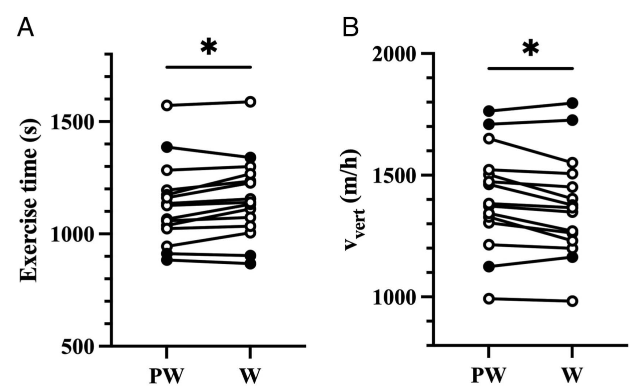

Figure 2 — (A) Elapsed time and (B) vertical velocity in the maximal PW and W test. Athletes who were faster without poles are shown in black. *$P < .05$ between conditions. PW indicates pole walking; v_{vert}, vertical velocity; W, walking without poles.

Table 2 Exercise Time and Physiological Parameters of the Outdoor Test

	PW_{max} (n = 15)	W_{max} (n = 15)	*P*	PW_{80} (n = 13)	W_{80} (n = 13)	*P*
Exercise time, min:s	18:51 (03:12)	19:19 (03:01)	**.013**	23:56 (03:43)	23:57 (03:45)	.540
v_{vert}, m/h	1409 (210)	1375 (212)	**.014**	1110 (173)	1110 (174)	.760
v_{diag}, (m/s	1.18 (0.18)	1.15 (0.18)	**.014**	0.93 (0.14)	0.93 (0.15)	.760
$\dot{V}O_2$, mL/min	4058 (553)	3942 (565)	.149	3151 (545)	3157 (515)	.938
$\dot{V}CO_2$, mL/min	3862 (569)	3801 (565)	.422	2738 (509)	2754 (473)	.825
$\dot{V}O_2$, mL·kg^{-1}·min^{-1}	59.3 (8.0)	57.7 (9.0)	.149	46.1 (9.3)	46.1 (8.9)	.977
CoTvert, J/kg·m	54.6 (2.8)	54.5 (2.3)	.848	54.1 (2.1)	53.0 (3.5)	.172
CoTdiag, J/(kg·m)	18.2 (0.9)	18.1 (0.8)	.899	18.0 (0.8)	18.1 (0.8)	.170
HR, beats·min^{-1}	174.2 (9.6)	173.5 (9.5)	.096	150.5 (12.8)	150.5 (11.9)	>.999
BLC, mMol/L	7.7 (2.9)	7.8 (2.7)	.857	2.1 (0.6)	2.2 (0.6)	.500
RPE	18.8 (1.3)	18.8 (0.9)	.924	11.5 (0.7)	11.9 (0.9)	.541
Step length, m	0.63 (0.13)	0.59 (0.11)	.081	0.58 (0.08)	0.60 (0.08)	.205
Step frequency, Hz	1.92 (0.30)	1.96 (0.33)	.286	1.66 (0.15)	1.68 (0.2)	.385

Abbreviations: BLC, blood lactate concentration; CoT_{diag}, diagonal cost of transport; CoT_{vert}, vertical cost of transport; HR, heart rate; PW, pole walking; RPE, rating of perceive exertion; v_{vert}, vertical velocity; W, walking without poles. Note: *P* represents the results of the *t* test between PW and W at maximal intensity and 80% of maximal intensity. RPE in PW_{80} and W_{80} resulted from the 2-way analysis of variance and refers to gait factor. The values are presented as mean (SD). Bold values denote $P < .05$.

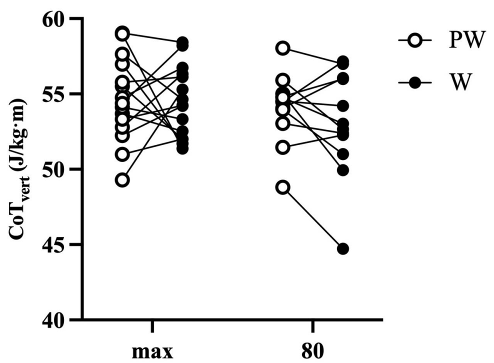

Figure 3 — The CoT_{vert} during PW_{max}, W_{max}, PW_{80}, and W_{80}. CoT_{vert} indicates vertical cost of transport; PW, pole walking; W, walking without poles.

PW_{max} and W_{max} Versus RCP Values

The average intensities maintained by the participants during PW_{max} and W_{max} were not different from the RCP identified during the incremental test. The $\dot{V}O_2/kg$ and HR measured during PW_{max} and W_{max} were not different (P = .099 and P = .765 for $\dot{V}O_2/kg$ and HR, respectively) (Figure 4A and 4B) than $\dot{V}O_2/kg$ and HR corresponding to RCP even though the v_{vert}s were different (P < .001). Compared to the v_{vert} values corresponding to RCP detected during the incremental test, the v_{vert} values during the trail tests were 6.7% (5.4%) and 9.0% (4.8%) slower for PW_{max} and W_{max}, respectively (Figure 4C). Also, the $\dot{V}_E$ was greater ($P < .001$) during PW_{max} and W_{max} compared to $\dot{V}_E$ at RCP (+24.5% [14.0%] and +21.5% [12.1%] for PW_{max} and W_{max}, respectively). These higher values were due to the higher (P < .001) respiratory frequency during PW_{max} and W_{max} (+28.5% [11.2%] and +26.3% [11.9%] for PW_{max} and W_{max}, respectively), whereas tidal volume did not differ. Also, RPE was higher (P < .001) during PW_{max} and W_{max} compared to the RPE corresponding to RCP.

Discussion

The main results of the present study are that, in a group of expert trail runners: (1) poles improves maximum performance on a steep incline and (2) during submaximal steep uphill walking, the metabolic CoT along with other metabolic and biomechanical parameters were not different between walking with/without poles.

As we hypothesized, during the outdoor test, PW_{max} averaged 2.6% (3.4%) faster than W_{max}. In fact, 12 out of 15 participants improved their performance when they used poles. We are confident that the athletes performed at their best in both trials. Indeed, none of the physiological parameters or RPE were significantly different between the 2 tests. However, the maximum performance improvement was small but in line with our previous study in which we reported a ~2.5% savings in metabolic power when using poles[1] at a slightly lower intensity (ie, 80% of v_{vert} at RCP). The difference in performance time was –28 (38) seconds, and it would be a significant improvement for high-level competitive athletes. For example, in the 2020 Italian VK national championships, the top 6 athletes finished within 32 seconds of each other (www.kilometroverticalelagunc.it). In that race, the use of poles is forbidden, and of course the elevation gain is 1000 m (ie, more than double compared with the segment that we used). Interestingly, in our study the 2 fastest athletes did not benefit by the use of poles. These results might be expected because they are among the best uphill racers in Italy (one of them was second in VK national championships). Indeed, being their level very high, they were able to run in the less steep sections during the PW_{max} and W_{max} tests. Likely, running with poles may decrease the performance by increasing the CoT due to the added weight in the hands, even if Foissac et al[7] reported no effects of carrying poles without using them during walking. The use of poles may only be advantageous when athletes use a walking gait. For example, in a previous study, authors reported that at fastest analyzed speed (>2.22 m/s) subjects had a higher CoT when they walked with poles.[1] At a similar treadmill belt speed (2.14 m/s), CoT was lower when running[18] suggesting that if the speed is faster than the walk/run transition speed, poles might be disadvantageous. Usually, the walk/run

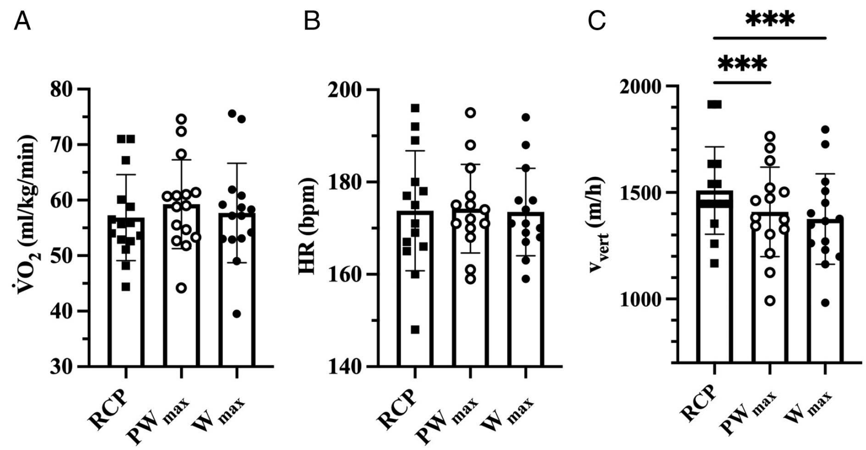

Figure 4 — (A) $\dot{V}O_2$/kg, (B) HR, and (C) v_{vert} corresponding to RCP identified during the incremental test and the same parameters averaged during PW_{max} and W_{max}. The 1-way analysis of variance revealed a significant different only in the PW_{max} and W_{max} vertical velocity in comparison to RCP (N= 15). HR indicates heart rate; RCP, respiratory compensation point; PW, pole walking; v_{vert}, vertical velocity; W, walking without poles. ***P < .001.

transition speed is ~2 m/s on level, but it is slower on uphill.[19–21] The 2 fastest athletes in the present study completed the test at – 1.44 m/s, which is faster than the preferred transition speed (1.32 m/s) derived by fitting the data of Brill and Kram[22] at this incline (~20°). Consequently, athletes may obtain an advantage by using poles on steeper or longer uphill or whenever the speed is slow enough that they choose walking rather than running. The other participant who performed better without poles was the least experienced with using poles. He reported using poles for a couple of years, which may be too short a period to develop an efficient technique. As previously suggested, optimal use of poles requires proper technique.[1,23] Likely, the overall better performance during the maximal trials may reflect a better efficacy of locomotion with poles. The use of poles may allow to reduce the lateral oscillation,[10] particularly at slow speeds and the leg muscle activity is reduced because the arms contribute in total mechanical work.[7] Consequently, at the same metabolic power, the mechanical power output should be higher.

We reject our second hypothesis, regarding the submaximal test. Indeed, previous studies reported that physiological parameters were higher when subjects use poles uphill on moderate grades (12°)[24] but poles were advantageous at steeper inclines.[1] For this reason, we hypothesized that at 80% of vertical velocity of the PW_{max} and W_{max}, the CoT and other parameters (ie, HR, RPE and lactate) should be lower. However, we found out no differences in any of the analyzed parameters (nor in biomechanics). Previously, only Foissac et al[7] reported that there were no differences in energy cost of walking with poles on a treadmill inclines at 11.3°. We decided to use the 80% of v_{vert} maintained during the maximum tests in order to emulate the intensity of a long-lasting effort of ~6 hours.[25] At this intensity, we found no differences between poles and no poles. That stands in contrast to the study of Grainer et al[11] who reported higher energy expenditure and HR with similar RPE when subjects used poles. Our present finding also contrasts with our results for maximal steep uphill PW. We are aware that athletes were not fatigued like during a trail running race and this aspect might influence the results since fatigue could affect the CoT.[26] Consequently, for looking at possible benefit obtained using poles in a long-lasting event, we suggest that researchers perform similar measurements (with and without poles) after a long competition and in a fatigue state. Indeed, the use of poles at low intensity may be especially useful when athletes are fatigued, in particular after uphill and downhill in which poles reduce exercise-induced muscle damage.[27] In such a case, the use of the upper limbs might be helpful in assisting the work performed by lower limbs so as to maintain the same vertical speed while reducing the activation of the fatigued lower limbs.[7]

We detected no differences in CoT_{vert} between intensities and conditions. However, the CoT_{vert} we measured is ~35% higher than those reported by Minetti et al[28] and ~20% higher than Giovanelli et al[18] at similar incline but without poles. Giovanelli et al[1] measured similar values in a recent work. The differences among studies may be due to the different experimental design (in particular the vertical velocity and the type of gait). It is also likely due to the natural terrain involved in the present study. Indeed, variations in terrain characteristics (eg, trail surface and incline) require continuous adjustment in pace (longitudinal speed) and type of gait, which could affect CoT. Nonetheless, we expected higher difference in comparison with a recent study,[1] since it is reported that in Nordic walking, overground walking is ~30% more expensive than treadmill Nordic walking.[5] It should be noted that in a small group of participants in our study (n = 6), overground PW_{80} was ~8% more expensive than PW on a treadmill at the same average incline and v_{vert}.[29] Interestingly, PW_{max} and W_{max} were performed at an intensity similar to the RCP measured during the incremental test but at lower v_{vert} (Figure 4). We expected that the relative intensity would be higher due to the short duration of the trial (range: ~15–25 min). The RCP corresponded to ~85% of the $\dot{V}O_2$max and this intensity typically can be maintained for ~60 minutes in level running.[30] However, during the steep uphill locomotion in this experiment, participants maintained this intensity for less than 20 minutes. This difference may be attributed to different type of muscle contractions involved. In contrast to level locomotion, on steep uphill (>9°), only positive work is done to raise the body[31,32] and only concentric contraction is present, as in cycling. In fact, the time limit for cycling at RCP is similar to the time for completing PW_{max} and W_{max} in this study. This suggest that cycling and uphill walk/run, although different disciplines, share some similarities.[33] However, understanding the limits to steep uphill locomotion will require further investigation.[34] It is worth noting that, presumably due to the terrain, at the same relative intensity ($\dot{V}O_2$ and HR), the vertical velocity was ~9%

slower on the mountain path compared to on the treadmill. This information may be useful to coaches who test their athletes on a treadmill and then propose training HR zones for outdoor conditions.

Limitations

In this study, the trail presented 3 flat sections. The first was ~20 m long, the second ~10 m long, and the third was ~60 m long. These sections influence specifically the v_{vert} that would be higher if a similar study is performed only up. Another limitation is that the use of metabolic device required to set up a design that elicit to be well supported by the participants. To ask them to exercise for a longer period of time may be uncomfortable and we decided to use a section shorter than the official VK or other trail running races.

Practical Applications

Athletes should use poles during steep uphill maximal efforts to obtain the best performance. Conversely, during submaximal steep uphill walking, the use of poles does not provide advantages from a physiological point of view.

Conclusions

In summary, most high-level athletes obtained a competitive advantage by using poles during a maximum effort on an uphill of 433 m of elevation gain. We have not found other data about the use of poles during a maximum uphill effort, and this represents the first study in which athletes were studied during this type of performance. Conversely, during a submaximal effort, we found no advantage of using poles.

Acknowledgments

The authors acknowledge all the participants and the running clubs who helped in managing this work. The authors thank Dr Mirco Floreani for the insight about the statistics and Dr Rodger Kram for helpful editing. N.G. and S.L. involved in conception and design of research; N.G., L.M, and A.P. conducted experiments; N.G. statistically analyzed data; N.G., L.M., A.P., and S.L. interpreted results of experiments; N.G. prepared figures and drafted manuscript; N.G., L.M., A.P., and S.L. edited, revised, and approved final version of manuscript. This study was supported by the Interreg V-A Italia-Austria—CLLD, project code ITAT4460-P.

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