Skiing uphill using resort-touring skis: effects of simulated altitude

James Brown
Nottingham Trent University
Ben Nevill
Nottingham Trent University
Henry Spenk
Nottingham Trent University
India Fraser
Nottingham Trent University
James Hanly
Nottingham Trent University
David Donkin
Nottingham Trent University
Morris Owen
Nottingham Trent University
William Kinnear (William.Kinnear@ntu.ac.uk)
Nottingham Trent University

Research Article

Keywords: Skiing, Ski-touring, Altitude, Anaerobic threshold, Respiration, Exercise

Posted Date: June 1st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1641250/v1

Abstract

We studied ten recreational skiers on W500RT skis (Decathlon) skis fitted with uni-directional “skins” on a treadmill with 25% slope. Speed was increased from 1km/hr by 0.3 km/hr every minute until the subject was unable to maintain pace. The test was repeated in an environmental chamber with an oxygen content of 14%, equivalent to an altitude of 3000m.

We measured oxygen consumption (VO_2), carbon dioxide production (VCO_2) and ventilation (VE). The anaerobic threshold (AT) was determined from V-slope and the respiratory compensation point (RCP) from VE/VCO_2.

The mean (SD) speed attained at sea level as 4.2(0.6)km/hr, with a VO_2 of 45(8)ml/kg/min. HR was 75(6)% of predicted maximum at AT, 85(8)% at RCP.

At 3000m, SpO2 was 79(3.6)% and speed 3.4(0.5)km/hr at peak exercise (both $P < 0.05$ compared to sea-level). There were no significant differences in VO_2 at peak exercise, AT or RCP.

Altitude reduces maximum ski touring pace. We recommend that recreational ski-tourers should adjust their pace so that HR is maintained around 80% of their predicted maximum.

Introduction

Whilst the vast majority of skiers use mechanical lifts to ascend a mountain, some choose to ski uphill in order to access the “back-country” where the skiing is more challenging and the ambience different to that of a ski resort. This is called ski-touring or, in its more extreme form, ski-mountaineering.

Skiing uphill requires the use of unidirectional “skins” (originally using the direction of the hairs of sealskin, but now synthetic) attached to the underside of the ski, so that it can slide forwards but not backwards. These skins are removed prior to descent. Ski-touring requires the use of a binding which allows the heel of the ski boot to lift off the ski when walking uphill; the boot is then fixed back into the rear binding for the descent. Ski-touring skis are similar in size and shape to downhill skis (unlike the thin cross-country skis used to race over flatter terrain), but lighter. Ski-touring boots are also lighter than downhill ski boots, with more flexibility at the ankle.

Recognizing that many skiers enjoy the physical challenge of ascending a mountain under their own steam, many resorts have started to create specific tracks for “resort-touring” (sometimes also referred to as “front-country” ski-touring). This is safer than back-country skiing and can be done with less expensive (but heavier) equipment than traditional ski-touring. Cardiovascular fitness becomes more important than mountaineering skills.

Ski-touring has been increasing in popularity over recent years. This trend has accelerated during the Covid epidemic, since it allows access to the ski slopes when lifts are closed. It also avoids the use of enclosed cable cars and gondolas, with their inherent risk of viral transmission. The introduction of ski-mountaineering at the 2026 winter Olympics is likely to stimulate interest in the physiology of uphill skiing.

The aim of the present study was to develop a protocol for investigation the physiology of resort-touring in the laboratory setting. We then used this to assess the effect of simulated altitude on resort-touring performance.

Methods

Ten recreational skiers took part in the study, eight male and two female, four of whom had previous experience of ski-touring. Their mean age was 31.9 (range 20–65) years. Written informed consent was obtained from each subject.

We used Wedze W500RT 158cm hybrid resort-touring skis (Decathlon) fitted with Tyrolia Ambition 10 bindings. These bindings permit the use of conventional downhill ski boots. A uni-directional “skin” was attached to the underside of each ski. The heel riser of the ski binding was set to its highest setting, so that the boots were effectively horizontal on the treadmill (see Fig. 1).

We used a conventional running treadmill (h/p/cosmos, Pulsar 4.0, Nussdorf-Traunstein, Germany), set at its maximum slope of 25 percent (14 degrees) throughout the study. In order to protect the belt of the treadmill, ski poles were not used.

Subjects skied for a one minute warm-up at 0.5 km/hr. Recording was started with a treadmill speed of 1 km/hr. The speed was increased by 0.3 km/hr every minute until they could no longer keep pace with the treadmill. Our aim was to assess maximum exercise capacity, with a test lasting 8–12 minutes. During the test, subjects selected their own step rate.

Ventilation $(\dot{V}_E)$, oxygen consumption (VO_2) and carbon dioxide output (VCO_2) were measured breath by breath using a metabolic cart (JAEGER™ Vyntus™ CPX, incorporating SentrySuite software Version 2.21.1; Vyaire Medical Products Ltd, Chineham, Basingstoke) connected to an oronasal mask (Hans Rudolph). The mask was connected to a low-resistance (< 1.0 cm $H_2O \cdot L - 1 \cdot s^{-1}$ at < 15 $L \cdot s^{-1}$) digital volume transducer with a combined dead space of 270 mL. The flow sensor was calibrated automatically using a built-in flow generator, producing precise constant airflows. Gas concentrations were sampled ($50 mL \cdot min^{-1}$) at the mouth via a 2.4 m sample line and analysed using a high speed digital O_2 sensor based on an electrochemical principle, and a fast response digital CO_2 sensor based on the principle of infrared absorption. These were calibrated using ambient air and gases of known concentration (5% CO_2, 15% O_2, balance N_2; BOC, Guilford, UK). During the test, breath-by-breath data were averaged over 10 seconds.

Heart rate was recorded using a heart rate monitor (Polar Electro, Kempele, Finland). Predicted maximum HR was estimated as 220 – age in years. Peripheral oxygen saturation (SpO_2) was recorded continuously using a finger probe (Ohmeda). When the subject reached their peak effort and the treadmill was stopped, a finger-prick blood sample was taken and analysed for lactic acid (Biosen, EKF diagnostics).

At peak effort we noted HR, VO_2 (VO_2max) and treadmill speed. Anaerobic threshold (AT) was determined automatically by the SentrySuite software, using the V-slope method. The respiratory compensation point (RCP) was determined automatically from the VE/VCO2 plot.

Having determined the speed of the treadmill at AT during the maximal test at sea level, five subjects returned on a different day to ski at this speed for 40 minutes. As for the maximal test, the slope of the treadmill remained constant at 25%. After 40 minutes, a finger-prick blood sample was analysed to see if there had been any significant accumulation of lactic acid.

The combined weight of each ski with skin and binding was 2.5 kg. With these bindings, subjects were able to use conventional downhill ski boots, each boot also weighing around 2.5 kg. In order to see the effect of equipment weight, we studied five subjects with and without a one kilogram ankle weight strapped to each boot (Fig. 1). VO_2 and HR were recorded whilst the subject skied for ten minutes at their AT speed (as previously determined from the maximal protocol). Subjects were studied with and without the added weights in random order, leaving a ten minute break between the two conditions.

To study the effect of altitude, each subject underwent two ski tests to exhaustion on separate days, in random order: one at sea level and one in an environmental chamber (WIR52-20HS, Design Environmental Ltd., Gwent, Wales, U.K) with an oxygen content of 14% (equivalent to an altitude of 3000m). The temperature and humidity of the chamber were set to the ambient settings of the day when the subject performed their sea-level test. SpO_2 was monitored continuously, and the test was terminated if it fell below 75%.

Comparisons between sea-level and simulated altitude were made using paired t-tests on the SPSS statistical package, taking 0.05 as the level of statistical significance. For any data that were not normally distributed, we used non-parametric Wilcoxon sign-rank tests.

The study was approved by the Nottingham Trent University Human Ethics Committee, and all procedures conformed to the standard set by the Declaration of Helsinki. No specific funding was received for the study.

Results

All subjects completed the protocol without adverse incident, despite not using ski poles for stabilisation. The median time of skiing until exhaustion was 11.7 minutes (range 9–15). At sea level, mean VO_2max was 45 ml/kg/min, at a speed of 4.2km/hr (Table 1). The AT was passed at an average speed of 2.5

km/hr, when the VO_2 was 69% of VO_2max and HR 75% of predicted maximum. On average, the RCP was seen when VO_2 was 82% of VO_2max, with HR at 85% of predicted maximum.

At simulated altitude, SpO_2 was lower and maximum speed was reduced by 19% compared to sea-level. VO_2 was not significantly reduced at peak exercise, AT or RCP. Despite the lower maximum speed, subjects attained a similar peak HR to that recorded at sea level.

Peak exercise:		**Sea level**	**3000m**
Speed	km/hr	4.2 (0.6)	3.4 (0.5)*
Distance	km	5.97 (1.97)	4.02 (1.43)*
Ascent	m	149 (49)	101 (36)*
SpO_2	%	91.8 (3.6)	79 (3.6)*
Lactate	mmol/l	7.3 (2.7)	6.8 (2.9)
Heart rate	bpm	179 (10)	174 (13)
	% predicted	95.5 (6.0)	92.6 (6.7)
VO_2	l/min	3.29 (0.83)	3.10 (0.79)
	ml/kg/min	45 (8)	42 (7)
Ventilation	l/min	125 (37)	128 (6)
Anaerobic Threshold:			
Speed	km/hr	2.5 (0.5)	2.2 (0.6)
VO_2	l/min	2.28 (0.59)	2.12 (0.70)
	%VO_2max	69 (6)	68 (7)
Heart rate	% predicted maximum	75 (6)	77 (11)
Respiratory Compenstion Point:			
VO_2	l/min	2.67 (0.59)	2.52 (0.48)
	%VO_2max	82 (7)	83 (7)
Heart rate	% predicted maximum	86 (8)	86 (8)

At the end of the 40 minute ski at the AT speed, four of the five subjects had lactate levels less than 2.5 mmol/L.

Adding one kilogram to each boot resulted in mean change of + 12ml/min in VO_2 and − 3 bpm in HR, neither of which were statistically significant.

Discussion

We have demonstrated that a simple protocol can be used to evaluate ski-touring performance in the laboratory with a conventional treadmill. For simplicity, we chose to maintain a constant slope and gradually increase the speed of the treadmill belt. A 25% slope is possible on most commercial running treadmills and has been shown to be an efficient incline for ski touring. [1,2] Similar slopes have been used in previous studies. [3–5] We suggest that our protocol (1 km/hr, increasing by 0.3 km/hr every minute) is suitable for studying recreational ski-tourers, although a faster starting speed with larger incremental increases could be chosen for elite athletes. [4,6–7]

Some studies have used roller skis to emulate ski-touring. [2,8] We feel that our testing procedure more closely resembles the motion of ski-touring. Field studies on snow, using portable metabolic recording systems carried by the subjects, are expensive and inevitably must be performed at altitude. [1,8] Whilst they are more realistic, these studies are subject to the vagaries of the weather and snow conditions.

Published values for VO_2 max in ski tourers have tended to be higher than the mean of 45 ml/kg/min attained in our subjects, often over 60 ml/kg/min. [3–4,6,9–11] Many of these previous studies, however, used highly-trained elite competitive ski-tourers, who have higher aerobic capacities than recreational ski-tourers. [12]

Competitive ski-mountaineers spend the majority of the time above AT. [7] Our subjects reached AT at around 70% of VO_2max, which is consistent with previous studies [3–4,7,9,11] HR at the AT was in the region of 75% of predicted maximum. Again, this is consistent with published data. [6–7] Four of the five subjects who skied for 40 mins at their AT speed did not show any build-up of lactate, suggesting that this would be a sustainable speed for a recreational ski-tourer to adopt on the slopes. The reason for accumulation of lactate in the fifth subject was not clear.

Elite ski-mountaineers spend significant periods of time around the RCP. [7,11] Indeed, VO_2 at the RCP has been shown to predict overall race performance. [4,7,9–10] Published values for VO_2 at RCP in ski-touring have been around 90% of VO_2max, [3–4,7,9,11] with HR at 95% of maximum. Our subjects reached RCP somewhat earlier. This could be explained by their lower fitness compared to elite athletes, but factors related to the ski equipment or test set-up cannot be excluded.

The skis and bindings we used are designed for recreational rather than competitive ski-touring. With them, it is not necessary to purchase specific lightweight ski-touring boots, although the use of stiffer downhill boots may restrict stride length during the ascent. [1–2,8] The combined weight of a pair of resort-touring skis with downhill boots will be 5 kg or so heavier than a lightweight ski-touring setup. [7] For resort touring, skiers will probably carry a small rucksack, with a weight similar to the 2.5 kg carried by competitive ski mountaineers. (For hut-to-hut trips, ski tourers may carry over 10kg of additional equipment.) Taking account of their body mass, it has been suggested that the additional weight of resort-touring skis and downhill boots over a lightweight ski-touring set up will probably affect performance by less than 10%. [1,3,5,8] We were unable to detect any effect from an additional 2kg attached to the boots of our subjects, and suggest that for recreational resort-touring the use of a heavier ski and binding setup is unlikely to have a significant effect on performance.

Assessment of VO_2max, AT and RCP will be of interest when assessing the fitness of ski-tourers and developing training programmes for them. Recreational ski-tourers may choose to use a HR monitor to guide their effort. We suggest they could aim to keep their HR around 80% of predicted maximum, corresponding to that seen between the AT and RCP. HR may increase to 90% temporarily on steeper sections, as skiers approach the RCP. The strategy of using a zig-zag path across steeper slopes in order to reduce the gradient could be adopted when HR starts to approach 90%. Competitive ski-mountaineers, on the other hand, will aim to spend a higher proportion of their ascent near the RCP.

Simulated altitude caused our skiers to desaturate and forced them to stop earlier. It has previously been suggested that an altitude of 3000m should reduce performance by 20–25% [12], consistent with the value of 19% seen in our study. The effect on VO_2max was less pronounced, as has been previously documented. [12] Despite being at a slower speed, HR at peak exercise was similar at altitude compared to sea-level. It seems likely that the low partial pressure of inspired oxygen reduced that rate of transfer of oxygen into the blood of our subjects, so that they needed to increase heart rate in order to maintain oxygen delivery to their leg muscles. When skiing at the AT in a ski resort, recreational resort-tourers will probably not notice any effect of altitude. At most, they will find themselves reducing their speed only slightly in order to keep their HR at 80% of predicted maximum.

Further field studies would allow us to see if our findings can be extended to ski-touring on real snow in the mountains. We found that the subjects tended to lift rather than slide the skis up the treadmill, whereas a skin with less grip might allow a more realistic ski-touring step. Our subjects selected their own step rate; it would be of interest to examine the effect of longer or shorter stride lengths on VO_2, using a metronome to fix slower or faster step rates.

Conclusions

Recreational ski-tourers attain a peak VO_2 lower than published figures from competitive ski-mountaineers. In order to remain between the AT and RCP, we suggest that they should aim to keep their HR between 75 and 85% of their predicted maximum. This will require a small reduction in their speed at the altitudes they are likely to encounter whilst resort-touring.

Practical Implications

- Ski-touring performance can be assessed using a conventional running treadmill set at a slope of 25%.
- Using this technique, recreational skiers achieve a peak oxygen consumption of 45ml/kg/min.
- The anaerobic threshold and respiratory compensation point are reached when heart rate is 75% and 85% of predicted maximum, respectively. Recreational ski tourers should aim to maintain heart rate within this range.
- Normobaric hypoxia, simulating an altitude of 3000m, results in a fall in oxygen saturation and peak ski-touring speed from 4.2 to 3.4 km/hr.

Declarations

Funding

No specific funding was received for this study

Declaration of Interest

None of the authors have any conflicts of interest to declare.

Author Contributions

WK, JB and BN designed the study. All authors were involved in data collection. The manuscript was written by WK and JB. All authors reviewed the manuscript.

References

1. Menz M, Niedermeier M Stehle R, Mugele H, Faulhaber M. Assessment of maximal aerobic capacity in ski mountaineering: a laboratory-based study. Int J Environ Res Public Health 2021/18:7002.
2. Skinner ADC, Koehn D, Buchanan CA, Dallek LC. Effect of equipment weight on energy cost and efficiency during simulated uphill ski touring. Int J Res Ex Phys 2019;15:73–86.
3. Fornasiero A, Salvodelli A, Boccia G, Zignoli A, Bortolan L, Schena F, Pellegrini B. Physiological factors associated with ski-mountaineering vertical race performance. Sport Sci Health 2018;14:97–104.
4. Cassirame J, Tordi N, Fabre N, Duc S, Durand F, Mourot L. Heart rate variability to assess ventilatory threshold in ski-mountaineering. Eur J Sport Sci 2015;15:615–622.
5. Praz C, Leger B, Kayser B. Energy expenditure of extreme competitive mountaineering skiing. Eur J Appl Physiol 2014;114:2201–2211.
6. Praz C, Fasel B, Vuistiner Ph, Aminian K, Kayser B. Optimal slopes and speeds in uphill ski-mountaineering: a field study. Eur J Appl Physiol 2016;116:2017–2024.
7. Praz C, Fasel B, Vuistiner Ph, Aminian K, Kayser B. Optimal slopes and speeds in uphill ski-mountaineering: a laboratory study. Eur J Appl Physiol 2016;116:1011–1019.

8. Duc S, Cassirame J, Durand F. Physiology of ski mountaineering racing. Int J Sport Med 2011;32:856–863.
9. Lasshofer M, Seifert J, Worndle A-M, Stoggl T. Physiological responses and predictors of performance in a simulated competitive ski mountaineering race. J Sport Sci Med 2021;20:250–257.
10. Tosi P, Leonardi A, Schena F. The energy cost of ski-mountainerring: effects of speed and ankle loading. J Spor Med Phys Fit 2009;49:25–29.
11. Schenk K, Faulhaber M, Gatterer H, Burtscher M, Ferrari M. Ski mountaineering competition: fit for it? Clin J Sport Med 2011;21:114–118.
12. Faiss R, von Orelli C, Deriaz O, Millet GP. Response to exercise in normobaric hypoxia: comparison of elite and recreational ski mountaineers. Int J Spo Phys Perf 2014;9:978–984.

Figures

Figure 1

Legend not included with this version.