The ultra-short-term outcomes in performance, aerobic endurance, blood-related parameters, and anthropometrics following prolonged low-intensity ski trekking across Spitsbergen: A case study

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Abstract

This study aimed to evaluate changes in endurance capacity, blood-related variables, and anthropometrics following ultra-short-term, prolonged low-intensity ski trekking (LIST). One female (38 years) and one male (52 years) participated in the study in connection with a self-selected ski expedition (hauling ~40-kg sledges each) across Spitsbergen (~126 km), the largest island in Svalbard, Norway. Results revealed that the two moderately aerobically fit participants performed LIST at a mean velocity of ~3.4 km·h^{-1}, corresponding to ~54–63% of maximal heart rate, ~5 hours·day^{-1}, for eight days during this unsupported event. The mean daily energy intake during the expedition was ~7.8 MJ·day^{-1} (~1850 kcal·day^{-1}), of which ~49–61%, ~25–36%, and ~14–15% was derived from carbohydrates, fat, and protein, respectively. Body mass, absolute fat mass, and relative fat mass decreased by 2.2%, 10%, and 8%. In the male participant, time to exhaustion increased by 10% and 3.8% during a ~5 min and ~40 min incremental ski trek-simulated treadmill test. The number of leukocytes declined by 30–41%, as did low-density lipoprotein cholesterol levels. Free triiodothyronine level increased by 19% in the female, whereas thyroid-stimulating hormone concentration increased by 23% in the male. In this category of ski trekkers, one can conclude that ultra-short-term, prolonged LIST can cause slimmer body composition without loss of lean mass, improve performance, reduce low-density lipoprotein cholesterol level, and affect metabolic hormones associated with the pituitary-thyroid axis. However, such an event may impair the immune system.

Key words: expedition, low-intensity exercise, body composition, substrate utilization, macronutrients, hematology, lipids, enzymes, hormones.

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Introduction

The short-term to long-term (14–95 days) changes in endurance capacity, blood-related variables, or anthropometrics following prolonged low-intensity ski trekking (LIST, ~5–15 hrs·day^{-1}, ~60% of maximal heart rate (HR_{max})) in polar regions have been investigated in several studies in moderately and well-trained recreational individuals (females and males, pre-trek relative maximal oxygen uptake ($\dot{V}O_{2max}$) of ~40–70 mL·kg^{-1}·min^{-1}) (Booth et al. 1991, Stroud et al. 1997, Sandbæk et al. 1997, Frykman et al. 2003, Helge et al. 2003, 2006; Péronnet et al. 2009, Boushel et al. 2014, 2015; Paulin et al. 2015, Anton-Solanas et al. 2016, Parent et al. 2018, Jarstad and Mamen 2022, Jarstad et al. 2023). In those studies, data have showed performance improvements (Boushel et al. 2014, Jarstad and Mamen 2022), enhanced, maintained, or impaired aerobic endurance (*i.e.* $\dot{V}O_{2max}$, lactate/ventilatory threshold %$\dot{V}O_{2max}$, and/or work economy) (Booth et al. 1991, Stroud et al. 1997, Sandbæk et al. 1997, Frykman et al. 2003, Helge et al. 2003, 2006; Péronnet et al. 2009, Boushel et al. 2014, 2015; Parent et al. 2018, Jarstad and Mamen 2022), and improved or unchanged fat oxidation (Helge et al. 2003, Péronnet et al. 2009, Jarstad et al. 2023). Results have also revealed either change or no change in blood-related parameters (Stroud et al. 1997, Frykman et al. 2003, Helge et al. 2003, 2006; Péronnet et al. 2009), maintained or decreased body mass (Booth et al. 1991, Stroud et al. 1997, Sandbæk et al. 1997, Frykman et al. 2003, Helge et al. 2003, 2006; Péronnet et al. 2009, Boushel et al. 2014, 2015; Paulin et al. 2015, Anton-Solanas et al. 2016, Parent et al. 2018, Jarstad et al. 2023), and leaner body composition following such arduous events (Stroud et al. 1997, Sandbæk et al. 1997, Frykman et al. 2003, Helge et al. 2003, 2006; Paulin et al. 2015, Anton-Solanas et al. 2016, Parent et al. 2018, Jarstad et al. 2023). However, there seems to be a lack of scientific knowledge about the changes in the above characteristics following ultra-short-term (<14 days) prolonged LIST. Moreover, ultra-short-term ski expeditions in polar regions are relatively popular among recreational individuals (personal communication with Thea Torvund Langeland, Norrøna Hvitserk Adventure). Hence, it is of great interest to provide data about the bodily changes that may occur following such an event.

The present study aimed therefore to investigate the ultra-short-term outcomes in performance, aerobic endurance, blood-related parameters, and body composition following prolonged LIST.

Material and Methods

Subjects

One female (*subject A*, 38 years, body mass index of 23 kg·m^2) and one male (*subject B*, 52 years, body mass index of 27 kg·m^2) volunteered to participate in this study in connection with an ultra-short-term ski expedition in the Arctic. Both participants were healthy and performed aerobic exercise (moderate-intensity and high-intensity running or cycling) and strength training (weights and body weight) usually ~3–4 times·week^{-1}, and had moderate aerobic fitness at baseline (relative $\dot{V}O_{2max}$ of ~110% of reference values for age (Edvardsen et al. 2013)). During the ~6–8 month preparation period for the expedition, they focused on ski trek-simulating exercise (walking while pulling tires), activity-specific training (ski trekking while hauling a sledge), or cross-country skiing when snow conditions were suitable, as well as strength training, ~3-4 times·week^{-1}.

Prior to the study, the project was evaluated by the South-Eastern Norway Regional Committee for Medical and Health Research Ethics (reference number: 532996). The committee confirmed that the project did not need their approval, as it did not aim to provide new information in medicine or health, but to enhance knowledge of exercise physiology. Both participants gave written informed consent before the study.

Energy intake

To estimate the daily energy intake prior to the study, the two participants described in a single report what they considered to be their usual food and liquid intake. During the expedition, the participants logged their daily food and liquid intake into a diary. Calculation of energy intake before and during the expedition was performed using the Norwegian publicly available diet planner[1] and, when necessary, the macronutrient information on the food packages or the website of the food supplier.

Blood samples

Blood samples were collected by a trained bioengineer 5–6 days before and 2–3 days after the expedition at approximately the same time of day in each participant (between ~8:00–9:20 a.m., with a maximum time difference of ~25 min. between pre- and post-trek sampling) following ~10–12 hours of overnight fasting. During the procedure, a stasis tube was tightened around the upper arm and venous blood was sampled with a syringe from the antecubital vein and drawn into appropriate test tubes (CAT serum separator, LH lithium-heparin, EDTA). Twenty to 40 min. after collection, the blood samples were centrifuged for 12 min at 4500 revolutions per min, then stored in a refrigerator (maximum 24 hours), and finally sent for the below-specified analyses at the Unilabs laboratories (private/commercial provider of health services) in Oslo.

Body composition

Body composition was measured by a skilled technician 5–6 days before and 2–3 days after the expedition at approximately the same time of day (between ~9:15 – 10:20 a.m., maximum time difference of ~30 min. between pre- and post-trek measurements) in each participant following ~11–13 hours of overnight fasting. For this purpose, dual-energy x-ray absorptiometry (DXA) was used (the specific DXA model is described below in the "Measurement instruments" section). During the scanning procedures, the participants lay on their back for ~5–6 min. in a standardized position (fastened in straps over the feet and knees) on the bed of the DXA machine.

Treadmill tests

The treadmill tests were performed 5–8 days before and 2–5 days after the expedition by an experienced test engineer (exercise physiologist) at about the same time of day (afternoon) using the same ski trek-simulating test procedures and precautions as those in the studies by Jarstad and Mamen (2022) and Jarstad et al. (2023). Long-distance performance (time to exhaustion), lactate threshold, work economy, and substrate utilization were evaluated using an incremental stepwise walking test lasting ~40 min. After measurement of body weight, the walking test was initiated with a 10-min. warm-up (*subject A*: 1 km·h^{-1} and 0% incline, *subject B*: 2 km·h^{-1} and 0% incline). The treadmill speed was then increased every fifth min by 1 km·h^{-1}, up to 3 km·h^{-1} in *subject A* and 4 km·h^{-1} in *subject B*, after which the incline was increased by 2.5 percent-points every fifth min until volitional exhaustion. Oxygen uptake ($\dot{V}O_2$) for evaluation of work economy and lactate threshold $\dot{V}O_2$, pulmonary respiratory gas-exchange ratio (RER ($\dot{V}CO_2/\dot{V}O_2$)) for assessment of substrate utilization, and heart rate (HR) were measured in steady state phase between the 8th and 10th min during warm-up, and between the 3rd and 5th min. during the 5-min. steps, while blood lactate concentration (BLC) was measured immediately after each step (thus 8 blood lactate samples for each subject) during a 30-sec. break. Lactate threshold was estimated using a delta value of 2 mmol·L^{-1} above the BLC during warm-up, which has been shown to be a useful estimation of the maximal lactate steady state (Mamen et al. 2011).

Short-distance performance (time to exhaustion), $\dot{V}O_{2max}$, and HR_{max} were assessed using an incremental stepwise walking test lasting ~4–6 min. Following measurement of body weight and a standardized warm-up (~25 min.), the walking test was performed at an individual velocity (4 km·h^{-1} in *subject A*, 5 km·h^{-1} in *subject B*), where the incline was increased each min. by 2 percent-points in *subject A* and 4 percent-points in *subject B* until volitional exhaustion. The classic $\dot{V}O_2$ leveling off, despite increased workload, was used as the main criterion for achievement of $\dot{V}O_{2max}$ (Taylor et al. 1955). If $\dot{V}O_2$ leveling off was not observed, the following secondary criteria had to be met to establish that $\dot{V}O_{2max}$ was achieved: a BLC of ≥7.0 mmol·L^{-1} 2 min. after exhaustion and a RER of ≥1.10 in *subject A*, a BLC of ≥6.0 mmol·L^{-1} 2 min. after exhaustion and a RER of ≥1.05 in *subject B*, a rate of perceived exertion corresponding to ≥17 on the BORG 6-20 scale (Edvardsen et al. 2014), and visible exhaustion of the subject (Esfarjani and Laursen 2007). $\dot{V}O_{2max}$ was calculated as the mean of the two highest consecutive 30-sec $\dot{V}O_2$ measurements (Tønnessen et al. 2014). For estimation of HR_{max}, peak heart rate (HR_{peak}) +5 beats·min^{-1} was used (Ingjer 1991).

During both test procedures, the participants pulled weights of 12.5 kg via a rope connected to a stand ~2.5 meters behind the treadmill (Fig. 1). This corresponds to a ~70-kg sledge on snow on level ground (Juhani et al. 1986), which was a mid-range sledge weight in several ski expeditions (~40–120 kg) (Helge et al. 2003, 2006; Péronnet et al. 2009, Boushel et al. 2015, Anton-Solanas et al. 2016, Parent et al. 2018, Jarstad and Mamen 2022). The test engineer did not inform the participants about their results until all tests were completed.

Measurement instruments

Blood samples were centrifuged using a Universal 320 centrifuge (Hettich, Tuttlingen, Germany) and analyzed using three different ADVIA instruments: models 2120 and 2400, and Centaur XP (Siemens, Munich, Germany). Based on the analytical and intra-individual biological variability (Unilab's own test analyses), the total measurement variability of the different blood parameters was calculated using the equation:

$$CVt = \sqrt{CVa^2 + CVbw^2}$$

where CVt is the total coefficient of variation, CVa^2 is the analytical coefficient of variation, and $CVbw^2$ is the intra-individual biological coefficient of variation. The CVt of the blood parameters presented in this study ranged between 1.6–25%.

Fig. 1. Treadmill walking test while pulling weights (ski trek-simulation). *Photo*: Even Jarstad.

The DXA scanning system used was a Lunar iDXA (GE Healthcare, Madison, WI). This system has shown excellent total body composition measurement precision: same-day test-retest coefficient of variation (CV) of 0.2% for body mass (Dordevic et al. 2018), 0.5–0.6% for bone mineral content (Hind et al. 2011, Rothney et al. 2012, Henriksen et al. 2021), 0.4–0.5% for lean mass (Hind et al. 2011, Rothney et al. 2012, Dordevic et al. 2018, Henriksen et al. 2021), 0.7–1.0% for absolute fat mass (Hind et al. 2011, Rothney et al. 2012, Dordevic et al. 2018, Henriksen et al. 2021), and 0.8–0.9% for relative fat mass (Hind et al. 2011, Dordevic et al. 2018). It has also shown high measurement precision (same-day test-retest CV of 3.5%) for subcutaneous adipose tissue mass and volume (Henriksen et al. 2021), and relatively high to moderate measurement precision (same-day test-retest CV of 5.3–16%) for visceral adipose tissue mass and volume (Dordevic et al. 2018, Henriksen et al. 2021). Furthermore, the longitudinal day-to-day test-retest CV (three visits over three months) has been reported to be 0.8% for body mass, 1.2% for lean mass, 2.5% for absolute fat mass, 2.5% for relative fat mass, and 42% for visceral adipose tissue mass and volume (29% when including only participants with visceral adipose tissue mass > 0 g for all three visits) (Dordevic et al. 2018). This indicates low total measurement variability (high reproducibility) for total body composition variables, but high total measurement variability (low reproducibility) for visceral adipose tissue mass and volume, for the Lunar iDXA.

The exercise tests were performed on a Woodway PPS 55 treadmill (Woodway GmbH, Weil am Rhein, Germany). $\dot{V}O_2$, carbon dioxide production ($\dot{V}CO_2$), RER, and minute ventilation ($\dot{V}E$) were analyzed using the Jaeger Vyntus CPX metabolic system with mixing chamber (Vyaire Medical, Höchberg, Germany). To the author's knowledge, this system has not been validated against the gold standard Douglas bag method during exercise. However, the previous metabolic system, Jaeger Oxycon Pro (Vyaire Medical, Höchberg, Germany), using a mixing chamber, has shown good agreement with the Douglas bag method for gas exchange ($\dot{V}O_2$ and $\dot{V}CO_2$) and $\dot{V}E$ measurements over a wide range of workloads and ventilations (Foss and Hallén 2005). Furthermore, the Vyntus CPX and Oxycon Pro have shown good mutual agreement for gas-exchange and $\dot{V}E$ measurements during submaximal exercise (workloads ≤ 120 Watts) using breath-by-breath methods (Groepenhoff et al. 2017). These reports (Foss and Hallén 2005, Groepenhoff et al. 2017) therefore indicate indirectly that the Vyntus CPX with a mixing chamber is a valid system for measurement of gas exchange and $\dot{V}E$. Also, during incremental walking-specific testing to exhaustion (~4–8 min duration), the day-to-day test-retest CV has been shown to be ~6% for $\dot{V}O_{2max}$ ($L \cdot min^{-1}$ and $mL \cdot kg^{-1} \cdot min^{-1}$) and 3.4% for RER when using the Vyntus CPX with mixing chamber (Glesaaen et al. 2023), indicating relatively low total measurement variability (relatively high reproducibility) for this metabolic analyzer. The day-to-day test-retest CV for RPE (Borg 6-20) at exhaustion was 3.9% in the study by Glesaaen et al. (2023). Moreover, the mean day-to-day test-retest CV (three laboratory visits a week for nine weeks) has been reported to be 3.8%, 2.1%, and 2.6% for submaximal running-specific $\dot{V}O_2$, HR, and RER (steady state values below lactate threshold), respectively, and 5.1% for time to exhaustion, 1% for HR_{peak}, and 18% for BLC (Lactate Pro 2 LT-1730, Arkray Inc., Kyoto, Japan) during exhaustive incremental running-specific testing (~7.5–9-min duration) (Zinner et al. 2023). It is reasonable to assume that the CV findings by Zinner et al. (2023) are similar to expectations following a walking-specific mode, in accordance with the results reported by Glesaaen et al. (2023), who found approximately similar CVs following walking-specific and running-specific modes.

Volume and gas calibration of the Vyntus CPX was performed step-by-step in accordance with the manufacturer's recommendations; volume was calibrated using a built-in pump blowing air through a turbine at rates of 2 $L \cdot s^{-1}$ and 0.2 $L \cdot s^{-1}$, whereas gas calibration was performed against room air and against a gas container with a known content of O_2 (~16%) and CO_2 (~5%).

HR during the treadmill tests was measured with a Polar HR monitor (Polar Electro Oy, Kempele, Finland). BLC was analyzed using the Lactate Pro 2 LT-1730 (Arkray Inc., Kyoto, Japan). Time was measured with a Hanhart Prisma 200 digital stopwatch (Hanhart 1882 GmbH, Gütenbach, Germany), whereas body weight was measured using a Seca Model 877 digital scale (Seca GmbH, Hamburg, Germany).

The expedition

The expedition took place between 25 April and 2 May 2023; the two participants performed LIST while hauling ~40-kg sledges ~126 km from Agardhbukta in the east to Finneset in the west of Spitsbergen in Svalbard (Fig. 2 shows the expedition route).

Fig. 2. The expedition route in Svalbard's largest island, Spitsbergen (adapted and edited from GPSMAP 66i (Garmin)). *Credits*: TopoSvalbard, a service of the Norwegian Polar Institute[2], Stig Tore Røe, and Asbjørn Horn.

Fig. 3. Low-intensity ski trekking across Spitsbergen. *Photo credit*: Kine Gotfredsen.

During ski trekking, the participants recorded HR with HR monitors; *subject A* used a Polar RCX5 (Polar, Kempele, Finland) and *subject B* used a Garmin Forerunner 935 (Garmin, Olathe, Kansas, USA). Total distance covered was measured using a GPS system (GPSMAP 66i, Garmin). The mean velocity ($km \cdot h^{-1}$) during LIST was calculated by dividing the total distance covered by the number of ski trekking days, which in turn was divided by the mean duration of LIST per day. During the expedition, the air temperature varied between approximately -18°C and 5°C (Norwegian Climate Service Center[3]). Figures 3 and 4 show some of the ski trekking and tent site conditions, respectively, during the event.

Data analysis and interpretation

Data are presented individually in the text and tables. For calculation of mean values ± SD, Excel spreadsheets (Microsoft Corp., Redmond, WA, USA) were used. Numerical changes in the dependent variables that were within total measurement variability are interpreted as no changes.

Fig. 4. A tent site during the expedition across Spitsbergen. *Photo credit*: Kine Gotfredsen.

Results

Exercise duration and intensity

The two participants performed 4.7 ± 2.0 hours of LIST per day, for eight consecutive days, at a mean velocity of ~3.4 km·h^{-1}. This corresponded to a mean relative exercise intensity of 63 ± 3% HR_{max} in *subject A* and 54 ± 7% HR_{max} in *subject B*.

Energy intake

The usual energy intake in *subject A* prior to the expedition was ~8.5 MJ·day^{-1} (~2033 kcal·day^{-1}), where ~39% (~3.1 g·kg^{-1}·day^{-1}), ~38% (~1.3 g·kg^{-1}·day^{-1}), and ~23% (~1.8 g·kg^{-1}·day^{-1}) of the energy came from carbohydrates, fat, and protein, respectively. During the expedition, the mean daily energy intake in this participant was ~7.8 MJ·day^{-1} (~1868 kcal·day^{-1}), where ~61% (~4.4 g·kg^{-1}·day^{-1}) of the energy was from carbohydrates, ~25% (~0.8 g·kg^{-1}·day^{-1}) from fat, and ~14% (~1.0 g·kg^{-1}·day^{-1}) from protein (Table 1).

In *subject B*, the usual energy intake before the expedition was ~9.3 MJ·day^{-1} (~2226 kcal·day^{-1}), where ~41% (~2.7 g·kg^{-1}·day^{-1}) of the energy came from carbohydrates, ~38% (~1.1 g·kg^{-1}·day^{-1}) from fat, and ~22% (~1.4 g·kg^{-1}·day^{-1}) from protein. During the expedition, this participant's mean daily energy intake was ~7.7 MJ·day^{-1} (~1838 kcal·day^{-1}), of which ~49% (~2.6 g·kg^{-1}·day^{-1}), ~36% (~0.9 g·kg^{-1}·day^{-1}), and ~15% (~0.8 g·kg^{-1}·day^{-1}) of the energy was from carbohydrates, fat, and protein, respectively (Table 2).

The energy intakes of the two participants on the final expedition day were greater than the previous days, as they enjoyed a dinner (pizza/hamburger, dessert, and four units of alcoholic beverage each) at a restaurant in Longyearbyen in the evening to celebrate successful completion of their great event. Furthermore, their energy intakes the day before the post-trek tests were approximately the same as in their everyday diet prior to the expedition, but of different content (hotel breakfast, pizza/hamburger/soda/candy) due to traveling.

Meals and type of food	*Net weight*	*Carbohydrates*	*Fat*	*Protein*
Breakfast				
Fruit muesli (drytech)	116	77	5	17
Lunch*				
Meat soup/pasta (drytech)	64	31	10	12
Potato wedges	11	6.8	2.8	0.5
Nut mixture	93	67	5.2	8.7
Dried mango	19	11	0	0.6
Cured ham	8.8	0	0.8	2.6
Dinner				
Various stews (drytech)	136	65	29	23
Beverage with energy				
Iced tea	375	26	0	0
Sum	**823**	**284**	**53**	**64**

Table 1. Macronutrient distribution (grams) of the mean daily ration in *subject A* during the expedition. *Note*: * – Includes lunch, and snacks consumed in the breaks during LIST.

Meals and type of food	*Net weight*	*Carbohydrates*	*Fat*	*Protein*
Breakfast				
Fruit muesli (drytech)/ hotel breakfast day 1	233	78	7	19
Lunch*				
Various stews (drytech)	154	73	30	27
Chocolate	13	7.4	3.8	0.9
Peanuts	13	1.2	6.4	3.3
Dinner				
Various stews (drytech)	131	65	26	20
Sum	**544**	**225**	**73**	**70**

Table 2. Macronutrient distribution (grams) of the mean daily ration in *subject B* during the expedition. *Note*: * – Includes lunch, and snacks consumed in the breaks during LIST.

Body composition

Changes in total body composition, and visceral and subcutaneous adipose tissue mass and volume are shown in Table 3. Both participants decreased body mass and body mass index by 2.2%. Lean mass increased by 1.4% in *subject A*, but did not change in *subject B*. Absolute and relative fat mass decreased by 10% and 8%, respectively, in both participants. Bone mineral content decreased by 1.0% in *subject A* and 0.9% in *subject B*. Visceral adipose tissue mass and volume did not change in the two participants, whereas subcutaneous adipose tissue mass and volume decreased by 19% in *subject A* and 18% in *subject B*.

Variables	***Subject A***			***Subject B***		
	Pre-trek	Post-trek	Change	Pre-trek	Post-trek	Change
Total						
Body mass (kg)	65.1	63.7	-1.4	84.8	82.9	-1.9
Body mass index (kg·m^2)	22.8	22.3	-0.5	27.1	26.5	-0.6
Lean mass (kg)	42.1	42.7	0.6	59.0	59.4	0.4
Absolute fat mass (kg)	20.0	18.1	-1.9	22.5	20.3	-2.2
Relative fat mass (%)	32.3	29.8	-2.5	27.6	25.5	-2.1
Bone mineral content (kg)	2.97	2.94	-0.03	3.25	3.22	-0.03
Visceral adipose tissue						
Mass (g)	0	0	0.0	1169	924	-245
Volume (cm^3)	0	0	0.0	1239	980	-259
Subcutaneous adipose tissue						
Mass (g)	991	800	-191	1748	1442	-306
Volume (cm^3)	1050	848	-202	1853	1528	-325

Table 3. Total body composition, and visceral and subcutaneous adipose tissue mass and volume, pre- and post-trek.

Endurance capacity and substrate utilization

Body weight decreased by ~2.9% in *subject A* and ~2.3% in *subject B* (Tables 4 and 5). Time to exhaustion during the ~4–6 min (Table 4) and the ~40 min stepwise walking test (Table 5) did not change in *subject A*, but improved by 10% (Table 4) and 3.8% (Table 5), respectively, in *subject B*. No changes in $\dot{V}O_{2max}$ (Table 4), lactate threshold, or work economy (Table 5) were observed in the two participants. At pre- and post-trek, $\dot{V}O_2$ cost ($mL \cdot kg^{-1} \cdot m^{-1}$) was 15–20% lower in *subject B* than in *subject A* at 2 $km \cdot h^{-1}$ and 3 $km \cdot h^{-1}$ (Table 5). Furthermore, there were no notable changes in HR_{max}, HR_{peak}, $\dot{V}E_{peak}$, or secondary criteria for $\dot{V}O_{2max}$ (RER_{peak}, BLC, RPE_{peak}) in *subject A* or *subject B* (Table 4 and Table 5). No changes were found in RER or $\dot{V}E/\dot{V}O_2$ in *subject A*, whereas in *subject B* these variables increased by 4–9% and 4–12%, respectively (Table 6).

Variables	*Subject A* Pre-trek	Post-trek	Change	*Subject B* Pre-trek	Post-trek	Change
Body weight (kg)	65.8	64.1	-1.7	85.0	82.9	-2.1
Short-distance performance						
Velocity ($km \cdot h^{-1}$)	4.0	4.0	0.0	5.0	5.0	0.0
Peak incline (%)	10.0	10.0	0.0	16.0	16.0	0.0
Time to exhaustion (min)	6.08	6.18	0.10	4.18	4.58	0.40
$\dot{V}O_{2max}$						
$L \cdot min^{-1}$	2.71	2.73	0.02	3.43	3.38	-0.05
$mL \cdot kg^{-1} \cdot min^{-1}$	41.2	42.6	1.4	40.3	40.7	0.4
HR_{max} ($s \cdot min^{-1}$)	182	187	5	182	179	-3
RER_{peak} ($\dot{V}CO_2/\dot{V}O_2$)	1.21	1.18	-0.03	1.34	1.31	-0.03
BLC ($mmol \cdot L^{-1}$)	16.6	17.6	1.0	16.8	18.9	2.1
$\dot{V}E_{peak}$ ($L \cdot min^{-1}$)	124	121	-3	158	163	5
RPE_{peak} ($Borg_{6\text{-}20}$)	19.5	19.5	0.0	19.5	19.5	0.0

Table 4. Short-distance performance and maximal aerobic power pre- and post-trek. *Note*: $\dot{V}O_{2max}$ = maximal oxygen uptake, HR_{max} = maximal heart rate, RER_{peak} = peak pulmonary respiratory gas-exchange ratio, BLC = blood lactate concentration, $\dot{V}E_{peak}$ = peak pulmonary ventilation, RPE_{peak} = peak rate of perceived exertion.

Hematology

Hematology outcomes are presented in Table 7. In *subject A*, the number of erythrocytes and hematocrit, and the amount of hemoglobin concentration, increased by 4.8%, 10%, and 3.2%, respectively, while the number of reticulocytes decreased by 14%. These parameters did not change in *subject B*, with the exception of an 82% increase in the number of reticulocytes. Furthermore, the number of leukocytes decreased by 30% in *subject A* and 41% in *subject B*, whereas the number of thrombocytes only changed (-7%) in *subject A*. The concentration of vitamin B_{12} decreased by 19% in *subject A* and 14% in *subject B*, whereas the levels of ferritin and bilirubin were unchanged in *subject A*, but ferritin increased by 19% and bilirubin decreased by 40% in *subject B*.

Variables	Subject A Pre-trek	Subject A Post-trek	Subject A Change	Subject B Pre-trek	Subject B Post-trek	Subject B Change
Body weight (kg)	66.5	64.4	-2.1	85.0	83.2	-1.8
Long-distance performance						
Peak velocity ($km \cdot h^{-1}$)	3.0	3.0	0.0	4.0	4.0	0.0
Peak incline (%)	12.5	12.5	0.0	12.5	12.5	0.0
Time to exhaustion (min)	44.03	43.87	-0.16	41.13	42.68	1.55
HR_{peak} ($s \cdot min^{-1}$)	182	186	4	167	162	-5
BLC ($mmol \cdot L^{-1}$)	11.8	13.5	1.7	18.1	16.2	-1.9
RPE_{peak} ($Borg_{6\text{-}20}$)	19.5	19.5	0.0	19.5	19.5	0.0
Lactate threshold						
BLC ($mmol \cdot L^{-1}$)	2.9	3.1	0.2	3.2	3.0	-0.2
Incline (%)	4.6	5.1	0.5	2.3	2.2	-0.1
Velocity ($km \cdot h^{-1}$)	3.0	3.0	0.0	4.0	4.0	0.0
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot min^{-1}$)	32.2	33.4	1.2	31.6	31.3	-0.3
$\%\dot{V}O_{2max}$	78	78	0	78	77	-1
$\%HR_{max}$	85	83	-2	72	72	0
Work economy						
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot m^{-1}$) 1 $km \cdot h^{-1}$	0.83	0.83	0.00	-	-	-
HR ($s \cdot min^{-1}$) 1 $km \cdot h^{-1}$	105	94	-11	-	-	-
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot m^{-1}$) 2 $km \cdot h^{-1}$	0.64	0.61	-0.03	0.52	0.49	-0.03
HR ($s \cdot min^{-1}$) 2 $km \cdot h^{-1}$	119	113	-6	100	99	-1
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot m^{-1}$) 3 $km \cdot h^{-1}$	0.55	0.55	0.00	0.47	0.46	-0.01
HR ($s \cdot min^{-1}$) 3 $km \cdot h^{-1}$	137	132	-5	110	111	1
$\dot{V}O_2$ ($mL \cdot kg^{-1} \cdot m^{-1}$) 4 $km \cdot h^{-1}$	-	-	-	0.44	0.43	-0.01
HR ($s \cdot min^{-1}$) 4 $km \cdot h^{-1}$	-	-	-	122	122	0

Table 5. Long-distance performance, lactate threshold, and work economy pre- and post-trek. *Note*: HR_{peak} = peak heart rate, BLC = blood lactate concentration, RPE_{peak} = peak rate of perceived exertion, $\dot{V}O_2$ = oxygen uptake, $\%\dot{V}O_{2max}$ = work intensity percentage of maximal oxygen uptake, $\%HR_{max}$ = work intensity percentage of maximal heart rate, HR = heart rate.

Variables	*Subject A* Pre-trek	Post-trek	Change	*Subject B* Pre-trek	Post-trek	Change
1 km·h^{-1}						
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.83	0.85	0.02	-	-	-
$\dot{V}E/\dot{V}O_2$	27	28	1	-	-	-
$\%\dot{V}O_{2max}$	34	33	-1	-	-	-
2 km·h^{-1}						
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.81	0.83	0.02	0.85	0.93	0.08
$\dot{V}E/\dot{V}O_2$	25	24	-1	26	29	3
$\%\dot{V}O_{2max}$	52	48	-4	43	40	-3
3 km·h^{-1}						
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.88	0.89	0.01	0.88	0.93	0.05
$\dot{V}E/\dot{V}O_2$	25	24	-1	27	28	1
$\%\dot{V}O_{2max}$	67	65	-2	58	56	-2
4 km·h^{-1}						
RER ($\dot{V}CO_2/\dot{V}O_2$)	-	-	-	0.91	0.95	0.04
$\dot{V}E/\dot{V}O_2$	-	-	-	28	30	2
$\%\dot{V}O_{2max}$	-	-	-	72	70	-2

Table 6. Substrate utilization (RER) at three work intensities pre- and post-trek. *Note*: RER = pulmonary respiratory gas-exchange ratio, $\dot{V}CO_2$ = carbon dioxide production, $\dot{V}O_2$ = oxygen uptake, $V_E/\dot{V}O_2$ = ventilatory equivalent for oxygen, $\%\dot{V}O_{2max}$ = exercise intensity percentage of maximal oxygen uptake.

Variables	*Subject A* Pre-trek	Post-trek	Change	*Subject B* Pre-trek	Post-trek	Change
Erythrocytes (10^12·L^{-1})	4.2	4.4	0.2	4.8	4.9	0.1
Hematocrit (%)	39	43	4	48	47	-1
Hemoglobin (g·dL^{-1})	12.5	12.9	0.4	15.1	15.3	0.2
Retikulocytes (10E9·L^{-1})	87	75	-12	67	122 **	55
Leukocytes (10^9·L^{-1})	4.4	3.1 *	-1.3	6.1	3.6	-2.5
Thrombocytes (10^9·L^{-1})	188	175	-13	219	225	6
Ferritin (ug·L^{-1})	6 *	5 *	-1	54	64	10
Vitamin B_{12} (pmol·L^{-1})	360	293	-67	302	260	-42
Bilirubin (umol·L^{-1})	12	11	-1	10	6	-4

Table 7. Hematology pre- and post-trek. *Note*: * – below the reference area, ** – above the reference area.

Glucose, lipids, and albumin

Results for glucose, lipids, and albumin are shown in Table 8. Glucose concentration increased by 6% in *subject A*, whereas no change was observed in *subject B*. Total and LDL cholesterol levels decreased by 14% and 41%, respectively, in *subject A*, and 17% and 30% in *subject B*. LP(a) concentration remained <100 mg·L^{-1} in *subject A*, while the same variable decreased by 8.8% in *subject B*. No changes in HDL cholesterol levels were observed. Triglyceride concentrations were 75% and 31% higher post-expedition in *subject A* and *subject B*, respectively. The level of albumin did not change in *subject A*, whereas a 5% decrease was observed in *subject B*.

Variables	***Subject A***			***Subject B***		
	Pre-trek	Post-trek	Change	Pre-trek	Post-trek	Change
Glucose (mmol·L^{-1})	4.8	5.1	0.3	5.7	6.0	0.3
Total cholesterol (mmol·L^{-1})	3.5	3.0 *	-0.5	5.3	4.4	-0.9
LDL cholesterol (mmol·L^{-1})	1.7	1.0 *	-0.7	4.4	3.1	-1.3
LP(a) (mg·L^{-1})	<100	<100	-	194	177	-17
HDL cholesterol (mmol·L^{-1})	1.5	1.6	0.1	0.9	0.9	0.0
Triglycerides (mmol·L^{-1})	0.4 *	0.7	0.3	1.3	1.7	0.4
Albumin (g·L^{-1})	38	38	0	40	38	-2

Table 8. Glucose, lipids, and albumin pre- and post-trek. *Note*: LDL = low-density lipoprotein, HDL = high-density lipoprotein, LP(a) = lipoprotein small a. * – below the reference area.

Enzymes

Table 9 shows results for enzymes. The level of creatine kinase increased by 196% in *subject A*, but no change was found in *subject B*. Further, the concentrations of aspartate aminotransferase (ASAT) and alanine aminotransferase (ALAT) increased by 135% and 123% in *subject A*, and 67% and 68% in *subject B*.

Variables	***Subject A***			***Subject B***		
	Pre-trek	Post-trek	Change	Pre-trek	Post-trek	Change
Creatine kinase (U·L^{-1})	144	426 **	282	265	294 **	29
ASAT (U·L^{-1})	23	54 **	31	18	30	12
ALAT (U·L^{-1})	31	69 **	38	22	37	15

Table 9. Enzymes pre- and post-trek. *Note*: ASAT = aspartate aminotransferase, ALAT = alanine aminotransferase. ** – above the reference area.

Hormones

The changes in the levels of selected hormones are shown in Table 10. Thyroid stimulating hormone (TSH) did not change in *subject A*, but increased by 23% in *subject B*. In *subject A*, free triiodothyronine (T3) increased by 19%, while no change in free thyroxine (T4) was observed. Free T3 and free T4 did not change in *subject B*. Further, cortisol concentration did not change in either participant. In *subject A*, the level of estradiol increased by 667%, while no change was observed in the concentration of testosterone in *subject B*.

	Subject A			***Subject B***		
Variables	Pre-trek	Post-trek	Change	Pre-trek	Post-trek	Change
TSH ($mU \cdot L^{-1}$)	0.8	0.7	-0.1	1.3	1.6	0.3
Free T3 ($pmol \cdot L^{-1}$)	4.7	5.6	0.9	5.8	5.8	0.0
Free T4 ($pmol \cdot L^{-1}$)	14	15	1	14	13	-1
Cortisol ($nmol \cdot L^{-1}$) (morning)	296	358	62	525	513	-12
Testosterone ($nmol \cdot L^{-1}$)	-	-	-	18	19	1
Estradiol ($nmol \cdot L^{-1}$)	0.09	0.69	0.60	-	-	-

Table 10. Hormones pre- and post-trek. *Note*: TSH = thyroid stimulating hormone, T3 = triiodothyronine, T4 = thyroxine.

Discussion

This study appears to be the first to investigate changes in ski trek-simulated endurance capacity, blood-related variables, and anthropometrics following ultra-short-term prolonged LIST in an Arctic region. Somewhat surprisingly, the results indicated lower daily energy intake during the expedition than before it, despite ~5 hours of exercise each day for eight consecutive days in a cold environment. This caused considerable weight loss in both participants, given the short duration of the event. Furthermore, ski trek-simulated performance improved in one of the two participants. Another interesting finding was that both participants decreased their levels of LDL cholesterol substantially. Blood concentrations of skeletal muscle enzymes increased, whereas the levels of white blood cells decreased. Moreover, increased concentrations of metabolic hormones associated with the pituitary-thyroid axis were observed.

Exercise duration and intensity

The mean duration during LIST (~5 $hours \cdot day^{-1}$) in this study was close to those (~6–7 $hours \cdot day^{-1}$) in some short-term (Jarstad and Mamen 2022) and medium-term studies (Helge et al. 2006, Boushel et al. 2015), but substantially shorter than the duration (~8–15 $hours \cdot day^{-1}$) in other studies of short-term (Péronnet et al. 2009, Paulin et al. 2015), medium-term (Helge et al. 2003, Parent et al. 2018), and long-term prolonged LIST in polar regions (Booth et al. 1991, Stroud et al. 1997, Frykman et al. 2003). Further, the mean relative exercise intensity

($\%HR_{max}$) differed somewhat between the two participants during LIST, similar to that during submaximal treadmill trekking in the laboratory. This difference was probably due to dissimilar work economy between them (*see* the section "Endurance capacity and substrate utilization" below). Nevertheless, both relative exercise intensity and mean velocity during LIST in the present study were similar to those reported during short-term (Jarstad and Mamen 2022), medium-term (Helge et al. 2006, Boushel et al. 2015, Anton-Solanas et al. 2016), and long-term prolonged LIST (Frykman et al. 2003). Overall, this shows that ski trekkers prefer a low pace during expeditions, regardless of daily exercise duration (~5–15 hours) and total distance (~125–2900 km). This is primarily to avoid sweating, which increases the risk of feeling cold, leading to muscle shivering (personal communication with Lars Ebbesen, experienced polar explorer (Jarstad and Mamen 2022)). Muscle shivering can increase whole body metabolism ~3–5-fold (McArdle et al. 2015, p. 616), thus wasting valuable energy in polar conditions.

Energy intake and body composition

The results indicated that the participants' daily energy intake during the expedition was ~8–17% lower than their usual energy intake. Feedback verbally and in a written diary confirmed that *subject A* did not experience greater appetite during the expedition than in her normal life (she actually had poorer appetite during some lunch and dinner meals), whereas *subject B* stated that the breaks during LIST were too short (~10 min) to consume enough food and fluid during the day. These circumstances, in addition to the substantial increase in energy output of performing ~5 hours of LIST for 8 consecutive days, led to a significant loss of body mass in the two participants, corresponding to ~1.2–1.7 $kg \cdot week^{-1}$. The changes are in line with weekly weight loss reported following short-term (~1.3–2.4 $kg \cdot week^{-1}$) (Péronnet et al. 2009, Paulin et al. 2015, Jarstad and Mamen 2022), medium-term (~0.9–1.5 $kg \cdot week^{-1}$) (Helge et al. 2003, 2006), and long-term prolonged LIST (~1.6–1.8 $kg \cdot week^{-1}$) (Stroud et al. 1997), indicating a common energy deficit per unit of time in the present study compared to those studies. Furthermore, the loss of body mass in this study was solely due to decreased fat mass. This shows similarities with body composition changes observed in short-term (Paulin et al. 2015, Jarstad et al. 2023) and medium-term studies of prolonged LIST (Helge et al. 2003, Parent et al. 2018), in which the loss of body mass ranged from ~0.9 to ~2.2 $kg \cdot week^{-1}$ (Helge et al. 2003, Paulin et al. 2015, Parent et al. 2018, Jarstad et al. 2023). In this context, it is interesting to note that the relative (%) contribution of energy from carbohydrates, fat, and protein to the total energy intake in this study and the others (Helge et al. 2003, Paulin et al. 2015, Parent et al. 2018, Jarstad et al. 2023) ranged between ~17–61%, ~25–67%, and 9–16%, respectively. Overall, this indicates that a loss in body mass of ~1-2 $kg \cdot week^{-1}$ can be achieved/ allowed and lean mass can still be maintained during ultra-short-term to medium-term LIST expeditions, regardless of the relative energy distribution in the diet.

The decrease in bone mineral content in the two participants was slightly larger than the analytical variation for this parameter in the Lunar iDXA. However, as far as the author knows, the total measurement variability for bone mineral content is unknown when the Lunar iDXA is used, and the findings must therefore be interpreted with caution. Nevertheless, the changes probably had no clinical significance for the two participants.

The estimated visceral adipose tissue mass and volume were zero pre- and post-trek in *subject A*, while this variable decreased by 21% in *subject B* following the trek. However, as total measurement variability is high for visceral adipose tissue mass and volume (*see* "Measurement instruments" in the method section), the numerical decrease in this variable in *subject B* is interpreted as no change. Furthermore, the decrease in subcutaneous adipose tissue mass and volume in the two participants was larger than the analytical variation, but should be interpreted with caution as the total measurement variability in this parameter, to the author's knowledge, has not been assessed when using the Lunar iDXA. On the other hand, as the total fat mass decreased in both participants, it is reasonable to assume that subcutaneous adipose tissue mass also declined.

Endurance capacity and substrate utilization

The results revealed no change in short-distance or long-distance performance in *subject A*, but *subject B* achieved moderate improvements. Further, no changes in $\dot{V}O_{2max}$, lactate threshold %$\dot{V}O_{2max}$, or work economy were observed, indicating no enhancements in aerobic endurance. Also, the RER data indicated no improvement in fat oxidation. The lack of performance enhancements in *subject A* may have been due to insufficient muscle recovery (possibly muscle damage, as indicated by the increase in creatine kinase, ASAT, and ALAT, *see* the "Enzymes" section below), and/or the fact that she was nursing a cold during the post-trek tests. It is also quite simply possible that eight days of LIST was too short a period of exercise at low work intensity to affect aerobic endurance and performance in this individual. This may be the most plausible explanation, as she felt recovered, and actually fitter, during the post-trek tests than the pre-trek tests. In *subject B*, the performance improvements may have been due to a learning effect. On the other hand, there was no change in short-distance performance (time to exhaustion) between the habituation and pre-trek test in this participant (habituation test data not shown in table). Therefore, it seems reasonable to believe that small physiological changes ($\dot{V}O_{2max}$, lactate threshold %$\dot{V}O_{2max}$, and/or work economy), which were not detected due to measurement variability, may explain the performance improvements in *subject B*. In addition, the small decrease in body mass could also have been a slight contributing factor to the performance enhancements. The improvements of performance in this participant are similar to those reported in one of two well-trained recreational athletes (*subject B*) following short-term (23 days) prolonged LIST across the length of Spitsbergen (~640 km) (Jarstad and Mamen 2022).

The two participants in the present study had similar relative $\dot{V}O_{2max}$ (mL·kg^{-1}·min^{-1}) and lactate threshold %$\dot{V}O_{2max}$, but different work economy. In terms of performance, the difference in work economy in favor of *subject B* was clearly revealed during the exhaustive long-distance incremental test, where this participant covered ~2.4 km in ~42 min (2–4 km·h^{-1}, 0–12.5% incline), while *subject A* covered ~1.8 km in ~44 min (1–3 km·h^{-1}, 0–12.5% incline). The superior work economy in *subject B* could possibly be attributed to a higher oxidative capacity of the exercise-specific muscles or a more efficient technique of movement (Pate and Kriska 1984) and/or greater maximal muscle strength (Støren et al. 2008).

Hematology

In *subject A*, the results revealed small increases in erythrocyte count, hematocrit, and hemoglobin concentration, accompanied by a concomitant decrease in the level of reticulocytes. As the altitude exposure was low during the present expedition, these changes were possibly because she started a new menstrual cycle the day the pre-trek blood tests were performed, and the post-trek blood samples were collected 14 days later in the ovulatory phase of her menstrual cycle. This assumption may be supported by the fact that the change in the number of erythrocytes and hemoglobin concentration in *subject A* after 14 days points in the same direction as that reported after 14–16 days (ovulatory phase) in healthy young females (speed and endurance athlete students) (Yadav et al. 2022).

The substantial decrease in the number of leukocytes indicates that the immune system was impaired in the two ski trekkers following the traverse (*subject A* did in fact experience a cold the day after the last post-trek test). An explanation for this could be the modest energy intake during the expedition, which may have resulted in an inadequate supply of key substances for blood formation, such as *e.g.* vitamin B_{12} (decreased in both participants) and folic acid (McArdle et al. 2015, p. 43). Further, as the erythrocyte levels increased slightly in *subject A*, and the number of reticulocytes increased substantially in *subject B*, perhaps their bodies prioritized formation of red blood cells due to the nature of daily prolonged oxygen demanding exercise during the expedition. It could also be speculated whether insufficient day-to-day recovery (no rest days and little sleep at night (4-5 hours in *subject* B)) during the trek may have affected the participants' white blood cell formation.

Glucose, lipids, and albumin

The percentage increase in glucose concentration in *subject A* was slightly larger than the CVt for this variable. However, the absolute change was of such a modest nature that it probably had no clinical significance. Further, the results indicated decreased total, LDL, and LP(a) cholesterol levels, stable HDL cholesterol concentration, and increased levels of triglycerides. The decrease in total, LDL, and LP(a) cholesterol concentrations may have been due to the substantial energy deficit and the apparently lower fat content (~18–38%) in the expedition versus everyday diets. By comparison, the decrease in total cholesterol concentration in the present study is unlike the relatively stable levels observed in a study of long-term (95 days) prolonged LIST (moving ~2.4 $km \cdot h^{-1}$ with sledges of ~220 kg initially for ~10 $hrs \cdot day^{-1}$ over ~2300 km across Antarctica) (Stroud et al. 1997). The different total cholesterol results may be explained by the difference between fat intake in the present study and in the study by Stroud et al. (1997) (~30% versus ~57% of total energy contribution, respectively). Furthermore, the increased triglyceride levels observed in the present study may have been due to the extraordinary food and beverage intake (*e.g.* the celebration dinner and fast food/ soda/candy during traveling) in the time gap between the completed expedition and the post-trek tests. Additionally, it cannot be excluded that the change from ~5 hours of daily exercise for eight consecutive days to sudden physical inactivity (and thus substantially reduced oxidation of fatty acids) in the days between the expedition and the post-trek tests could also partially explain the elevated triglyceride concentrations.

The results showed relatively stable albumin levels (only a slight decrease in *subject B*) following the trek, which is similar to the findings in the long-term study by Stroud et al. (1997). Overall, this may indicate that a substantial energy deficit during LIST expeditions does not significantly affect albumin. An unchanged albumin level may possibly reflect maintained whole-body protein synthesis (Stroud et al. 1996, 1997).

Enzymes

The elevated creatine kinase, ASAT, and ALAT levels to above the reference values in *subject A*, and the increased concentrations of ASAT and ALAT in *subject B*, may indicate a certain degree of skeletal muscle damage following the ski trek. This is also seen in individuals following acute weightlifting (Pettersson et al. 2008), training for "tough mudder" (a 10–12 mile military-style obstacle course) (Pavletic et al. 2015), and "intensive exercise training regimes six times a week" (Delicata et al. 2018). Although it is discussed above (in the "Endurance capacity and substrate utilization" section) that muscle damage may be one possible explanation for the lack of performance improvements in *subject A*, it is important to note that oral feedback indicated no obvious signs of poor muscle recovery in the two participants, suggesting that the increased concentrations of creatine kinase, ASAT, and ALAT probably had little or no practical significance. This appears to concur with the case reports by Pavletic et al. (2015) and Delicata et al. (2018).

Hormones

It has been suggested that secretion of TSH and thyroid hormones may increase as a response to exercise (and remain elevated for several days) in order to raise the metabolism and thus accommodate an increased energy demand (Arkader et al. 2016). LIST per se could therefore be one possible explanation for the increased free T3 concentration observed in *subject A* (similar changes were observed in the long-term study by Stroud et al. (1997)) and the elevated TSH level seen in *subject B* after the expedition. It may also be possible that other energy-demanding processes, such as thermogenesis, protein synthesis, glucogenesis and/or lipogenesis (McArdle et al. 2015 p. 12, 13, 123, 156, 952; Brownstein et al. 2022), during and/or after the event can help explain the increased levels of these metabolic hormones. In this context, it should be emphasized that post-trek signs of increased thyroid hormones due to thermogenesis during the expedition are probably unlikely, as T3 concentration appears to peak after ~2 hours of cold exposure, and then return to baseline levels (Zhang et al. 2018). It should also be noted that glucogenesis has been found to be impaired in a hyperthyroidism state (animal studies) (Hasan Al-bayati and AL-Khateeb 2021). Nevertheless, more research is necessary to provide further information on the influence of prolonged LIST expeditions on the metabolic hormones related to the pituitary-thyroid axis.

The levels of cortisol did not change significantly in the two participants, nor did testosterone in *subject B*, from pre- to post-expedition. As the present study appears to be the first to assess these hormones following ultra-short-term prolonged LIST, there is a lack of studies with which to compare the findings. However, the results are approximately in line with those observed from the 10th expedition day (pre-trek values not assessed) to post-trek in the long-term study by Stroud et al. (1997). In this context, it should be noted that Stroud et al. (1997) also assessed changes in cortisol and testosterone levels regularly (every 10th day) throughout the 95-day expedition. The results showed that cortisol levels increased substantially concomitantly with hypoglycemia in the last ~30 days, and there were also clear signs of a gradual decrease in testosterone concentrations throughout the expedition (Stroud et al. 1997). These findings probably reflect the role of cortisol in promoting fat oxidation to maintain stable blood glucose concentration during malnutrition and indicate that such a serious state of energy deficit may also have a negative effect on testosterone levels. Moreover, the results by Stroud et al. (1997) indicate that pre- and post-data do not necessarily reveal the cortisol and testosterone changes that may occur during an expedition. This must also be taken into account in the present study, although the expedition lasted only eight days and the post blood samples were collected only 2–3 days after completion of the event.

During the menstrual cycle, higher estrogen levels are expected in the late follicular and ovulatory phases (days ~6–12 and ~13–15, respectively, of a 28-day menstrual cycle) than in the early follicular phase (day ~1–5 of a 28-day menstrual cycle) (McNulty et al. 2020, Carmichael et al. 2021). The increased estradiol concentration observed in *subject A* is therefore consistent with the pre- and post-expedition blood samples being collected in the early follicular phase (day 1) and in the ovulatory phase (day 14), respectively, of her menstrual cycle (28 days). Furthermore, the observation that performance (time to exhaustion) did not change during this period (from the early follicular to the ovulatory phase) in this participant, although her perceived performance improved, appears to be in line with findings in other studies (Carmichael et al. 2021).

Practical implications

This study indicates that ultra-short-term prolonged LIST, performed with a substantial energy deficit, does not have a negative effect on lean body mass. On the other hand, the results show that such an event may impair the body's immune system. Therefore, during skiing expeditions, energy deficit should be limited to a minimum, even in ultra-short-term events. Further, if the purpose is to reduce LDL cholesterol level, this study indicates that prolonged low-intensity exercise can help affect this variable significantly even after a short period of time. The present study also indicates that only ~1 week of daily prolonged low-intensity exercise can improve short-distance and long-distance performance when aerobic fitness is moderate initially. This may be interesting information for *e.g.* competitive recreational athletes, as low-intensity training (< aerobic threshold/the first ventilatory threshold) appears to constitute ~60–80% of their exercise time (Muñoz and Varela-Sanz 2018, Selles-Perez et al. 2019).

Limitations

In this study, substrate utilization was investigated indirectly using RER. This method of assessing change in oxidation of carbohydrates versus fat is quite sensitive to differences in breathing pattern. For example, overbreathing, which causes non-metabolic CO_2 to be "blown off" from the lungs, leads to an increase in RER that does not reflect the respiratory quotient from aerobic metabolism (McArdle et al. 2015, p. 189). Furthermore, the calculation of the participants' energy intakes prior to the study was based on a single report of what they considered to be their typical everyday food and liquid intake. Misreporting of usual energy intake must therefore be taken into account. Moreover, the results of this study rely on data from only two cases. It is therefore important to exercise caution in interpreting and generalizing the outcomes, and in comparing the findings to other studies.

Conclusions

This study indicates that ultra-short-term prolonged LIST, performed with a substantial caloric deficiency, can lead to a slimmer body composition without loss of lean mass in moderately trained recreational individuals. Furthermore, such an event can improve short-distance and long-distance performance and reduce LDL cholesterol levels. It also appears that metabolic hormones related to the pituitary-thyroid axis may be affected. However, this kind of skiing expedition does not seem to influence fat oxidation in this subclass of ski trekkers. Moreover, the immune system can be impaired following such an arduous, albeit short, event.

References

ANTON-SOLANAS, A., O'NEILL, B. V., MORRIS, T. E. and DUNBAR, J. (2016): Physiological and cognitive responses to an Antarctic expedition: A case report. *International Journal of Sports Physiology and Performance*, 11(8): 1053-1059. doi: 10.1123/ijspp.2015-0611

ARKADER, R., ROSA, M. R. and MORETTI, G. (2016): Physiological changes of exercise of thermogenesis, thyroid homeostasis and inflammation. *International Journal of Endocrinology and Metabolism*, 3(4): doi: 10.15406/emij.2016.03.00055

BOOTH, M. A., THODEN, J. S., REARDON, F. D., JETTE, M. and RODE, A. (1991): The 1988 Polar Bridge Expedition: Effects of the three-month trans-polar ski-trek on aerobic fitness and skiing economy. *Proceedings of 8th International Congress of Circumpolar Health, Whitehorse. Arctic Medical Research*, pp. 542–544.

BOUSHEL, R., ARA, I., GNAIGER, E., HELGE, J. W., GONZÁLEZ-ALONSO, J., MUNCK-ANDERSEN, T., SONDERGAARD, H., DAMSGAARD, R., VAN HALL, G., SALTIN, B. and CALBET, J. A. (2014): Low-intensity training increases peak arm VO2 by enhancing both convective and diffusive O_2 delivery. *Acta Physiologica* (*Oxford, England*), 211(1): 122-134. doi: 10.1111/apha.12258

BOUSHEL, R., GNAIGER, E., LARSEN, F. J., HELGE, J. W., GONZÁLEZ-ALONSO, J., ARA, I., MUNCH-ANDERSEN, T., VAN HALL, G., SØNDERGAARD, H., SALTIN, B. and CALBET, J. A. (2015): Maintained peak leg and pulmonary VO_2 despite substantial reduction in muscle mitochondrial capacity. *Scandinavian Journal of Medicine & Science in Sports*, 25(Suppl 4): 135-143. doi: 10.1111/sms.12613

BROWNSTEIN, A. J., VELIOVA, M., ACIN-PEREZ, R., LIESA, M. and SHIRIHAI, O. S. (2022): ATP-consuming futile cycles as energy dissipating mechanisms to counteract obesity. *Reviews in Endocrine & Metabolic Disorders*, 23(1): 121-131. doi: 10.1007/s11154-021-09690-w

CARMICHAEL, M. A., THOMSON, R. L., MORAN, L. J. and WYCHERLEY, T. P. (2021): The impact of menstrual cycle phase on athletes' performance: A narrative review. *International Journal of Environmental Research and Public Health*, 18(4): 1667. doi: 10.3390/ijerph18041667

DELICATA, N. P., DELICATA, J. and DELICATA, L. A. (2018): Strenuous exercise–an unusual cause of deranged liver enzymes. *Case Reports in Clinical Medicine*, 07(03): 177-181. doi: 10.4236/crcm.2018.73016

DORDEVIC, A., BONHAM, M., GHASEM-ZADEH, A., EVANS, A., BARBER, E., DAY, K., KWOK, A. and TRUBY, H. (2018): Reliability of compartmental body composition measures in weight-stable adults using GE iDXA: Implications for research and practice. *Nutrients*, 10(10): 1484. doi: 10.3390/nu10101484

EDVARDSEN, E., HANSEN, B. H., HOLME, I. M., DYRSTAD, S. M. and ANDERSSEN, S. A. (2013): Reference values for cardiorespiratory response and fitness on the treadmill in a 20- to 85-year-old population. *Chest*, 144(1): 241-248. doi: 10.1378/chest.12-1458

EDVARDSEN, E., HEM, E. and ANDERSSEN, S. A. (2014): End criteria for reaching maximal oxygen uptake must be strict and adjusted to sex and age: A cross-sectional study. *PLoS ONE*, 9(1): e85276. doi: 10.1371/journal.pone.0085276

ESFARJANI, F., LAURSEN, P. B. (2007): Manipulating high-intensity interval training: Effects on VO2max, the lactate threshold and 3000 m running performance in moderately trained males. *Journal of Science and Medicine in Sport*, 10(1): 27-35. doi: 10.1016/j.jsams.2006.05.014

FOSS, Ø., HALLÉN, J. (2005): Validity and stability of a computerized metabolic system with mixing chamber. *International Journal of Sports Medicine*, 26(7): 569-575. doi: 10.1055/s-2004-821317

FRYKMAN, P. N., HARMAN, E. A., OPSTAD, P. K., HOYT, R. W., DELANY, J. P. and FRIEDL, K. E. (2003): Effects of a 3-month endurance event on physical performance and body composition: The G2 trans-Greenland expedition. *Wilderness & Environmental Medicine*, 14(4): 240-248.

GLESAAEN, O. J., LARSSEN, T., KALHOVDE, J. M., STRAND, M. F., TØNNESSEN, E. and HAUGEN, T. (2023): The validity and reliability of walking as exercise modality during VO_{2max} testing. *The Journal of Sports Medicine and Physical Fitness*, 63(7): 812-818. doi: 10.23736/S0022-4707.23.14865-1

GROEPENHOFF, H., DE JEU, R. C. and SCHOT, R. (2017): Vyntus CPX compared to Oxycon pro shows equal gas-exchange and ventilation during exercise. Respiratory Function Technologists/Scientists September 2017: PA3002. *European Respiratory Society*. doi: 10.1183/1393003.congress-2017.PA3002

HASAN AL-BAYATI, A. A., AL-KHATEEB, S. M. J. (2021): The effects of thyroid hormones and their abnormalities on intestinal and hepatic glucose metabolism. *Scholars International Journal of Biochemistry*, 4(3): 26-36. doi: 10.36348/sijb.2021.v04i03.002

HELGE, J. W., LUNDBY, C., CHRISTENSEN, D. L., LANGFORT, J., MESSONNIER, L., ZACHO, M., ANDERSEN, J. L. and SALTIN, B. (2003): Skiing across the Greenland icecap: Divergent effects on limb muscle adaptations and substrate oxidation. *Journal of Experimental Biology*, 206(Pt 6): 1075-1083. doi: 10.1242/jeb.00218

HELGE, J. W., OVERGAARD, K., DAMSGAARD, R., SØRENSEN, K., ANDERSEN, J. L., DYRSKOG, S. E., HERMANSEN, K., SALTIN, B. and WOJTASZEWSKI, J. F. (2006): Repeated prolonged whole-body low-intensity exercise: effects on insulin sensitivity and limb muscle adaptations. *Metabolism: Clinical and Experimental*, 55(2): 217-223. doi: 10.1016/j.metabol.2005.08.015

HENRIKSEN, H. B., ALAVI, D. H. and BLOMHOFF, R. (2021): Precision of lunar dual-energy x-ray absorptiometry (iDXA) in measuring body composition among colorectal cancer patients and healthy subjects. *Clinical Nutrition ESPEN*, 44: 316-323. doi: 10.1016/j.clnesp.2021.05.025

HIND, K., OLDROYD, B. and TRUSCOTT, J. G. (2011): *In vivo* precision of the GE Lunar iDXA densitometer for the measurement of total body composition and fat distribution in adults. *European Journal of Clinical Nutrition*, 65(1): 140-142. doi: 10.1038/ejcn.2010.190

INGJER, F. (1991): Factors influencing assessment of maximal heart rate. *Scandinavian Journal of Medicine & Science in Sports*, 1(3): 134-140. doi: 10.1111/j.1600-0838.1991.tb00285.x

JARSTAD, E., FELBERG, H. A. and MAMEN, A. (2023): A case study of the short-term development of body composition and substrate utilization following prolonged low-intensity ski trekking with inadequate energy intake in Svalbard. *Arctic*, 76(3). doi: 10.14430/arctic78286

JARSTAD, E., MAMEN, A. (2022): The short-term development of performance and aerobic endurance following prolonged low-intensity ski trekking in Svalbard: A case study. *Polar Record*, 58: e21. doi: 10.1017/S0032247422000201

JUHANI, I., PEKKA, S. and TIMO, A. (1986): Strain while skiing and hauling a sledge or carrying a backpack. *European Journal of Applied Physiology and Occupational Physiology*, 55(6): 597-603. doi: 10.1007/BF00423203

MAMEN, A., LAPARIDIS, C. and VAN DEN TILLAAR, R. (2011): Precision in estimating maximal lactate steady state performance in running using a fixed blood lactate concentration or a delta value from an incremental lactate profile test. *International Journal of Applied Sports Sciences*, 23(1): 212-224. doi: 10.24985/ijass.2011.23.1.212

MCARDLE, W. D., KATCH, F. I. and KATCH, V. L. (2015): Exercise physiology: nutrition, energy, and human performance. 8th edn. Wolters Kluwer Health/Lippincott Williams & Wilkins, Philadelphia, pp. 12, 13, 43, 123, 156, 189, 616, 952.

MCNULTY, K. L., ELLIOTT-SALE, K. J., DOLAN, E., SWINTON, P. A., ANSDELL, P., GOODALL, S., THOMAS, K. and HICKS, K. M. (2020): The effects of menstrual cycle phase on exercise performance in eumenorrheic women: a systematic review and meta-analysis. *Sports Medicine* (*Auckland, N.Z.*), 50(10): 1813-1827. doi: 10.1007/s40279-020-01319-3

MUÑOZ, I., VARELA-SANZ, A. (2018): Training intensity distribution and performance of a recreational male endurance runner. A case report. *Journal of Physical Education and Sport*, 18(04): 2257-2263. doi: 10.7752/jpes.2018.04340

PARENT, A.-A., MARTIN, D., MORALES, S., BOUCHER, J. and COMTOIS, A.-S. (2018): XP-Antarctik expedition: the effect of a month-long expedition in Antarctica on physiological performance. *Journal of Human Performance in Extreme Environments*, 14(1). doi: 10.7771/2327-2937.1093

PATE, R. R., KRISKA, A. (1984): Physiological basis of the sex difference in cardiorespiratory endurance. *Sports Medicine* (*Auckland, N.Z.*), 1(2): 87-98. doi: 10.2165/00007256-198401020-00001

PAULIN, S., ROBERTS, J., ROBERTS, M. and DAVIS, I. (2015): A case study evaluation of competitors undertaking an antarctic ultra-endurance event: Nutrition, hydration and body composition variables. *Extreme Physiology & Medicine*, 4: 3. doi: 10.1186/s13728-015-0022-0

PAVLETIC, A. J., PAO, M. and WRIGHT, M. E. (2015): Exercise-induced elevation of liver enzymes in a healthy female research volunteer. *Psychosomatics*, 56(5): 604-606. doi: 10.1016/j.psym. 2015.03.002

PÉRONNET, F., ABDELAOUI, M., LAVOIE, C., MARRAO, C., KERR, S., MASSICOTTE, D. and GIESBRECHT, G. (2009): Effect of a 20-day ski trek on fuel selection during prolonged exercise at low workload with ingestion of ^{13}C-glucose. *European Journal of Applied Physiology*, 106(1): 41-49. doi: 10.1007/s00421-009-0987-8

PETTERSSON, J., HINDORF, U., PERSSON, P., BENGTSSON, T., MALMQVIST, U., WERKSTRÖM, V. and EKELUND, M. (2008): Muscular exercise can cause highly pathological liver function tests in healthy men. *British Journal of Clinical Pharmacology*, 65(2): 253-259. doi: 10.1111/j.1365-2125.2007.03001.x

ROTHNEY, M. P., MARTIN, F.-P., XIA, Y., BEAUMONT, M., DAVIS, C., ERGUN, D., FAY, L., GINTY, F., KOCHHAR, S., WACKER, W. and REZZI, S. (2012): Precision of GE Lunar iDXA for the measurement of total and regional body composition in nonobese adults. *Journal of Clinical Densitometry*, 15(4): 399-404. doi: 10.1016/j.jocd.2012.02.009

SANDBÆK, G., STEINE, K., RØSETH, A. G., FALCH, J. A. and STEINE, S. (1997): [Skiing over Greenland--physical and psychological changes]. *Tidsskrift for den Norske Laegeforening*, 117(8): 1104-1107.

SELLES-PEREZ, S., FERNÁNDEZ-SÁEZ, J. and CEJUELA, R. (2019): Polarized and pyramidal training intensity distribution: relationship with a half-ironman distance triathlon competition. *Journal of Sports Science & Medicine*, 18(4): 708-715.

STØREN, O., HELGERUD, J., STØA, E. M. and HOFF, J. (2008): Maximal strength training improves running economy in distance runners. *Medicine and Science in Sports and Exercise*, 40(6): 1087-1092. doi: 10.1249/MSS.0b013e318168da2f

STROUD, M. A., JACKSON, A. A. and WATERLOW, J. C. (1996): Protein turnover rates of two human subjects during an unassisted crossing of Antarctica. *British Journal of Nutrition*, 76(2): 165-174. doi: 10.1079/bjn19960022

STROUD, M. A., RITZ, P., COWARD, W. A., SAWYER, M. B., CONSTANTIN-TEODOSIU, D., GREENHAFF, P. L. and MACDONALD, I. A. (1997): Energy expenditure using isotope-labelled water ($^2H_2{}^{18}O$), exercise performance, skeletal muscle enzyme activities and plasma biochemical parameters in humans during 95 days of endurance exercise with inadequate energy intake. *European Journal of Applied Physiology and Occupational Physiology*, 76(3): 243-252. doi: 10.1007/s004210050243

TAYLOR, H. L., BUSKIRK, E. and HENSCHEL, A. (1955): Maximal oxygen intake as an objective measure of cardio-respiratory performance. *Journal of Applied Physiology*, 8(1): 73-80. doi: 10.1152/ jappl.1955.8.1.73

TØNNESSEN, E., SYLTA, Ø., HAUGEN, T. A., HEM, E., SVENDSEN, I. S. and SEILER, S. (2014): The road to gold: Training and peaking characteristics in the year prior to a gold medal endurance performance. *PLoS ONE*, 9(7): e101796. doi: 10.1371/journal.pone.0101796

YADAV, T. S., PANDEY, G. and KUMAR, G. (2022): Comparison of hematological profile of athletes in various phases of menstrual cycle. *Asian Pacific Journal of Health Sciences*, 9(3): 218-222. doi: 10.21276/apjhs.2022.9.3.44

ZHANG, Z., BOELEN, A., KALSBEEK, A. and FLIERS, E. (2018): TRH neurons and thyroid hormone coordinate the hypothalamic response to cold. *European Thyroid Journal*, 7(6): 279-288. doi: 10.1159/000493976

ZINNER, C., GERSPITZER, A., DÜKING, P., BOONE, J., SCHIFFER, T., HOLMBERG, H. and SPERLICH, B. (2023): The magnitude and time – course of physiological responses to 9 weeks of incremental ramp testing. *Scandinavian Journal of Medicine & Science in Sports*, 33(7): 1146-1156. doi: 10.1111/sms.14347

Web sources / Other sources

[1] Norwegian publicly available diet planner
http://www.kostholdsplanleggeren.no

[2] Norwegian Polar Institute
http://www.polar.no

[3] Norwegian Climate Service Center
http://www.klimaservicesenter.no