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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

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ABSTRACT. This case study aimed to examine the short-term development of body composition and substrate utilization (i.e., contribution of fat and carbohydrates to energy supply) following prolonged low-intensity ski trekking (LIST) with inadequate energy intake in an Arctic region. For 23 days, two highly aerobically fit, male recreational athletes (24 and 26 years) performed ~2–11 hours of LIST each day, while pulling supply sledges (initially ~80 kg) across the length of Svalbard's largest island, Spitsbergen (~640 km). We estimated body composition using bioelectrical impedance analysis (BIA). For evaluation of substrate utilization, we analyzed pulmonary respiratory gas-exchange ratio (RER) using an ergospirometry system during treadmill trekking (ski trekking simulation). Results indicated that the energy intake of each participant during this unsupported expedition was ~21.4 MJ·day^{-1} (~5107 kcal·day^{-1}), of which ~33% (~5.0 g·kg^{-1}·day^{-1}), ~51% (~3.4 g·kg^{-1}·day^{-1}), and ~16% (~2.4 g·kg^{-1}·day^{-1}) came from carbohydrates, fat, and proteins, respectively. Body mass decreased by 7.2 kg (8.4%) in Subject A, and 4.4 kg (5.2%) in Subject B. Absolute fat mass decreased by 5.4 kg (37%) and 4.7 kg (30%) in Subject A and Subject B, respectively, whereas the changes in fat-free mass (–1.8 kg in Subject A, and +0.3 kg in Subject B) were within the random measurement error of the BIA analyser. Changes in RER in Subject A (–0.01 to –0.02 units) were within the random measurement error, whereas the RER data in Subject B were not interpretable due to excessive fluctuations in ventilatory equivalent for oxygen. In conclusion, this study indicates that short-term, prolonged LIST, performed with an energy deficit corresponding to a weight loss of ~2 kg·week^{-1}, can lead to leaner body composition without notable changes in fat-free mass in well-trained, male recreational athletes. Furthermore, substrate utilization does not appear to be affected by short-term, prolonged LIST in this subgroup of athletes.

Keywords: polar expedition; low-intensity exercise; energy intake; energy deficit; macronutrients; bioelectrical impedance analysis; body mass; fat-free mass; fat mass; fat oxidation

RÉSUMÉ. La présente étude de cas examine le développement à court terme de la composition corporelle et l'utilisation du substrat (c'est-à-dire l'apport des lipides et des glucides en matière d'approvisionnement énergétique) après une longue randonnée à ski de faible intensité (RSFI) moyennant un apport énergétique inadéquat dans une région de l'Arctique. Pendant 23 jours, deux sportifs amateurs en très bonne forme aérobique (des hommes de 24 et 26 ans) ont fait environ deux à onze heures de RSFI par jour tout en tirant des traîneaux de vivres (d'environ 80 kg initialement) sur toute la longueur de la plus grande île du Svalbard, soit l'île de Spitsbergen (environ 640 km). Nous avons estimé la composition corporelle au moyen d'une analyse d'impédance bioélectrique (AIB). Pour ce qui est de l'évaluation de l'utilisation du substrat, nous avons analysé le rapport des échanges gazeux respiratoires au niveau des poumons (RER) à l'aide d'un ergospiromètre dans le cadre d'un exercice de randonnée sur tapis roulant (pour simuler une randonnée à ski). Selon les résultats, l'apport énergétique de chaque participant pendant cette expédition sans assistance était d'environ 21,4 MJ·jour^{1} (~5107 kcal·jour^{1}), dont ~33 % (~5,0 g·kg^{-1}·jour^{1}), ~51 % (~3,4 g·kg^{-1}·jour^{1}) et ~16 % (~2,4 g·kg^{-1}·jour^{1}) provenaient des glucides, des lipides et des protéines, respectivement. La masse corporelle a diminué de 7,2 kg (8,4 %) chez le sujet A, et de 4,4 kg (5,2 %) chez le sujet B. La masse grasse absolue a diminué de 5,4 kg (37 %) et de 4,7 kg (30 %) chez le sujet A et le sujet B, respectivement, tandis que les changements caractérisant la masse maigre (-1,8 kg chez le sujet A et +0,3 kg chez le sujet B) se situaient à l'intérieur de l'erreur de mesure aléatoire de l'analyse d'impédance bioélectrique (AIB). Les changements en matière de RER chez le sujet A (–0,01 à –0,02 unité) se situaient à l'intérieur de l'erreur de mesure aléatoire, tandis que les données de RER du sujet B n'étaient pas interprétables en raison des fluctuations excessives de l'équivalent respiratoire pour l'oxygène. Pour conclure, cette étude indique qu'une longue RSFI de courte échéance effectuée avec un déficit énergétique correspondant à une perte de poids d'environ 2 kg·semaine^{-1} peut mener à une composition corporelle plus maigre, sans changements remarquables sur

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le plan de la masse maigre chez les hommes sportifs amateurs bien entraînés. De plus, l'utilisation du substrat ne semble pas touchée par une longue RSFI de courte échéance dans ce sous-groupe de sportifs.

Mots-clés: expédition polaire; exercice de faible intensité; apport énergétique; déficit énergétique; macronutriments; analyse d'impédance bioélectrique; masse corporelle; masse maigre; masse grasse; oxydation des graisses

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INTRODUCTION

Energy deficit, and consequently loss of body mass, is relatively common during prolonged low-intensity ski trekking (LIST) in polar regions (Stroud et al., 1997; Helge et al., 2003, 2006; Péronnet et al., 2009; Paulin et al., 2015; Anton-Solanas et al., 2016). However, there appears to be sparse scientific data on the short-term development of body composition in highly aerobically fit recreational athletes (maximal aerobic power ($\dot{V}O_{2max}$) relative to body mass of ~60 $ml \cdot kg^{-1} \cdot min^{-1}$ and higher) following prolonged LIST with inadequate energy intake. In the only study we are aware of in this particular field, Paulin et al. (2015) reported that three male recreational athletes who won an ~800-km ski trek race to the South Pole in 14 days by moving ~3–4+ $km \cdot h^{-1}$ for ~15 $hours \cdot day^{-1}$ (categorized as "faster finishers"), lost ~3.5 kg of body mass due to a substantial decrease in absolute fat mass (~5.6 kg) and an increase (~1.9 kg) in lean body mass (i.e., fat-free mass plus essential body fat; McArdle et al., 2015). Energy intake in the faster finishers was ~5333 $kcal \cdot day^{-1}$ (~22.3 $MJ \cdot day^{-1}$), where the contributions of energy from carbohydrates, fat, and proteins were ~17% (~2.7 $g \cdot kg^{-1} \cdot day^{-1}$), ~67% (~4.7 $g \cdot kg^{-1} \cdot day^{-1}$) and ~16% (~2.0 $g \cdot kg^{-1} \cdot day^{-1}$), respectively (Paulin et al., 2015). This indicates that highly aerobically fit recreational athletes can afford a loss in body mass of ~2 $kg \cdot week^{-1}$ and still maintain lean body mass during short-term, prolonged LIST when ingesting a low-carbohydrate-, high-fat, and moderate-protein diet. It is therefore of great interest to provide more scientific data about the development of body composition following short-term, prolonged LIST performed with inadequate energy intake in this subgroup of athletes.

During prolonged, low-intensity exercise (>20 min), fat contributes more than carbohydrates to energy supply, and the contribution of fat increases with increasing duration (Åstrand et al., 2003). Theoretically, then, it is reasonable to believe that several hours of LIST (usually performed at ~40% $\dot{V}O_{2max}$) can affect fat oxidation (breakdown and use). However, the short-term development of ski trek–simulated substrate utilization (or change in the contribution of fat and carbohydrates to energy supply) following prolonged LIST has, to the best of our knowledge, been examined in only one study (Péronnet et al., 2009). Those authors found no change in pulmonary respiratory gas-exchange ratio (RER), indicating no improvement of fat oxidation, in five moderately trained male subjects following 20 days of supported (mid-way) prolonged LIST (~2 $km \cdot h^{-1}$, ~10 $hours \cdot day^{-1}$) from the northern to the southern part of Lake Winnipeg (~415 km), Canada. It is therefore also of interest to generate scientific knowledge about the short-term development of substrate utilization following prolonged LIST in recreational athletes with high aerobic fitness.

The present study aimed to examine the short-term development of body composition and substrate utilization in highly aerobically fit recreational athletes following prolonged LIST performed with inadequate energy intake.

METHODS

Subjects

Two male recreational athletes (age: 24 and 26 years, height: 180 and 183 cm, body mass: ~84 and ~86 kg, body mass index: ~26 and ~26 $kg \cdot m^2$) requested an evaluation of body composition and substrate utilization before and after a self-selected ski trek in Svalbard (Fig. 1). Usually, they performed moderate- to high-intensity aerobic exercise, such as running, rowing, mountain walking, or cross-country skiing, two to three $times \cdot week^{-1}$. During the preparation period for the expedition, exercise became more activity-specific, i.e., walking while pulling tires, and ski trekking while hauling a sledge. Not unexpectedly, the two participants had a high relative $\dot{V}O_{2max}$ ($ml \cdot kg^{-1} \cdot min^{-1}$) pre-expedition (~124–128% of the reference values in Norwegian males between 20–29 years; Edvardsen et al., 2013).

Before the study commenced, the South-Eastern Norway Regional Committee for Medical and Health Research Ethics reviewed the project (reference number: 2016/465A). As the present study aimed to generate scientific information about anthropometry and energetics in healthy, young, well-trained subjects, but not to provide knowledge in the fields of medicine or health, the committee concluded that the study was outside the remit of the Act on Medical and Health and, therefore, did not need their approval. Prior to the study, both participants gave written, informed consent.

Energy Intake

We calculated participants' regular energy intake prior to the expedition based on detailed notes they provided about their typical, non-expedition, daily diet. Participants self-selected the expedition diet, which they carefully pre-packaged in equal daily rations and documented in writing for type of food and macronutrient content (Table 1). For thorough calculations of the energy content of everyday life

FIG. 1. Map of Svalbard and the expedition route. Credit: TopoSvalbard, a servive of the Norwegian Polar Institute (www.npolar.no).

and expedition diets, we used a reliable, publicly available, Norwegian diet planner: www.kostholdsplanleggeren.no.

Body Composition

We measured body composition six days before, and 10 – 11 days after, the expedition, which is approximately in line with other studies in this field (e.g., Sandbæk et al., 1997; Stroud et al., 1997; Parent et al., 2018). We carried out these measurements at approximately the same time of day (difference of ~40 – 55 min between pre- and post-trek test for the same subject) between 4:00 p.m. and 7:00 p.m. During measurement of body composition, each LIST participant stood barefoot in his underwear, in an upright position, with his feet in contact with the plantar electrodes on the platform of a bioelectrical impedance analysis (BIA) analyser (described below). BIA estimates body composition based on measurement of the impedance (resistance) of the body to a small electric current (Wells and Fewtrell, 2006). As this impedance is affected by alterations in hydration level (changes in hydration level affect the current flow, regardless of actual changes in body

TABLE 1. Food and macronutrients (in grams) in a daily ration provided to the two LIST participants for the length of the expedition.

Type of food	Food mass	Carbohydrates	Fat	Protein
Breakfast				
Oats	75	47	6	9
Crüsli (granola)	75	48	10	5
Milk powder	10	4	3	3
Sugar	12	12	0	0
Oils	30	0	30	0
Lunch*				
Cake	135	67	34	13
Chocolate	150	80	48	12
Peanuts	100	8	49	26
Müesli bar	110	10	24	7
Dried meat	70	0	0	49
Noodles	70	51	1	8
Sour wine gums	30	23	0	1
Dinner				
Hiking food	149	45	59	27
Dried fish	50	0	1	39
Butter/oils	30	0	24	0
Hot chocolate/black currant	32	27	1	2
Sum	1128	422	290	201

* Includes lunch and snacks consumed at breaks during LIST.

composition) (McArdle et al., 2015), we took a number of precautions for the two LIST participants: 1) on the test day pre- and post-trek, participants ingested similar amounts of food and fluid prior to the body composition measurement, 2) we took body composition measurements before the treadmill exercise tests, both pre- and post-trek, to avoid dehydration through sweating, 3) pre- and post-trek, participants emptied their bladders just before the body composition measurement.

Substrate Utilization

We estimated substrate utilization pre- and post-trek in the laboratory at approximately the same time of day, between 4:00 p.m. and 7:00 p.m., using assessment of RER, supported by measurement of ventilatory equivalent for oxygen ($\dot{V}_E/\dot{V}O_2$) during a graded, submaximal ski trek-simulated, treadmill test procedure. Initially, we performed a habituation test to familiarize the two participants with the exercise test equipment. We then performed the pre-trek test 11 days before the expedition, and the post-trek test 7 – 10 days after the expedition. The test procedure consisted of walking at three velocities: 10 min warm-up at 3 km·h^{-1}, and then 5 min each at 4 km·h^{-1} and 5 km·h^{-1} (0% incline). This represented the speed range (~3 – 5 km·h^{-1}) during LIST in the present study (corresponding to ~33 – 53% of pre-expedition $\dot{V}O_{2max}$). During the test, participants pulled 12.5 kg weights using a rope. The rope was attached to a hook on the back of the participant's pelvic belt and extended ~3 m behind the treadmill to a stand (~1 m high) where the rope passed through a pulley at the top of the stand and the weights hung freely from the end of the rope ~40–50 cm above the floor surface. The oxygen cost when pulling 12.5 kg weights during treadmill walking at 3.6 km·h^{-1} and 0% incline appears to correspond to the oxygen cost when hauling a sledge of around 70 kg during ski trekking at 3.6 km·h^{-1} on level ground (Juhani et al., 1986). We measured oxygen uptake ($\dot{V}O_2$), heart rate, RER, and $\dot{V}_E/\dot{V}O_2$ in steady state phases (when each had plateaued) between the eighth and tenth min during the 10 min warm-up, and between the third and fifth min during the two 5 min steps (Jarstad and Mamen, 2019).

As RER has been shown to be affected by different nutritional states (fasted vs. fed state) during low exercise intensities (22 – 59% $\dot{V}O_{2max}$) in trained individuals (Bergman and Brooks, 1999), and the type and amount, as well as the timing of carbohydrate ingestion before exercise may influence RER (Achten and Jeukendrup, 2004), the two participants made an effort to ingest the same type and amount of food and fluid and adhere to the same time interval from meal to test execution pre- and post-trek.

Maximal Aerobic Power

For assessment of $\dot{V}O_{2max}$, we used an incremental test procedure previously described in detail (Jarstad and Mamen, 2022). In short, the participants walked on the treadmill while pulling 12.5 kg weights starting at 6 km·h^{-1} and 0% incline. The incline was then increased by 4% each min until voluntarily exhaustion (participants decided when they had reached exhaustion) in ~5 min. We took the mean of the two highest 30 sec $\dot{V}O_2$ measurements as $\dot{V}O_{2max}$. We estimated maximal heart rate (HR_{max}) 5 beats·min^{-1} above peak heart rate achieved during the test (Ingjer, 1991).

Instruments

We assessed body composition pre- and post-trek using a Tanita BC-420MA foot-to-foot BIA analyzer, which estimates body composition using a constant current source with a high frequency current (50 kHz, 90 µA) (Tanita Corp., Tokyo, Japan). Foot-to-foot BIA calculates fat-free mass based on the sum of resistance in the legs and the lower part of the trunk. And while dual-energy x-ray absorptiometry (DXA) is considered the gold standard in assessing body composition, foot-to-foot BIA has been shown to be a valid method for estimation of fat-free mass and relative fat mass, and thus calculation of body composition, in adult populations (18 – 74 years) of women and men with mean BMI of ~24 – 28 kg·m^{-2} (Beam and Szymanski, 2010; Bousbiat et al., 2011). Furthermore, the BIA model used in the present study (Tanita BC-420MA) has shown good repeatabliity of measurements, with one study finding showing that its test-retest coefficient of variation (CV) was ~5.5% (González-Ruíz et al., 2018). As far as the authors know, our study is the first to use BIA for evaluation of body composition following LIST in polar regions.

We performed the treadmill test procedures pre- and post-trek on a Woodway PPS 55 treadmill (Woodway GmbH, Weil am Rhein, Germany). We analyzed $\dot{V}O_2$, $\dot{V}CO_2$, RER,

FIG. 2. Low-intensity ski trekking during the expedition. Photo credit: Teodor Glomnes Johansen.

FIG. 3. A selected tent site during the expedition. Photo credit: Lars Pahle Tønsberg.

and $\dot{V}_E/\dot{V}O_2$ using a SensorMedics Vmax 29 ergospirometry system with a mixing chamber (Vyaire Medical, Höchberg, Germany). To the best of our knowledge, this system (Vmax 29) has not been validated directly. However, Medbø et al. (2002) validated it indirectly; they compared the Vmax 29 against the MetaMax II metabolic system (CORTEX Biophysik GmbH, Leipzig, Germany) and also ran a comparison of the MetaMaxII with the Douglas bag method. Based on their tests, it may be possible that the Vmax 29 measures $\dot{V}O_2$ at workloads of ~60 – 100% $\dot{V}O_{2max}$ ~4% higher, and RER between ~0.85 – 1.00 ~4% lower, than the Douglas bag method. Furthermore, the Vmax Encore 29 ergospirometry system (Vyaire Medical, Höchberg, Germany), which relies on the same measurement technique as the Vmax 29, has been shown to have a within-subject CV of ~3% for RER assessment during rest (Cooper et al., 2009). This may indicate approximately which CV can be expected for RER during low-intensity work using the Vmax 29 system. We assessed heart rate using a Polar S210 heart rate monitor (Polar Electro Oy, Kempele, Finland). Before the exercise tests pre- and post-trek, we manually volume calibrated the Vmax 29 with a 3 L syringe, while we performed gas calibration against room air and containers with known content (Bottle 1: 4% CO_2, 16% O_2, and stable N_2, Bottle 2: 0% CO_2, 26% O_2, and stable N_2). We measured time using a digital stopwatch (Hanhart Prisma 200, Hanhart, Germany).

The Expedition

We previously described the expedition in detail elsewhere (Jarstad and Mamen 2022), but briefly, on 11 April 2016, the two LIST participants started the unsupported expedition at Verlegenhuken in the north of Svalbard. From there, the participants performed LIST ~2 – 11 hours·day^{-1} for 23 consecutive days, with skins under their skis and pulling sledges that were approximately 80 kg initially, and about 55 kg when the expedition was completed. The average speed during the trek was ~3.9 km·h^{-1}, corresponding to ~40% $\dot{V}O_{2max}$/~60% HR_{max}. After skiing to Sørneset in the south of Svalbard, the ~640 km ski trek (~11,000 m ascent and descent) continued north again to Doktorbreen, where it was completed on 3 May 2016. According to the Norwegian Climate Services Center (www.klimaservicesenter.no), the daily mean air temperature during the traverse gradually increased from approximately –16˚C at Verlegenhuken, to –2˚C at Doktorbreen. Figures 2 and 3 show some of the conditions in which the two participants trekked and camped, respectively.

RESULTS

Prior to the expedition, the usual energy intake of each participant was ~11 MJ·day^{-1} (~2600 kcal·day^{-1}), of which ~50% (~3.9 g·kg^{-1}·day^{-1}), ~30% (~1.1 g·kg^{-1}·day^{-1}), and ~20% (~1.5 g·kg^{-1}·day^{-1}) was derived from carbohydrates, fat, and proteins, respectively. The energy intake of each participant during the expedition was ~21.4 MJ·day^{-1}/~5107 kcal·day^{-1}, where the contributions of energy from carbohydrates, fat, and proteins were ~33% (~5.0 g·kg^{-1}·day^{-1}), ~51% (~3.4 g·kg^{-1}·day^{-1}), and ~16% (~2.4 g·kg^{-1}·day^{-1}), respectively (Table 1). Following the expedition, body mass decreased by 7.2 kg (8.4%), corresponding to ~2.5 kg·week^{-1}, in Subject A, whereas the same variable decreased by 4.4 kg (5.2%), corresponding to ~1.5 kg·week^{-1}, in Subject B (Table 2). Body mass index decreased by 2.2 kg·m^2 (8.6%) in Subject A, and 1.3 kg·m^2 (5.0%) in Subject B (Table 2). Absolute and relative fat mass decreased by 5.4 kg (37%) and 5.3 percent points (31%), respectively, in Subject A, whereas the same variables decreased by 4.7 kg (30%) and 4.8 percent points (26%), respectively, in Subject B (Table 2). Fat-free mass did not change significantly in the two participants (–1.8 kg in Subject A and + 0.3 kg in Subject B*)* (Table 2). There were no notable changes in RER, $\dot{V}_E/\dot{V}O_2$ or %$\dot{V}O_{2max}$ following the trek (Table 3). As described previously (Jarstad and Mamen, 2022), absolute $\dot{V}O_{2max}$ did not change significantly (changed from 5.36 to 5.34 L·min^{-1} in Subject A, and from 5.11 to 4.99 L·min^{-1} in Subject B), whereas the relative $\dot{V}O_{2max}$ increased from 62.4 to 67.7 ml·kg^{-1}·min^{-1} in Subject A, but did not change significantly (changed from 60.5 to 62.5 ml·kg^{-1}·min^{-1}) in Subject B. HR_{max} changed from 196 to 190 s·min^{-1} in Subject A, and from 193 to 197 s·min^{-1} in Subject B.

DISCUSSION

The main finding of the present study was that the two participants lost a substantial amount of body mass, mainly due to decreased fat mass following short-term, prolonged LIST. Another interesting observation, apparently, was that substrate utilization did not change.

The energy intake of the two participants during the expedition, which was about the same as that reported among the faster finishers in the study by Paulin et al. (2015), was approximately twice the energy intake in their everyday lives. Despite this doubling of energy intake, the energy output was significantly higher, as body mass was substantially decreased in both participants. In Subject A, the loss of body mass was 2.8 kg greater than observed in Subject B. This difference appeared to be mainly due to a poorer ski trekking economy (a higher energy cost of ski trekking) in Subject A vs. Subject B, as indicated by the fact that the oxygen cost (energy cost) during the treadmill trekking at 4 km·h^{-1} (the same velocity as the mean pace during LIST; ~3.9 km·h^{-1}) was ~8% higher in Subject A than in Subject B (Jarstad and Mamen, 2022). Additional explanations for the dissimilar weight loss between the two trekkers could relate to different energy intakes (actual food intake was unfortunately not logged) and unequal abilities to handle the cold environment (avoid freezing and muscle shivering).

In both participants, losses of fat mass were greater than the random measurement error, whereas the changes in

TABLE 2. Body composition in the two LIST participants pre- and post-trek.

	Subject A		Subject B	
Variables	Pre-trek	Post-trek	Pre-trek	Post-trek
Body mass (kg)	85.9	78.7	84.3	79.9
Body mass index ($kg \cdot m^2$)	25.7	23.5	26.0	24.7
Fat-free mass (kg)	71.3	69.5	68.7	69.0
Absolute fat mass (kg)	14.6	9.2	15.6	10.9
Relative fat mass (%)	17.0	11.7	18.5	13.7
Total body water (kg)	48.9	49.0	47.4	48.4
Impedance (Ω)	441	397	452	399

fat-free mass were within the random measurement error. Overall, therefore, the body composition findings in the present study may indicate that a decline in body mass of ~2 $kg \cdot week^{-1}$ can be achieved without noteworthy changes in fat-free mass in this subgroup of athletes during short-term, prolonged LIST. This is approximately in line with the body composition results among faster finishers in the Paulin et al. (2015) study. Furthermore, the changes in body composition of the present study, and that of Paulin et al. (2015), are approximately the same as those reported following medium-term (30 – 42 days), prolonged LIST in moderately trained males (pre-trek $\dot{V}O_{2max}$ of ~43 – 50 $ml \cdot kg^{-1} \cdot min^{-1}$) (Helge et al., 2003; Parent et al., 2018). In this context, it is interesting to note that the distributions of energy from carbohydrates (~44 – 60%), fat (~31 – 41%), and proteins (~9 – 15%) in the food intakes (~18.6 – 25.9 MJ day^{-1}; ~4500 – 6200 $kcal \cdot day^{-1}$) reported by Helge et al. (2003) and Parent et al. (2018) were different compared to those in the present study and in Paulin et al. (2015). From an anthropometric point of view, this may indicate that the main focus during prolonged LIST expeditions should be to control the size of the energy deficit/weight loss, rather than paying too much attention to the distribution of energy from different macronutrients in the diet. However, this issue needs to be further investigated in comparative studies, as the different studies we have discussed here, including our own, used diverging methods for body composition measurements (e.g., DXA, BIA and skinfold analysis [pinching skin and underlying adipose tissue with calipers to assess body fat]) (Helge et al., 2003; Paulin et al., 2015; Parent et al., 2018).

The RER data in Subject B cannot be used in the interpretation of the changes in substrate utilization due to the excessive fluctuations in $VE/\dot{V}O_2$. In Subject A, we observed small decreases in RER, with no notable changes in $VE/\dot{V}O_2$, at 3 – 5 $km \cdot h^{-1}$. However, the changes in RER in this participant were of such a modest nature that they fell within the random measurement error. It can be assumed, therefore, that there were no significant changes in substrate utilization following the expedition in Subject A. Such a finding is probably quite surprising to many, as it seems to be a common belief among, for example, athletes and coaches (based on our practical experience) that fat oxidation will improve following prolonged, low-intensity training and, as some research has reported, that substantial

TABLE 3. Substrate utilization (assessed by RER and $\dot{V}_E/\dot{V}O_2$) at three different work intensities during treadmill trekking by the two LIST participants pre- and post-trek.

	Subject A		Subject B	
Variables	Pre-trek	Post-trek	Pre-trek	Post-trek
3 $km \cdot h^{-1}$				
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.76	0.75	0.90	0.88
$\dot{V}_E/\dot{V}O_2$	18	18	22	22
$\%\dot{V}O_{2max}$	33	32	35	34
$\%HR_{max}$	59	57	52	52
4 $km \cdot h^{-1}$				
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.76	0.74	0.84	0.89
$\dot{V}_E/\dot{V}O_2$	18	17	19	23
$\%\dot{V}O_{2max}$	42	38	40	41
$\%HR_{max}$	62	63	56	57
5 $km \cdot h^{-1}$				
RER ($\dot{V}CO_2/\dot{V}O_2$)	0.79	0.78	0.90	0.92
$\dot{V}_E/\dot{V}O_2$	18	17	21	23
$\%\dot{V}O_{2max}$	52	49	53	52
$\%HR_{max}$	69	71	63	63

RER = pulmonary respiratory gas exchange ratio, $\dot{V}CO_2$ = carbon dioxide production, $\dot{V}O_2$ = Oxygen uptake, $\dot{V}_E/\dot{V}O_2$ = ventilatory equivalent for oxygen, $\%\dot{V}O_{2max}$ = exercise intensity percentage of maximal aerobic power, %HRmax = exercise intensity percentage of maximal heart rate.

increases in fat intake beyond normal can enhance fat utilization during exercise (Phinney et al., 1983; Lambert et al., 1994). However, as the two LIST participants carried out a considerable amount of activity-specific training in preparation for this expedition, it is reasonable to believe that they had already adapted their fat oxidation ability to such a level that more exercise at only low intensity for only three weeks would not lead to further development of this characteristic. As well, the relative fat intake during the present expedition was high, but lower than those (≥70% of total energy distribution) in the well-trained subjects (cyclists) in the studies by Phinney et al. (1983) and Lambert et al. (1994). This indicates that a diet where ~50% of the energy is derived from fat is not sufficient to affect fat metabolism significantly in highly aerobically fit recreational athletes. The latter must, however, be interpreted with caution, as the two participants of this study consumed their normal diets again between the end of the trek and the post-trek tests, with a time gap of 7 – 10 days. Nevertheless, the finding in Subject A of our study supports results in Péronnet et al. (2009), indicating that overall, short-term prolonged LIST does not appear to have an impact on whole-body fat oxidation in moderately and highly aerobically fit individuals. However, more research is necessary to provide more knowledge about this issue.

Limitations of this study

This is a case study with only two participants, where body composition and substrate utilization were evaluated on the basis of indirect measurement methods. Additionally, although the two participants claimed it was no challenge to ingest the daily pre-packaged meals, as their appetite was excellent during the expedition, they did not log the actual intake of foods in a diary. Also, the participants' travel schedule, which caused a time gap of 6 – 11 days from the pre-trek tests to the start of the expedition, and a time gap of 7 – 11 days from the completion of the expedition to the post-trek tests, may have affected the results for body composition and substrate utilization to some extent. These limitations mean that the outcomes of this study must be interpreted and compared to other studies with caution.

CONCLUSIONS

The present study indicates that short-term, prolonged LIST performed with an energy deficit corresponding to a weight loss of ~2 kg·week^{-1}, can lead to leaner body composition without notable changes in fat-free mass in well-trained male recreational athletes. Furthermore, substrate utilization does not appear to be affected by short-term, prolonged LIST in this subgroup of athletes.

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