Differences in Horizontal vs. Uphill Running Performance in Male and Female Swiss World-Class Orienteers

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Abstract

Lauenstein, S, Wehrlin, JP, and Marti, B. Differences in horizontal vs. uphill running performance in male and female Swiss world-class orienteers. *J Strength Cond Res* 27(11): 2952–2958, 2013—In orienteering, athletes must choose the quickest route from point to point, considering if they want to run a longer flat distance rather than a shorter distance with an incline to reach the next point. Our aim was therefore, to determine an athlete's equivalence factor (EF, ratio between horizontal and uphill running performance) enabling coaches to provide individual route choice recommendations during orienteering competition. Ten male and 8 female orienteers performed 1 horizontal ($MST_{horizontal}$; 0% incline) and 1 uphill (MST_{uphill}; 22% incline) maximal running stage test to exhaustion on a treadmill in randomized order. The EFs were calculated based on maximal speeds achieved in both tests ($MRV_{horizontal}/_{uphill}$). In addition, $\dot{V}O_2peak$ was measured. $MRV_{horizontal}$ was 20.4 ± 0.6 and17.3 ± 0.8 $km \cdot h^{-1}$, and MRV_{uphill} was 8.8 ± 0.7 and 7.2 ± 0.5 $km \cdot h^{-1}$ (men and women). The EF was 6.3 ± 0.7 and ranged between 5.2 and 7.4. Relative $\dot{V}O_2peak_{uphill}$ was 69.2 ± 5.7 and 59.1 ± 3.7 $ml \cdot kg^{-1} \cdot min^{-1}$, whereas $\dot{V}O_2peak_{horizontal}$ was lower 66.4 ± 3.5 ($p < 0.05$) and 55.7 ± 3.1 $ml \cdot kg^{-1} \cdot min^{-1}$ ($p < 0.01$) than in $\dot{V}O_2peak_{uphill}$. Relative $\dot{V}O_2peak_{uphill}$ correlated strongly with MRV_{uphill} (men: $r = 0.85$, $p < 0.01$; women: $r = 0.84$, $p < 0.01$), whereas relative $\dot{V}O_2peak_{horizontal}$ showed no strong correlation with $MRV_{horizontal}$ (men: $r = 0.51$, $p = 0.12$; women: $r = 0.41$, $p = 0.32$). These data show that there are relevant differences in the relation between uphill and horizontal running capacity in these athletes. Tailoring the route selection to the athletes' advantage based on the relation between their uphill and horizontal running performance and individual EF may positively impact on overall performance in orienteering competition.

Key Words exercise testing, exercise physiology, orienteering, training, oxygen update, route choice recommendations

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Introduction

Orienteering is a running sport with a navigational component; using a map and compass, the athlete navigates a given course in the shortest possible time. The sport is performed mostly off-trail through diverse and often hilly terrain. An orienteer's ability to run uphill is a determining factor of performance in orienteering competition (3). Uphill running ability, specifically on steep inclines ranging from 20–25%, was acknowledged to be a key factor of performance at many previous World Orienteering Championships (WOC). Because of the navigational nature of the sport, an athlete must choose the quickest route from point to point, considering strategic factors such as horizontal and vertical elements of the course to best suit the athletes' skills. Equating the physical workload and duration of an uphill climb to horizontal distance depends on the individual performance ability in both horizontal and uphill running. Understanding individual strengths and weaknesses of each athlete will allow strategic decisions to be made regarding route selection during competition. Research examining the physiological workload of orienteering is limited (3,8,9), and the effect of workload differences on route choice in orienteering has only been investigated in 2 previous studies (11,19). Currently, there is no research in orienteering that has examined individual differences in uphill and horizontal running ability, thus limiting the provision of direct feedback for use in competitions.

In addition to making individual assessments for athletes, organizers of orienteering or trail running competitions must appropriately estimate the completion time of a course. A standardized method, such as an equivalence factor (EF), is required to determine how many meters of horizontal distance equates to 1 m of climb. Naismith's Rule states that 1 unit of climb equates to 7.93 units of distance; however, in orienteering an EF of 10 (1 m of climb equates to 10 m of horizontal distance) is often used (22,26). To our knowledge, investigations specifically exploring possible EF in uphill and horizontal running have only occurred in field settings and have documented an EF ranging from 1.8 (including the descent in a given route) to 8, which is a more commonly accepted value (12,21,22). This wide range of reported EF values may be explained by the differences in footing during running outdoors, which affects running speed. Therefore, a more objective standardized laboratory research approach, including the measurement of physiological data, is required.

Overall, previous research on physiological parameters of conventional uphill motion such as running, walking, ladder climbing (2,11,13,15–19,23–25) is well documented, with the exception of observations with inclines above 15% (12,14,17,19). To our knowledge, no research in uphill performance testing with orienteers has been done, although previous WOC terrains show that climbing gradients above 20% typically occurs during competition. Orienteers typically perform a horizontal maximal stage test to measure running performance. This performance testing practice, which does not include the uphill component of the sport, may not adequately measure the skills needed to be successful in orienteering. With this knowledge of the performance profile of orienteering and the limited research available examining inclines above 15%, it is evident there is a lack of knowledge of uphill running performance of orienteers. Uphill running ability in orienteers should be examined separately from horizontal running performance, specifically at an incline above 20%.

Therefore, the aims of this study were to (a) compare the horizontal and uphill maximal running velocity in a stage test; (b) calculate individual and average EF measured in a laboratory setting; and (c) assess the potential physiological differences in horizontal and uphill running in elite orienteers. We hypothesized that the individual physiological and performance response of uphill and horizontal running will differ sufficiently to affect the EF and thus impact on route choice recommendations during competition.

METHODS

Experimental Approach to the Problem

This study used a randomized crossover design to assess maximal running performance in uphill and horizontal conditions, to determine potential differences in running ability of the Swiss national orienteering team. A secondary aim was to calculate the individual EF for each athlete. Each subject performed the national orienteering standardized test protocol for horizontal running, the maximal stage test ($MST_{horizontal}$: 0% incline), and the newly developed uphill running maximal stage test (MST_{uphill}: 22% incline) in randomized order. The 2 tests were separated by a minimum of 72 hours and were completed within a 3-week period.

Subjects

Ten male and 8 female athletes of the Swiss national orienteering team participated in this study. The training status of the athletes included the current 20-time world champion (female), 3-time world champion (male), and 2-time world championship silver medalist in long distance (male). All participants were briefed as to the risks of the study before providing written informed consent. The study was approved by the Institutional Review Board of the Swiss Federal Institute of Sport and carried out according to the recommendations of the Declaration of Helsinki. Physiological characteristics of all subjects are shown in Table 1.

TABLE 1. Physical characteristics of the subjects ($n = 18$).

	Men ($n = 10$), mean ± *SD*	Women ($n = 8$), mean ± *SD*
Weight, kg	71.2 ± 5.6	55.4 ± 4.7
Height, cm	180.7 ± 6.7	168.0 ± 5.5
Body mass index, $kg\cdot m^{-2}$	21.8 ± 0.6	19.58 ± 1.0
Age, y	24.0 ± 2.3	22.9 ± 2.6
5 km best time, min:s	15:39 ± 0:26	18:27 ± 0:37

Procedures

The study was conducted in the preseason training period. Athletes were given written instructions to standardize training, nutritional, and sleep behaviors before the experimental trials. A questionnaire completed by the athletes the morning of each test was used to control for previous training load, nutritional intake, and previous sleep and health status of the athletes. Athletes were excluded from the study if the conditions for a maximal effort were not favorable (i.e., training load was too high or occurrence of illness).

Test Protocol: Horizontal Maximal Stage Test

Each athlete completed a standardized 10-minute warm-up at a pace corresponding to or slower than the first stage of the test. Afterward, athletes started the $MST_{horizontal}$ at a running velocity of 7.2 or 9.0 $km\cdot h^{-1}$ for women and 10.8 or 12.6 $km\cdot h^{-1}$ for men, depending on previous testing results or current physical fitness (6). Stage duration was 3 minutes, and the velocity increased by 1.8 $km\cdot h^{-1}$ each stage with an incline of 0%. Athletes were instructed to run to exhaustion. Maximal running velocity (MRV) was normalized for time if the last stage was incomplete (6). A 30-second break between stages was used to take capillary blood samples from the ear lobe to determine blood

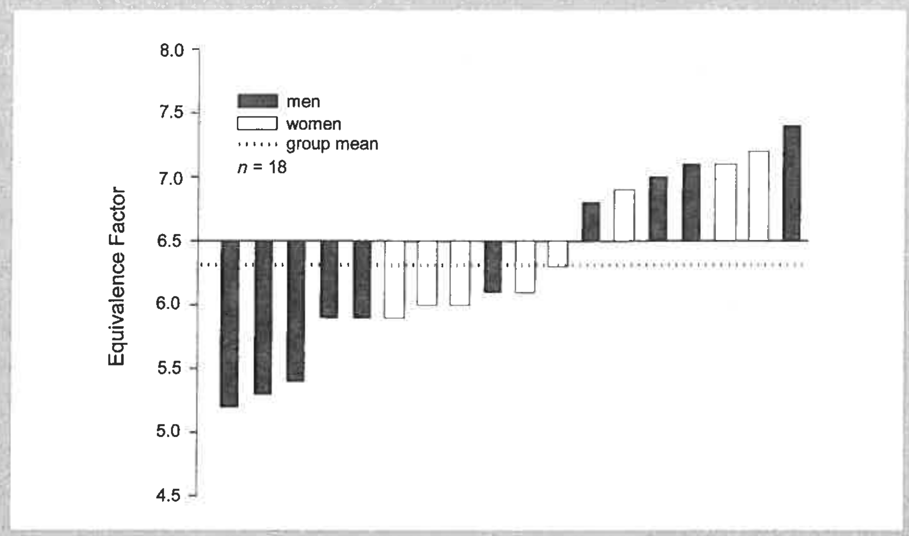

Figure 1. Individual distribution of equivalence factor (EF; $n = 10$ men and $n = 8$ women) from EF 6.5 used in the development of MST_{uphill}. Group mean (6.3 ± 0.7) is indicated with the dotted line.

lactate concentration ($[La^-]_b$; in mmol·L^{-1}), and to assess subjects' RPE with Borg's RPE scale (1). Maximal blood lactate ($[La^-]_{bmax}$) and maximal rating of perceived exertion (RPE_{max}) were defined as the highest measured value. Heart rate (HR; ·per minute) and $\dot{V}O_2$ (in ml·kg^{-1}·min^{-1}) was measured continuously for the duration of the test and were calculated by taking the mean of the last minute of each stage. Maximal heart rate (HRmax) and $\dot{V}O_2$peak was defined as the highest mean for a 30-second period during the test. Step rate (per second) and step length (meter per step) were measured for the duration of the test and presented as the mean of the last minute of each stage. Maximal step rate (step $rate_{max}$) and maximal step length (step $length_{max}$) were defined as the highest mean for a 30-second period during the test.

Test Protocol: Uphill Maximal Stage Test (22% Incline)

The uphill maximal stage test (MST_{uphill}) was developed through a pilot test to represent similar workloads and duration to the standardized $MST_{horizontal}$ test. By averaging previous world orienteering championship WOC terrains, the gradient in the MST_{uphill} was set at 22%. In pilot testing ($n = 6$), an EF of 6.5 was determined to achieve similar workloads per stage of the $MST_{horizontal}$ and the time to voluntary exhaustion of both tests were similar.

Each athlete completed a 10-minute warm-up of horizontal running at a velocity corresponding to or slower than the first stage of the $MST_{horizontal}$ test before the start of the test procedure. Athletes started the MST_{uphill} test at a velocity of 2.9 or 3.6 km·h^{-1} for the women and 4.3 or 5.0 km·h^{-1} for the men, depending on the initial stage of the $MST_{horizontal}$ test, with a 22% incline. Stage duration was 3 minutes, and velocity per stage increased by 0.7 km·h^{-1}. Athletes were instructed to run to exhaustion. Maximal running velocity was normalized for time if the last stage was incomplete (6). All data ($[La^-]_b$, RPE, HR,

Table 2. Physiological data and stride characteristics of horizontal vs. uphill maximal running ($n = 18$).*

	Men (n=10)		Women (n=8)	
	$MST_{horizontal}$, mean ± *SD*	MST_{uphill}, mean ± *SD*	$MST_{horizontal}$, mean ± *SD*	MST_{uphill}, mean ± *SD*
$\dot{V}O_2$peak (ml·kg^{-1}·min^{-1})	66.4 ± 3.5	69.2† ± 5.7	55.7 ± 3.1	59.1‡ ± 3.7
HRmax (per min)	185 ± 9.1	182 ± 8.7	192 ± 7.9	189† ± 4.7
HR_{AT} (per min)	169.3 ± 8.6	166.9 ± 7.8	177.8 ± 5.7	171.8† ± 7.6
$[La^-]_{bmax}$ (mmol·L^{-1})	8.4 ± 2.3	8.5 ± 2.7	7.9 ± 0.9	8.3 ± 1.4
RPE_{max}	19.5 ± 0.9	19.6 ± 0.7	19.4 ± 0.7	19.6 ± 0.5
Step $rate_{max}$ (per s)	3.0 ± 0.1	2.7‡ ± 0.1	3.0 ± 0.2	2.8‡ ± 0.2
Step $length_{max}$ (m per step)	1.9 ± 0.1	0.9‡ ± 0.03	1.6 ± 0.1	0.7‡ ± 0.1

*HRmax = maximal heart rate; HR_{AT} = heart rate at the anaerobic threshold; $[La^-]_{bmax}$ = maximal blood lactate; RPE_{max} = maximal rating of perceived exertion; Step $rate_{max}$ = maximal step rate; Step $length_{max}$ = maximal step length.
†$p < 0.05$.
‡$p < 0.01$.

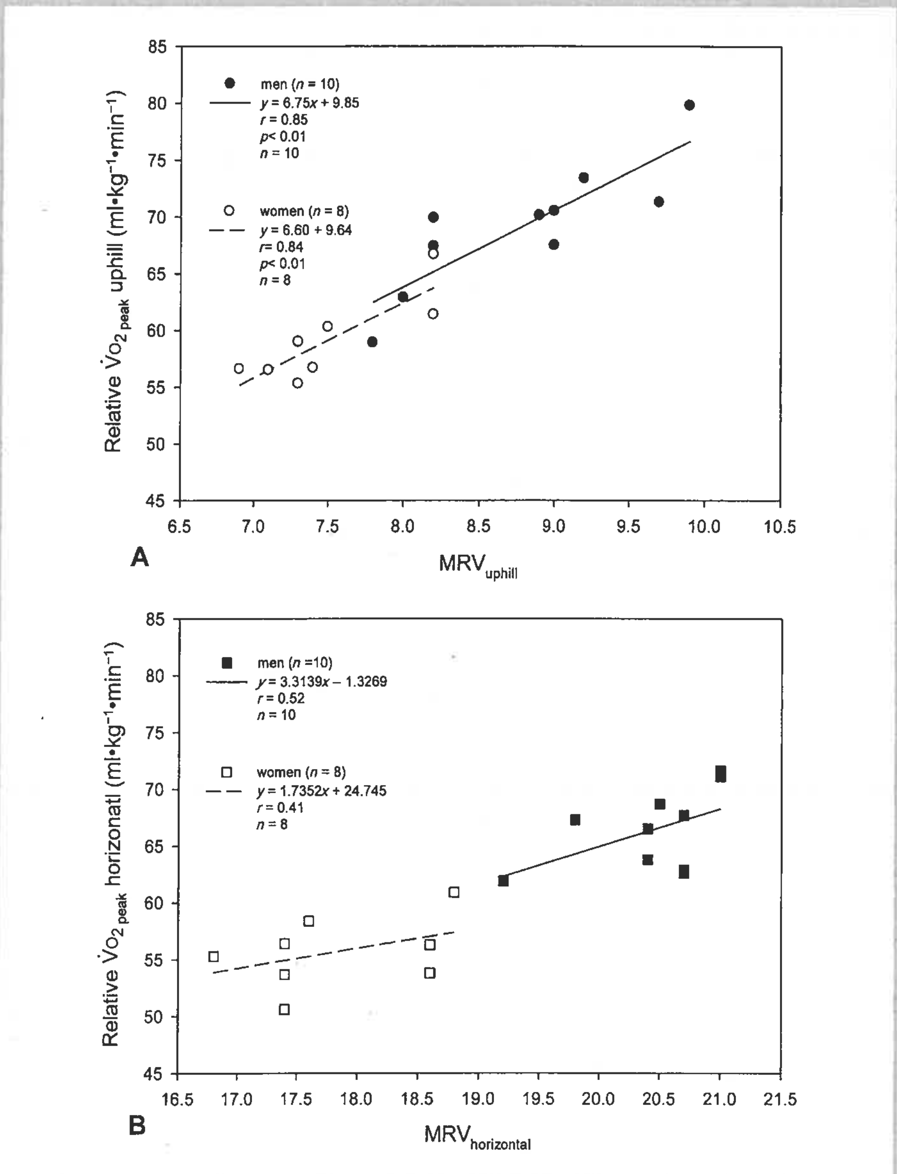

Figure 2. A) Mean maximal uphill running velocity (MRV_{uphill}) compared with $\dot{V}o_2peak_{uphill}$ in elite orienteers ($n = 10$ men [•] and $n = 8$ women [○]). B) Maximal horizontal running velocity ($MRV_{horizontal}$) compared with $\dot{V}o_2peak_{horizontal}$ in elite orienteers ($n = 10$ men [■] and $n = 8$ women [□]). The regression line line for men and dotted line for women, regression equation, Pearson's correlation coefficient (r), and statistical significance ($p < 0.01$) are given.

$\dot{V}o_2$, step rate, and step length) collection and processing were conducted as described in the test protocol for $MST_{horizontal}$.

Instruments

Both tests were completed on the same motorized treadmill (Model Venus; h/p cosmos sports & medical gmbh, Traunstein, Germany) in constant ambient conditions (18.4 ± 0.5° C and 29.4 ± 7.8% humidity) controlled by an air conditioner (Strulz, Hamburg, Germany). The treadmill was calibrated for speed and incline before the commencement of the study. Heart rate was monitored with a Polar heart rate monitoring system (Polar S610i; Polar Electro Oy, Kempele, Finland). Oxygen uptake was measured breath-by-breath with an open-circuit spirometry system (Oxycon Pro; Erich Jaeger GmbH, Hoechberg, Germany). The Oxycon Pro system was pre-calibrated with gas standards for oxygen (15.99 vol%), and carbon dioxide (5.02 vol%) and turbines were calibrated with a 4L volume pump (Carefusion, San Diego, CA, USA). $[La^-]_b$ was determined by taking a 10 μl blood sample from the right ear lobe and measured with a table-top lactate analyzer (Super GL; Hitado Diagnostic System, Endingen, Germany). The Super GL was pre-calibrated with 2 standards (pathological 1.6 ± 0.3 $mmol \cdot L^{-1}$ and normal 3.7 ± 0.8 $mmol \cdot L^{-1}$; Glucocapil; Hitado Diagnostic System) before every test. Step rate and step length were measured using an accelerometer (Actigraph GT1M Accelerometer, Walton Beach, FL, USA) (28).

Analytical Procedures

Individual EF was calculated for each subject using the following formula:

$$EF_{(\alpha)} = \frac{MRV_{horizontal} - MRV_{uphill}}{MRV_{uphill} \times \tan(\alpha) \times \cos(\alpha)},$$

where α = angular degree (i.e., α of 22% climb = 12.41).

Anaerobic threshold was determined using the Dickhuth approach of baseline concentration plus 1.5 $mmol \cdot L^{-1}$ (4). Velocity ($km \cdot h^{-1}$) and heart rate (HR_{AT}) at the anaerobic threshold were calculated for both $MST_{horizontal}$ and MST_{uphill}.

Table 3. Recommendations for the application of individual equivalence factor.

Individual equivalence factor	Recommendation
>7.0	Uphill running ability weak; may not be advantageous to take climb in a route choice
5.6–7.0	Uphill running ability neutral; a balanced horizontal and uphill running ability
<5.6	Uphill running ability strong; may be advantageous to take climb in a route choice

Statistical Analyses

Differences among group means for velocity and physiological parameters were assessed with a 1-way analysis of variance. Differences between athletes in measures of EF were analyzed with unpaired *t*-tests. Linear regression analysis was used to test associations between variables, and Pearson correlations were compared using Steiger's *Z* test. Results were analyzed with the statistical package SPSS 14.0 (SPSS, Chicago, IL, USA) and are presented as mean ± *SD* and significance was set at $p < 0.05$, except when stated otherwise.

Results

Horizontal vs. Uphill Running Performance

Mean $MRV_{horizontal}$ and horizontal anaerobic threshold velocity was 20.4 ± 0.6 and 17.8 ± 0.7 $km \cdot h^{-1}$ and 17.3 ± 0.8 and 14.8 ± 0.8 $km \cdot h^{-1}$ in men and women, respectively. Mean MRV_{uphill} and uphill anaerobic threshold velocity was 8.8 ± 0.7 and 7.5 ± 0.5 $km \cdot h^{-1}$ and 7.2 ± 0.5 and 5.8 ± 0.5 $km \cdot h^{-1}$ in men and women, respectively. The MRV_{uphill} and velocity at the anaerobic threshold were significantly lower ($p < 0.001$) in the MST_{uphill} compared with horizontal running.

Equivalence Factor

Equivalence factors ranged between 5.2 and 7.4 between the athletes (Figure 1), which equates to an additional horizontal running distance (i.e., the "detour") of 520 and 740 m for every 100 m of climb in this population of runners. The mean EF was 6.2 ± 0.8 for men and 6.4 ± 0.5 for women, with a group mean of 6.3 ± 0.7.

Physiological Parameters and Stride Characteristics

Relative $\dot{V}O_2peak_{uphill}$ was 4.2% higher than $\dot{V}O_2peak_{horizontal}$ in men ($p < 0.05$) and 6.1% higher in women ($p < 0.01$). The HRmax and HR_{AT} were 1.6 and 3.4% lower, respectively, in the MST_{uphill} in women ($p < 0.05$) compared with the $MST_{horizontal}$. No significant difference was measured in average HRmax and HR_{AT} between the 2 tests in men. $[La^-]_{bmax}$ and RPE_{max} were not significantly different for men or women between $MST_{horizontal}$ and MST_{uphill}, indicating that both tests were run to exhaustion. Step $rate_{max}$ was approximately 10% lower in the MST_{uphill} in both men ($p < 0.001$) and women ($p < 0.01$) compared to the $MST_{horizontal}$. Moreover, step $length_{max}$ was more than 50% shorter in the MST_{uphill} for both men and women ($p < 0.01$) than in the $MST_{horizontal}$. Results of all measurements are shown in Table 2.

Relative $\dot{V}O_2peak_{uphill}$ correlated strongly (men: $r = 0.85$, $p < 0.01$; women: $r = 0.84$, $p < 0.01$) with MRV_{uphill}. Conversely, relative $\dot{V}O_2peak_{horizontal}$ showed only moderate correlation with $MRV_{horizontal}$ (men: $r = 0.51$, $p = 0.12$; women: $r = 0.41$, $p = 0.32$) (Figure 2).

Discussion

Because of the nature of the sport of orienteering, which involves traversing uneven terrain with speed, uphill running ability is a determining factor of performance. In orienteering competition, navigating the fastest route based on the athletes' running ability will influence overall performance. This investigation was undertaken to determine if testing orienteers in uphill and horizontal running will allow for measured differences in running performance, therefore differentiating in individual EF values to aid in route choice recommendations during competition.

The main finding of this study was the interindividual variation in the EF ranging from 5.2 to 7.4 between athletes, with a mean value of 6.3. To our knowledge, the variation in the EF has not been documented by previous studies specifically calculating the EF in a laboratory setting, among elite athletes. Several studies (5,15,21,22) have reported similar values to Naismith's Rule (1 unit of climb is equivalent to 7.92 units of distance) after analyzing race results in either fell or trail running races. Our lower reported mean EF at 22% incline was measured on a treadmill in a laboratory setting and therefore eliminated the effect of footing that occurs in the field. It is possible that rough outdoor terrain may have limited the runner's ability to physically exert themselves to the same degree as on a treadmill, effectually raising the EF. Additionally, differences in air resistance between indoor and outdoor settings were not compensated for in our horizontal test (10). These stated differences to outdoor running may potentially explain the varying results between studies conducted in the field vs. our laboratory results. Nevertheless, it can be concluded that an EF of 6.2 and 6.4 at 22% incline for world-class male and female orienteers, respectively, has not been reported thus far and that the EF of 10 commonly used in orienteering appears to be an overestimation (22,26).

Route choice in orienteering competition often requires strategic decisions regarding the choice of direct routes with climbing (recommended for those with a low EF) or flat usually substantially longer detours to avoid climbing (recommended for those with a high EF). Because orienteering performance is dependent on the athlete's ability to cover a course in the shortest amount of time, route choices made on the basis of individual running performance can be advantageous to total performance (3,9). It must however be noted that our individual recommendations based on the athlete's EF does not take into consideration the descent in a given route (14,20). Hayes and Norman (5) suggest that when a gradual descent is taken, the EF becomes smaller, and yet, if a steep rough downhill is involved, additional time must be expected to complete the route, increasing the EF (5,15). Therefore, using EF strictly based on uphill running ability may have limitations in competition, because of the influence of descent on a route.

Peak oxygen uptake measurements on this population of orienteers are in accordance to findings on orienteers from the 1990s (3,7,8,20). In this study, maximal uphill running elicited a higher relative $\dot{V}O_2$peak by 2.8 and 3.4 $ml \cdot kg^{-1} \cdot min^{-1}$ in men and women, respectively, than in maximal horizontal running. Higher $\dot{V}O_2$max values have also been reported in previous studies of uphill running (11,16–19,23,24,27). In addition, our findings show a strong correlation between maximal running velocity uphill and $\dot{V}O_2peak_{uphill}$, whereas only a weak correlation between maximal running velocity horizontal and $\dot{V}O_2peak_{horizontal}$ was observed (Figure 2). These results are similar to those reported in the Paavolainen et al. (18) study on muscle power factors and $\dot{V}O_2$max as determinants of horizontal and uphill running performance.

Mean HRmax and HR_{AT} from combined data for men and women were not significantly different in the uphill vs. horizontal tests. Similarly, there were no significant differences in maximal lactate concentrations between conditions, for men and women. These results imply that both tests were run to exhaustion and that relative maximal workloads were similar between tests. We can therefore eliminate the possibility that only submaximal efforts were given in the horizontal tests and that the lower reported $\dot{V}O_2$peak may be partly because of physiological variations.

It was expected that the athletes with superior uphill running ability would be better able to maintain a relatively high step rate at near maximal to maximal velocities, as compared with those with lower maximal uphill running ability. However, after evaluation of the stride data, it was concluded that the relatively broad interindividual variation in EF could not be explained by a specific step pattern (i.e., step length or step rate) at maximal speed.

Practical Applications

Based on the results of this study, it can be suggested that testing orienteers in uphill and horizontal running performance offers information strategically important for orienteering competition. The wide range of individual EF measured in this population justifies the need for individual recommendations regarding route selection and strategic decision making during competitions in hilly terrain. An example of the individual recommendations for the application of EF can be found in Table 3. These recommendations were established by analyzing the EF group mean and *SD* of combined male and female data and expert knowledge from coaches experienced in the sport of orienteering. Tailoring the route selection to the athletes' advantage based on their uphill running performance and the EF may positively impact on overall performance in competition. This subsequently adds another element to orienteering training, whereby uphill running performance is emphasized and developed to the same extent as horizontal running, given the clear correlation between peak oxygen uptake and maximal uphill velocity.

Measuring maximal and threshold speeds for horizontal and uphill running allows for a more complete performance diagnostic in orienteering. Thus, determining individual EF offers elite orienteers recommendations on route choice during competitions in hilly terrain. Uphill running performance correlated strongly with $\dot{V}O_2$peak suggesting a true physiological limitation associated with uphill running ability. These findings can not only influence the strategy taken in orienteering competition, tailoring it individually based on uphill and horizontal running performance, but also affects training for orienteers, emphasizing uphill running performance as a vital factor of performance.

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