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The changes in maximal oxygen uptake ($\dot{V}O_{2MAX}$) induced by physical exertion during an Antarctic expedition depend on the initial $\dot{V}O_{2MAX}$ of the individuals: a case study of the Brazilian expedition

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ABSTRACT

Antarctic climate is challenging, since the cold, wind and sensory monotony are stressful stimuli to individuals. Moreover, camp activities and heavy clothes may contribute to increase physiological strain. Thus, we aimed to characterise the physiological demand of a 24-day period in the Antarctic field and then to evaluate the effect of this expedition on the aerobic fitness in individuals with heterogeneous initial aerobic fitness (as determined by estimating maximum oxygen consumption – $\dot{V}O_{2MAX}$). Before and after the 24-day period in Antarctica, 7 researchers and 2 mountaineers were subjected to incremental tests to estimate their $\dot{V}O_{2MAX}$. Field effort was characterised by measuring heart rate (HR). During the field trips, their HR remained 33.4% of the recording time between 50–60% HR_{MAX}, 22.3% between 60–70% HR_{MAX}, and only 1.4% between 80 and 90% HR_{MAX}. The changes in estimated $\dot{V}O_{2MAX}$ during the expedition depended on the pre-expedition aerobic fitness. The post-expedition $\dot{V}O_{2MAX}$ increased by 5.9% and decreased by 14.3%in individuals with lower (researchers) and higher (mountaineers) initial $\dot{V}O_{2MAX}$, respectively. We concluded that physical effort in the Antarctic field is characterised as predominantly of low- to moderate-intensity. This effort represented an effective training load for individuals with lower initial $\dot{V}O_{2MAX}$, but not for those with higher $\dot{V}O_{2MAX}$.

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Introduction

Environmental conditions in Antarctica are considered extreme due to low temperatures, the wind chill factor, the polar light-dark cycle (with long periods of light and darkness during the summer and winter, respectively) and sensory monotony. Also, field activities during polar expeditions demand the use of heavy clothing and long displacements in a rugged and/or snow covered terrain, which represent physical and physiological strains upon the human body that are qualitatively distinct from those routinely experienced by the individuals. In this sense, human performance during polar explorations is a hot topic since the heroic era (i.e. the late 19th century and early 20th century) [1].

Because of the physical effort required to subsist and work in Antarctica [2], studies have sought to understand the changes in aerobic fitness caused by Antarctic expeditions, as determined by changes in maximum oxygen consumption ($\dot{V}O_{2MAX}$). Aerobic fitness increased after 42 [3] or 75 [4] days of work; however, divergent results include reduced aerobic fitness reported after the Soviet-Canadian 1988 Polar Bridge Expedition that lasted 90 days [5].

We hypothesise that these controversial findings may reflect different aerobic fitness between individuals prior to expeditions, as the initial fitness levels determine the magnitude of physiological adaptations to aerobic training [6]. Of note, the impact of different initial aerobic fitness was not addressed in these earlier studies. Since fieldwork consists of a more intense effort than those routinely performed by the individuals, it would represent a training load that may result in improved aerobic fitness, particularly in individuals with lower initial aerobic fitness. In contrast, we expect that well-conditioned individuals would present no or only modest improvements.

Cardiac adaptations usually contribute to the improvement in aerobic fitness induced by a physical training. These adaptations include better cardiac contractility that leads to a lower heart rate (HR) at a given submaximal

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work rate [7,8]. Moreover, modifications in the autonomic nervous system (ANS) activity, which can be determined through the non-invasive monitoring of the resting heart rate variability (HRV), have been associated with training-induced changes in aerobic fitness in both sedentary [9] and trained subjects [9,10]. Effective training stimuli with adequate recovery periods increase HRV and improve sympathovagal balance by increasing vagal tone in healthy individuals [11] or patients [12]. Thus, we hypothesise that increases in aerobic capacity after an Antarctic expedition (which are more likely in less-conditioned individuals) would be associated with lower HR during submaximal exercise, resulting from reductions in cardiac sympathetic activity and increases in parasympathetic activity.

Considering that greater aerobic fitness is advantageous for carrying out intense physical work [1] and for regulating body temperature during a cold exposure [13], it is relevant to study the changes in aerobic fitness during an Antarctic expedition, as well as to characterise physical exertion and physiological responses during fieldwork. The comprehension of the changes in aerobic fitness induced by an Antarctic expedition will contribute to discuss the human physiological condition as predictive of the performance of different individuals in cold environments.

Thus, we evaluated the influence of a 24-day period in the Antarctic field (i.e. fossil prospection) on the aerobic fitness and HRV in Brazilian individuals with heterogeneous $\dot{V}O_{2MAX}$ prior to expedition. Because daily physical effort and the resulting physiological responses may have influenced the changes in aerobic fitness, we also recorded the daily distance travelled, HR and skin temperature of volunteers during the displacements for prospection.

Materials and methods

Experimental approach to the problem

This study followed a descriptive longitudinal approach. Brazilians volunteers who engaged in prospective fieldwork were evaluated at two moments (i.e. at pre- and post-expedition). The expedition lasted 24 days and the researchers stayed in a camp settled in the Antarctic field, more specifically in the Snow Island located in the South Shetland Islands (62°43′51.8″ S, 61°12′33.1″ W). Our experiments were conducted between January and February during the summer season in Antarctica. Pre- and post-expedition data collection was carried out on board of the Brazil's Navy polar ship "Almirante Maximiano" (number of tack H-41). Data were also collected daily in the peninsula of the Antarctic continent (in field data collection).

Prior to (3 weeks before leaving the ship for the camp) and after the Antarctic Field Expedition (24–72 h after coming back from the camp to the ship), all volunteers performed incremental tests to estimate their $\dot{V}O_{2MAX}$ and to assess HR at submaximal intensities and maximal heart rate (HR_{MAX}). Anthropometric measures of the volunteers were also registered on the days when the incremental tests were carried out. HRV was recorded twice, with the volunteers always at resting conditions; the first measure was performed inside the ship (3 weeks before leaving the ship for the camp) and the second measure was performed by the end (at the 22nd or 23rd day) of the camp.

To characterise physical exertion during camp work, the individual distance travelled and number of steps were measured daily. The physical exertion associated with camp work was also characterised by measuring HR and blood lactate (BLa) in only one day for each volunteer. Body and facial skin temperatures were also assessed during different moments of a typical day consisting of prospection.

Ethics

This experimental study followed the regulations established by the Brazilian National Health Council (Resolution 466/2012) and was approved by the Research Ethics Committee of the Universidade Federal de Minas Gerais (protocol number 1.761.933). The volunteers were informed about the objectives and all experimental procedures before giving their written informed consent for participation in this study.

Subjects

Nine volunteers – seven paleontologists (five men and two women researchers) and two professional mountaineers (both men) – were recruited to participate. The presence of professional and experienced mountaineers in scientific camps is a requirement for the safety of researchers. The anthropometric characteristics of the participants are shown in Table 1.

Procedures

Assessment of anthropometric characteristics

Body mass was measured with volunteers wearing shorts (men) or shorts and top (women). Skinfold thickness was measured at seven different sites (triceps, subscapular, pectoral, mid-axillary, mid-abdominal, suprailiac and mid-thigh); skinfolds were measured to the nearest millimetre in duplicate using a skinfold caliper (Lange, MI, USA). These seven measures were

Table 1. Anthropometric characteristics of the volunteers (n = 9) before and after 24 days of Antarctic fieldwork. The volunteers were separated in researches (n = 7) and mountaineers (n = 2). The results are expressed as means ± SD.

	Paleontologists (n = 7)		Mountaineers (n = 2)	
	Pre-Antarctic Field Expedition	Post-Antarctic Field Expedition	Pre-Antarctic Field Expedition	Post-Antarctic Field Expedition
Age (years)	36.0 ± 8.0		57.0 ± 7.1	
Height (cm)	170.3. ± 10.0		175.5 ± 0.7	
Body mass (kg)	85.1 ± 26.5	84.3 ± 24.3	82.15 ± 11.9	81.25 ± 11.10
Body fat (%)	29.5 ± 8.7	27.6 ± 7.44	20.5 ± 10.1	19.9 ± 9.9
∑Skinfold (mm)	180.3 ± 45.5	170.4 ± 38.3	121.5 ± 65.7	118.0 ± 65.0

then summed to determine the ∑Skinfolds. Body fat was calculated according to the protocol proposed by Jackson and Pollock [14].

Aerobic fitness assessment

Aerobic fitness was evaluated by performing incremental tests until fatigue on a treadmill, except for one volunteer that reported knee pain while running and, therefore, performed a bicycle test. Incremental tests on the treadmill were performed according to the protocol proposed by Ellestad & Kemp [15]. The incline of the treadmill was set at 10% in the first four stages and then it was increased to 15%, an incline that was maintained until the end of the test. The initial speed corresponded to 2.7 km/h (1.7 mph); it was increased to 4.8 km/h (3.0 mph) in the second stage and then was increased by 1.6 km/h (1.0 mph) every stage; the only exception was the transition between the fourth and fifth stages, when speed was not increased. The stages lasted between 2 and 3 min; most of them lasted 2 min, except the first and fifth stages. Cycle ergometer incremental tests started at 25 W and this power output was increased by 25–30 W at every stage until fatigue; the stages lasted between 2 and 3 min, and the volunteer cycled at 50 rpm.

In both tests (i.e. on the treadmill or cycle ergometer), fatigue was determined when subjects could no longer maintain the predetermined speed or power, voluntarily stopped exercising or rated 20 on the Borg's scale of perceived exertion [16]. Each volunteer was tested on the same ergometer.

Before each test for estimating $\mathring{V}O_{2MAX}$, the volunteers received the following recommendations: to sleep at least 8 h on the night before testing; to eat normally and to abstain from alcohol, caffeine and strenuous physical exercise 24 h before and drink at least 500 ml of water 2 h before the tests [17]. During the tests, the volunteers wore top (only women), shorts, socks and their regular tennis shoes. $\mathring{V}O_{2MAX}$ was estimated using appropriate equations for both the treadmill [15] and cycle ergometer tests [18]. These equations provided $\mathring{V}O_{2MAX}$ estimations in mL.kg^{-1}.min^{-1}.

HR was recorded every minute (Polar® S810i, Polar, Finland) and rating of perceived exertion (RPE) was assessed at the end of each stage. RPE was indicated by the volunteer through a 15-point scale (6 to 20), where 6 represents the lowest effort and 20 the greatest possible effort during an exercise [16].

HRV measures

HRV was determined via recordings of the RR interval (Polar® S810i, Polar, Finland). During this measurement, the volunteers remained seated in a chair for 20 min in a sheltered environment – both inside the ship and in the camp. In the latter condition, the tent was heated and the volunteers wrapped themselves to ensure thermal comfort. All measurements were taken in the morning between 6:30 and 8:00 h.

The RR intervals were continuously recorded during the last 10 min of rest. All tachograms were visually inspected to exclude artifacts and ectopic heart beats [19], which did not exceed 3% of the recorded data. From the 10 min recordings, 5 min were analysed (i.e. the interval between the 3rd and the 8th min after recordings have been initiated). Data analysis was performed using the Kubios HRV® free software (University of Eastern Finland).

The following time domain parameters were calculated: the square root of the mean squared differences of successive RR intervals (RMSSD, expressed in ms), the natural log applied to the RMSSD (Ln RMSSD), the number of interval differences of successive normal-to-normal (NN) intervals greater than 50 ms (NN50), the percentage of adjacent RR intervals with a time difference greater than 50 ms (pNN50).

For frequency-domain analysis, power spectral density was quantified using Fast Fourier transform. The spectral power was expressed in ms^2 and integrated into two frequency bands of interest: the high frequency (HF) power band (0.15–0.40 Hz), which reflects the parasympathetic influence and is related to the respiratory sinus arrhythmia [20], and the low frequency (LF) power band (0.04–0.15 Hz), which is assumed to have a dominant sympathetic component [21]. In addition, the LF band has been associated with modulation of cardiac autonomic outflows by baroreflexes [22]. The total spectral power in ms^2 was calculated by summing the LF to the HF band [23,24]. During the HRV recording, the investigator surveyed visually the volunteers' breathing frequency for accuracy; breathing rate was kept higher than 12 cycles per minute.

Measurements of physical effort and changes in physiological parameters during camp work

The activity pattern was measured daily using a pedometer (Omron Healthcare Co., Ltd., HJ-321LA, Kyoto, Japan) placed in the clothing, near the waist of the volunteers. Pedometers were provided to the volunteers on the evening of the second day of camp. The volunteers spent their first 3 days assembling the structures of the camping site and, on the fourth day, hiking activities were started in order to prospect the Antarctic field. Because pedometers measure steps, the step length of each volunteer was measured during a 35-m walk in an Antarctic flat area. Individual step length was determined as the number of steps divided by 35 m. HR was measured only in researchers during 6 different camp days (one researcher per day, n = 6). The researchers wore a HR monitor (Polar® S810i, Polar, Finland) and a strap that was adjusted around their chest. The HR recording was initiated immediately before leaving the camp, with this physiological parameter being monitored for 246 ± 46 min during approximately 6 h of field prospection. The HR data were downloaded (Polar Precision Performance, v. 4.0) and classified into the following HR zones: below 50%, 50–60%, 60–70%, 70–80% and 80–90% of HR_{MAX}. Next, we calculated the percentage of the total time that the researchers spent in the above-mentioned HR zones. HR_{PEAK} (185 ± 10 bpm) was considered as the highest value reached by each individual during the incremental tests performed prior to the expedition.

BLa was only measured in researchers. Digital puncture was performed inside a camp tent at the initiation and end of a workday. The BLa concentration was determined using a portable analyzer (Accutrend Plus Roche®, Switzerland).

Skin temperature (Tsk) measurements were performed only in researchers inside a camping tent at the beginning (*Basal*) and end of a workday (*Arrival at camp*). Tsk was also measured in predetermined moments along the day: *Walk up*, after about 40 min of walking up a sloping hill, which was required to move away from the camp; *Outcrop Point*, when arriving at the main point of excavation after about a 60-min walking; *Excavation/Prospection*: these measurements were carried out during the researchers' specific activities (i.e. excavations and short walks to prospect); in particular, the *Excavation/Prospection* measurements were performed before (1) and after the snack (2; after stop working for a snack that lasted approximately 30 min).

Tsk probes (400A Series, Yellow Springs Instruments, Yellow Springs, OH, USA,) connected to a thermometer (4600 Series, Yellow Springs Instruments) were attached to five skin sites: upper arm, chest, thigh, foot and hand, and then the mean body Tsk was calculated as follows $0.43\ T_{chest} + 0.25\ T_{arm} + 0.32\ T_{thigh}$ [25]. The Tsk of forehead, nose and cheek were measured using an infrared thermometer (Fluke 568, © 1995–2010 Fluke Corporation, OH, USA) and then the mean face temperature was determined by calculating the arithmetic mean of these three temperatures.

Statistical analysis

The Shapiro–Wilk test showed that there was no significant departure from a normal distribution in the parameters evaluated. Equal variance was as tested and confirmed in SigmaPlot (Systat Software, Inc.) by checking the variability between the group means. Data are shown as mean ±SD.

When analysing all volunteers together (n = 9) or only the researchers (n = 7), Student's *t* tests were used to compare the influence of the Antarctic expedition on the estimated $\dot{V}O_{2MAX}$, maximal workload, mean HR, BLa, body mass, fat and Σskinfolds (pre vs. post expedition). A two-way repeated-measures analysis of variance (ANOVA) was used to compare HR measured during incremental exercises between situations (pre vs. post expedition) and across time points (stages of the incremental exercises). One-way repeated-measures ANOVAs were used to compare temperatures across time points. When a significant *F* value was found, we performed Student–Newman–Keuls tests as *post hoc* analysis. Pearson's correlation was used to evaluate the association between two variables through the determination of the r coefficient. The *α* level was set at 0.05.

Cohen d magnitude effect-size (ES) was calculated to assess the magnitude of difference between experimental trials within (pre vs. post expedition, when analysing all data together, only researchers or only mountaineers) and between subjects (researchers vs. mountaineers). ES was calculated by subtracting the mean value for one group from the mean value of the group it was being compared to. The result was then divided by a combined standard deviation for the data. The ES values were classified as trivial (ES <0.2), small (ES = 0.2–0.6), medium (ES = 0.6–1.2) or large (ES ≥1.2) [26]. Calculation of the effects sizes was particularly important to evaluate the expedition-induced changes in mountaineers (n = 2).

Results

Aerobic fitness increased and decreased in researchers and mountaineers, respectively, after the Antarctic field expedition

When all volunteers (n = 9) were evaluated together, the estimated $\mathring{V}O_{2MAX}$ (P = 0.90; ES = 0.04) and HR values measured during the incremental tests (P = 0.711) were not changed after the expedition compared to values measured before the expedition. We then divided the volunteers into researchers (n = 7) and mountaineers (n = 2) because of the large differences in their estimated $\mathring{V}O_{2MAX}$ prior to the expedition (researchers 37.9 ± 4.1 mL.kg^{-1}.min^{-1} vs. mountaineers 46.6 ± 4.4 mL.kg^{-1}.min^{-1}; ES = 2.04).

Aerobic fitness in researchers increased after the Antarctic field expedition, as shown by a 5.9 ± 6.4% increase in estimated $\mathring{V}O_{2MAX}$ (P = 0.043; ES = 0.548; (Figure 1(a)). In addition, there was a reduction in HR at the same absolute intensity during the incremental test after the expedition (P = 0.016; (Figure 2(a)), as evidenced by a lower mean HR at the 7th stage of the test (pre-expedition, 175 ± 8 bpm vs. post-expedition, 166 ± 13 bpm, P = 0.012, ES = 0.83; (Figure 2(c)). No differences were observed in the body mass (P = 0.448; ES = 0.03) and body fat (P = 0.135; ES = 0.23) in researchers when comparing measurements at pre- and post-expedition Table 1.

When analysing the only two mountaineers that participated in this study, estimated $\mathring{V}O_{2MAX}$ was largely decreased for both of them (by 17.2 and 11.4%) after the expedition (ES = 1.30; (Figure 1(b)). Moreover, a large increase in HR for the same absolute intensity was observed during the post-expedition incremental test (Figure 2(b)), as evidenced by a higher mean HR at the 7th stage of the test (120 ± 1 bpm vs 146 ± 2 bpm; ES = 14.41). Trivial differences were observed in body fat (ES = 0.064) and body mass (ES = 0.078) when comparing post- and pre-expedition values Table 1.

Considering that mountaineers exhibited higher initial estimated $\mathring{V}O_{2MAX}$ but reduced values following expedition, whereas researchers exhibited lower initial estimated $\mathring{V}O_{2MAX}$ but increased values following expedition, we decided to assess the correlation between initial estimated $\mathring{V}O_{2MAX}$ and expedition-induced changes in this parameter. In fact, when analysing all volunteers collectively (n = 9), the initial estimated $\mathring{V}O_{2MAX}$ correlated negatively and significantly (r = -0.75, P = 0.019) with expedition-induced changes in $\mathring{V}O_{2MAX}$ Figure 3. Because the changes in aerobic fitness greatly differed between researchers and mountaineers, all the following data were evaluated separately for each group.

Resting HRV measures

The 24-day expedition did not change the resting HR in researchers (P = 0.726; ES = 0.25), but induced a large increase in mountaineers (ES = 1.64). There were no differences for the variability parameters in the time domain – RMSSD, Ln RMSSD, NN50 and pNN50% – for researchers between the pre-camp and end-of-camp

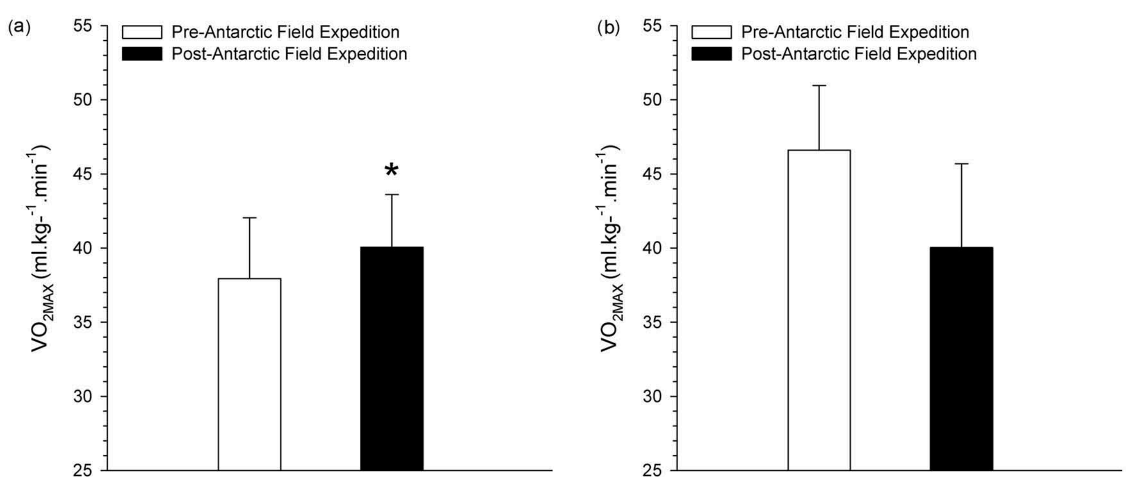

Figure 1. Maximal oxygen consumption ($\mathring{V}O_{2MAX}$) estimated before and after the expedition in researches (n = 7; panel (a) and in mountaineers (n = 2; panel b). *Significantly different (P < 0.05) from the pre-expedition moment. ES = 1.30 for mountaineers.

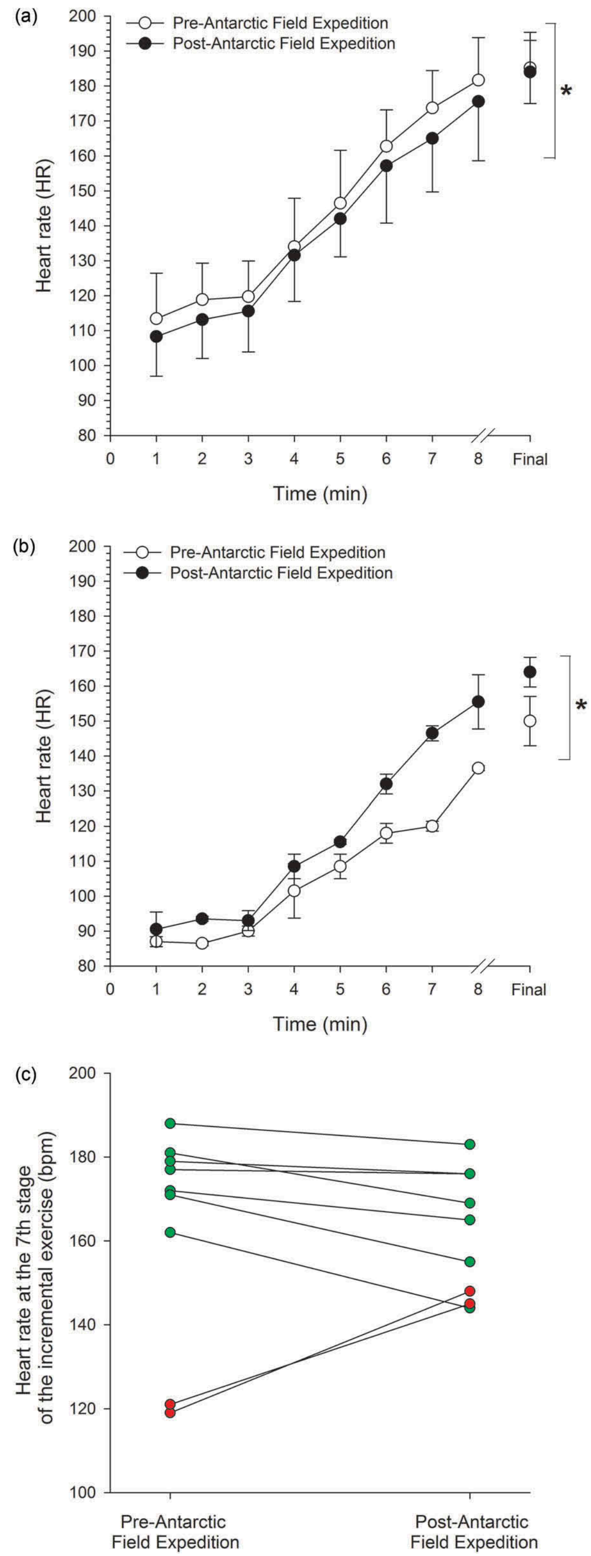

Figure 2. Heart Rate (HR) during the incremental tests performed before and after the Antarctic expedition in researches (n = 7; panel (a) and in mountaineers (n = 2; panel b).*Significantly different ($P < 0.05$) from the pre-expedition moment. The panel c shows the HR of each volunteer during the 7th stage of the incremental tests performed before and after the expedition. The red symbols indicate the volunteers (i.e. mountaineers) who exhibited an increase in HR, whereas the green symbols indicate those (i.e. researchers) who exhibited a reduction in HR after the expedition.

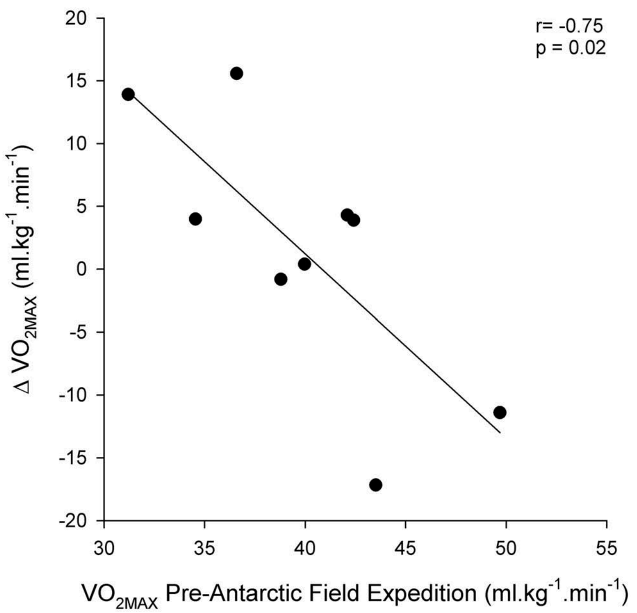

Figure 3. Correlation between the pre-expedition $\mathring{V}O_{2MAX}$ estimated and the expedition-induced changes in $\mathring{V}O_{2MAX}$ estimated. Each point represents an individual.

moments (all parameters showed *ES* lower than 0.6). In contrast, the mountaineers presented a medium-magnitude decreases in NN50 (*ES* = 0.75) and pNN50% (*ES* = 0.77) at the end of the camp.

Regarding the variability parameters in the frequency domain, the researchers exhibited a reduction in the LF band at the end of the camp ($P = 0.038$), with this reduction being characterised by a medium effect size (*ES* = 1.05); this effect was not observed in mountaineers (*ES* = 0.29). Because no changes were detected in the HF band in researchers ($P = 0.68$), the decreased LF band resulted in a significant, medium-magnitude reduction in the absolute spectral power (LF + HF; $P = 0.011$; *ES* = 1.03). The effect sizes regarding the changes in spectral variables for mountaineers were all small or trivial (<0.3; Table 3).

Characterisation of physical exertion in the field

The average distance travelled by each volunteer (n = 9) corresponded to 6.2 ± 1.9 km per day and to a total of 130.9 ± 40.6 km during the 21 days of recordings. In addition, the average number of steps for the volunteers throughout the camp was 176,261 ± 46,628. The difference in the total distance travelled between researchers (132.9 ± 44.3 km) and mountaineers (124.0 ± 35.9 km; *ES* = 0.22) was small, likewise the difference in the total number of steps (researchers 178,439 ± 50,623 steps vs. mountaineers 168,639 ± 43,221 steps; *ES* = 0.21). These small differences between groups were expected, since all volunteers performed most of the displacements together.

During field prospection, researchers (n = 6) HR fluctuated markedly, attaining values that ranged from low- to high-intensity efforts. Of the total time that was recorded (246 ± 46 min), subjects remained 35.2 ± 25.6% below 50% HR_{MAX}, 33.4 ± 11.9% between 50 and 60% HR_{MAX}, 22.3 ± 13.3% between 60 and 70% HR_{MAX}, 7.7 ± 5.3% between70 and 80% HR_{MAX} and 1.4 ± 1.0% between 80 and 90% HR_{MAX} Figure 4.

Blood lactate of researchers

There was no difference in BLa concentration in researchers before and after a working day in the field (before 1.80 ± 0.51 mM vs. after 1.48 ± 0.68 mM; $P = 0.404$; *ES* = 0.532).

Body temperatures of researchers in the field

During physical exertion in the field, there was a significant effect for time/moments analysis in weighed Tsk ($P = 0.049$), with this temperature tending to decrease from *Baseline* to the first point of *Excavation/Prospection* ($P = 0.077$; *ES* = 1.01) and from *Baseline* to *Arrival at Camp* ($P = 0.094$; *ES* = 0.87).

Concerning the mean face Tsk, there was also a significant effect for time/moments analysis ($P < 0.001$), with this temperature decreasing from *Baseline* to all moments investigated ($P < 0.05$), except for at the *Arrival at Camp* ($P = 0.159$; *ES* = 0.89). Moreover, mean face Tsk was higher at the *Arrival at Camp* when compared to the *Outcrop Point* ($P = 0.063$;

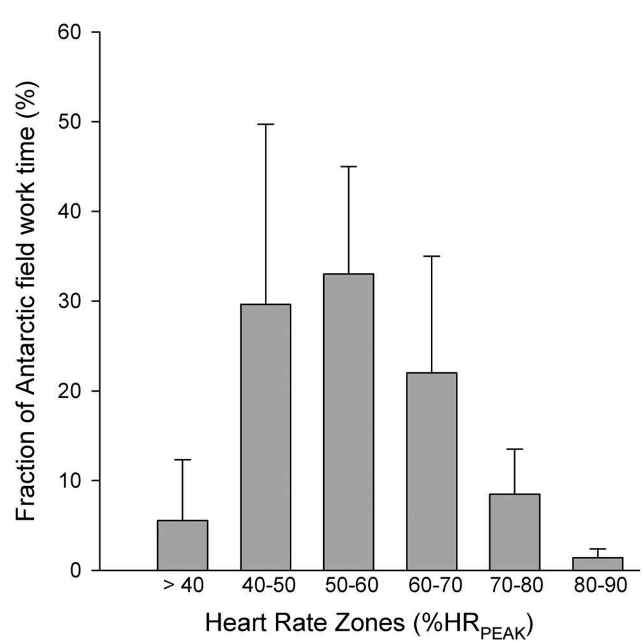

Figure 4. Fraction of the work time spent by the researchers (n = 6) in different heart rate zones.

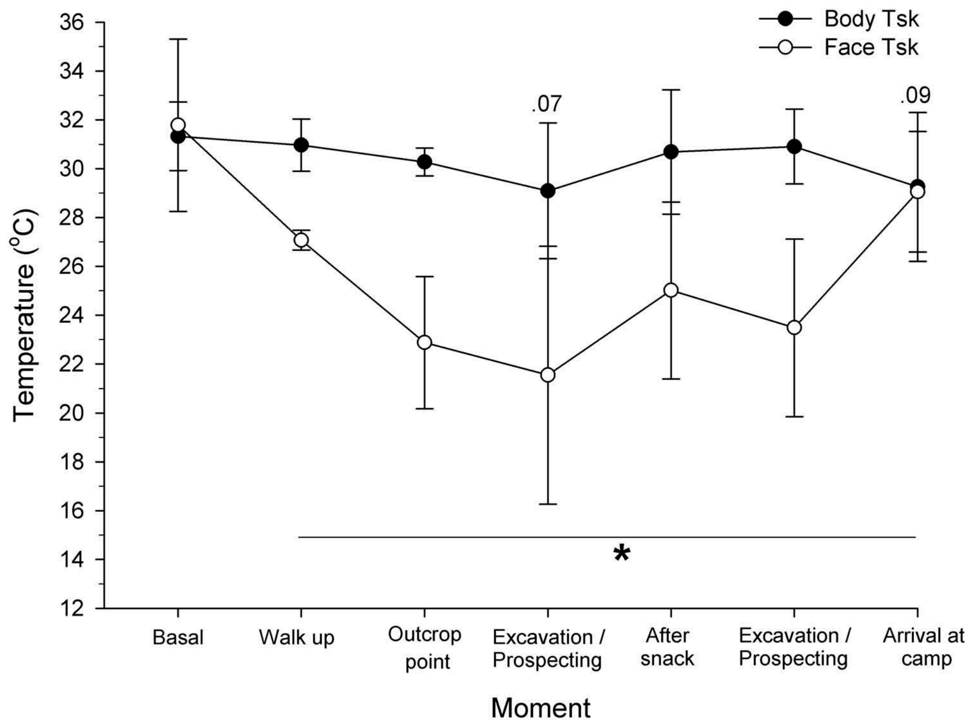

Figure 5. Skin temperatures measured in different body surfaces (Body Tsk) and face (Face Tsk) in researchers during a day of fieldwork in Antarctica (n = 5). *Significantly different ($P < 0.05$) from the basal moment.

Table 2. Temperatures measured in researchers at different moments during Antarctic fieldwork. The results are expressed as means ± SD.

	Basal (°C)	Walk up (°C)	Outcrop Point (°C)	Excavation/Prospection (°C)	After snack (°C)	Excavation/Prospection (°C)	Arrival at camp (°C)
Arm	30.80 ± 1.65	32.19 ± 0.97	31.79 ± 1.32	30.38 ± 2.50	31.72 ± 2.07	32.28 ± 1.69	29.57 ± 2.92
Chest	32.72 ± 1.50	33.25 ± 0.47	31.84 ± 2.21	30.65 ± 4.59	32.65 ± 4.05	33.24 ± 2.06	31.34 ± 4.03
Thigh	29.85 ± 1.81	26.92 ± 2.11	26.98 ± 1.69	25.98 ± 1.96	27.24 ± 1.11	26.69 ± 1.88	29.85 ± 2.63
Forehead	33.98 ± 0.70	28.1 ± 4.03	27.12 ± 4.27	24.52 ± 5.47	27.7 ± 5.02	25.37 ± 5.25	30.86 ± 4.11
Cheek	30.94 ± 3.99	23.53 ± 4.97	17.32 ± 3.65	17.54 ± 5.12	24.67 ± 4.00	22.55 ± 2.19	26.84 ± 4.99
Nose	30.42 ± 6.41	29.57 ± 0.71	24.17 ± 6.73	22.58 ± 7.35	22.67 ± 4.86	22.52 ± 5.49	29.46 ± 5.09
Hand	29.57 ± 2.39	26.39 ± 1.35	26.27 ± 2.85	25.32 ± 2.83	25.96 ± 2.66	24.16 ± 6.21	26.43 ± 4.60
Foot	27.94 ± 2.10	31.44 ± 1.95	32.39 ± 1.70	32.54 ± 1.89	29.97 ± 3.20	31.1 ± 1.57	32.10 ± 0.89
Tympanic	32.00 ± 3.53	32.80 ± 5.37	32.87 ± 3.44	32.66 ± 3.54	34.10 ± 2.22	33.22 ± 2.78	29.48 ± 9.15

ES = 2.39) and the first point of *Excavation/Prospection* (P = 0.008; ES = 1.82) (Figure 5; Table 2).

Discussion

Physical exertion in the Antarctic field was characterised as predominantly of low- (below 60% HR_{MAX}) to moderate-intensity (60–70% HR_{MAX}), with some moments of high-intensity activity (70–90% HR_{MAX}). This physiological demand was sufficient to reduce cardiovascular strain during the post-expedition incremental test and to increase the aerobic fitness in individuals with lower pre-expedition estimated $\mathring{V}O_{2MAX}$ (i.e. researchers). In contrast, mountaineers with a greater initial aerobic fitness showed a reduction in their estimated $\mathring{V}O_{2MAX}$, indicating that physiological demand was not enough to configure an effective training load to them. In addition, compared to pre-camp condition, researchers presented a reduction in the total HR spectral density, whereas mountaineers presented a large increase in resting HR at the end of the camp.

The increased aerobic fitness in researchers agrees with two previous studies that included strenuous work during Antarctic field expeditions [4,27], but disagrees with two other studies reporting reductions in aerobic fitness [5,28]. Regarding the discordant results, it is noteworthy that the individuals who took part in the expedition called *Skitrek* [5] were in a high training level at pre-expedition; therefore, the physical effort they performed likely did not represent an appropriate aerobic training load. Interestingly, Brotherhood *et al.* [28] and Goldsmith *et al.* [4] performed experiments with the same individuals during the same trip. However, Brotherhood *et al.* [28] measured aerobic capacity when individuals returned to Australia, whereas Goldsmith *et al.* [4] measured during

Table 3. Heart rate variability (HRV) parameters measured before and at the end of expedition in researches (n = 7) and mountaineers (n = 2). Cohen's d effect size (ES) was calculated to assess the magnitude of difference between experimental trials.

	Paleontologists (n = 7)			Mountaineers (n = 2)		
	Pre-Antarctic Field Expedition	22–23 days of Antarctic Field Expedition	Effect sizes Cohen's d	Pre-Antarctic Field Expedition	22–23 days of Antarctic Field Expedition	Effect sizes Cohen's d
HR (bpm)	77.94 ± 12.93	75.37 ± 6.67	0.25	54.38 ± 6.47	62.45 ± 2.54	1.64[L]
RMSSD (ms)	22.20 ± 3.11	22.87 ± 8.89	0.10	23.65 ± 17.18	18.59 ± 11.87	0.34
Ln RMSSD (ms)	3.09 ± 0.14	3.07 ± 0.39	0.07	3.01 ± 0.80	2.81 ± 0.69	0.27
NN50	7.80 ± 5.40	12.83 ± 17.59	0.39	23.50 ± 33.23	5.50 ± 7.78	0.75[M]
pNN50 (%)	2.78 ± 2.10	4.38 ± 6.03	0.35	10.15 ± 14.35	2.14 ± 3.03	0.77[M]
LF (ms^2)	431.20 ± 180.94	230.17 ± 200.41*	1.05[M]	276.00 ± 289.91	386.40 ± 455.94	0.29
HF (ms^2)	274.40 ± 88.73	224.67 ± 133.15	0.44	195.00 ± 251.73	134.90 ± 139.87	0.30
LF+ HF	705.60 ± 239.10	454.83 ± 245.87*	1.03[M]	471.00 ± 541.64	521.30 ± 595.81	0.09

*Significantly different ($P < 0.05$) from pre-expedition moment. [M]Medium effect size. [L]Large effect size. The results are expressed as means ± SD.

the period in the field. Thus, the inactivity in the ship during the trip back to Australia has probably reverted the improved $\mathring{V}O_{2MAX}$ reported during the fieldwork period in Antarctica.

Similar results to those reported by Brotherhood *et al.* [28] and Shephard [5] were observed in our mountaineers. Considering that they presented a higher pre-expedition $\mathring{V}O_{2MAX}$ than researchers, physiological demands during the Antarctic camp were not sufficiently high to produce a significant training load. Thus, the different outcomes in estimated $\mathring{V}O_{2MAX}$ between researchers and mountaineers could be due to the minimum workload needed to improve $\mathring{V}O_{2MAX}$ in individuals with different aerobic fitness [29,30]. In this context, the physiological demands related with fieldwork seemed to be appropriated for researchers (lower initial $\mathring{V}O_{2MAX}$), but insufficient for mountaineers (higher initial $\mathring{V}O_{2MAX}$).

The lack of gas exchange measurements (e.g. open-circuit indirect calorimetry) to access $\mathring{V}O_{2MAX}$ and of a verification exercise bout to ensure that $\mathring{V}O_{2MAX}$ values were indeed attained [31] are relevant limitations of the present study. However, the estimated $\mathring{V}O_{2MAX}$ along with $\mathring{V}O_{2MAX}$ data [7] support the finding that aerobic fitness was increased in researchers and decreased in mountaineers. The $\mathring{V}O_{2MAX}$ increases resulting from aerobic training are largely mediated by augmented blood volume. This higher blood volume, in association with a greater cardiac contractility, increases stroke volume under resting, submaximal and maximal exercises, thereby reducing the HR required for maintaining a given cardiac output [8]. Thus, the reduction in HR for a given exercise intensity, as observed in researchers during the incremental test after the expedition, indicates a physiological adaptation induced by aerobic training. In contrast, the increase in HR for a given exercise intensity in mountaineers suggests the reduction of aerobic fitness.

After the period in Antarctica the changes in HRV of researchers consisted of decreased LF and LF+HF powers (both characterised as medium effect sizes). These changes, particularly the LF decrease, suggests decreased sympathetic activity in these individuals. In contrast, the lack of changes in HRV and the medium-magnitude reductions in PNN50 and NN50 observed in mountaineers, which are suggestive of reduced parasympathetic cardiac activity, agree with the fact that the fieldwork did not improve aerobic fitness in these individuals. In summary, the changes in HRV and $\mathring{V}O_{2MAX}$ induced by the Antarctic field were coherent in both groups (e.g. researchers, who improved their aerobic fitness, presented increases in HRV parameters associated with lower cardiac sympathetic activity).

The HR was measured in days of prospecting activity, which included long-distance hiking. In addition to the horizontal distance travelled, several displacements were made in areas with slopes and rocky slopes that contributed to increase the physiological demands. At these moments, the researchers presented greater HR increases as indicated by the HR values characteristics of moderate- (60–70% HR_{MAX}) and high- (>70% HR_{MAX}) intensity activities. Despite these activities, the physiological demand during the fieldwork was majority of low-intensity (<50% HR), while intense demand (time spent in the 70–80 and 80–90% HR_{MAX} zones) represented only 9.9% of the recording time. When the data were expressed as absolute values, the time under high-intensity physical exertion corresponded to 24 min per day.

In addition to the physical/physiological demands related to prospecting activities, the Antarctic climate per se may be another factor underlying the aerobic fitness improvement in researchers because of shivering, an involuntary pattern of rhythmic and repetitive muscle contractions aimed at producing metabolic heat [32]. A previous study reported $\mathring{V}O_2$ increments of about 15% $\mathring{V}O_{2MAX}$ in young men resting at 5°C with a wind at a speed of 1m/s [33]. During physical exercise, $\mathring{V}O_2$ can be higher in cold than in temperate conditions, depending on the exercise intensity. During low-intensity exercise, shivering is added to metabolic heat production to prevent reductions in core and skin temperatures [34], whereas during intense physical effort, the metabolism increases sufficiently to supersede shivering. In this sense, Hong and Nadel [35] showed that $\mathring{V}O_2$ (attributable to shivering) and EMG activity were inversely proportional to the intensity of a cycling exercise at 10°C and consequently to the core body temperature attained during this exercise. Despite our volunteers have performed predominantly physical activities of low-intensity (<50% HR_{MAX}), they were dressed with insulated clothes that are appropriate to face the severe Antarctic environment, thereby decreasing the incidence of shivering. In this sense, preliminary data collected in this camp revealed a 1.6°C maximal increase in the core body temperature (measured by telemetry; Coretemp®) of one individual during a day of fieldwork, including hikes (*data not showed*). Thus, although we do not exclude a role for cold-induced shivering in increasing $\mathring{V}O_2$ demand during the fieldwork, the moments of high-intensity physical effort (<70% HR_{MAX}) are likely the major cause of aerobic fitness improvement in researchers that were studied.

BLa is a metabolite whose concentrations is related to exercise intensity and may be influenced by ambient temperature. After a day of prospective work, when researchers were exposed to cold and performed specific moments of high-intensity activities, blood lactate concentrations did not increase. A likely explanation for the lack of differences in lactate is the fact that these high-intensity moments were interleaved with low-intensity walks, which probably favoured the removal of lactate from circulation [36,37]. Indeed, high-intensity exercises can increase BLa to concentrations higher than 10 mM [38,39] and short-periods (~ 30 min) of passive or active recovery allow the return of BLa to levels recorded before a bout of intense running [40]. It is noteworthy that, despite our attempts to collect BLa in the field, the severe climatic conditions made the collection inside the tent as the only viable option. These adverse conditions included the very low temperatures that prevented the lactate analyzer from reading the tapes and the intense winds that made it difficult to manipulate the materials. In addition, cold exposure minimally reduced Tsk, which levels were maintained above 28°C. This Tsk values suggest that individuals were thermally comfortable [41] and, therefore, muscle temperature was not decreased to low values (i.e. under 28°C) that would accelerate muscle glycolysis and increase BLa concentrations [42].

Conclusion

The changes in estimated $\mathring{V}O_{2MAX}$ during an Antarctic expedition depend on the pre-expedition aerobic fitness of the individuals. For those with lower initial estimated $\mathring{V}O_{2MAX}$ (i.e. researchers), physical exertion in the field, which mainly consisted of low- to moderate-intensity efforts, represented an effective training load, thereby increasing aerobic capacity and reducing cardiac strain; this reduced strain likely results from cardiac autonomic adaptations, as evidenced by greater parasympathetic activity. In contrast, individuals with greater initial estimated $\mathring{V}O_{2MAX}$ (i.e. mountaineers) showed reduced aerobic fitness, indicating that physical demand was not enough to configure an effective training load to them. Our results also indicate that there is a physiological strain associated with labour in Antarctica, as demonstrated by some activities that require high HR values, for which individuals should prepare themselves in advance.

Perspectives

Considering that shivering influences energy expenditure and may contribute to improve $\mathring{V}O_{2MAX}$, future studies should measure $\mathring{V}O_2$ using indirect calorimetry during expeditions in Antarctica. In addition, the lactate turnover and the possible effect of lower muscle temperatures in increasing BLa concentrations should also be evaluated. Regarding thermoregulation, as the physical effort during fieldwork may activate responses aimed at dissipating heat (e.g. sweating), which results in increased body water loss, we suggest the quantification of regional sweating rates and number of active sweat glands, as well as the recording of core body temperatures. Finally, the challenging technical and logistical conditions of investigating physiological responses/adaptations induced by fieldwork in Antarctica is another issue that should be overcome. If considered the increasing number of visitors, military and researchers that have reached Antarctica every year in the last decades, we believe that it is paramount to publish, develop and improve methodologies that allow data collection in these settings.

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