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Assessment of the efficiency of intermittent and continuous walking strategies in hypoxia

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A B S T R A C T

In normoxia, work efficiency (total oxygen cost of work) is lower in intermittent than continuous exercise, however, this has yet to be confirmed in hypoxia. We measured the efficiency of two matched-work, hypoxic uphill walks: (1) continuous, slow-steady walk, and (2) intermittent, high-speed walk and rest. Fourteen volunteers naive to high-altitude (8 females, 6 males; age = 21 ± 2 years; height = 170 ± 11 cm; body mass = 66.7 ± 12.5 kg; peak walking speed [PWS] = 7.3 ± 0.6 km·h^{-1}*) completed two experimental sessions, in a normobaric chamber at an equivalent altitude of 3,500 m (*FiO_2 *0.135;* $FiCO_2$ *0.04). The continuous strategy required participants to complete a 30-min walk at 50% of their pre-determined PWS (i.e., transition point between walking and running) with distance recorded. During the intermittent strategy participants completed the 30-min distance at their PWS, interspersed with self-determined rests. Breath-by-breath oxygen consumption, heart rate, and arterial oxygen saturation were measured throughout. The intermittent walk resulted in a 13% shorter 30-min distance completion time (1584 ± 301 s, p = 0.019) compared to the continuous walk, but at a 37% higher total* VO_2 *(continuous* VO_2 *= 73.2 ± 35.2 L vs. intermittent* VO_2 *= 46.1 ± 26.2 L, p = 0.001) and 39% greater energy expenditure (continuous energy expenditure = 1,473 ± 724 kJ vs. Intermittent energy expenditure = 962 ± 548 kJ, p < 0.001). The lower efficiency of the intermittent strategy compared to the continuous, agrees with those data reported for normoxia. It provides useful information for high altitude trekkers and potentially for those looking to identify exercise conditions to maximise weight loss.*

1. Introduction

Adventure tourism is becoming increasingly popular (Kurtzman & Caruso, 2018) and transport links to remote destinations mean virtually anyone, rather than just experienced mountaineers, can visit anywhere in the world, given sufficient funds (Apollo, 2017). Hypoxia limits exercise tolerance (Wehrlin & Hallén, 2006), this coupled with low cardiorespiratory fitness, is likely to increase rating of perceived exertion (RPE) (Rossetti et al., 2017). Mellor et al. (2014) found that participants who exhibited a higher RPE during a 10-day trek to 5,129 m had a higher incidence of acute mountain sickness (AMS). These factors could have serious implications for those unfamiliar with high altitude environments, or the exercise naïve.

Aerobic exercise in hypoxic conditions is less efficient than the equivalent in normoxia due to the reduction in availability of oxygen caused by the reduced barometric pressure. This reduction in available oxygen lowers an individual's maximal rate of oxygen uptake resulting in an increase in relative exercise intensity and reliance on anaerobic energy systems (Campbell et

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al., 2015; Fulco et al., 1998; Roi et al., 1999; Sutton et al., 1988; Wehrlin & Hallén, 2006). When needing to complete a given amount of work (e.g., summit a mountain within a set time frame) evidence suggests an interval approach may be more beneficial than exercising continuously (Fornasiero et al., 2020). Typically, shorter exercise periods and more frequent breaks are adopted (Fornasiero et al., 2020), however this approach does not support the old adage that "slow and steady wins the race" (Roach et al., 2000).

Edwards et al. (1973) investigated the difference between continuous and intermittent exercise matched for work during a cycling exercise. They found that intermittent exercise equating to 50% maximum power output, separated with unloaded pedaling recovery bouts, resulted in an 8% higher oxygen intake ($\dot{V}O2$) compared to continuous cycling (2.16 ± 0.18 vs. 1.98 ± 0.14 L·min-1). Heart rate (HR), ventilation (VE), respiratory exchange ratio (RER) and blood lactate were also higher for the intermittent exercise.

The oxygen cost associated with different walking pacing strategies at high altitude has received limited investigation. Fornasiero et al. (2020) compared self-selected pace walk bouts with predetermined walks and rests of 6 min walk with 2 min rest or 3 min walk with 1 min rest. They found that the 6 min walk protocol resulted in higher HR and RPE and lower HR recovery. However, self-selection of walk-rest ratio at predetermined individualized paces has not yet been considered in relation to potential pacing strategies for high-altitude trekking. Quantifying the associated oxygen costs of continuous or intermittent walking when high-altitude trekking would help to inform decisions regarding pace setting when guiding large groups. Therefore, the aim of this study was to measure the efficiency (total oxygen cost) of two matched-work high-altitude uphill walks, (1) continuous, slow-steady walk, and (2) intermittent, high-speed walk and rest.

2. Methods

2.1. Participants

Fourteen volunteers (8 females, 6 males; age = 21 ± 2 years; height = 170 ± 11 cm; body mass = 66.7 ± 12.5 kg; peak walking speed [PWS] = 7.3 ± 0.6 $km \cdot h^{-1}$) provided written informed consent prior to completing a health screening questionnaire and participating in the study, which was approved by the University of Chichester Ethics Committee.

2.2. Task

Participants visited the laboratory on three occasions, first completing a peak walking speed test and then completing two exercise pacing sessions (continuous and intermittent) separated by a minimum of five days. All testing was carried out in a normobaric hypoxic chamber (TISS Model 201003-1, TIS Services UK, Medstead, UK) at conditions equivalent to an altitude of 3,500 m (FiO_2 0.135; $FiCO_2$ 0.04; N_2 balance; ambient temperature 10ºC; relative humidity 20%). All tests were completed on a motorized treadmill (HP Cosmos Pulsar, h/p/cosmos sport and medical gmbh, Nussdorf-Traunstein, Germany) set at a 10% gradient, with participants wearing a safety harness. Participants wore the same clothing ensemble (walking/training shoes, lightweight trousers, t-shirt) for all visits, with the addition of a 7 kg rucksack for the exercise pacing sessions.

2.3. Peak Walking Speed test

The test commenced with participants walking at 0.5 $km \cdot h^{-1}$ and the speed was increased by 0.5 $km \cdot h^{-1}$ every 30 s until the point where they transitioned into a run, at which point the test terminated. Participants were given verbal instructions not to run until they definitely could no longer maintain walking. Peripheral arterial oxygen saturation (SpO_2) and HR (Datex Ohmeda 3800, GE Healthcare, Hatfield, UK) were monitored continuously and peak speed recorded.

2.4. Exercise pacing sessions

The order of the exercise pacing session was not counter-balanced since the distance completed during continuous walk (where participants were permitted to adjust the treadmill speed) was required to match the distance to complete during the intermittent walk where the pace was not fixed.

For the continuous walk, participants were required to complete a 30 min continuous treadmill walk. The walk commenced at 50% of individual peak walking speed, if participants felt unable to maintain this pace, they were permitted to reduce the treadmill speed in increments of 5% until they felt able to walk continuously. At 30 min the total distance walked was recorded. Pilot work had suggested that the speed reduction option would be required, however, all study participants were able to complete 30 min walking at 50% peak walking speed.

For the intermittent session, the treadmill was set at participants' individual peak walking speed, and they were required to walk the same distance covered during their continuous walk. Participants walked until they felt unable to maintain the prescribed pace, at which point they stepped astride the treadmill belt to rest. Participants then rested and restarted walking when they felt able; no verbal instruction or encouragement to do this was provided. Total time to complete the distance was recorded and the walk-to-rest ratio was calculated.

For both sessions, HR, SpO_2, RPE (Borg, 1982), and breathlessness (Burdon et al., 1982) were recorded every minute. Expired gas was analyzed breath-by-breath using a portable respiratory gas analysis system, which was carried in the rucksack (Cosmed $K4b_2$, Cosmed, Rome, Italy) forming part of the carried load. Total oxygen consumption (L) was calculated by integration using the trapezium rule (Williams et al., 2008).

2.5. Statistical approach

Data are reported as mean ± standard deviation, and were analyzed using GraphPad Prism, (Version 8 for Windows, GraphPad Software, San Diego, California USA). Paired *t*-tests were used to compare time to complete the walk in each of the pacing strategies. Breath-by-breath variables ($\dot{V}O_2$, VE, RER, breathing frequency [Rf]), HR, and energy expenditure for walk vs. rest during the intermittent session were compared by paired *t*-test. The HR and SpO_2 were analyzed using a repeated measures

ANOVA with fixed effects for pacing strategy (2: continuous and intermittent) and time (10: where time points were analyzed as a percentage of total walk completion using 10% increments). Additionally, HR and SpO_2 throughout the walks were converted to both means and peak values and analyzed using paired *t*-tests. Mean fat and carbohydrate oxidation (Frayn, 1983) were compared between the two walks using paired *t*-test. The RPE and breathlessness ratings were analyzed using a Wilcoxon test. To control for the false discovery rate and correct for multiple comparisons, the two-stage step-up method was employed (Benjamini & Hochberg, 1995). Work completed was calculated from individual body mass and distanced covered.

3. Results

The mean total distance walked in the continuous session was 3.6 ± 0.3 km equating to a mean work completed of 120 ± 31 kJ. For the intermittent session, the time taken to complete the 30-min distance reduced by 217 s (13%) to 1584 ± 301 s ($p = 0.019$). The analysis of the walk-to-rest ratio showed that participants walked for longer than they rested (walk-to-rest ratio = 1023 ± 49 s : 561 ± 259 s, $p < 0.001$), but this decreased after the initial walk (first walk time: 118 ± 42 s), and then fell with rest time increasing.

The total oxygen cost of exercise was 37% greater for intermittent than for continuous (Figure 1; intermittent = 73.2 ± 35.2 L vs. continuous = 46.1 ± 26.2 L, $p = 0.001$; 95% CI [13.26, 41.02]). Exercise efficiency was greater for the continuous walk (continuous = 12.5% vs. intermittent = 8.2%).

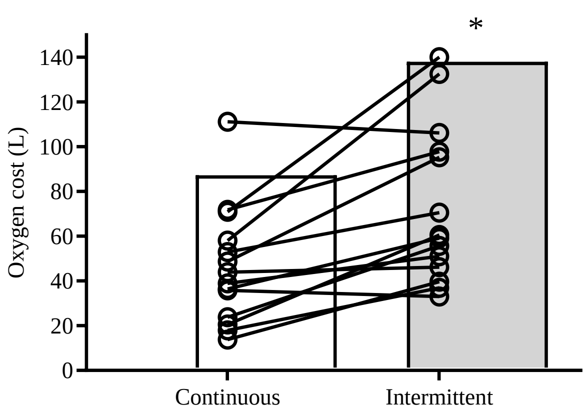

Figure 1: Oxygen cost of complete continuous and intermittent walk. Bars display the mean group response, and lines show each individual data point. *$p = 0.001$.

Breathing frequency was higher for the intermittent walk than continuous walk (mean total time including rests) ($p < 0.001$; 95% CI [12.81, 23.19]) (Table 1), as was $\dot{V}E$ ($p < 0.001$; 95% CI [27.92, 48.79]) (Table 1). Energy expenditure was 39% greater for the intermittent walk ($p < 0.001$, 95% CI [76.56, 217.80]; Table 1). Carbohydrate oxidation was higher for the intermittent walk than the continuous walk (intermittent: 0.5 ± 0.4 g·min^{-1} vs. continuous: 0.1 ± 0.1 g·min^{-1}, $p = 0.003$; 95% CI [0.2, 0.6]); fat oxidation was similar for both walks (intermittent: 1.1 ± 0.8 g·min^{-1} vs. continuous: 0.8 ± 0.6 g·min^{-1}, $p = 0.541$; 95% CI [-0.2, 0.1]).

Table 1: Comparative results for continuous vs. intermittent walks

	Continuous	Intermittent
Breathing frequency (Rf; breaths·min^{-1})	30 ± 6	45 ± 8
Minute ventilation (L·min^{-1})	30.3 ± 12.6	67.0 ± 19.7
Energy expenditure (kJ)	962 ± 548	1473 ± 724

Note: Data are presented in mean ± standard deviation.

For the intermittent walk, there were no differences between the walk and rest periods for breathing frequency (Rf) (walk = 49 ± 10 breaths·min^{-1} vs. rest = 49 ± 12 breaths·min^{-1}, $p = 0.581$; $\dot{V}E$ (walk = 71 ± 20 L·min^{-1} vs. rest = 69 ± 21 L·min^{-1}, $p = 0.072$; oxygen cost (walk = 35.71 ± 12.82 L vs. rest = 34.60 ± 14.77 L, $p = 0.167$); RER (walk = 0.8 ± 0.3 vs. rest 0.8 ± 0.3, $p = 0.077$; HR (walk = 158 ± 14 BPM vs. rest 156 ± 20 BPM, $p = 0.555$); or energy expenditure (walk = 749 ± 268 kJ vs. rest 724 ± 310 kJ, $p = 0.167$).

3.1. Physiological and perceptual responses

Mean HR and SpO_2 responses are presented in Figure 2. Heart rate was elevated throughout exercise during the intermittent walk compared to the continuous walk (main effect for both pacing strategies ($F(1, 26) = 57.95$, $p < 0.001$, $\eta^2 = 0.03$) and time, ($F(2.1, 54.36) = 12.25$, $p < 0.001$, $\eta^2 = 0.08$), though no pacing strategy × time interaction effect was found ($F(9, 234) = 1.35$, $p = 0.214$, $\eta^2 = 0.01$). Mean HR was 33 ± 11 BPM higher using the intermittent pacing strategy (intermittent: 160 ± 11 vs. continuous: 127 ± 15 BPM, $p < 0.001$). Similarly, peak HR was 24 ± 12 BPM higher during the intermittent walk compared to the continuous walk (intermittent: 189 ± 12 vs continuous: 165 ± 28 BPM, $p = 0.001$; Figure 2 upper inset). No main effect for pacing strategy ($F(1, 24) = 1.364$ $p = 0.254$, $\eta^2 = 0.03$) or pacing strategy × time interaction ($F(9, 216) = 0.520$, $p = 0.859$, $\eta^2 = 0.01$) was observed for SpO_2 during exercise. Mean SpO2 (continuous: 80.3 vs. intermittent: 80.1%, $p = 0.829$) and lowest recorded SpO_2 (continuous: 78.3% vs intermittent: 78.7%, $p = 0.799$) were similar between pacing strategies (Figure 2 lower inset). The intermittent walk was completed at a higher rating of both perceived exertion (between hard and very hard 16 ± 2, vs. very light 9 ± 2, $p < 0.001$) and sensation of breathlessness (severe/heavy 5.0 ± 1.1 vs. very slight 1.4 ± 0.8, $p < 0.001$).

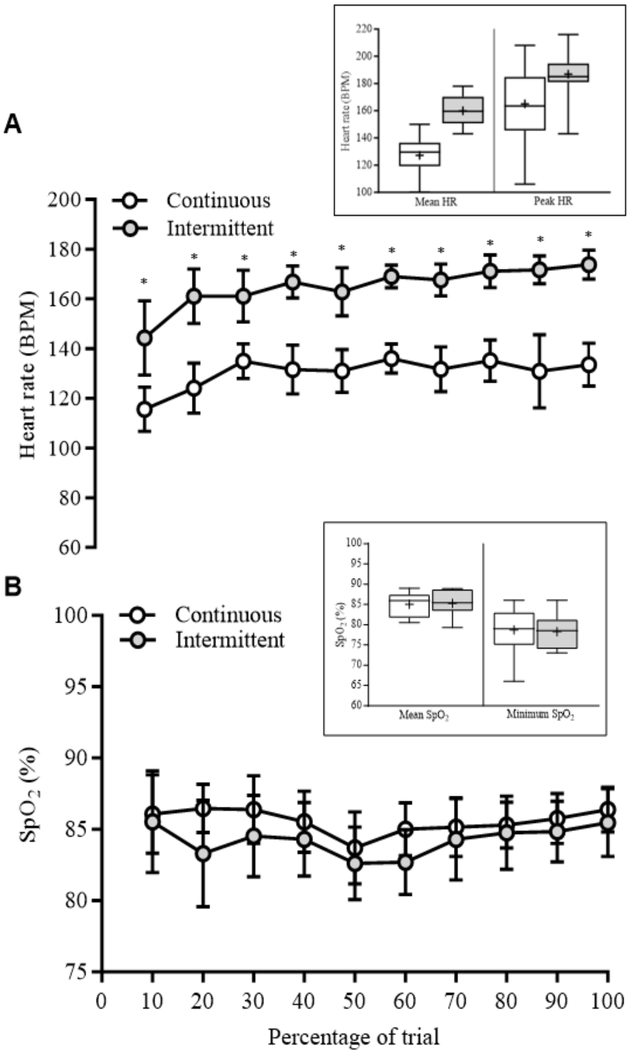

Figure 2: Group mean ± standard deviation, 95% confidence intervals for heart rate (A) and SpO2 (B) responses throughout exercise (*n* = 13). The exercise time is represented as a proportion of the exercise load completed (%). *$p < 0.010$. Upper inset shows a box and whisker plots for the mean and peak heart rate and the lower inset shows a box and whisker plot for the mean and lowest recorded SpO_2 throughout both pacing strategies. Box edges illustrate the upper and lower quartiles, the midline denotes the median value and the cross denotes the mean. The upper and lower observed values are shown by the whiskers.

4. Discussion

The aim of this study was to compare the efficiency of two walking strategies, a continuous and slow steady walk, and an intermittent rush and rest walk, in terms of time to complete a matched distance (work), total oxygen cost and energy expenditure. The intermittent strategy led to the walk distance being completed approximately three minutes faster than when employing a continuous pacing strategy, however at a ~37% greater oxygen cost and approximately 39% higher energy expenditure.

The benefit of the approximately 14% reduction in time to complete the walk distance observed for the intermittent strategy was arguably offset by the significantly greater oxygen cost and higher energy expenditure required, thus highlighting its inefficiency. While it has been reported that in normoxia the oxygen cost of intermittent exercise is greater than that of continuous exercise (Edwards et al., 1973), the magnitude of this inefficiency in hypoxia was worthy of investigation to establish whether the potential negative physiological impact would be offset by a meaningful improvement in work (walking distance) completion time.

On initial consideration of the results, the approximately 3.5 min faster walk completion time achieved during the intermittent approach could be interpreted as a beneficial gain. Although speculative from an approximately 30 min test this improvement would gain a person about 7 min per hour so for a 5-hour trekking day around 35 min if you were able to maintain this pace. For a summit day this kind of improvement may be meaningful, but for a trek it could be argued less so. The higher energy expenditure, and it being supplied predominately via carbohydrate oxidation, for the intermittent walking strategy is of practical interest, equating as it does to approximately an extra 240 kcal per hour or 1,200 kcal for a 5-hour trekking day. This is a substantially higher expenditure and important at high altitude given the reported difficulty of maintaining body weight at altitude (Kayser & Verges, 2013), typically high-altitude exposure alters substrate utilisation to favour carbohydrate rather than fat oxidation (Braun et al., 2000; Brooks et al., 1991). In the context of the present study, a pacing strategy which further increases carbohydrate oxidation may have negative implications for weight maintenance and therefore require additional dietary measures to counter the effects (Brooks et al., 1991; Roberts et al., 1996) and ultimately increasing pack weight due to needing to carry more food.

Again, accepting that the 30-min exercise window is not fully representative of a day's trekking or climbing, it is unclear how long individuals would have been able to maintain the intermittent pacing strategy beyond the 30-min in this study. The walk times decreased, and rest times increased after the initial walk which is suggestive of a finite end to this strategy, or at least a substantial rest would be required before it could be recommenced. There was a tendency for the last intermittent walk time to be longer, but this is likely to be a consequence of the spurt effect (Catalano, 1973) as participants were aware of the distance they had remaining. Future studies should consider increasing the overall walk distance to mimic a typical day's trekking or climbing to improve ecological validity.

The lack difference for Rf, VO_2, and $\dot{V}E$ between the walk and rest periods of the intermittent walk indicate that while the participant was resting, they were repaying the oxygen debt accrued during the walk. Our results are similar to those found by Edwards et al. (1973) who suggested that the elevated values throughout the rest periods are indicative of repletion of oxygen and phosphagen stores, aerobic metabolism of lactate, and a disturbance to basal metabolism possibly brought about by an increase in core temperature. Heart rates also remained high during the rest phases of the intermittent walk, remaining throughout approximately 22% higher than during the continuous walk, further suggesting that recovery was minimal during the intermittent walk.

The SpO_2 was similar between the two walks. Desaturation at rest is indicative of the development of AMS (Roach et al., 1998) and in general is an important predictor of AMS (Burtscher et al., 2019). During exercise SpO_2 lowers, particularly if the exertion is high. The similarity between the two pacing strategies in the present study could have been an effect of the normobaric hypoxia. Previous work has found that SpO_2 values are lower in hypobaric hypoxia, either in a chamber or in the field compared to normobaric hypoxia (Levine et al., 1988; Netzer et al., 2017; Self et al., 2011).

Subjective measures were reflective of the higher oxygen cost and HR in the intermittent pacing strategy. Sensations of breathlessness may directly influence ratings of perceived exertion. The interoceptive response is likely to increase the sensations of breathlessness when exercising at a higher intensity compared to lower intensity because of the expectation of having to work harder (Marlow et al., 2019). Although in the present study the physiological responses confirm that the participants were breathing harder when working intermittently, the psychological impact could have disproportionately heightened the sensation. In a field setting, higher RPE or sensation of breathlessness could have a negative impact on affect (overall emotion) and dampen the overall experience (Rossetti et al., 2017). Since individuals typically visit high altitude destinations as a leisure activity, this negative affect is not desirable.

The main limitation of this study was the acute nature of the exposure to a single simulated altitude. It would be of interest to see whether the magnitude of difference in oxygen cost was greater at a higher simulated altitude, or if an intermittent strategy could be adopted for longer to replicate a day's high-altitude trekking allowing the advantage of completing the walk distance more quickly to be maintained. The conditions were not counterbalanced for the reason highlighted in the methods, however given that no participants needed to reduce their treadmill speed, 50% PWS at 3,500 m appears to be achievable, so future studies should look to use this intensity for a counterbalanced protocol. The hypoxic exposure was acute in this setting so the results may differ if the participants were acclimatised; this could be assessed if a similar study was repeated in the field at high altitude with a more chronic exposure. If this study was repeated it would be of interest to continue to collect breath-by-breath measures following the completion of both walks to assess the time taken to return to resting levels for all variables. This information would provide a greater understanding of the detriment to the individual and therefore possible negative impact in a field setting.

Though not one of the aims of this study, the identification of a potentially time efficient, energy expenditure inefficient exercise strategy (approximately 26 min 1473 kJ vs. 30 min 962 kJ) is of interest to researchers working in the area of weight reduction. Research in this area should look to explore the acceptability of intermittent exercise in hypoxia to overweight/obese individuals, including what mode of exercise and prescription (controlled versus self-paced) is preferred. While prescribing a high altitude trekking trip to those looking to lose weight (adipose mass) is clearly neither practical or cost effective, the increasing availability of hypoxic chambers at universities and sports centres may facilitate a hypoxic exercise intervention as part of a weight loss plan.

We have shown that an intermittent peak walking speed pacing strategy decreases completion time of a fixed distance walking task by approximately 3.5 min (13.7%), but that this is offset by approximately 27 L (37%) increase in oxygen cost, a 39% increase in energy expenditure and elevated cardiovascular strain. Our results suggest that the adoption of a more economical, continuous pacing strategy when high altitude trekking, while slightly increasing time to complete the distance, is less metabolically stressful. Due to the difference in time to complete the distance being only a modest increase for the peak walk speed pace, the continuous slower pacing strategy is recommended as preferable. However, in an emergency situation, one could consider the intermittent pacing strategy if necessary.

Conflict of Interest

The authors declare no conflict of interests.

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