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XP-Antarctik Expedition: The Effect of a Month-Long Expedition in Antarctica on Physiological Performance

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Cover Page Footnote

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Abstract

Antarctica is a challenging habitat for humans. A group of 6 explorers (3 women and 3 men) participated in an expedition in Antarctica. The objective was to observe the physiological acclimatization of the explorers using the following strategies: physical preparation, high-caloric nutritional intake, and the latest physiological monitoring and outdoor equipment. Anthropometric measures (dual x-ray absorptiometry), specific maximal aerobic test, maximal aerobic running speed test, submaximal aerobic cold testing, strength tests (grip strength, leg press and chin up), and endurance tests (bar suspension and chair position) were conducted pre- and post-expedition. Due to the sample size, a paired *t*-test was used for normally distributed data and non-parametric (Wilcoxon) to compare values pre- and post-expedition. Effect sizes are presented as Cohen's *d*. The lean mass for the women was significantly higher after the expedition (45.4 ± 4.4 vs. 47.1 ± 4.1 kg; $p = 0.040$, $d = 1.86$); however, no significant difference was observed for the men (66.7 ± 7.3 vs. 66.0 ± 5.7 kg; $p = 0.581$, $d = 0.11$). Pre- and post-expedition values were significantly different for the specific maximal aerobic test, where the VO_2peak was 40.8 ± 4.2 vs. 46.9 ± 7.4 ml/kg/min, respectively ($p = 0.027$, $d = 1.01$), but no significant difference was observed for the other aerobic tests. The muscular testing did not change significantly, except for the left leg one maximal repetition (295 ± 110 vs. 364 ± 135 lb, pre- and post-expedition respectively, $p = 0.031$, $d = -0.56$). The overall preparation for the expedition appears to be a key aspect in order to countermeasure the physical ability decay during an Antarctica expedition. However, further studies will need to be developed to discern the importance of the preparation components.

Keywords: Antarctica expedition, fitness, physiological acclimatization

Introduction

Explorers venturing to Antarctica are exposed to one of the most demanding environments on Earth. Despite modern technology and research knowledge, Antarctica is still extremely hostile to humans (Acheson, Campbell, Edholm, Miller, & Stock, 1980; Bishop, Grobler, & Schjoii, 2001; Frykman et al., 2003). Antarctica holds the world's record for the coldest temperature that has been registered, as well as the windiest, highest, and driest continent (Kennedy, 1993; Simpson, 2010; Stocks, Taylor, Tipton, & Greenleaf, 2004). However, only a few studies have reported physiological consequences of a prolonged expedition without external support (complete autonomy) in the Polar environment (Bishop et al., 2001; Frykman et al., 2003; Halsey et al., 2016; Halsey & Stroud, 2012; Stroud, Coward, & Sawyer, 1993). During a completed autonomy expedition, most explorers use sledge pulling with skis to trek across the Polar environment where the equipment and scientific knowledge have improved much since the Antarctica expedition golden age (Halsey & Stroud, 2012; Simpson, 2010). Moreover, there is still much to discover about human responses in this extreme environment.

Fitness Effect from Polar Expedition

The impact of a Polar expedition on fitness performance is controversial and depends on activity patterns and the time and conditions of exposure (Simpson, 2010). Physical fitness improvements that occurred after six weeks of outdoor work in a cold environment have been shown by Budd (1965). However, it is not known if they were attributed to cold exposure

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or the work intensity during the study. Nonetheless, similar results were observed by Frykman et al. (2003) where one person from a crew of two improved his maximal aerobic capacity and strength after a 3-month ski-trek and sledge-pulling Polar expedition. However, anaerobic capacity and vertical jump power decreased for both participants. Thus, the majority of studies about fitness and Polar ski-trek expeditions have been conducted on men and with small sample sizes. Furthermore, these studies indicated that pulling a sledge required high energy demands. This is particularly impacting on smaller men, where they typically expend energy faster. This high energy expense can have a detrimental effect on muscle performance due to the fact that energy store depletion can reach a critical level for muscle function (Halsey & Stroud, 2012). In fact, a ski-trekking expedition can induce negative balance energy, where the energy that can be ingested cannot reach the amount of the energy expended such as due to the intensity of sledge pulling, the altitude, sleep deprivation, the snow resistance, and the cold temperature (Frykman et al., 2003; Halsey & Stroud, 2012; Simpson, 2010). Furthermore, muscle performance deterioration has also been linked to fluid retention in response to malnutrition (Halsey & Stroud, 2012). As well, muscle performance decreases when exposed to cold, even for a single short exposure time (Stocks et al., 2004). Thus, cold exposure decreases maximal strength, muscular endurance, and cardiovascular performance, and significantly increases the metabolic cost of physical activities (Mäkinen, 2007; Oska et al., 2004; Stocks et al., 2004). However, this deterioration can be minimized by an appropriate initial preparation and caloric intake equal to the energy uptake during the expedition. Nonetheless, cold exposure has a high impact on energy uptake and still needs to be better understood.

Physiological Responses to Cold Exposure

Cardiorespiratory responses and performance at cold temperatures

It is still not well established how the cold affects physiological responses, such as the oxygen uptake during exercise. Some studies observed no changes in VO_2max (Sandsund, Sue-Chu, Helgerud, Reinertsen, & Bjermer, 1998), while other studies reported decreases as a function of temperature (Oska et al., 2004; Patton & Vogel, 1984; Quirion et al., 1989). Moreover, some studies observed a higher oxygen uptake requirement during submaximal exercise in cold exposure (Kruk, Pekkarinen, Harri, Manninen, & Hanninen, 1990; Oksa et al., 2004; Sandsund et al., 1998; Therminarias, 1992), while other investigators reported no significant difference (Jacobs, Romet, & Kerrigan-Brown, 1985; Patton & Vogel, 1984). Thus, knowledge about oxygen consumption during a sledge-pulling ski trek in cold environments is a key aspect in order to estimate nutritional rations needs and meet the energy expenditure to prevent or minimize the impact of body weight loss that may lead to the deterioration of physical performance.

Power and strength during expedition in Antarctica

Several investigators observed that human cooling causes a decrement in maximal muscle force, reducing velocity, and an increase time to reach peak force (Bergh & Ekblom, 1979; Davies & Young, 1983). Thus, the impaired power and force production of cooled muscles may be due to changes in their neuromuscular function that can decrease performance and increase injury risks (Mäkinen, 2007). Furthermore, the muscular performance decreases during dynamic exercises, especially during fast contraction velocities (Oksa et al., 2004). This decrement in muscle contraction during cooling has been explained by Oska, Rintamaki, Makinen, Hassi, and Rusko (1995) where the agonist muscle function decreased via a decrement in electromyography activity accompanied by an increase in electromyography activity in the antagonist muscle group. Thus, this power and strength decline at cold temperatures decreases performance and could increase risks during a ski-pulling trek where the load is high.

Adaptation/acclimatization to cold environments

Repeated cold exposures lead to physiological changes, but there are still controversies surrounding the precise nature of adaptation/acclimatization to cold environments (Cheung, 2015; Mäkinen, 2010). However, studies have agreed that thermal sensations and sensation of pain decrease with time and repeated exposure to cold temperatures (Barwood, Corbett, & Wagstaff, 2014; Geurts, Sleivert, & Cheung, 2006; Mekjavic, Dobnikar, & Kounalakis, 2013). At the same time, these thermal sensation and pain decreases induce a greater risk of cold injuries, such as frost bite (Leppäluoto, Korhonen, & Hassi, 2001; Mäkinen, 2010). Despite this risk, cold adaptations represent one of the means for the prevention of pathophysiology effects from exposure to cold environments according to Launay and Savourey (2009). The authors explain that adaptation to cold induces less discomfort, preserves dexterity, prevents general and local cold illnesses and injuries, and improves survival in a cold environment. However, previous studies did not often differentiate between acclimation, acclimatization, adaptation, and habituation. Launay and Savourey(2009) describe the term *adaptation* as the changes that reduce the physiological strain produced by the cold, unlike the term *acclimation* where the changes are in response to an experimentally and specific condition (e.g., wind or temperature) or the term *acclimatization* where the changes occur as a response to a natural climate, as is the case in the present study. The last term defined by Launay and Savourey (2009) was *habituation* used to elicit new physiological responses or more pronounced physiological reactions induced by an acclimatization or acclimation. Thus, the mechanisms that occur under conditions of acclimatization and habituation can help one to propose more efficient physiological preparation for Polar explorers before an expedition.

Present Strategies during Expedition in Antarctica

Actual strategies proposed in order to succeed surviving in the Antarctic environment include the ingestion of a high-calorie diet, favoring fats and carbohydrates over proteins to reduce wasting and degradation in performance (Halsey & Stroud, 2012). The strategy is based on a hypothesis used for marathon races (Tsintzas, Williams, Singh, Wilson, & Burrin, 1995) that is still controversial, mostly because of the impossibility for some people to absorb high-fat diets (Stroud, 1998). Moreover, modern endurance rations include micronutrients in abundance, which is a new process that was not present during the heroic age of Antarctic exploration (Halsey & Stroud, 2012). Another strategy is a specific physical training before an expedition. During a sledge-pulling expedition the adventurers must haul sufficient food and equipment to survive the journey, and thus must physically prepare adequately as athletes would do for their specific sport. Furthermore, present-day explorers aim to begin their journeys with a heightened body mass in order to counter the high energy expenditure during the expedition, even though this can perhaps prove difficult since they have to bear the extra weight. Finally, due to technological advancements, clothes and equipment are lighter and more efficient in protecting against the cold, the wind, and the humidity (Halsey & Stroud, 2012). Nevertheless, in spite of all available new information, technological advancements, and strategies, modern explorers remain uncertain about optimal strategies to use, such as dietary rations and exact fitness preparation. Further research on these strategies is critical due to the access to Antarctica via tourism and travel adventures in extreme environments that are growing in popularity. Finally, the majority of research reported concerning Antarctica was mostly on men and outcomes on women are needed (Simpson & Maynard, 2012). The aim of the current study was to investigate the effects of a month-long expedition in Antarctica on a mixed-gender crew of six explorers, to observe changes in physical fitness while being sustained on a high-fat diet, using latest technologies in equipment, and fitness preparation strategies. Specifically, measurements before and after the expedition were taken to assess acclimatization to a cold environment: (1) maximal and submaximal aerobic fitness and (2) muscular endurance and strength fitness. The hypothesis was that adventurers would have no or minimal decrease in their fitness after the expedition due to the balanced energy intake and energy expenditure that was maintained with a high-fat diet, efficient low-weight equipment, and proper physical preparation to support the expedition load.

Methodology

A part of the following methodology was reported in another paper (Parent et al., submitted). The present paper focuses on measurements taken before and after the expedition (pre- and post-expedition, respectively), as illustrated in Figure 1.

Participants

The study was approved by the University of Quebec in Montreal ethics committee. The crew was composed of 6 members (3 men and 3 women, 25 $\pm$ 4 years old where the range was 23 to 30 years old). All members except one had experience in expeditions (3 adventure tourism guides, an experienced climber, and an ex-military man). A photographer was added to the team 3 months prior to the expedition. The entire crew participated in a 7-day acclimatization and logistical pre-expedition in the Columbia ice field to prepare and review team techniques, and physical and psychological challenges.

Procedure

Preparation

In addition to the pre-expedition preparation, participants kept a daily diary of their work activities, most of them

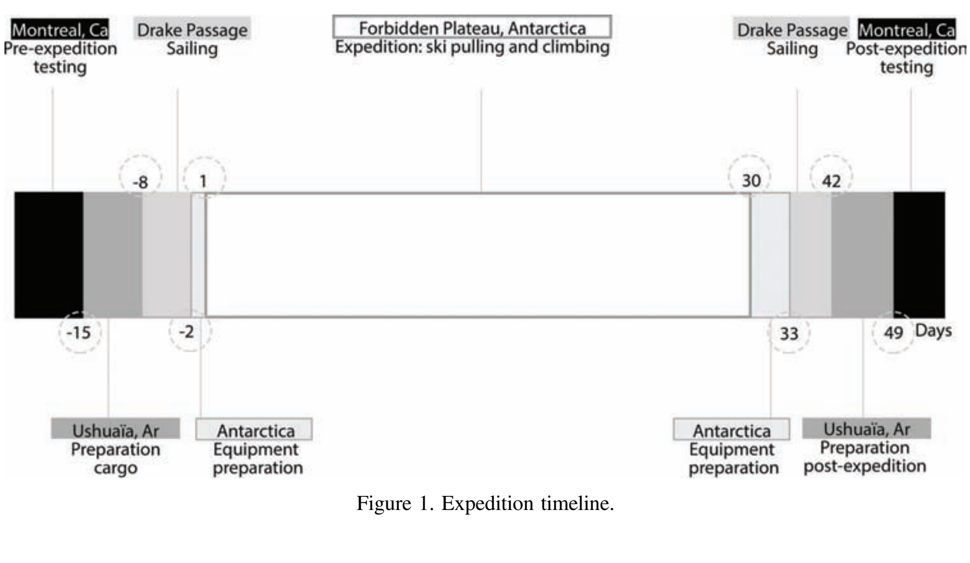

Figure 1. Expedition timeline.

as adventure tourism guides, in the year leading up to the Antarctica expedition. The diary was used to keep track of the distance covered during the adventure tourism, calories consumed, and heart rate monitored with heart rate monitor (RS800, Polar, Fi). On top of their physically demanding work as tourism guides, specific calisthenic exercises (exercises to be achieved with the body weight that do not require equipment) were sent to the crew to increase individual strength and endurance that is required to do their work. The training volume provided by the calisthenic exercises was determined as a function of the physical demand required by their individual work prior to the expedition. Furthermore, participants were encouraged to gain weight (fat and muscle) for physical sustainment during the expedition.

Expedition

The participants performed the tests in Canada before staying one week at Ushuaïa, Argentina, to finalize the crew and cargo manifests. The Antarctic expedition was composed of sailing across the Drake passage (~1700 km sea travel), followed by a 30-day expedition in Antarctica on the Forbidden Plateau completing an entirely autonomous ski-trekking, sledge-pulling progression, and finished by returning to Ushuaïa by sailing across the Drake passage. The participants remained in Ushuaïa one week before returning to Canada. The conditions on the Forbidden Plateau were, for most of the expedition, spent in complete isolation; however, satellite phone and wireless (satellite) connection to social media was available. The participants progressed, most of the time on skis, each pulling approximately 100 kg equipment-laden sleds and backpacks. The average daily progress time was 10–15 hours with a daily sunshine duration of 12 hours. The food intake was freeze-dried food and caloric bars with mineral additives (Happy Yack and Xact nutrition, Montreal, Qc, Canada) totaling around 5800 calories per person per day for the 2 first weeks and 6500 calories per person per day for the other weeks. This amount of calories was set in individual packages for every meal and the team was instructed to finish all the meals prepared. The same instruction was given to take snacks during the day and water in the morning that was provided by melting snow (6 L per person per day). If one or more of the crew members were not able to finish the prepared food package, the crew was required to inform the scientist in charge. There were frequent "white-outs" where visibility and contrast were severely reduced by snow, terrain elevation, and undetectable troughs, with temperatures around −20 to −40℃ recorded in the ship weather report. The altitude peak reached was around 2200 m, the plateau altitude was around 1400 m, and the distance travelled more than 160 km according to open source satellite pictures. The clothing was latest technology used in an expedition; the thermal insulation was provided by several layers with light and efficient technologies Mammoth, Gore-Tex, Switzerland; Icebreaker, Merino, Canada; and Mountain Hard Wear, USA).

Assessments Pre- and Post-Expedition

Fitness testing was performed before and after the Antarctica expedition in the Human Performance Laboratory at the University of Quebec in Montreal.

Anthropometric measurements

Total body fat was measured by dual x-ray absorptiometry (GE Prodigy Lunar, USA) as established by others (Sillanpää, Häkkinen, & Häkkinen, 2013). The measurements were taken on each participant three times: during the week before the pre-expedition (three months before the expedition), during the week before the flight to Argentina to take the boat, and the week after the return from Argentina.

Muscular fitness tests

The grip strength test protocol consisted of exerting a maximal grip on a dynamometer (Lafayette hand dynamometer, model 78010, USA). The test was performed twice on each hand. The best result from each hand was noted at ±0.5 kg and summed.

The hang maximal suspension time (bar suspension) protocol (SMT) consisted of maintaining a flexion at the elbow at an angle of 90° where the body was in suspension for a maximum time without support. The test finished when the participant was unable to sustain the elbow angle after two consecutive warnings or if the participant voluntarily stopped due to exhaustion. The total time in seconds was noted.

The chair position for a maximal time protocol (CMT) consisted of maintaining knees at an angle of 90° whilst leaning back against a wall. The test finished when the participant was unable to maintain the knee angle after two consecutive warnings or via voluntary termination by the participant due to exhaustion. The total time in seconds was noted.

The strength test protocol consisted of six maximal repetitions (6MR). The participant tried to perform six repetitions, when a seventh repetition was not possible to do. In the situation where they succeeded to perform seven repetitions, the weight was increased for the next set. A minimum of three minutes rest was taken between the sets and a maximum of four sets were performed per day. The 6MR was performed using a leg press and chin up exercise with a weighted jacket. The leg press was performed per leg in order to have enough weight to perform the test. The 1MR was extrapolated to the 6RM measurement with the ACSM equivalent table (Heyward & Gibson, 2014).

Specific maximal aerobic test (SMAT)

The specific aerobic test protocol consisted of a maximal progressive walk test on a self-propelled treadmill (Hi-trainer, Bromont, Canada). The participant had to push the treadmill belt with their feet while resting their hips on a support that simulated the cargo-laden sled. The treadmill resistance began at 10 lb for one minute followed by a 15 s rest period; it increased 10 lb every minute until exhaustion. The participant needed to maintain a minimum speed of 1 m/s. The test was terminated when participants were exhausted or unable to maintain the minimum speed. The gas collection and cardiorespiratory parameters (ventilation (VE), oxygen uptake (VO_2), and heart rate (HR)) were measured with a portable metabolic analyzer (K4b2, Cosmed, Italy), and the maximal treadmill resistance and the effort perception (Borg scale) were noted.

Maximal aerobic running speed test (MARS)

The maximal aerobic test protocol consisted of a maximal progressive running test to exhaustion on a motorized treadmill (Quantum LK, USA). The initial treadmill running speed was set at 8 km/h with 1% inclination for a three-minute warm-up. Following the warm-up, every minute, running speed was increased by 1 km/h until exhaustion. The gas collection and cardiorespiratory parameters (VE, VO_2, and HR) were measured with a portable metabolic analyzer (K4b2, Cosmed, Italy), and the maximal speed and effort perception were noted.

Muscular tests and aerobic submaximal test at control (CTL) and cold environmental temperatures (ASMT)

Participants took part in a submaximal test at a controlled ambient temperature (20 $\pm$ 1℃) and at a cold temperature (-1 $\pm$ 8℃). The participants did the tests at the ambient controlled temperature before acclimatization to the cold temperature environment for approximately 30 minutes and performed the tests again. The participants kept the same amount of clothing for both the controlled temperature and cold environment tests, and for the tests before and after the expedition (approximately 1 Clo). The tests consisted of a grip strength protocol and the maximal suspension time as described before.

The submaximal test consisted of a single step test at a tempo of two beats to step up and two beats to step back down to the initial start position. The initial tempo was 18 steps per minute for three minutes with 15 s of rest, followed by two further stages where the tempo was increased to 24 and 30 steps per minute. The same clothes were worn during the tests at the controlled ambient and cold temperatures. Gas collection and cardiorespiratory parameters (HR and VO_2) were measured with a portable metabolic analyzer (K4b2, Cosmed, Italy). The tympanic temperature (Braun Thermoscan Pro 4000, Braun, USA) was measured after the exercise. It is worth noting that for the cold environment measurements, we asked the participants to quickly take the temperature due to the cold temperature. Furthermore, the temperatures taken are not the body/core temperatures, because the cold temperature may influence the temperature in the ear. However, it gives a good estimate of the skin temperature close to the head and cerebral thermoregulation response (Mariak, Lewko, Luczaj, Polocki, & White, 1994). An extrapolation of the maximal oxygen uptake was calculated by the linear regression equation from the relation between heart rate and oxygen uptake for every participant and extrapolated to the maximal heart rate reached during the MARS. Furthermore, a comparison between the control temperature and cold temperature was calculated from subtracting the control response to cold response (Δctl-cold).

Statistical Analysis

Due to the sample size, a Shapiro–Wilk test was used to test the normal distribution (Razali & Wah, 2011). The effect of the expedition (pre- vs. post-) on fitness was analyzed using the non-parametric test (Wilcoxon) for two related samples for the data that were not normally distributed and paired *t*-test for the normally distributed data. Significance was set at the p = 0.05 level. Effect size (ES) was calculated and presented using Cohen's *d*. The following scale was used for the ES interpretation (*d*): small effect size: 0.2; moderate effect size: 0.5; large effect size: 0.8; very large effect size: 1.3 (Sullivan & Feinn, 2012). Results are reported as mean $\pm$ standard deviation. The statistical analysis was performed using SPSS Statistic 20 (IBM, USA).

Results

Anthropometric Measures

The participants' anthropometric measures are presented in Table 1. The % of body fat was significantly lower after the expedition (p = 0.014). It should be noted that one of the explorers was sick during the expedition and did not eat the recommended diet. Furthermore, the women's lean mass increased significantly after the expedition. However, the weight, the BMI, and lean mass for the entire group and the men's group did not change significantly.

Strength and Muscular Endurance

Strength and muscular endurance measurements are presented in Table 2. The pre- vs. post-expedition measurements indicated no significant difference except for the RM extrapolated left leg test.

Cardiorespiratory Fitness

Cardiorespiratory fitness measurements are presented in Table 2. The VO_2peak after the expedition, for the SMAT, significantly increased. Furthermore, the VO_2 and the %VO_2 at ventilation threshold (VT) significantly increased for both

Table 1
Participants' anthropometric characteristics.

	Pre-expedition			Post-expedition			p values (ES)		
	Women	Male	Group	Women	Male	Group	Women	Male	Group
Weight (kg)	64.1 ± 5.5	84.9 ± 10.2	74.5 ± 13.6	65.5 ± 4.9	81.1 ± 7.6	73.3 ± 10.3	0.105	0.147	0.422 (0.09)
Height (cm)	172 ± 7	183 ± 5	177 ± 8	N/A	N/A	N/A	N/A	N/A	N/A
BMI (kg/m^2)	21.6 ± 1.9	25.5 ± 2.3	23.5 ± 2.8	22.1 ± 2.0	24.3 ± 1.9	23.2 ± 2.1	0.116	0.133	0.481 (0.12)
Body Fat (%)	25.7 ± 6.7	18.2 ± 8.0	22.0 ± 7.7	24.6 ± 6.3	15.5 ± 7.5	20.1 ± 7.9*	0.158	0.147	0.014* (0.24)
Lean mass (kg)	45.4 ± 4.4	66.7 ± 7.3	56.1 ± 12.8	47.1 ± 4.1*	66.0 ± 5.7	56.5 ± 11.2	0.040*	0.581	0.345 (−0.03)

Note. Mean ± SD. ES, Cohen's d effect size.
*$p \leq 0.05$.

maximal cardiorespiratory tests. From the MARS test a significant decrease of VEpeak post-expedition was also observed. However, no significant difference was observed for the other parameters.

Response to the Cold

The measurements for muscular tests and aerobic submaximal tests at control and cold environmental temperatures are presented in Table 3 and the results for Δctl-cold environment are presented in Figure 2. The VO_2 during stages 2 and 3 (last stage) and the HR at the end of stage 2 were significantly lower post-expedition.

Pre- vs. post-expedition

The difference between ctl and the cold environment (Δctl-cold) was significantly higher after the expedition for the grip strength (1.8 ± 8.6 kg pre- vs. 8.8 ± 6.7 kg post-expedition, $p = 0.058$ ($d = 0.91$)), the VO_2 at stage 2 (0.0 ± 1.7 ml/kg/min pre- vs. 3.5 ± 3.1 ml/kg/min post-expedition, $p = 0.007$ ($d = 1.39$)), and the VO_2 at last stage (0.8 ± 3.4 pre- vs. 4.7 ± 2.9 post-expedition, $p = 0.32$ ($d = 1.23$)). However, for the other parameters, Δctl-cold was not significantly different pre- vs. post-expedition.

Control vs. cold environment for pre- vs. post-expedition

Pre-expedition, the HR at stages 1 and 3 was significantly lower in the cold environment ($p = 0.036$ ($d = 0.53$) and $p = 0.054$ ($d = 1.20$), respectively) and the tympanic temperature was significantly lower in the cold environment ($p = 0.027$ ($d = 3.25$)). However, the other parameters were not significantly different between the control and cold environment pre-expedition. Nonetheless, after the expedition, the grip strength ($p = 0.024$ ($d = 0.44$)), the HR for all three stages (HR stage 1, $p = 0.039$ ($d = 0.67$); HR stage 2, $p = 0.025$ ($d = 0.71$); and HR stage 3, $p = 0.001$ ($d = 0.99$)), the VO_2 at stages 2, 3 and extrapolated ($p = 0.042$ ($d = 1.29$); $p = 0.011$ ($d = 1.39$); and $p = 0.053$ ($d = 0.91$), respectively), and the tympanic temperature ($p = 0.028$ ($d = 2.03$)) were significantly lower at cold temperatures, but no significant difference was observed for the other parameters

Discussion

The main findings of the present study are that fitness capacity was maintained post-expedition. Furthermore, there were improvements in aerobic capacity and strength as shown by the SMAT results and the maximal strength leg press test. These results are possibly due to the measures taken to maintain the explorers' muscle mass. Furthermore, previous expeditions (Halsey & Stroud, 2012; Stroud, 2001) reported lean mass loss. A surprising result was significant improvement of lean mass in the women's group. Moreover, this study observed acclimatization in a cold environment. After the expedition, explorers performed submaximal aerobic exercises in a cold environment; VO_2 decreased significantly for a same intensity without observing a significant difference at control temperature. This is something that, to the best of our knowledge, has never been reported after an expedition in a cold environment.

Maintenance of Lean Body Mass

During the expedition, weight loss was minimized, possibly due to an adequate high-calorie diet. More interestingly, the lean mass was maintained in the men's group, and increased in the women's group, promoting an improvement in physical fitness. A similar finding was observed in previous studies, where ski-trekkers slightly increased their lean mass (Frykman et al., 2003), promoting an increase in physical capacity. However, many other ski-trekkers decreased their lean mass after a similar expedition (Frykman et al., 2003; Halsey & Stroud, 2012; Helge et al., 2003; Paulin, Roberts, Roberts, & Davis, 2015). Furthermore, a previous study explained that a sledge-pulling expedition induced vigorous physical activity, promoting gains in lean mass if the energy deficit is minor (Frykman et al., 2003). However, the lean mass improvement in this study was minor and not significant.

The present study observed a significant loss of total percent body mass pre- vs. post-expedition. However, the ES was small, possibly indicating a minor energy deficit, where the lean mass was preserved and corroborating findings of previous studies. Furthermore, the minor energy deficit was similar to that of the Frykman et al. (2003) study, where they observed a low percent body fat decrease,

Table 2
Physical fitness results.

	Pre-expedition			Post-expedition			p values (ES)		
	Women	**Male**	**Group**	**Women**	**Male**	**Group**	**Women**	**Male**	**Group**
Muscular tests									
Grip strength (kg)	72.0 ± 5.3	126 ± 7.9	99.0 ± 30.2	74.7 ± 17.0	115.0 ± 13.9	94.8 ± 26.1	0.655	0.109	0.464 (0.15)
SMT (s)	38 ± 17	73 ± 10	55 ± 23	55 ± 47	61 ± 20	64 ± 34	0.655	1.000	0.446 (0.31)
CMT (s)	180 ± 79	189 ± 46	185 ± 58	150 ± 57	139 ± 48	164 ± 50	0.109	0.593	0.133 (0.39)
LP_{LL},$1MR_{ext}$ (lb)	221 ± 28	405 ± 78	295 ± 110	279 ± 23	492 ± 133	364 ± 135*	0.180	0.180	0.031* (0.56)
$LP_{RL}1RM_{ext}$ (lb)	223 ± 31	420 ± 56	302 ± 114	271 ± 24	532 ± 190	376 ± 172	0.285	0.180	0.124 (0.51)
Chin-up$1RM_{ext}$ (lb)	77 ± 11	119 ± 3	98 ± 24	76 ± 10	114 ± 9	95 ± 23	0.593	0.285	0.241 (0.13)
Aerobic tests									
SMAT									
VO_2 peak (ml/kg/min)	38.9 ± 1.7	42.8 ± 5.4	40.8 ± 4.2	42.6 ± 4.6	51.3 ± 7.6	46.9 ± 7.4*	0.109	0.102	0.027* (1.01)
VO_2 peak (ml/kg lean mass/min)	55.6 ± 4.4	54.1 ± 2.9	54.9 ± 3.4	58.7 ± 1.0	62.4 ± 14.1	60.5 ± 9.2	0.285	0.180	0.104 (0.81)
HR peak (bpm)	176 ± 6	187 ± 6	182 ± 8	187 ± 10	186 ± 7	186 ± 8	0.109	1.000	0.262 (0.5)
VE peak (L/min)	98.3 ± 11.9	143.7 ± 8.4	121.0 ± 26.5	93.7 ± 7.6	142.7 ± 16.2	118.2 ± 29.1	0.109	1.000	0.560 (0.10)
%VO_2 at VT	69.8 ± 3.6	60.9 ± 4.8	65.3 ± 6.2	82.9 ± 5.1	71.6 ± 7.8	77.2 ± 8.5*	0.109	0.109	0.003* (1.60)
VO_2 at VT (ml/kg/min)	27.2 ± 2.1	26.0 ± 2.8	26.6 ± 2.3	35.1 ± 1.8	36.4 ± 4.1	35.8 ± 2.9*	0.109	0.109	0.027* (3.52)
MARS									
VO_2 peak (ml/kg/min)	42.8 ± 4.7	45.0 ± 3.6	44.0 ± 3.9	41.6 ± 3.3	47.9 ± 9.3	44.7 ± 7.0	0.655	0.655	1.000 (0.12)
VO_2 peak (ml/kg lean mass/min)	59.1 ± 3.3	56.2 ± 4.5	57.6 ± 4.0	60.2 ± 2.9	59.5 ± 16.1	59.8 ± 10.4	0.276	1.000	0.916 (0.28)
HR peak (bpm)	193 ± 13	192 ± 3	193 ± 7	192 ± 4.9	187 ± 3.8	89 ± 4	0.655	0.180	0.241 (0.70)
VE peak (L/min)	115.0 ± 10.0	145.7 ± 7.5	130.3 ± 18.6	108.0 ± 12.8	131.0 ± 5.6	119.5 ± 15.4*	0.109	0.180	0.037* (0.63)
%VO_2 at VT	85.4 ± 3.5	76.2 ± 3.8	80.8 ± 5.8	89.6 ± 5.1	88.7 ± 1.1	89.1 ± 3.3	0.285	0.109	0.020* (1.76)
VO_2 at VT (ml/kg/min)	35.8 ± 3.5	33.6 ± 3.3	34.7 ± 3.3	37.3 ± 3.5	42.5 ± 8.7	39.3 ± 6.6	0.285	0.109	0.046* (0.88)

Note. Mean ± SD. ES, Cohen's *d* effect size. SMT, suspension maximal time; CMT, chair maximal time; LP_{LL}, $1RM_{ext}$, leg press left leg 1 maximal repetition; LP_{RL}, $1RM_{ext}$, leg press right leg 1 maximal repetition; SMAT, specific maximal aerobic test; VT, ventilation threshold; MARS, maximal aerobic running speed.
*$p \leq 0.05$.

Table 3
Physical performance at ambient vs cold temperatures.

	Pre-expedition (Ctl/Cold)			Post-expedition (Ctl/Cold)			p values (ES)(Ctl/Cold)		
	Women	Male	Group	Women	Male	Group	Women	Male	Group
Grip strength (kg)	70.3 ± 2.1/ 68.0 ± 4.0	120.7 ± 11.7/ 119.3 ± 3.1	95.5 ± 28.6/ 93.7 ± 28.3	75.3 ± 18.6/ 69.3 ± 17.0	107.0 ± 4.4/ 96.3 ± 11.0	91.7 ± 20.7/ 82.8 ± 19.6	0.593/0.655	0.276/0.109	0.605 (0.15)/ 0.171 (0.45)
SMT (s)ǂ	59 ± 48/ 60.7 ± 32.7	167ǂ/156ǂ	86 ± 67ǂ/ 85 ± 55ǂ	44 ± 38/ 46 ± 44	92ǂ/117	56 ± 39/ 64 ± 50	0.109/0.285	N/A	0.148 (0.55)/ 0.170 (0.40)
Aerobic submaximal test									
$VO_{2Stage1}$ (ml/kg/min)	16.7 ± 0.6/ 19.3 ± 1.2	17.7 ± 1.2/ 17.3 ± 3.1	17.2 ± 0.98/ 18.3 ± 2.3	17.3 ± 2.1/ 14.7 ± 5.0	16.7 ± 1.5/ 15.3 ± 1.5	17.0 ± 1.7/ 15.0 ± 3.3	0.564/0.180	0.180/0.157	0.888 (0.14)/ 0.066 (1.16)
HR_{Stage1} (bpm)	103 ± 4/ 101 ± 7	101 ± 5/ 96 ± 5	102 ± 4/ 99 ± 6	101 ± 8/ 95 ± 11	97 ± 6/ 92 ± 2	99 ± 7/ 94 ± 8	0.593/0.285	0.655/0.285	0.425 (0.53)/ 0.093 (0.71)
$VO_{2Stage2}$ (ml/kg/min)	21.7 ± 0.6/ 21.3 ± 1.2	21.3 ± 0.6/ 21.7 ± 2.5	21.5 ± 0.5/ 21.5 ± 1.8	21.0 ± 1.7/ 16.3 ± 4.2	21.3 ± 2.3/ 19.0 ± 2.6	21.2 ± 1.8/ 17.7 ± 3.4*	0.655/0.102	1.000/0.109	0.683 (0.23)/ 0.027* (1.40)
HR_{Stage2} (bpm)	115 ± 2/ 112 ± 6	107 ± 4/ 105 ± 2	111 ± 5/ 109 ± 5	109 ± 7/ 103 ± 12	106 ± 5/ 100 ± 5	107 ± 6/ 102 ± 8*	0.285/0.109	1.000/0.109	0.314 (0.72)/ 0.025* (1.05)
$VO_{2last\ stage}$ (ml/kg/min)	24.7 ± 0.6/ 23.3 ± 1.2	26.0 ± 1.0/ 25.7 ± 4.5	25.3 ± 1.0/ 24.5 ± 3.2	25.0 ± 1.7/ 19.0 ± 4.4	26.3 ± 2.5/ 23.0 ± 4.0	25.7 ± 2.1/ 21.0 ± 4.3*	0.584/0.180	0.785/0.102	0.589 (0.24)/ 0.042* (0.92)
$HR_{last\ stage}$ (bpm)	130 ± 5/ 121 ± 4	121 ± 8/ 117 ± 5	125 ± 8/ 119 ± 5	124 ± 8/ 118 ± 6	121 ± 6/ 113 ± 8	122 ± 6/ 115 ± 8	0.593/0.285	1.000/0.414	0.507 (0.90)/ 0.241 (0.99)
$VO_{2max\ extrapolated}$ (ml/kg/min)	45.4 ± 6.8/ 35.2 ± 5.5	55.7 ± 9.2/ 55.2 ± 12.8	50.5 ± 9.0/ 45.2 ± 14.1	48.0 ± 6.4/ 33.2 ± 9.3	54.7 ± 3.0/ 51.7 ± 6.4	51.3 ± 5.8/ 42.5 ± 12.4	0.593/1.000	1.000/0.593	0.847 (0.11)/ 0.517 (0.20)
Tympanic temperature at the end (℃)	36.4 ± 0.3/ 34.4 ± 0.5	36.1 ± 0.9/ 33.6 ± 1.0	36.3 ± 0.6/ 34.0 ± 0.8	36.7 ± 0.5/ 34.3 ± 1.1	36.5 ± 0.6/ 34.8 ± 1.6	36.6 ± 0.5/ 34.6 ± 1.3	0.285/0.593	0.109/0.180	0.058 (0.54)/ 0.345 (0.56)

Note. Mean ± SD (ES). Ctl, control; Cld, cold; ǂ, device lost the measurements (n = -2) because the suspension bar was broken.
*$p \leq 0.05$.

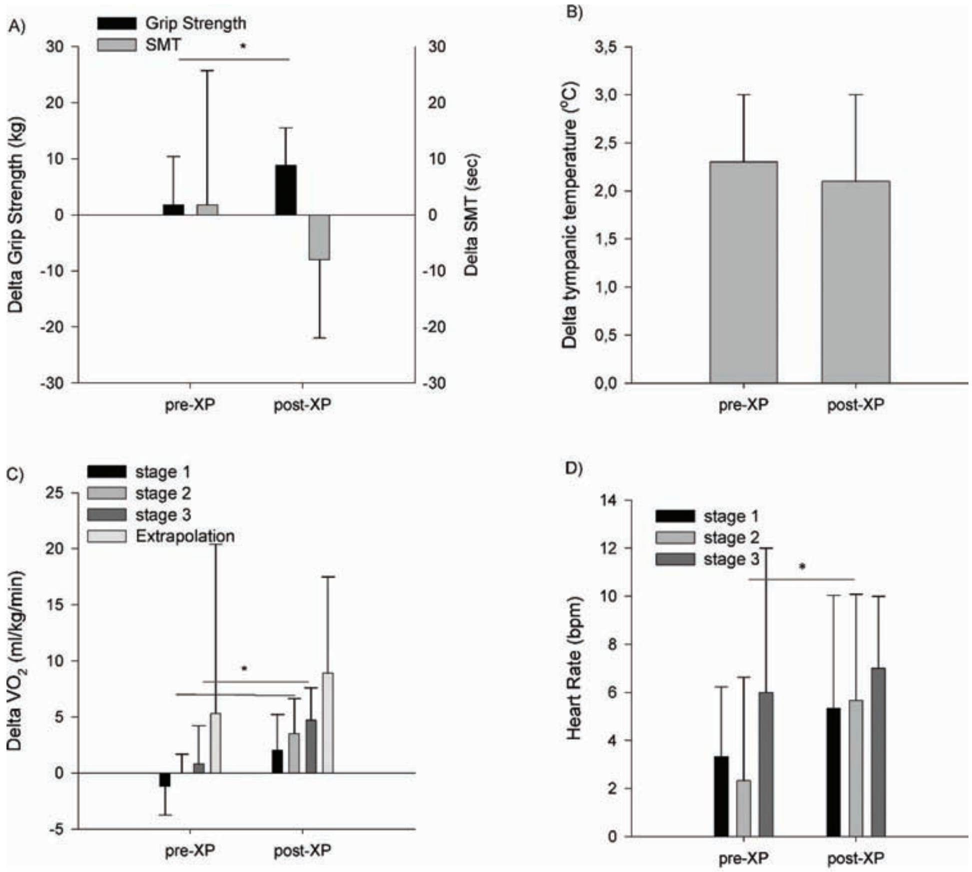

Figure 2. Response to cold. (A) Relationship between Δctl-cold for muscular parameters and time. (B) Relationship between Δctl-cold for tympanic temperature at the end of tests and time (pre-XP, pre-expedition; post-XP, post-expedition). (C) Relationship between Δctl-cold for VO_2 at submaximal exercise parameters and time. (D) Relationship between Δctl-cold for HR at submaximal exercise parameters and time (*$p \leq 0.05$).

but remained in a healthy percent fat range. Previous studies observed decreasing fitness and lean mass where the diet was inadequate; the energy intake was insufficient to compensate for the energy expenditure of the expedition (Stroud, 1998; Stroud, 2001), but the present study observed maintenance of or a gain in lean mass.

Fitness Improvement

Muscle Strength and Endurance

The maintenance, and improvement, of muscular strength and endurance indicated the possibility of maintaining physical capabilities by the absence of deleterious physical effects. Previous studies showed controversial results about muscle endurance and strength after sled pulling in Polar expeditions. Frykman et al. (2003) showed that two explorers reacted inversely, where one improved his strength and the other one decreased, and vice versa for endurance. Stroud (2001) observed a strength loss after the expedition where the author attributed it to a negative energy balance. The present study does not show a significant decline in endurance or strength, surprisingly a significant improvement in the leg press for the left leg, possibly due to using this leg to initiate the first step of sledge-pulling or using this leg as a support when climbing a slope. Furthermore, according to Stocks et al. (2004), high levels of physical endurance work can influence cold resistance. Previous studies reported an improvement in cold tolerance and an elevation of thermoregulatory sensitivity with endurance-trained subjects (Bittel, Nonotte-Varley, Livecchi-Gonnot, Savoury, & Hanniquet, 1988; Kollias, Boileau, & Buskirk, 1972). However, this thermoregulation efficiency can be disturbed by exercise-induced fatigue, sleep deprivation, and food restriction where this can induce a lower cold tolerance due to reduced tissue insulation (fat loss) (Young et al., 1998). The present expedition members seem to be able to gauge the amount of exercise intensity during the progression versus recovery, and the calorie intake to keep their thermoregulation efficient in order to maintain and improve muscular capacity.

Aerobic Capacity

Aerobic capacity assessment showed no impairment to cardiorespiratory fitness after the expedition even if the participants performed high-intensity exercise in a severe cold environment during the expedition. Moreover, the

SMAT showed a significantly increased VO_2peak after the expedition. However, it is also possible that the improvement was mostly due to the lean mass increase. Where, when the VO_2peak is presented in relation to the lean mass, no significant difference was observed pre- vs. post-expedition. However, a large ES was observed for the specific aerobic maximal test pre- vs. post-expedition. Moreover, the VE peak reached at exhaustion was significantly lower after the expedition with the MARS. This measure can indicate an improvement in the cardiorespiratory function due to a similar VO_2peak (not significantly different pre- vs. post-expedition) where the participants needed to ventilate less. This was something that was not observed with the SMAT, probably due to a higher VO_2peak reached. Another useful index for aerobic endurance in sports, like triathlon and cycling, is the VT (Bentley & McNaughton, 2003) and this can distinguish aerobic fitness when expressed in relation to $\%VO_2$max (Loftin & Warren, 1994). The ability to sustain high aerobic intensity exercise during an endurance exercise appears to be related to VT relative to $\%VO_2$peak (Amann et al., 2004; Roels et al., 2005). VT increased significantly for the SMAT showing an improvement in the cardiorespiratory function in addition to the improvement of the VO_2peak reached. Moreover, previous studies suggest physiological changes due to high-volume endurance workloads during a Polar expedition, which transform muscles into type 1, slow-twitch, and it was observed that type 2, fast-twitch muscles degraded (Frykman et al., 2003; Schantz, Henriksson, & Jansson, 1983), showing a reduction in anaerobic capacity, and improvement in aerobic capacity. This change can favor the improvement of the maximal aerobic tests, as observed in the present study. However, previous studies do not corroborate this improvement in the aerobic capacity (Helge et al., 2003; Stroud, 2001), where the VO_2max decreases after the expedition. The previous studies used treadmill running progressive tests where VO_2max was analyzed, but not measured during a progressive specific test. The present study suggests that it is possible to maintain and improve aerobic capacity, but the choice of the test is important and has to be specific in order to observe an improvement as was observed with assessment of athletes (Girard, Chevalier, Leveque, Micallef, & Millet, 2006). Moreover, the higher lean mass can explain a part of this improvement.

Acclimatization to Cold Environments

Submaximal aerobic test

Acclimatization to cold environments seems to show an improvement during the submaximal aerobic test. The improvement can be observed by the metabolic cost (VO_2) during the second and last stage of the test; for the same intensity level the crew needed to consume significantly less energy after the expedition and, even if at the control temperature, no significant difference was observed. Furthermore, the Δctl-cold temperature for the VO_2 at stage 2 was significantly different pre- vs. post-expedition, and a strong ES was observed for the VO_2 at the last stage. Previous studies are somewhat contradictory about the oxygen uptake during submaximal exercise intensity in cold environments. Oksa et al. (2004) observed the VO_2 increasing at cold temperatures compared to ctl temperatures for a different range of intensities during a progressive exercise. This observation was corroborated at a low exercise intensity (Kruk et al., 1990) at cold environmental temperatures between -15℃ and 9℃. However, other studies did not observe a significant difference between the VO_2 at a submaximal exercise intensity for temperatures between 20 and -20℃ (Jacobs et al., 1985; Patton & Vogel, 1984). These last studies corroborate our measurements before the expedition, but not after a prolonged exposure to cold temperatures (post-expedition). Oksa et al. (2004) explain this contradiction by different levels of exercise intensity and a different temperature range. The authors observe that the VO_2 increases significantly in cold environments when the exercise intensity was set at 25% VO_2max for a temperature range of -15℃ vs. 20℃. Furthermore, the VO_2 increased significantly at cold temperatures when an exercise intensity was set at 50% VO_2max for when the temperature range is between 0℃ vs. -15℃, compared to an exercise at 25% VO_2max for the same temperature range. Stocks et al. (2004) go further by suggesting that for a submaximal exercise in cold environments the metabolic cost increases proportionally with the work rate, but inversely with the temperature, i.e., that VO_2 will increase with the intensity level, but will also increase when the temperature decreases (colder environment). The present study did not corroborate this statement where the VO_2 was not significantly different between ctl and the cold environment before the expedition. Furthermore, after the expedition, the VO_2 at stage 2 (around 50% VO_2peak), at stage 3 (around 57% VO_2peak), and the extrapolated VO_2max at cold temperatures for submaximal exercise were lower than the same intensity for the ctl environment. This inverse result can possibly be explained by the clothing, where Oksa et al. (2004) increased the number of Clo and weight from the clothing for colder temperatures. The present study used the same clothing for the ctl and cold temperatures and for pre- vs. post-expedition. Furthermore, no indication was given as an explanation for the time at rest in the cold environment before the submaximal exercise in the previous studies. Moreover, there can be multiple mechanisms causing the contradictory results about oxygen uptake in cold environments. Three hypotheses were proposed by Oska et al. (2004) to explain the lower results in VO_2peak: the amount of circulating blood may be less in cold environments, the possibility of cooling-induced neuromuscular changes where the muscle contraction and/or nerves are slower, and a bronchus constriction induced by the cold environment which decreases the amount of air ventilated and possibly a more severe constriction at colder temperatures. Some hypotheses were proposed for the inverse effect (higher oxygen uptake for cold environments) (Jacobs et al., 1985; Timmons, Araujo, & Thomas, 1985), such as increasing thermoregulatory tonus of the muscles, co-activation altering neuromuscular function, and additional clothing, where in the present study the amount of clothes was the same between controlled and cold environmental temperatures. However, after a long prolonged time at cold temperatures, the ΔCTL-cold VO_2 was significantly lower, possibly due to a cold acclimatization where the neuromuscular and thermoregulation at cold temperatures can be more effective and allow a lower cost energy for the same exercise intensity without being explained by a fitness improvement. However, this hypothesis needs more investigation. It was also possible to observe a significant difference for the HR response for control temperatures and cold environments at submaximal exercise. The HR responses for cold environments during rest and exercise are lower than for control temperatures in previous studies (Oksa et al., 2004; Therminarias, 1992), which corroborate our data. Finally, the cardiorespiratory response after a long exposure to cold temperatures needs more investigation for a better caloric intake estimation in Polar expedition. The food composition is calculated based on energy expenditure during the expedition where the weight of food also plays an important role in the energy expenditure.

Tympanic temperature

Furthermore, the tympanic temperature, ΔCTL-cold, was not significantly different. The tympanic temperature to measure body temperature is generally accepted for an ambient controlled environment, but can be influenced by a cold environment (Livingstone, Grayson, Frim, Allen, & Limmer, 2002). Even if Brinnel and Cabanac (1989) showed that tympanic temperatures taken precisely in the anterior, inferior quarter of the tympanic membrane were unaffected by skin temperature, it still remains that the infrared thermometer can be affected at a temperature lower than 10℃. It is for this reason that, for the present study, the tympanic temperature was mainly used to measure cold acclimatization of the head thermoregulation, mostly because the heads of participants were exposed to cold temperatures without head protection during the tests (hat, helmet, etc.). The tympanic measurement recorded temperature changes in the head, more precisely than the ears and cerebral thermoregulation (Mariak et al., 1994). This non-invasive and easily accessible measure gives an estimation of changes in the internal carotid artery, which supplies the hypothalamus, a brain region where the temperature is regulated (Lim, Byrne, & Lee, 2008), and the cerebrospinal fluid between the perilymphatic spaces in the internal ear that could play a role in heat transfer (Mariak et al., 1994). These indicators provide information on the head thermoregulation acclimatization to cold environments; however, no significant difference was observed pre- vs. post-expedition.

The muscular tests for cold environments seem to maintain and even show a trend to decrease the performance after the expedition. In the present study, the grip strength Δctl-cold pre- vs. post-expedition was significantly higher, where the grip strength value at cold temperatures was not significantly different pre- vs. post-expedition, but with a moderate size effect. This trend corroborates previous studies about decreasing grip strength at cold environments after long-term cold temperature exposure (Cheung, 2015; Heus, Daanen, & Havenith, 1995). However, the grip strength p value reported alone corroborates previous studies that observed no significant differences for the grip strength performance after long-term or repeated exposure to cold temperatures in workers (Cheung, Montie, White, & Behm, 2003). Thus, it was reported in Cheung et al. (2003) that some protection mechanisms can be involved by repeated cold temperature exposures, mostly for hand exposures. Vasoconstrictions and neurotransmitters can be involved in order to protect the core temperature, explaining, in part, the results of the present study. This may explain how only the Δctl-cold pre- vs. post-expedition is significant due to the complexity of factors that can influence blood flow and neurotransmitters in a day (hydration, fatigue, mood, etc.) and can be controlled by use the Δ in the CTL environment. Moreover, no significant difference was observed with the maximal suspension time, where this endurance measurement at cold temperatures seems to be maintained.

Strategies Used and Limitations

The strategies developed from the present research seemed to protect the crew during their expedition in Antarctica. However, it is difficult to attribute a value to the different strategies used due to the absence of a control group. However, with the knowledge of previous studies (Halsey & Stroud, 2012; Stroud, 2001) and the present study, the high-caloric diet seems to be an effective way to preserve the lean mass by keeping an important energy intake in order to support an energetic balance. Furthermore, the physical preparation needs to be sufficient for the crew to bring the necessary amount of food (due to the weight of this food) during a ski-pulling trek in complete autonomous expedition and should use low-weight and effective material for clothes and equipment. The choices about weight and effective equipment have to be considered carefully to prevent deleterious physical impact as was observed in previous expeditions in extreme environments where a lack of preparation can decrease performance and increase risks (Frykman et al. 2003; Halsey & Stroud, 2012;Stroud, 2001).

The present study used newest material technologies to minimize weight from clothing and equipment, and to minimize the energy expenditure from that weigh transportation during an expedition (Teitlebaum & Goldman, 1972). However, they are essential in protection against cold injuries (Geng et al., 2006). The improvement of material technology can help to protect against extreme environment (cold, wind, etc.) at lower weights, inducing lower energy expenditure. A previous study (Teitlebaum & Goldman, 1972) showed that multilayer clothing weighed 11.19 kg for an Arctic expedition. However, the expedition in this current study used multilayer clothing during the Polar progression that was lighter (~6 kg) than in the Teitlebaum and Goldman (1972) study, suggesting a lower energy expenditure due to new technology clothing.

Even if the present study sample is larger than the majority of expedition crews, the physiological variation makes the analysis complicated to interpret with this small sample, where a strong risk of Type 2 error can result. Furthermore, it is difficult to analyze gender influence with this small sample. However, even with the small sample, this study highlights some significant differences in the lean mass changes with gender, showing the importance of continuing research in gender differences in physiological changes in an extreme environment.

Conclusion

Maintenance of lean body mass and muscular fitness appears to help improve specific aerobic capacity in adventurers on an Antarctic expedition. Furthermore, acclimatization to cold seems to show a lower energy demand during submaximal exercises. The maintenance and even improvement of physical fitness may be explained by strategies that include modern material technology, high caloric intake, and physical preparation. These countermeasures may be crucial in preventing lean body mass loss and physical ability decay in an extreme cold environment. However, further research needs to be done to know the importance of the different strategies.

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