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Daily energy balance and eating behaviour during a 14-day cold weather expedition in Greenland

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Novelty bullets: points that summarize the key findings in the work:	Energy intake increases during the second half of a 14-day expedition in the cold realized by French soldiers, Energy compensation was likely facilitated by providing participants with easy-to-eat palatable and familiar foods in excess., Hunger scores and explicit liking for energy-dense foods were associated with high energy intakes and low body mass changes.
Keyword:	energy intake, energy expenditure, arctic, raid, explicit liking, food preferences, FPQ-S16, military, rations
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1 **Daily energy balance and eating behaviour during a 14-day cold weather expedition in**
2 **Greenland**

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21 **Abstract**

22 We assessed energy compensation, appetite and reward value of foods during a 14-day
23 military expedition in Greenland realized by 12 male French soldiers during which energy
24 compensation was optimized by providing them with easy-to-eat palatable foods in excess.
25 Although daily energy expenditure (estimated by accelerometry) stayed relatively constant
26 throughout the expedition (15 ± 9 MJ.d⁻¹), energy intake (EI estimated by self-reported
27 diaries) was 17% higher during the D8-D14 than D1-D7 period, leading to a neutral energy
28 balance (EB). Body fat mass (BFM) significantly decreased (-1.0 ± 0.7 kg, $p < 0.001$) but not
29 body mass (BM). Neither hunger scores (assessed by visual analog scales), nor components
30 of the reward value of food (explicit liking [EL] and food preference) were significantly altered.
31 However, changes in EL at D10 positively correlated with changes in BM ($r = 0.600$, $p < 0.05$)
32 and BFM ($r = 0.680$, $p < 0.05$) and changes in hunger with the EI of the relevant period
33 ($r = 0.743$, $p < 0.01$ for D1-D7, $r = 0.652$, $p < 0.05$ for D8-14). This study shows that the negative
34 EB and BM loss can be attenuated by an appropriate food supply and that subjective
35 components of eating behaviour, such as hunger and EL, may be useful to predict the
36 magnitude of energy compensation.

37

38

39 **Keywords:** energy intake, energy expenditure, arctic, raid, explicit liking, food preferences,
40 FPQ-S₁₆, military, rations

41 **Résumé**

42 La compensation énergétique, l'appétit et la valeur de récompense de la nourriture ont été
43 évalués pendant une expédition militaire de 14 jours au Groenland réalisée par 12 soldats
44 français. Bien que la dépense énergétique était relativement stable pendant l'expédition
45 ($15 \pm 9 \text{ MJ} \cdot \text{j}^{-1}$), la prise énergétique (PE) était plus élevée de 17% pendant la période J8-J14
46 que la période J1-J7, conduisant à une balance énergétique (BE) neutre. La masse grasse
47 (MG) a significativement diminué ($-1.0 \pm 0.7 \text{ kg}$, $p < 0.001$) mais pas la masse corporelle (MC).
48 Ni les scores de faim (évalués par échelles analogiques visuelles), ni les composantes de
49 la valeur de récompense de la nourriture (explicit liking [EL] et préférence alimentaire) étaient
50 significativement modifiés. Cependant, des modifications d'EL à J10 étaient positivement
51 corrélés avec des modifications de MC ($r = 0.600$, $p < 0.05$) et de MGC ($r = 0.680$, $p < 0.05$) et
52 des modifications de scores de faim avec la PE de la période correspondante ($r = 0.743$,
53 $p < 0.01$ pour J1-J7, $r = 0.652$, $p < 0.05$ pour J8-J14). Cette étude montre que la BE négative et
54 la perte de MC peuvent être atténuées par l'approvisionnement de nourriture adaptée et que
55 les composantes subjectives du comportement alimentaire, telles que les scores de faim et
56 l'EL, peuvent être utiles pour prédire l'amplitude de la compensation énergétique.

57

58

59 **Mots-clef:** prise énergétique, dépense énergétique, arctique, raid, explicit liking, préférences
60 alimentaires, FPQ-S₁₆, militaires, rations

61 **Introduction**

62 Training or expeditions in cold environments (from 3 to 33 days) are generally associated
63 with decreased body mass (BM) (Campbell 1981, Morgan et al. 1988, Edwards and Roberts
64 1991, Edwards et al. 1992, Jones et al. 1993, King et al. 1993, Hoyt et al. 2001, Johnson et
65 al. 2017, Karl et al. 2017, Beals et al. 2019). This is mostly due to the loss of body fat mass
66 (BFM) (Kyrolainen et al. 2008, Tassone and Baker 2017), despite the availability of excess
67 food. Thus, the increase in energy expenditure (EE) is not adequately compensated by
68 energy intake (EI) (Johnson et al. 2017, Beals et al. 2019). This inability to maintain energy
69 balance (EB) is likely to alter physical (Murphy et al. 2018, Church et al. 2019) and cognitive
70 performance (Cherif et al. 2016), and also mood (Karl et al. 2015), potentially jeopardizing
71 the success of the mission/expedition (Organization. 2010, Day et al. 2012). Even the
72 incorporation of supplemental food packs only partially improves the energy deficit (Edwards
73 and Roberts 1991, Margolis et al. 2016, Karl et al. 2017). Thus, certain mechanisms to match
74 EI and EE do not operate when performing a high level of physical activity (PA) in cold
75 weather. The contribution of cold to this phenomenon is unclear. Observational studies
76 conducted in athletes and soldiers, both populations that face frequent and regular periods of
77 high levels of PA-induced EE, show that the EB is regularly negative, even at neutral
78 temperatures (Loucks 2004, Tharion et al. 2005, Richmond et al. 2014, McAdam et al. 2018).
79 This suggests that above a certain threshold of PA, spontaneous EI fails to match EE. Over
80 time, decreased EE due to BM loss and a spontaneous increase in EI reduces the magnitude
81 of this negative EB. Indeed, modeling of energy compensation during exercise (Riou et al.
82 2015) shows that EI may progressively increase over the first weeks and eventually reach a
83 plateau.

84 In the short-term, cold has been shown to be an orexigenic environmental strain (White et al.
85 2005, Wasse et al. 2013, Crabtree and Blannin 2015, Charlot et al. 2017, Mandic et al.
86 2019). Therefore, the negative EB is expected to be less in cold than hot weather. Indeed,
87 Johnson and colleagues (Johnson et al. 2017) reported 36% greater EI during a 4 to 5-day

88 Special Operations Forces field training exercise in cold as compared to hot and warm
89 weather, although EE ($\sim 4,500 \text{ kcal}\cdot\text{d}^{-1}$) and the amount of available food were similar for both
90 conditions. However, these studies only reported mean EI and EE and not their day-to-day
91 variation. Furthermore, the modalities of such a negative EB were not assessed, notably
92 important features of eating behaviour, such as appetite and hedonic factors, the latter often
93 being associated with the reward value of foods. They may provide useful information, as
94 they are strongly involved in the physiology of energy homeostasis (Chapelot and Charlot
95 2019) and may partially explain why humans fail to increase EI and maintain EB in a
96 sustained cold environment. A classic model is that proposed by Kent Berridge and based on
97 the wanting and liking paradigm (Berridge 1996). Explicit liking (EL), implicit wanting (IW),
98 and food preferences (FP) have even been proposed to discriminate between individuals
99 who compensate for the increase in EE and those who do not (Finlayson et al. 2009,
100 Finlayson et al. 2011, Buckland et al. 2019).

101 The aim of this study was to investigate the various dimensions of eating behaviour of this
102 *“loose coupling of daily EE and EI”* (Drenowatz 2015) during a 14-day cold weather
103 expedition in Greenland performed by French soldiers. We assessed daily EI, EE, appetite,
104 and the reward value of food. Based on the available scientific evidence, we hypothesized
105 that 1) EI would progressively increase to reach EB by the end of the expedition, 2) appetite
106 and reward levels would be consistently associated with this increase in EI, and 3) increased
107 appetite and reward levels would be higher in individuals who were the less inclined to lose
108 BM.

109 **Methods**

110 *Design*

111 French soldiers planned this expedition in Greenland as part of an extreme cold inoculation
112 program. They travelled from the north of Liverpool Land in Greenland to the city of
113 Ittoqqortoormiit in the south. The journey lasted two weeks. They skied most of the time but
114 sometimes had to walk with snowshoes. They brought food for 21 days that they towed with
115 a pulka, along with all their materials. In a paper notebook, they were requested to 1)
116 evaluate their appetite in the morning before breakfast and in the evening before dinner, 2)
117 report all food and beverages consumed during the day, and 3) assess the reward value of
118 foods just before dinner on the day prior to the expedition (D0) and the first (D1) and tenth
119 days (D10) of the expedition. Each participant wore a wrist actigraph to estimate EE. Finally,
120 BM and body composition were measured before breakfast on the morning before D0 (D-1)
121 and the day following their arrival (D15).

122 *Participants*

123 The participants were 12 young males specialized in mountain environment activities (skiing,
124 climbing, and snowshoeing) and extreme conditions (cold and altitude). They were briefed
125 several months before leaving France and were informed of the benefits and risks of the
126 investigation prior to giving their written consent, in accordance with the Declaration of
127 Helsinki. This study was performed at the request of the Armée de Terre and approved by
128 the scientific leadership of the French Armed Forces Biomedical Research Institute. All
129 participants were screened by military physicians and required to be healthy. Maximal
130 oxygen uptake (VO_{2max}) was estimated using their last Cooper 12-min run test performance
131 (Cooper 1968) based on correlation coefficients between 0.897 and 0.920 (Cooper 1968,
132 Grant et al. 1995). Their individual and mean main characteristics are shown in Table 1.

133 *Measurements*

134 Body mass and composition

135 On the morning before leaving for Greenland (D0), the participants had their BM and body
136 composition assessed at a hotel in Reykjavik (Iceland). The measurements were performed
137 before breakfast, with an empty bladder. Their BM was measured to the nearest 0.1 kg using
138 a calibrated scale (Seca 877, Hambourg, Germany), with participants wearing only their
139 underwear. Absolute and relative BFM were estimated using skinfold thickness values
140 according to the Durnin & Womersley method and standard equations (Durnin and
141 Womersley 1974). In brief, skinfolds were measured on the right side of the body using a
142 Harpenden skinfold caliper (British Indicators, West Sussex, UK) to the nearest millimeter in
143 triplicate at the four recommended sites: biceps, triceps, and the subscapular, and suprailiac
144 regions. All measurements were performed by the same investigator, under the same
145 conditions, and at the same location, on the day following the end of the expedition to
146 improve reproducibility.

147 Energy intake

148 Before the expedition, each participant packed 21 bags, each containing all the food
149 products necessary for their daily intake. The composition of the diet was similar in energy
150 content and food items for all bags. It was primarily based on the participants' eating habits
151 during prior similar expeditions and consisted of lyophilized muesli and cakes for breakfast;
152 energy bars, chocolate bars, jerky meat, soup, dried cheese, flat bread, candies, and cakes
153 for the day while moving; and lyophilized dishes and dessert for dinner. Each bag provided
154 approximately 19 MJ (4,500 kcal) and participants were allowed to bring a supplementary
155 bag containing ready-to-eat foods (essentially bars) and to consume some or all of it if they
156 felt hungry or the need to. At the end of each day, prior to sleep, they had to complete a form
157 on which they accurately reported which foods they had consumed from the daily and
158 supplementary bags. The daily energy and macronutrient intakes of each participant were
159 then calculated using the nutritional composition of the foods provided by the manufacturers.

160 Energy expenditure

161 Participants were outfitted with a wrist-worn tri-axial actigraph (MotionWatch 8, CamNTEch,
162 Papworth Everard, UK) on the non-dominant arm to assess daily EE. This technology has
163 been found to be reliable for assessing EE during activities under 6 METs (Sirichana et al.
164 2017) and showed good reliability in assessing physical activity, albeit this was assessed in
165 older adults only (Landry et al. 2015, Chakravarthy and Resnick 2017). The highest intensity
166 during the expedition was estimated to be approximately 6 METs. This specific device is
167 designed to record accelerations ranging in magnitude from 0.01G to 8G with a frequency of
168 3-11Hz. It is equipped with a filter that removes artifacts from movements with frequencies
169 higher than the typical range of human movements (vibration or tremor). Data were recorded
170 using 60-s epochs, as recommended (Ward et al. 2005). The time spent in each class of
171 physical activities was determined using the device software (MotionWare 1.0.27,
172 CamNTEch, Papworth Everard, UK): sedentary activities (< 1.5 MET), light activities
173 (between 1.5 and 3.0 METs), moderate activities (between 3.0 and 4.5 METs), and vigorous
174 activities (> 4.5 METs). After calculating the resting metabolic rate (RMR; i.e. 1 MET) using
175 the Mifflin-St Jeor equation (Mifflin et al. 1990), the daily EE was then estimated using the
176 following formula

$$177 \text{ EE (MJ.d}^{-1}\text{)} = \text{RMR.t}_{\text{SED}} + 2.25 \times \text{RMR.t}_{\text{LIGHT}} + 3.75 \times \text{RMR.t}_{\text{MOD}} + 5 \times \text{RMR.t}_{\text{VIG}}$$

178 Where t is the time in seconds associated with 1, 2.25, 3.75, and 5 METs for sedentary
179 (SED), light (LIGHT), moderate (MOD), and vigorous (VIG) activities, respectively.

180 Energy balance was then calculated by subtracting EE from EI.

181 Appetite

182 Appetite was assessed by rating hunger on visual analog scales (VAS). The participant had
183 to draw a vertical dash on a horizontal 10-cm scale preceded by the question: "How hungry
184 do you feel?" and anchored at the left and right ends by "not at all" and "extremely",

185 respectively. The distance from the extreme left to the participant's vertical dash represented
186 the rating score, expressed in cm. Participants were asked to rate these VAS over the last
187 two weeks prior to the expedition and familiarize themselves with the material and the
188 appetite scales.

189 Reward value of food

190 Several years ago, Finlayson et al. (Finlayson et al. 2007, Finlayson et al. 2008) developed
191 the Leeds Food Preference Questionnaire (LFPQ). This questionnaire measures several
192 components of food reward, *i.e.*, EL, IW, and FP (Dalton and Finlayson 2014). We recently
193 validated a shorter version of this questionnaire, called the Food Preference Questionnaire
194 (FPQ-S₁₆), using 16 food items and adapted to the French context (Charlot et al. 2018). This
195 version was found to be reliable, with correlation coefficients between 0.83 and 0.88, and
196 less time-consuming, but only assesses EL and FP by choice-reaction time. Given the
197 difficulties of using a computer during the expedition, such as the weight of the equipment
198 and the very low temperatures, the FPQ-S₁₆ was adapted to paper. Briefly, the questionnaire
199 is composed of 16 pictures of food items categorized according to their fat content (high-fat
200 [HF] or low-fat [LF]) and taste (sweet [SW] or savory [SA]). This results in four specific food
201 categories (HF, LF, SW, and SA) with eight food items in each, and four combined
202 categories (HFSW, HFSA, LFSW, and LFSA) with four food items in each. First, to assess
203 EL, participants had to answer the question "How pleasant would it be to taste some of this
204 food now?" for each food on a VAS. Then, to assess FP, the 16 food items were presented
205 on the same page in a randomized order. Participants were asked to rank these items in four
206 groups, ranging from the one that contained the four food items that they "wanted to eat the
207 most now" (++), to the one that contained the four food items that they "wanted to eat the
208 least now" (--). The number of food items from a specific (HF, LF, SW, or SA) or combined
209 (HFSW, HFSA, LFSW, or LFSA) category was multiplied by the group coefficient (3 for ++, 2
210 for +, 1 for -, and 0 for --) and then the scores from each group added. The score ranges for
211 the specific (8 food items) and combined (4 food items) categories are therefore 4 to 20 and

212 0 to 12, respectively. Absolute scores were used to assess EL and bias scores were
213 calculated for FP by subtracting a score from each category with its opposite one (e.g., HF vs
214 LF or HFSA vs LFSA). Thus, a positive or negative score indicates a preference for one
215 category over the other. This procedure was conducted in a hungry state prior to dinner, just
216 before the beginning of the expedition (D0), just after (D1), and 10 days later (D10). As the
217 expedition was expected to last 21 days, we planned the FPQ-S₁₆ at the midpoint (D10) and
218 end of the expedition (D20). However, it was shortened to 14 days (see part 3.1.) and the
219 D20 measurement was not performed.

220 *Statistical analyses*

221 Given the highly variable conditions of such expeditions, e.g., weather and distance travelled
222 per day (see part 3.1 for details), we divided the temporal analysis into two periods: D1-7 and
223 D8-14. Indeed, comparing day-to-day differences would have required highly conservative
224 corrections for multiple comparisons and would have been subjected to artifacts due to
225 certain single-day events. After ensuring that the data were normally distributed using a
226 Shapiro-Wilk test, Student's *t*-tests were used for all outcomes, except EL and FP. EL and
227 FP were compared using a single mixed-model repeated-measures 3x1 ANOVA with day
228 (D0, D1, and D10) as the within-subject factor. Correlations between variables were tested
229 using Pearson correlation coefficients. Data are presented as the means \pm SD. Significance
230 was defined as $p < 0.05$. Analyses were performed using STATISTICA software (v10,
231 Statsoft, Tulsa, OK, USA).

232 **Results**

233 *Details of the expedition*

234 Meteorological conditions faced between D2 and D4 caused a modification of the initially
235 planned route. Indeed, a windstorm (maximal wind speed recorded 180 km.h⁻¹) prevented
236 the participants from leaving their tents on D3 and D4 and caused major material damage
237 (mostly tent tears). The need to make repairs forced the soldiers to modify their itinerary and
238 to reach a shelter. The remainder of the expedition was therefore shortened by the
239 expedition chief. The details of the route are shown in Figure 1. They remained in the same
240 locations for a total of five days (D3 and D4: facing the windstorm, D6: repairing the
241 equipment, D10: climbing near the base, and D14: waiting for jet skis to reach airport).
242 They travelled 123 km (56 and 67 km in the first and second halves of the expedition,
243 respectively) for a mean daily distance of 8.79 km with +312 m and -318 m. The weather
244 became less windy and colder as the expedition progressed. Mean temperatures (relative
245 humidity) were -8.7°C (77.5%) during the first half and -13.4°C (68.6%) during the second
246 half of the expedition, with mean wind speeds of 32.7 and 14.7 km.h⁻¹, respectively.

247 *Energy intake and expenditure*

248 Individual and mean EI, EE, and EB are shown in Figure 2. Time spent for sedentary, light,
249 moderate, and vigorous activities were 888 ± 37, 176 ± 31, 111 ± 14, and 265 ± 38 min.d⁻¹,
250 respectively. There was a statistically significant period effect for EI ($p = 0.007$) and EB ($p =$
251 0.014). EI was ~17% higher for D8-14 than D1-7 (12.6 ± 2.1 vs 14.7 ± 3.4 MJ.d⁻¹).
252 Consequently, the EB was higher for D8-14 than D1-7 (-0.4 ± 3.6 MJ.d⁻¹ vs -2.3 ± 2.4 MJ.d⁻¹;
253 $p = 0.014$). The difference between EI and EE was only significant in the first half of the
254 expedition (D1-7; $p = 0.007$), indicating that the participants were in negative EB during this
255 period and in neutral EB during the second one.

256 Absolute and relative macronutrient intake is shown in Table 2. We observed a period effect
257 for all absolute macronutrients ($p = 0.005$, 0.017 , and 0.003 for CHO, fat, and protein,
258 respectively), which was ~15, 14, and 16% higher, respectively, for D8-14 than D1-7.

259 *Body mass and composition*

260 Individual and mean changes in BM and body composition between the beginning and end of
261 the expedition are shown in Figures 3A and 3B. Body mass was 76.1 ± 6.8 before and $75.0 \pm$
262 6.3 kg after the expedition, the difference (-1.1 ± 1.8 kg, $-1.3 \pm 2.2\%$) failing to reach
263 statistical significance ($p = 0.091$). BFM and body fat-free mass (BFFM) were 15.8 ± 2.4 and
264 60.3 ± 6.0 kg, respectively, before the expedition and 14.8 ± 2.6 and 60.2 ± 5.8 kg,
265 respectively, after the expedition. The change in BFM was significant (-1.0 ± 0.7 kg, $-6.4 \pm$
266 4.7% , $p < 0.001$) but not the change in BFFM (-0.1 ± 1.5 kg, $-0.1 \pm 2.4\%$).

267 Individual changes in BM and EB are presented in Figure 3C, showing that there was a wide
268 variation and a continuum of responses to the expedition-induced increase in EE. These two
269 variables positively correlated with each other ($r = 0.702$, $p = 0.011$), indicating that the larger
270 the energy deficit, the larger the loss of BM.

271 *Appetite*

272 ANOVA revealed no time effect for the morning and evening measurements of the hunger
273 scores (Figure 4).

274 *Explicit liking and food preference*

275 The absolute scores (EL) for each specific and combined category and bias scores (FP)
276 between specific and combined categories are shown in Table 3. ANOVA revealed no effect
277 of the day for EL or FP, suggesting that the expedition did not alter the mean reward value of
278 food.

279 *Correlations*

280 Meaningful correlations between all the variables measured in this study are shown in Table
281 4. First, changes in BM (in %) were positively associated with EI, EB, absolute fat and protein
282 intake, and relative fat intake, and negatively associated with relative CHO intake. Then, they
283 were also positively associated with the EL score of the HFSW food items, but only at D10.
284 Second, changes in BFM (in %) were positively associated with the EL scores of HF foods at
285 D1 and D10, but not D0. Finally, the mean total EI was positively associated with mean total
286 hunger scores; this correlation was also significant between these variables during both
287 halves of the expedition *i.e.*, EI with hunger on D1-7 and EI with hunger on D8-14.

Draft

288 Discussion

289 One of the main differences between this expedition and others featuring in studies
290 assessing EB was the mean EE level. In our expedition, participants expended 14.9 MJ.d⁻¹,
291 whereas a mean of 20 MJ.d⁻¹ has been generally reported (range = 16.5 to 25.8 MJ.d⁻¹)
292 (Morgan et al. 1988, Edwards and Roberts 1991, Edwards et al. 1992, Jones et al. 1993,
293 King et al. 1993, Margolis et al. 2016). This is likely the result of differences in activities and
294 their duration, objectives, and environment. The variety of activities was wider in the other
295 expeditions than this one, notably including highly demanding specific military tasks. For
296 example, some programs required “establishing a defensive position, constructing defensive
297 obstacles, and erecting camouflage tents” (Edwards et al. 1992), survival tasks (“compass
298 training, ice fishing, and hunting” (Jones et al. 1993), “avalanche avoidance and rescue and
299 night land navigation” (Morgan et al. 1988)), or sports activities (6 km ski race and 10-km
300 biathlon (Morgan et al. 1988)). Moreover, the duration of these activities was longer (5-13
301 h.d⁻¹ (Jones et al. 1993) vs ~ 5 h.d⁻¹ in the present study), with shorter sleep periods (4–6 h.d⁻¹
302 (Edwards and Roberts 1991, Edwards et al. 1992) vs 7-8 h.d⁻¹ in the present study). When
303 the activities were similar (only skiing), the objective was higher (51 km in 4 days (Margolis et
304 al. 2016) vs 123 km in 14 days in the present study). Finally, although environmental
305 temperatures in the present study (between -19 and -6 °C) were in the usual reported range
306 (between -48 and +12 °C) (Morgan et al. 1988, Edwards and Roberts 1991, Edwards et al.
307 1992, Jones et al. 1993, King et al. 1993), they were not among the harshest.

308 Despite a relatively low EE, mean EI (13.6 MJ.d⁻¹) was in the upper range of similar studies
309 (mean = 12.2 MJ.d⁻¹; range = 8.3 to 14.8 MJ.d⁻¹) (Morgan et al. 1988, Edwards and Roberts
310 1991, Edwards et al. 1992, Jones et al. 1993, King et al. 1993, Margolis et al. 2016). King *et*
311 *al.* (King et al. 1992) stated that the total energy content of the provided rations, their
312 palatability and acceptability, their ease of preparation, and their diversity may influence EI in
313 the context of extreme cold. In the present study, the energy value of the rations (~19 MJ)
314 largely exceeded EE. The selected foods were a mix of lyophilized rations and personal

315 items that participants had previously consumed and appreciated, although acceptability was
316 not specifically assessed. Moreover, apart from the lyophilized items that had to be
317 rehydrated, foods were consumable in their natural form. Finally, a supplementary bag of
318 easy-to-eat and highly palatable food items was always available for extra food consumption.
319 Thus, the conditions favored optimal energy compensation. Although a large negative EB
320 (mean = $-8.3 \text{ MJ}\cdot\text{d}^{-1}$; range = -15.0 to $-4.1 \text{ MJ}\cdot\text{d}^{-1}$) (Morgan et al. 1988, Edwards and Roberts
321 1991, Edwards et al. 1992, Jones et al. 1993, King et al. 1993, Margolis et al. 2016) and BM
322 loss (mean = $-0.25 \text{ kg}\cdot\text{d}^{-1}$; range = -0.06 to $0.72 \text{ kg}\cdot\text{d}^{-1}$) (Campbell 1981, Morgan et al. 1988,
323 Edwards and Roberts 1991, Edwards et al. 1992, Jones et al. 1993, King et al. 1993, Hoyt et
324 al. 2001, Johnson et al. 2017, Karl et al. 2017, Beals et al. 2019) seems unavoidable during
325 such an expedition in the cold, the EB was only negative for the first period ($-2.3 \pm 2.4 \text{ MJ}\cdot\text{d}^{-1}$)
326 and the slight decrease in BM ($0.07 \text{ kg}\cdot\text{d}^{-1}$) was not significant.

327 Long-term sustained high levels of EE are known to lead to equilibrium with EI, resulting in
328 the maintenance of a neutral EB and therefore a stable BM (Mayer et al. 1956, Beaulieu et
329 al. 2018). However, the time required to reach this equilibrium is less documented. Whybrow
330 *et al.* (Whybrow et al. 2008) reported no modification of EI in lean men during a 14-day daily
331 training program eliciting an EE of 2 or 4 $\text{MJ}\cdot\text{d}^{-1}$. Riou et al (Riou et al. 2015) used statistical
332 models and observed an increase in the degree of energy compensation during the first 20
333 weeks of a training program. However, the first four weeks were not considered in the
334 models. The kinetics of EI during expeditions (more than 20 days) in mildly cold to hot
335 environments have shown discrepant results, with no modification (Edwards et al. 1992,
336 Booth et al. 2003) or a slight increase of $\sim 1.0 \text{ MJ}\cdot\text{d}^{-1}$ (Campbell 1981, DeLany et al. 1989)
337 after the first two weeks. Given these scarce results, it is difficult to draw unequivocal
338 conclusions. It must be noted that the aforementioned studies were not designed to assess
339 modifications of EI throughout the period of measurements. Nevertheless, these results
340 suggest that energy compensation may require 14 days to be observable. Our results
341 suggest that such compensation may occur more rapidly (from the second week) in a cold

342 environment and may be larger ($+2.1 \pm 2.2 \text{ MJ}\cdot\text{d}^{-1}$). It could be argued that once the storm
343 was over (after D6), the soldiers would have been able to eat more comfortably, which could
344 partially explain the increase in EI in the second period. Further studies are needed to
345 confirm the kinetics of such compensatory behaviour, *i.e.* when compensation occurs and
346 when it reaches a plateau.

347 Assessments of EI and EE during training or expeditions in the cold are most often
348 performed to calculate the mean EB and subsequent changes in BM and body composition
349 (Tassone and Baker 2017). This concern resonates well with the armed forces. Indeed,
350 sustained energy deficit has been shown to lead to decreased physical and cognitive
351 performance, increasing individual and collective risks and therefore jeopardizing the
352 success of an operative mission (Murphy et al. 2018, Church et al. 2019). One objective has
353 sometimes been to assess the efficiency of alternative meals (Morgan et al. 1988, Edwards
354 and Roberts 1991, Edwards et al. 1992, King et al. 1993) or supplemental foods (Edwards
355 and Roberts 1991, Margolis et al. 2016) to improve energy compensation and reach a more
356 neutral EB. However, attempts to better understand the “*loose coupling of daily EE and EI*”
357 (Drenowatz 2015) in identifying the kinetics of various components of eating behaviour are
358 missing. Therefore, we included tools that allowed us to assess two of the most determinant
359 components of eating behaviour, *i.e.* appetite and preferences. Subjective ratings of appetite
360 (the morning or evening prior to meals) were not altered, suggesting either that EI was
361 adequate or that the use of endogenous energy from body stores inhibited the motivation to
362 eat (Chapelot and Charlot 2019). In comparison, hunger scores increased during a four-day
363 arctic military training mission (Margolis et al. 2016). However, the energy deficit was much
364 larger in this study than in ours (-13.9 vs $-1.4 \text{ MJ}\cdot\text{d}^{-1}$), suggesting that the magnitude of
365 appetite-inhibiting endogenous energy may be limited.

366 Analyses of the correlations in our study favour a putative role of the reward value of foods
367 and the validity of the paper-version of the FPQ-S₁₆, as they revealed several positive
368 interindividual relationships between this hedonic component and objective parameters. First,

369 changes in appetite positively correlated with EI, showing that, overall, among the
370 participants, the higher their hunger scores, the greater the increase in their EI. The fact that
371 these correlations were only significant within the same period (D1-7, D8-14 or D1-14)
372 suggests the validity of this coupling between subjective and objective outcomes of appetite.
373 It must be noted that two recent reviews (Sadoul et al. 2014, Holt et al. 2017) reported that
374 the ability of pre-meal hunger scores to predict EI is uneven. Our results suggest that this
375 relationship may improve if mean hunger scores recorded over several days are used. In
376 addition, EL for foods with high energy density (HFSW and HF) positively correlated with
377 changes in BM and BFM. In other words, individuals who attributed a high reward value to
378 HF foods during the expedition were less likely to lose BM or BFM. It was previously
379 observed that individuals who compensated for the energy expended during a single
380 exercise or those who minimally responded to a 12-week training program (*i.e.* small
381 modifications in body composition) showed a higher preference for HFSW foods than non-
382 compensators (Finlayson et al. 2009) and responders (Finlayson et al. 2011), respectively.
383 Overall, these results suggest that participants who display an "orexigen" profile (increase in
384 appetite, increase in EL for HF foods) during an expedition in the cold may be more inclined
385 to compensate for high levels of EE and maintain their BM and body composition. Such
386 compensation may however have an upper threshold, as authors recently concluded from a
387 compilation of data that the "alimentary limit" (*i.e.* maximal EI) was reached for 2.5 fold the
388 basal metabolic rate (Thurber et al. 2019).

389 Any experiment under harsh environmental conditions is vulnerable to unexpected
390 contingencies. In this expedition, participants were confronted with a storm on days 3 and 4
391 that altered the planned route. The main consequence was the impossibility to maintain a
392 constant volume of physical activity over the 14 days of measurements. Another possible
393 consequence was an alteration in food intake. It can be argued that participants voluntarily
394 reduced their intake during the windstorm to spare food. However, they were informed about
395 the storm on day 2 by a weather specialist based in France and knew that it would only last

396 two days. This is therefore unlikely and, indeed, was not reported by participants after the
397 expedition. The quality of self-reporting or EI itself may theoretically be modified by such
398 adverse events. We were unable to evaluate their impact on our results. However, these
399 men were mentally prepared to face the consequences of extreme conditions, such as
400 spending two days in the tents because of the bad weather, repairing material after the
401 storm, or having to change their route. After the expedition, the participants assured us that
402 they did not neglect the completion of their food diaries. Compromises were made to select
403 the most accurate tools that participants agree to use under self-sufficiency conditions and in
404 extreme cold, without jeopardizing the mission. Thus, EE might have been assessed with
405 more accurate methods (e.g. the double labeled water technique (Margolis et al. 2016,
406 Johnson et al. 2017) or individual HR-VO₂ regression (Beals et al. 2019)) and FPQ-S₁₆ might
407 have been preferentially completed on tablets, as under laboratory conditions, than on paper.
408 Furthermore, it was not possible to infer IW from our data, as no time-reaction could be
409 measured in the FPQ-S₁₆ and thus this relationship is yet to be established. **Then, we**
410 **acknowledge that the observations presented in the present study concern a specific sample**
411 **of participants. They were considered to have the fitness level of highly trained/elite athletes**
412 **based on their usual volume of physical activity and estimated VO₂max. In addition, their**
413 **relatively high levels of BFM relative to their high fitness level suggest that they may have**
414 **adopted a high-calorie diet during the weeks/months prior to the expedition to increase their**
415 **energy stores. Body composition assessments well before the expedition to verify this**
416 **hypothesis are not available. Nonetheless, it is certain that the results obtained with this**
417 **sample are not generalizable to a broader group.** Another limitation is that we did not assess
418 thirst, fluid intake, or hydration status. This is a concern, since an influence of dehydration on
419 various dimensions of eating behaviour has been reported (Engell 1988, Mattes 2010).
420 Moreover, dehydration may alter the accuracy of BFM estimation. The effect of dehydration
421 has led to discrepant results in previous studies, which showed a small increase (Araujo et
422 al. 2018) or decrease (Rodriguez-Sanchez and Galloway 2015) in BFM values. Thus,
423 although some studies conducted under similar conditions suggest that fluid intake is in

424 accordance with need (Edwards et al. 1992, King et al. 1993), it is possible that our results
425 may have been somewhat influenced by a certain state of dehydration. Nonetheless, for the
426 first time, several markers of eating behaviour were accurately recorded and further explored
427 how trained individuals adapt to a prolonged period of high EE, coupled with a continuous
428 extreme cold exposure and an abundance of palatable food items at their disposal.

429 **Conclusion**

430 We observed an increase in EI after seven days during a 14-day expedition performed by
431 French soldiers, in agreement with the first hypothesis and suggesting that when eating
432 conditions are optimized with the appropriate amount, quality, and conditioning of foods, total
433 energy compensation may occur more rapidly than that generally described. Eating
434 behaviour components, such as hunger and the reward value of foods, were assessed for
435 the first time, and although they did not change during the expedition, in contradiction to our
436 second hypothesis, correlations show a certain amount of coupling between hunger and EI
437 and between EL for HF foods and body changes. Finally, as stated by the third hypothesis,
438 some of these elite individuals will respond more adequately than others to the energy
439 homeostasis challenge and this difference is detectable by hunger and hedonic factors.

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619 **Table 1. Individual and mean participant characteristics (Means \pm SD)**

# participant	Age (y)	Height (cm)	Body mass (kg)	Body fat mass (% of body mass)	Estimated VO_{2max} (ml.min ⁻¹ .kg ⁻¹)	Physical activity volume (h.w ⁻¹)
1	30	173	77.0	23.0	60	3
2	29	183	78.1	13.9	60	3
3	24	177	86.5	22.6	60	7
4	26	173	78.0	20.9	64	7
5	29	180	81.5	18.6	61	10
6	35	177	72.0	25.1	59	15
7	32	178	74.8	20.9	58	10
8	30	173	73.4	21.6	62	10
9	32	181	78.3	19.9	58	30
10	31	186	83.5	20.7	58	10
11	45	173	69.0	20.5	61	20
12	33	163	60.9	21.1	75	13
Mean \pm SD	31.3 \pm 5.2	176.4 \pm 6.0	76.1 \pm 6.8	20.7 \pm 2.7	61.5 \pm 4.6	11.5 \pm 7.5

620

621 **Table 2. Absolute and relative macronutrient intake**

	Days 1-7	Days 8-14	Mean Raid
CHO intake (g.d⁻¹)	314 ± 49	370 ± 64**	342 ± 50
CHO intake (% of TEI)	43.3 ± 7.3	43.5 ± 6.0	43.4 ± 6.6
Fat intake (g.d⁻¹)	151 ± 47	175 ± 59**	163 ± 51
Fat intake (% of TEI)	44.1 ± 5.9	43.7 ± 5.4	43.9 ± 5.6
Protein intake (g.d⁻¹)	93 ± 34	110 ± 39**	102 ± 36
Protein intake (% of TEI)	12.1 ± 2.2	12.3 ± 1.8	12.2 ± 1.9

622 Means ± SD. **different from D1-7; $p < 0.01$.

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623 **Table 3. Explicit liking and food preference**

	Day 0	Day 1	Day 10
Explicit liking			
High-fat (HF)	4.4 ± 1.7	5.0 ± 1.3	4.6 ± 1.3
Low-fat (LF)	5.0 ± 1.9	5.4 ± 1.5	5.8 ± 1.5
Sweet (SW)	4.6 ± 1.8	4.8 ± 1.6	5.1 ± 1.6
Savory (SA)	4.9 ± 1.6	5.6 ± 1.1	5.3 ± 1.0
High-fat and sweet (HFSW)	4.1 ± 2.4	4.3 ± 1.7	4.3 ± 2.0
High-fat and savory (HFSA)	4.7 ± 1.6	5.7 ± 1.2	4.9 ± 1.4
Low-fat and sweet (LFSW)	5.0 ± 2.2	5.3 ± 2.1	5.9 ± 2.1
Low-fat and savory (LFSA)	5.0 ± 1.8	5.5 ± 1.5	5.7 ± 1.1
Food preference			
HF minus LF	-1.0 ± 4.9	-1.2 ± 4.2	-3.7 ± 3.7
HFSW minus LFSW	-0.3 ± 4.2	-1.8 ± 2.8	-2.8 ± 3.5
HFSA minus LFSA	-0.8 ± 1.5	0.7 ± 2.2	-0.9 ± 1.4
SW minus SA	-1.8 ± 6.5	-3.3 ± 5.3	-0.5 ± 5.1
HFSW minus HFSA	-0.7 ± 3.8	-2.9 ± 2.6	-1.2 ± 3.4
LFSW minus LFSA	-1.2 ± 3.7	-0.4 ± 3.3	0.7 ± 3.0

624 Means ± SD. Explicit liking is scored from 0 to 10 using a VAS. Food preference was based
625 on the FPQ-S₁₆: scores in each category were subtracted to obtain a bias score comparing
626 two categories, with a negative score indicating that food preference is higher in the latter
627 than the former category.

628 **Table 4 – Correlation table**

Variables	<i>r</i>	Variables	<i>r</i>
Δ Body mass (%)		EI D1-7 (kcal.d⁻¹)	
vs Mean EI (kcal.d ⁻¹)	0.656*	vs Hunger D1-7 (cm)	0.743**
vs Mean EE (kcal.d ⁻¹)	-0.402	vs Hunger D8-14 (cm)	0.340
vs Mean EB (kcal.d ⁻¹)	0.702*	vs Mean Hunger (cm)	0.707**
vs Mean CHO intake (kcal.d ⁻¹)	-0.219	EI D8-14 (kcal.d⁻¹)	
vs Mean fat intake (kcal.d ⁻¹)	0.780**	vs Hunger D1-7 (cm)	0.252
vs Mean protein intake (kcal.d ⁻¹)	0.656*	vs Hunger D8-14 (cm)	0.652*
vs Mean CHO intake (% of EI)	-0.795**	vs Mean Hunger (cm)	0.617*
vs Mean fat intake (% of EI)	0.765**	Mean EI (kcal.d ⁻¹)	
vs Mean protein intake (% of EI)	0.544	vs Hunger D1-7 (cm)	0.471
vs EL HFSW D0 (cm)	0.098	vs Hunger D8-14 (cm)	0.563
vs EL HFSW D1 (cm)	0.564	vs Mean Hunger (cm)	0.692*
vs EL HFSW D10 (cm)	0.600*	vs EL HF D10 (cm)	0.646*
Δ Body fat mass (%)			
vs EL HF D0 (cm)	0.232		
vs EL HF D1 (cm)	0.706**		
vs EL HF D10 (cm)	0.680*		

629 'Mean' indicates the average value for the 14 days. Otherwise, the period is indicated (e.g.
630 D1-7). Significant correlations between two variables are highlighted in bold. * $p < 0.05$; ** $p <$
631 0.01. EI: energy intake; EE: energy expenditure; EB: energy balance; CHO: carbohydrate;
632 EL: explicit liking; HF: high-fat; SW: sweet.

633 **Figure legends**

634 **Figure 1. Details of the route of the expedition and meteorological conditions.** Open
635 circles indicate that they remained in the same location on the specific day.

636 **Figure 2. Daily (A, C, and E) energy intake, expenditure, and balance and their means**
637 **(B, D and F) for each half of the expedition.** The dotted lines indicate the mean value for
638 the entire expedition. ***different from D1-7; * $p < 0.05$, ** $p < 0.01$.^{αα}different from EE, $p <$
639 0.01.

640 **Figure 3. Individual (A) and mean (B) body mass and body composition and**
641 **comparison between individual body mass and changes in energy balance (C).**
642 ***different from before the expedition; $p < 0.001$.

643 **Figure 4. Daily (A and C) morning and evening hunger scores and their means (B and**
644 **D) for each half of the expedition.** The dotted lines indicate the mean value over the entire
645 expedition.

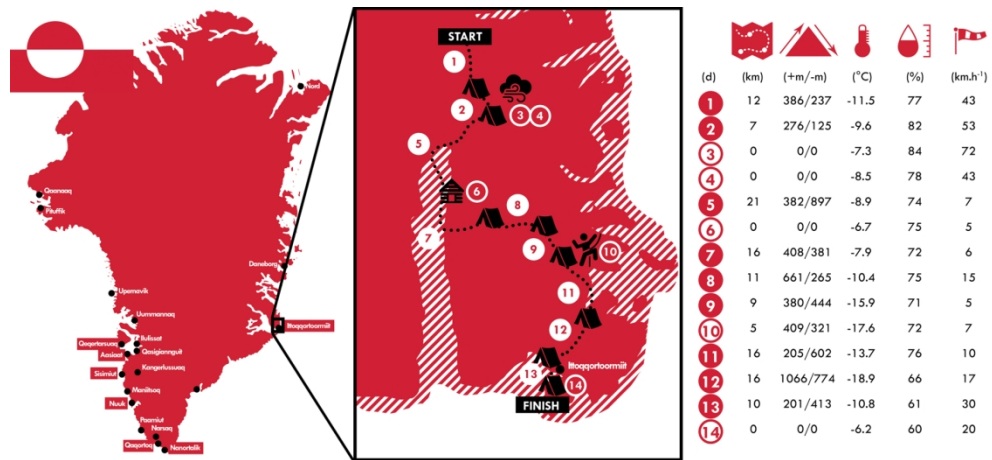


Figure 1. Details of the route of the expedition and meteorological conditions. Open circles indicate that they remained in the same location on the specific day.

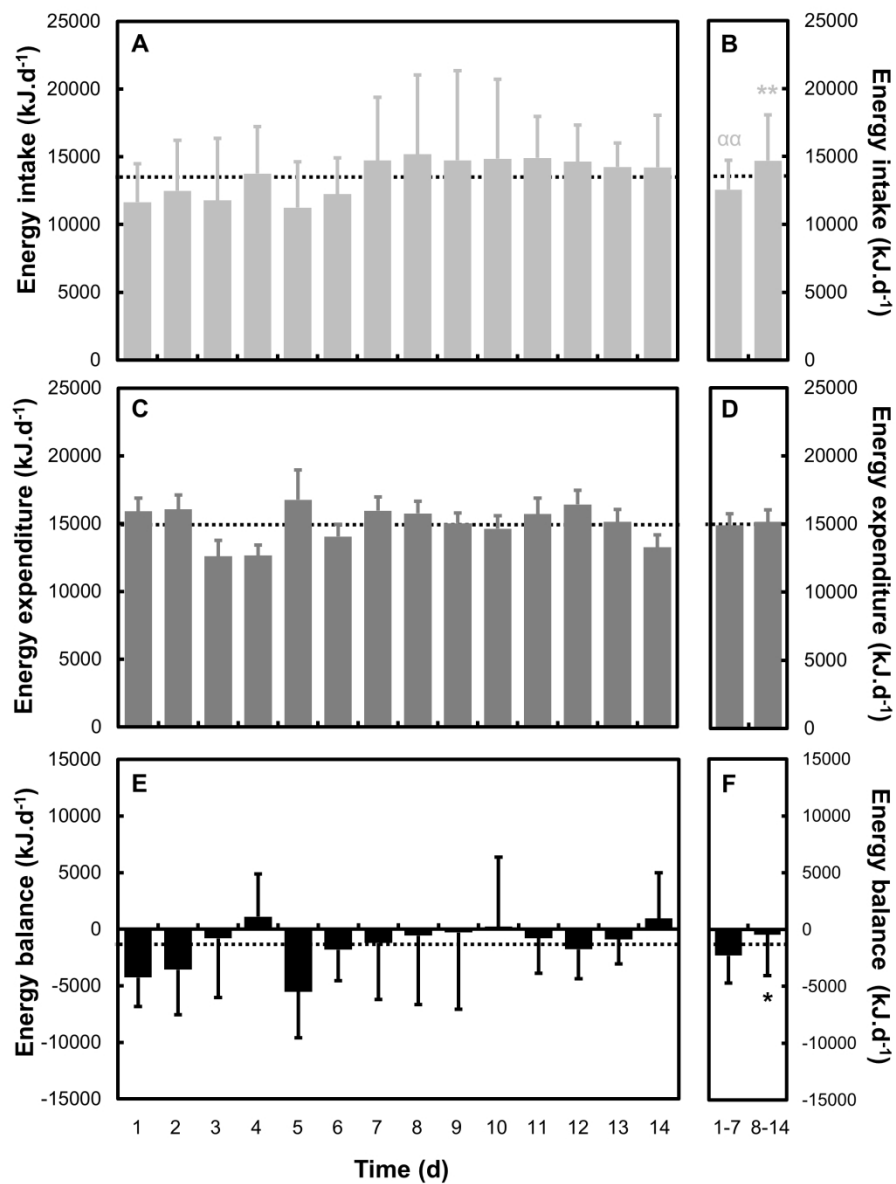


Figure 2. Daily (A, C, and E) energy intake, expenditure, and balance and their means (B, D and F) for each half of the expedition. The dotted lines indicate the mean value for the entire expedition. *,**different from D1-7; * $p < 0.05$, ** $p < 0.01$. αdifferent from EE, $p < 0.01$.

190x240mm (325 x 325 DPI)

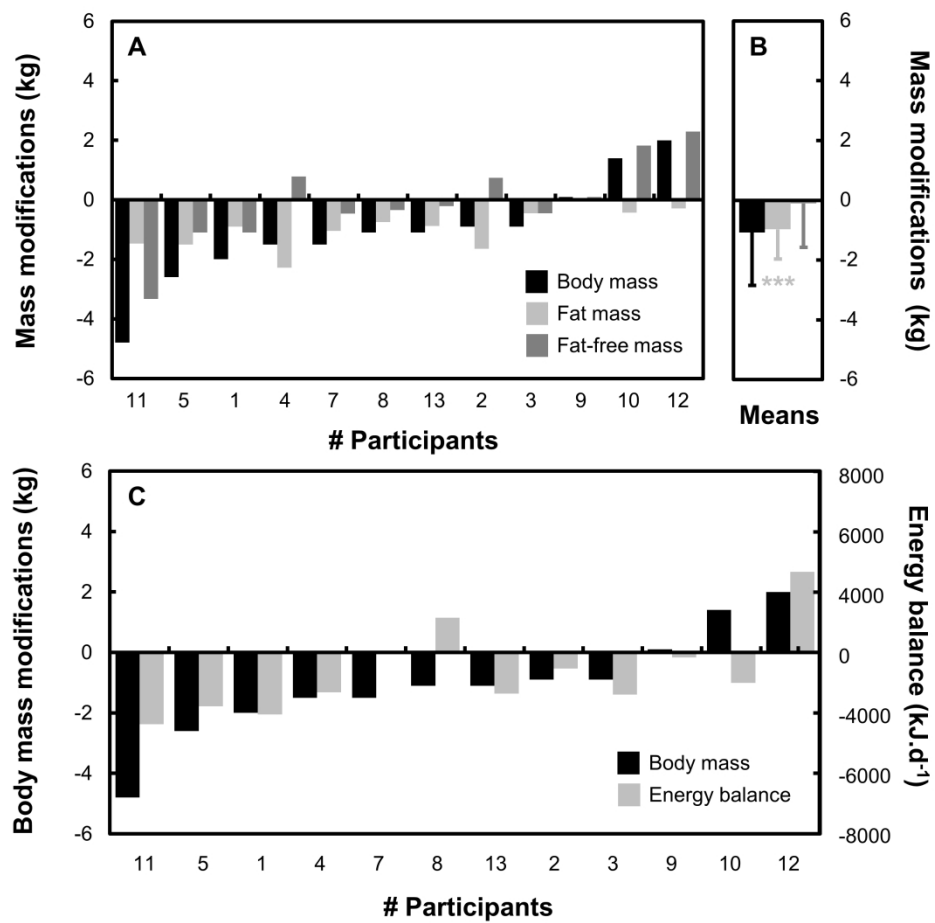


Figure 3. Individual (A) and mean (B) body mass and body composition and comparison between individual body mass and changes in energy balance (C). ***different from before the expedition; $p < 0.001$.

190x179mm (410 x 410 DPI)

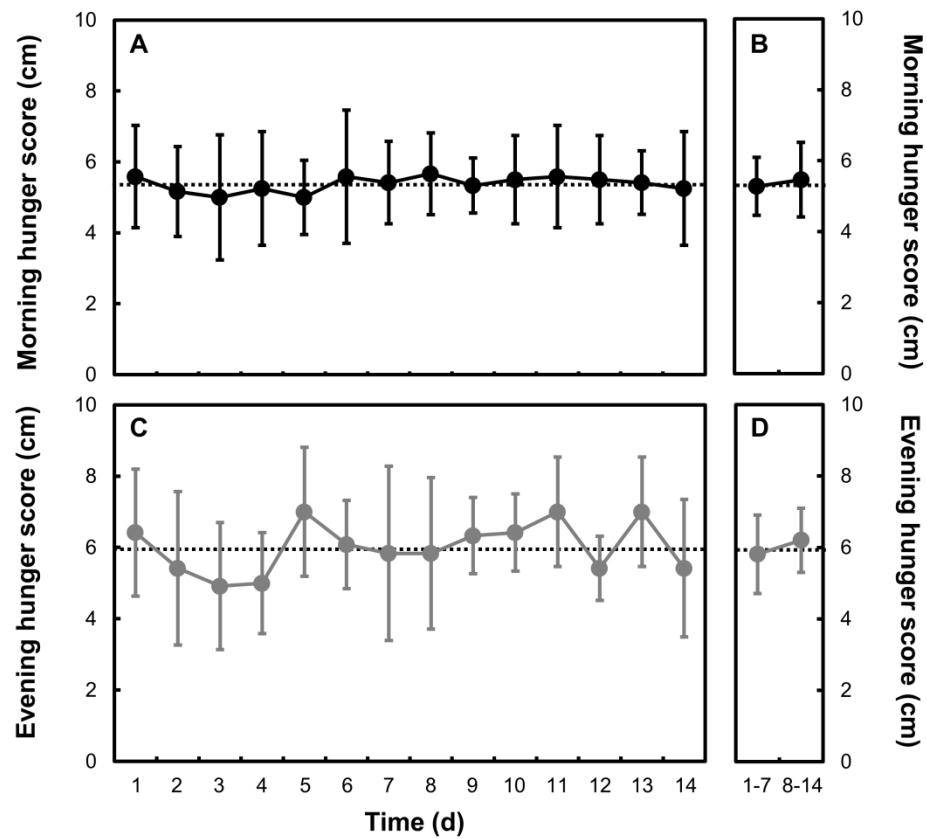


Figure 4. Daily (A and C) morning and evening hunger scores and their means (B and D) for each half of the expedition. The dotted lines indicate the mean value over the entire expedition.

190x169mm (410 x 410 DPI)