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ORIGINAL ARTICLE

Walking *versus* cycling test: physiological responses in normobaric hypoxia

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ABSTRACT

BACKGROUND: Races that take place in the mountains cover a variety of terrains at several altitudes. A test for predicting acute mountain sickness has been developed on the basis of a "normal" population but not on the basis of an athlete population. The aim of this study was to compare the Richalet Test to a specific test for athletes.

METHODS: Eleven subjects (age: 29.7±8.9 years, VO_{2peak}: 55.7±8.5 mL/kg/min) underwent two incremental tests on a cycle ergometer (CE) and treadmill (TR). Then, they underwent two tests on the CE and TR composed of: 1) five minutes of rest in normoxia; 2) five minutes of rest in hypoxia (fraction of inspired oxygen (11.5%); 3) five minutes of walking or cycling at an intensity of 80% of the respiratory compensation point in hypoxia; and 4) five minutes of rest in normoxia. We compared the following parameters at rest and during exercise: desaturation, ventilatory and cardiac response.

RESULTS: None of the mean values of the investigated parameters differed between the two tests (P>0.05), but some subjects who had out-of-range values on the CE did not have out-of-range values on the TR (or vice versa).

CONCLUSIONS: We showed that there were: 1) no differences in the mean values of the analyzed parameters between the two protocols; and 2) that the responses to the CE and TR protocols varied across individuals. For individuals who are planning to hike or run at a high altitude they should undergo a walking test. Additionally, when athletes plan to compete at high altitudes, the intensity of the test should be similar to that planned for the race.

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KEY WORDS: Altitude; Endurance training; Running.

Races that take place in the mountains (such as those in ski mountaineering, mountain running, etc.) cover a variety of terrains at several altitudes. These races are called "skyrunning" races[1] and cover technical terrains ranging in altitude from 0 to >4000 meters, including glaciers, moraines and snowfields of different inclines.[2] In particular, some of these races reach altitudes that are known to induce acute mountain sickness (AMS), the most common form of high-altitude illness.

Athletes who participate in skyrunning competitions should be aware that a high fitness level (*i.e.*, high maximal oxygen consumption) is not a predictor of success in high-altitude exercise.[3, 4] The performance of highly trained individuals at high altitudes can be lower than that of individuals with a lower fitness level because they experience severe desaturation induced by exercise in hypoxia.[5] In addition, AMS is highly related to the speed of ascent, which should be less than 400 meters per day during the acclimatization period.[6, 7] Since the aim of the athletes is to complete the racecourse in as little time as possible, they obviously cannot follow this recommendation.

However, even though many athletes who compete are highly trained, not all of them have experienced high altitudes, and exposure to a high-altitude environment can be deleterious. Rathat *et al.*[8] proposed a test for predicting AMS in a "normal" population (*i.e.*, not athletes). These authors validated a protocol to predict the risk of AMS and reported that 80% of the AMS cases can be predicted.[8] However, the authors did not administer a specific test for mountaineers since they used a cycle ergometer and set the intensity on the theoretically maximal heart rate. Usually, athletes and mountaineers reach a high altitude by skiing or by running/hiking. Hence, there is the need for a specific test for this population that determines their ability to exercise at a high altitude. Although many athletes train at a moderate altitude, those who train on level ground might require a specific evaluation to determine whether they can compete at a high altitude without complications caused by hypoxia. Thus, the aim of this study was to compare a test proposed by Richalet's group to a more specific test for mountain runners and mountaineers by measuring individuals' effort at an exercise intensity that is relatively similar to that maintained during a 2–3-hour race, which is a common exercise duration in skyrunning competitions (corresponding ~ to the gas exchange threshold/aerobic threshold). We hypothesized that due to the differences in the type of exercise, the parameters studied differ between the cycle ergometer (CE) and treadmill (TR).

Materials and methods

Participants

Eleven sport science students who actively participate in sports (age: 29.7±8.9 years; body mass: 67.6±11.1 kg; stature: 1.75±0.10 m, $\dot{V}O_{2peak}$: 55.7±8.5 mL/kg/min) were included in the study (Table I). They reported training (running and/or cycling) on average for 07:18±00:54 hours:minutes per week. The review board of the local university approved the testing procedures. The experiments were conducted in accordance with the Declaration of Helsinki. Before the study began, we explained the purpose and objectives of the study to each participant, and the participants provided informed consent.

Experimental design

We asked the subjects to visit the laboratory four times with an interval of 48 hours between each visit. Two days of rest or light training were included between the four test days. During the first two visits, the participants performed a graded exercise test using the CE and the TR in a random order under medical supervision. During the other two visits, the participants performed the protocol proposed by Richalet on the CE and on the TR at the intensity corresponding to ~80% of the respiratory compensation point (RCP), which was identified after each incremental test. Then, we compared the results of the two tests.

Treadmill incremental test

After electrocardiography (ECG) electrodes were placed on the participants, they stood at rest on the motorized treadmill (H/P/Cosmos Sports & Medical Gmbh, Nußdorf, Germany) for five minutes. Then, the test started with the treadmill moving at a velocity of 5 km/h and a slope of 10%. Every minute, the slope was increased by 2% until it reached a slope of 24%, and the velocity was maintained at 5 km/h. Then, the speed

TABLE I.—*Anthropometric and physiological characteristics of the participants.*

Parameters	Mean±SD	Cycle ergometer	Treadmill	P
Age (years)	29.7±8.9			
Body mass (kg)	67.6±11.1			
Stature (m)	1.75±0.10			
Training status h/week (hh:mm)	07:18±00:54			
$\dot{V}O_{2peak}$ (mL/[kg min])		50.6±7.9	55.7±8.5	<0.001
HR_{max} (bpm)		177.1±13.3	182.4±14.8	0.020
$\dot{V}O_2$ RCP (%max)		73.1±8.5	78.3±6.8	0.203
HR RCP (%max)		83.5±7.3	88.1±6.8	0.118

P values represent the significant difference between cycle ergometer and treadmill values.
$\dot{V}O_2$: Oxygen consumption; HR: heart rate; RCP: respiratory compensation point.

was increased by 0.4 km/h every minute until the subjects expressed exhaustion. We adopted this protocol because it allows the vertical velocity to increase 93-98 m/h every minute.

Cycle ergometer incremental test

After the ECG electrodes were placed on the subjects, they stood on the electrically braked cycling ergometer (Ergomed 839E, Monark, Vansbro, Sweden) for five minutes. Then, the test started at a power of 30 W, and every minute, the power was increased by 20 W until voluntary exhaustion. We required the subjects to continue moving at a constant revolution per minute (60-75 RPM) during the test, and the test was terminated when the participant was not able to maintain the RPM following an increase in the power.

During both the TR and CE tests, we measured oxygen consumption ($\dot{V}O_2$), carbon dioxide production ($\dot{V}CO_2$), ventilation ($\dot{V}E$) and heart rate (HR) using a metabolimeter (CPET, Cosmed, Rome, Italy). Before each test, we calibrated the flowmeter and gas analysers using a 3-L calibration syringe and calibration gas (16.00% O_2; 4.00% CO_2), respectively. Then, we determined the gas exchange threshold (GET) and the respiratory compensation point (RCP) on the basis of the V-slope method.[9]

Hypoxia/normoxia tests

After the two incremental tests, the participants visited the laboratory to undergo two hypoxic tests (on the CE and TR in a randomized order) following a modified protocol proposed by Richalet *et al.*[4]

The walking test consisted of five minutes of rest in normoxia, followed by five minutes of rest in hypoxia (fraction of inspired oxygen, FiO_2: 11.5%; Altitrainer, SMTEC, Kleinandelfingen, Switzerland). After this stage, the participants started to walk at ~50% of the vertical velocity at RCP and gradually (in approximately 2 minutes) reached the targeted intensity of 80% of the vertical velocity at the RCP recorded during the TR incremental test. After reaching this intensity, they continued to walk for 3 minutes. Then, they maintained the same speed for the remaining five minutes in normoxia (FiO_2=20.9%).

The protocol on the cycle ergometer was similar and included five minutes of rest in normoxia, five minutes of rest in hypoxia, five minutes of exercise in hypoxia and five minutes of exercise in normoxia. The mechanical power imposed was 80% of the power at RCP recorded during the CE incremental test.

During these tests, we measured saturation (SpO_2), VE, $\dot{V}O_2$ and $\dot{V}CO_2$.

Data analysis

After the participants completed the two tests in hypoxia/normoxia, we averaged the data over the last minute of each stage and calculated the variation in SpO_2 and ventilatory and cardiac responses at rest and during exercise in hypoxia, as previously described:[4, 8]

Desaturation at rest:

$$\Delta SpO_{2r}=SpO_{2rn}-SpO_{2rh}\ (\%) \quad (1)$$

Desaturation at exercise:

$$\Delta SpO_{2e}=SpO_{2en}-SpO_{2eh}\ (\%) \quad (2)$$

Ventilatory response at rest:

$$HVR_r=(VE_{rh}-VE_{rn})/\Delta SpO_{2r}/BW\times 100\ (L/min/kg) \quad (3)$$

Ventilatory response during exercise:

$$HVR_e=(VE_{eh}-VE_{en})/\Delta SpO_{2e}/BW\times 100\ (L/min/kg) \quad (4)$$

Cardiac response at rest:

$$HCR_r=(HR_{rh}-HR_{rn})/\Delta SpO_{2r}\ (beats/min/\%) \quad (5)$$

Cardiac response during exercise:

$$HCR_e=(HR_{eh}-HR_{en})/\Delta SpO_{2e}\ (beats/min/\%) \quad (6)$$

The indices "rh," "rn," "eh," and "en" correspond to rest in hypoxia, rest in normoxia, exercise in hypoxia, and exercise in normoxia, respectively, and BW corresponds to body weight (kg).

From these indices, we identified whether participants presented one or more values out of the ranges reported in previous studies.[4, 8] Athletes with at least two out-of-range parameters were considered at risk of developing AMS.

Statistical analysis

We analyzed the data using GraphPad Prism 8.0 (GraphPad Inc., La Jolla, CA, USA), and $P\leq 0.05$ indicated statistical significance. The normality of the data was tested using the Shapiro-Wilk Test. Sphericity was verified by Mauchly's Test. When the assumption of sphericity was not met, the significance of the F-ratios was adjusted according to the Greenhouse-Geisser procedure.

We investigated the differences using a two-tailed, paired sample *t*-test between the parameters measured on the CE and TR. We performed the ROUT method with Q=1%[10] to detect outliers in any of the parameters. None of the subjects had values that were outliers.

Results

Incremental test

The $\dot{V}O_{2peak}$ and HR_{peak} values reached during the TR incremental test were higher than the $\dot{V}O_{2peak}$ and HR_{peak} values reached during the CE incremental test (+10.2±6.6%, P<0.001 and +2.9±3.5%, P=0.020, respectively) (Table I).

The $\dot{V}O_2$ and HR (in % to peak values) values corresponding to the RCP did not statistically significantly differ between the TR and CE (P>0.05) (Table I).

Hypoxia/normoxia tests

Heart rate (in % to HR_{peak}) did not differ between the CE and TR tests in hypoxia (P=0.401), and the values for the CE and TR corresponded to 83.5±4.7 and 81.6±7.2% of HR_{peak}, respectively. Additionally, the relative $\dot{V}O_2$ did not differ (P=0.210) between the CE and TR tests in hypoxia, and the values for the CE and TR were 58.9±5.2% and 56.0±6.5% of $\dot{V}O_{2peak}$, respectively.

Heart rate (in % to HR_{peak}) did not differ between the CE and TR tests in normoxia (P=0.363), and the CE and TR values corresponded to 78.8±6.3% and 74.9±10.6% of HR_{peak}, respectively. Additionally, the relative $\dot{V}O_2$ did not differ (P=0.950) between the CE and TR tests in normoxia, and the values were 72.4±12.4 and 72.7±13.1% of $\dot{V}O2_{peak}$, respectively.

The SpO_2 values at rest in normoxia were 97.3±0.9% and 97.2±1.3% (P=0.686) during the CE and TR tests, respectively, whereas in hypoxia, they were 83.6±4.3% and 81.6±7.9% (P=0.171) during the CE and TR tests, respectively. The SpO_2 values during exercise in normoxia were 94.7±1.3% and 93.2±3.9% (P=0.135) during the CE and TR tests, respectively, whereas in hypoxia, they were 65.4±6.0% and 64.0±6.5% (P=0.122) during the CE and TR tests, respectively.

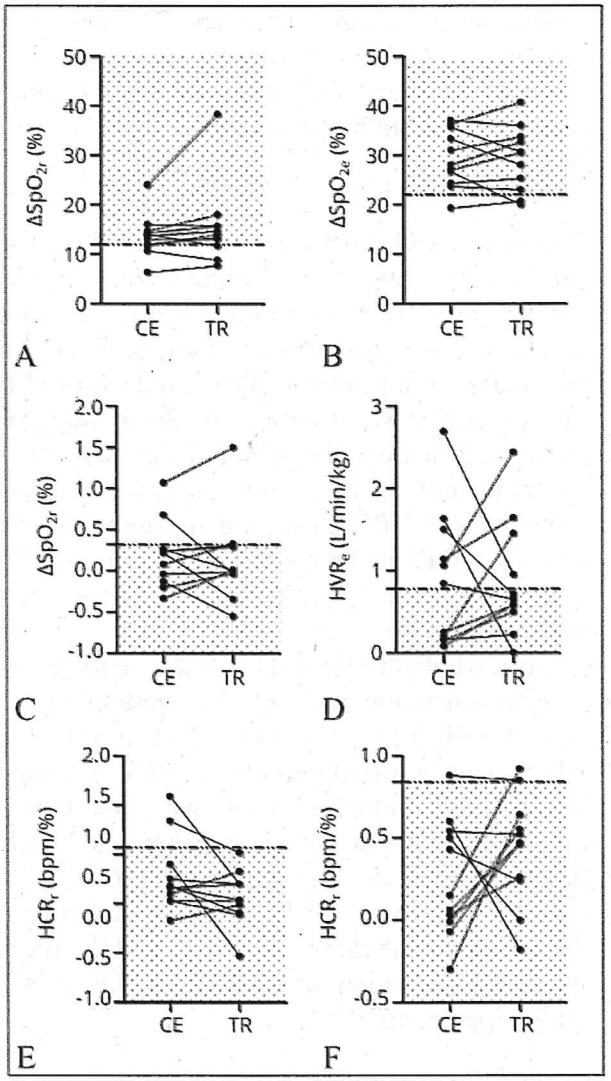

Figure 1.—(A-F) Analyzed parameters at cycle ergometer and treadmill during rest (A, C, E) and during exercise (B, D, F). Modified from Richalet *et al.*[4]
Dotted area represents values out-of-ranges.
Sa: Saturation; HVR: ventilatory response; HCR: cardiac response; r: rest; e: exercise; CE: cycle ergometer; TR: treadmill.

None of the mean values of the investigated parameters differed between the tests performed on the CE and TR (P>0.05) (Figure 1).[4] However, with the CE, we detected 1 participant who had one out-of-range parameter, 6 participants who had two out-of-range parameters and four participants who had three out-of-range parameters. Additionally, with the TR, we detected three participants who had one out-of-range parameter, two participants who had two out-of-range parameters and six participants who had three out-of-range parameters (Table II). Additionally, some subjects who were at risk ac-

TABLE II.—*Number of participants presenting 1, 2 or 3 out-of-range values for the three selected parameters during exercise in hypoxia at cycle ergometer and treadmill.*

One value	CE	TR	Two values	CE	TR	Three values	CE	TR
ΔSpO_2	1	1	ΔSpO_2, HVRe		1	ΔSpO_2, HVRe, HCRe	4	6
HVRe			ΔSpO_2, HCRe	5	1			
HCRe		2	HVRe, HCRe	1				
Total	1	3		6	2		4	6

Both at CE and TR, none of the 11 subjects had 0 out-of-range values.
SpO_2: saturation; HVR: ventilatory response; HCR: cardiac response; e: exercise; CE: cycle ergometer; TR: treadmill.

cording to the CE test were not considered at risk according to the TR test (and vice versa) (Figure 1).[4]

Discussion

The main results of the present study are that there were: 1) no differences in the mean values of the analyzed parameters (SpO_2, HVR, HCR) between the two protocols (TR *vs.* CE); and 2) but we detected different individual responses between the CE and TR protocols.

This result suggests that mountaineers and mountain runners should undergo the treadmill test rather than the CE test to determine their risk of developing AMS. In fact, people and athletes who exercise, *e.g.*, hike or run, at high altitudes, should undergo a specific test performed at an intensity similar to that maintained during the competition. Indeed, even though uphill walking/running at an incline greater than ~15% requires only concentric contractions,[2] as does cycling, some authors[11] have reported that these two types of locomotion have different effects on neuromuscular fatiguability. Particularly, cycling induces a larger decrease in knee extensor force production than does uphill walking (+25%) at the same relative intensity (same $\%HR_{peak}$), suggesting that even if the level of muscle activation (in terms of % maximum voluntary isometric contraction) is similar for the two types of exercise,[12] the timing of activation might be different.[13] However, the last study mentioned[13] was performed on a level treadmill; hence, some differences with uphill walking might be present since joint loads, joint angles and muscle activations differ between these types of locomotion.[14, 15] Because of these differences, a specific exercise should be used when the capacity of individuals to exercise at a high altitude (*i.e.*, uphill walking instead of cycling) is being tested.

Nonetheless, when we analyzed only the mean values, we found that there were no differences in performing the protocol on a CE or TR. However, when each subject was examined, the HVR and HCR responses during exercise differed, suggesting that different protocols lead to different individual responses. However, the responses during the resting condition were not the same for every single subject (although the average did not differ between the CE and TR tests), suggesting that these two parameters are not reliable. In theory, the responses at rest should be similar across subjects, even if the standing position requires different levels of effort compared to the sitting position on a bike. Indeed, in this position, the weight of the body is supported passively by the saddle and not actively sustained by the lower limb muscles.[16] Additionally, some subjects who were considered at risk on the basis of the CE results were not considered at risk on the basis of the TR results (and *vice versa*). This finding suggests that a specific analysis should be performed when a subject aim to exercise at a high altitude.

However, there are some points that need to be elucidated. First, ΔSpO_2 was similar between the two protocols, both in the resting and exercise conditions. Indeed, the mean and SD of the differences in ΔSpO_{2e} between the TR and CE tests was only -0.09±4.0%, confirming that ΔSpO_2 is probably the most reliable parameter among the three that we analyzed.

Additionally, in the present study, only one subject had an out-of-range ΔSpO_{2e} value on the CE, whereas it was in-range during the TR test. As reported by other authors,[17] we observed higher variability in the other parameters, particularly HVR_e, which does not seem to be an optimal parameter for predicting AMS, according

to some studies.[18, 19] However, the relationship between this parameter and AMS is debated (see the review by Burtscher *et al.*[17]). Additionally, the cardiac responses for the two protocols were not similar.

Second, all of the subjects in our study had at least one out-of-range parameter (Table II), suggesting that the participants in this study would be at risk if they are exposed to a high altitude. However, this result must be interpreted with caution. In fact, we adopted the ranges proposed in previous works,[4, 8, 20] but the authors of these studies tested participants when they performed exercise at a different relative intensity. They performed the CE exercise at a power corresponding to ~30% of the power at $\dot{V}O_{2peak}$, whereas the participants in our study performed exercise at a power of ~70% of $\dot{V}O_{2peak}$ (both on the CE and TR). This higher level of metabolic power might require longer adaptation times for SpO_2, HVR and HCR, or the ranges should be modified according to the different intensities. Unfortunately, to do this, a larger group of subjects needs to be tested, and the same analysis carried out by Rathat *et al.*[8] in their published works needs to be performed.[4, 20] Our preliminary data suggest that a new set of data should be collected in subjects who perform exercise on a treadmill with our protocol, exercise at a high altitude, and then report whether they developed AMS. Thus, it is necessary to define new ranges for the analyzed parameters, since the high intensity used in this study is probably not directly comparable with that used in the "original" protocol and its ranges.

Third, the fitness level and age of the subjects included in the study might have affected the results.[3, 5] In fact, a high $\dot{V}O_{2peak}$ value and young age are not preventive factors for AMS.[20, 21] The participants in this study reported training on average for ~7 hours per week, which might be an additional risk factor.

We proposed this protocol because even though studies[4, 8, 20] have been conducted in a wide variety of subjects, we thought that it would be more appropriate to perform the test on a treadmill because most individuals hike rather than cycle at high altitudes in the mountains.

However, our preliminary hypothesis was partially confirmed since we did not find differences in the mean values of the analyzed parameters; however, some subjects exhibited different responses during the CE and TR tests. Our results may have been affected by the intensity being higher than that used in previous papers.

Limitations of the study

We acknowledge that this study has some limitations that should be avoided in future investigations. We tested a small number of subjects to determine whether this analysis should be performed with a larger number of people going to a high altitude. Finally, we did not determine whether these participants developed AMS; hence, we can only speculate that the different protocols adopted might provide useful information regarding this condition.

Conclusions

In conclusion, we suggest that for individuals who plan to hike or run at a high altitude, a walking test is more specific. Additionally, when athletes go to high altitudes in the mountains for competitions, the intensity of the test should be similar to that used during the race. However, to validate these variations (locomotion and intensity) compared to the original protocol, more data must be collected.

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Conflicts of interest.—The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

Authors' contributions.—Alessandro Cigalotto and Stefano Lazzer have given substantial contributions to study conception and design, Nicola Giovanelli, Alessandro Cigalotto, Barbara Lesa and Stefano Lazzer to experiments conduction, Nicola Giovanelli and Stefano Lazzer to data analysis and interpretation, and manuscript writing, Nicola Giovanelli to figures editing, Nicola Giovanelli, Alessandro Cigalotto, Barbara Lesa and Stefano Lazzer to manuscript editing and revision. All authors read and approved the final version of the manuscript.

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