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ORIGINAL RESEARCH ARTICLE

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Body fat attenuates muscle mass catabolism among physically active humans in temperate and cold high altitude environments

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Abstract

Objective: Typical diet plans are based on an individual's body mass; however, body composition may be important to consider when an individual is in a negative energy balance. This study examines if high initial body fat and dietary macronutrient content reduce muscle mass catabolism during excursions in temperate and cold high altitude environments.

Methods: Subjects—53 healthy, un-acclimated volunteers (37 males and 16 females)—took part in 12-16 week-long outdoor education courses in moderately high altitude temperate and cold climates in the western United States. Body mass, body fat percentage, fat mass, and muscle mass were measured before and after each excursion. Total energy expenditure and dietary intake were also measured.

Results: In temperate and cold environments, both sexes lost significant amounts of body mass. In temperate climates both sexes lost a significant amount of fat mass, but not muscle mass. In cold climates, there was no significant change in fat mass for either sex; however, females gained muscle mass while males lost muscle mass. In both climates subjects with lower initial body fat percentages lost significantly more muscle mass than subjects with higher initial body fat percentages. There was no significant relationship between macronutrient intake and muscle mass loss for either sex.

Conclusion: These results suggests that during a negative energy balance dietary macronutrient content cannot abate the loss of muscle mass, but body fat may have a protective effect. This information should be used to improve individualized diets based on body composition, not body mass.

KEYWORDS
body composition, energetics, high altitude, nutrition

1 | INTRODUCTION

Body mass is the key variable used to estimate dietary needs and ration plans; however, these body mass based estimates do not take into account an individual's risk of body composition changes while in a negative energy balance, where energy expenditure exceeds energy intake. High levels of physical activity and stressful environments can contribute to creating this negative energy balance (Zaccagni, Barbieri, Cogo, & Gualdi-Russo, 2014). Currently, much of the work examining body composition changes in extreme conditions focuses on high altitude environments. Acclimatization to hypoxia and altitude related illness increases energy expenditure, which can lead to a 17-27% increase in basal metabolic rate (Boyer & Blume, 1984; Butterfield et al., 1992; Rose et al., 1988; Wagner, 2010; Wee & Climstein, 2015; West,

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Abbreviations: BM, body mass; FM, fat mass; Flex-HR, flex-heart rate method; IEA, in-field energy assessment; MM, muscle mass; NOLS, National outdoor leadership school; RMR, resting metabolic rate; TEE, total energy expenditure.

2010; Westerterp, Kayser, Brouns, Herry, & Saris, 1992; Westerterp, Kayser, Wouters, Le Trong, & Richalet, 1994; Westerterp, Meijer, Rubbens, Robach, & Richalet, 2000; Tschop, Strasburger, Hartmann, Biollaz, & Bartsch, 1998; Zaccagni et al., 2014). A similar increase in basal metabolic rate is also seen among individuals in cold climates in order to maintain core body temperature (Moran, 2008; Steegmann, 2007). The increased metabolic costs due to cold climate and high altitude, in conjunction with high levels of activity, create a negative energy balance that leads to a reduction in body mass from fat and muscle mass. Many researchers have focused on these changes and how nutrition can be used to abate them; however, few have investigated how initial body composition affects body composition outcome. The work presented here investigates the importance of initial body composition and dietary macronutrient content to body composition changes incurred during physically demanding excursions in high altitude temperate and cold climates.

When in a negative energy balance, energy stores within the body, which come from glycogen, fat, and skeletal muscle protein, must meet metabolic demands. Glycogen is the most readily available source of energy during exercise. Once glycogen stores have been depleted, which can happen in less than four hours of strenuous exercise, fat is then used as an energy source (Edwards, Margaria, & Dill, 1934; McArdle, Katch, & Katch, 2013). However, fat stores cannot be fully depleted during a sustained negative energy balance. Humans require a minimum amount of fat, 4–8% in males and 8–19% in females, to maintain basic health and physiological functions (Achten, Gleeson, & Jeukendrup, 2002; Achten & Jeukendrup, 2004; FAO, 1998; Friedl et al., 1994; Gallagher et al., 2000; Venables, Achten, & Jeukendrup, 2005). Once this lower limit of essential fat has been reached, the body relies on protein stores to meet energetic needs (Carbone, McClung, & Pasiakos, 2012; Friedl et al., 1994; Horton, Pagliassotti, Hobbs, & Hill, 1998; Kayser, 1994; Wagenmakers, 1998).

How and when the body catabolizes skeletal muscle during a negative balance is still poorly understood (Kumar, Atherton, Smith, & Rennie, 2009). However, limited evidence suggests that after endurance exercise there is immediate protein breakdown, the rate of which can remain elevated for 24 h (Koopman et al., 2004; Kumar et al., 2009; Tipton, Ferrando, William, & Wolfe, 1996). This protein breakdown normally comes from dietary protein. However, in a negative energy balance, the protein is catabolized from skeletal muscle, which can result in muscle damage not only from catabolism but also from a lack of repair (Belcastro, Shewchuk, & Raj, 1998; Tipton & Wolfe, 2001). A diet with protein levels exceeding the recommended daily allowance has been shown to mitigate this potential muscle mass loss (Carbone et al., 2012; Farnsworth et al., 2003; Layman et al., 2003; Rodriguez & Garlick, 2008; Skov, Toubro, Ronn, Holm, & Astrup, 1999).

Having a greater reservoir of fat is another possible way to limit muscle mass catabolism, suggesting that those with higher body fat percentages experience reduced muscle mass loss. A number of studies have demonstrated the loss of fat and muscle mass during high altitude excursions, but these changes have not been related to initial body composition. For instance, Reynolds et al. (1999) found that Mt. Everest climbers and base camp workers lost fat mass while experiencing a negative energy balance. Among nonacclimatized individuals of European descent taking part in a Himalayan expedition, those with lower initial fat mass experienced greater muscle mass loss than those with a higher initial fat mass (Zaccagni et al., 2014). Two separate American Medical Research Expeditions to Mt. Everest found that expedition members experienced significant fat and muscle mass loss in the face of the high altitude and high levels of physical activity, but the relationship to initial body composition was not established (Boyer & Blume, 1984; West, 2010).

Further research is needed among individuals taking part in high levels of physical activity at high altitudes to determine the impact of initial body composition on final body composition outcome during a negative energy balance. Students taking part in a month-long National Outdoor Leadership School (NOLS) course experienced significant changes in body composition (Ocobock, Gookin, & Baynes, 2011). To expand upon that, total energy expenditure (TEE), energy balance and body composition changes were measured among NOLS students who took part in 12–16-week-long courses in the western U.S. backcountry in high altitude temperate and cold climates. TEE, energy intake, and macronutrient content were assessed to determine if NOLS students experienced a negative energy balance. Body mass, body fat percentage, and muscle mass were measured among these students before and after each climate regime to test two hypotheses that subjects with high initial body fat percentages experience (1) a greater fat mass loss and (2) reduced muscle mass catabolism. Macronutrient content was estimated to test the hypothesis that consuming greater amounts of dietary protein reduces muscle mass catabolism. Results from this study can be used to inform more individualized dietary plans and food ration preparation for physically demanding excursions.

2 | SUBJECTS AND METHODS

2.1 | Subjects

In this study 53 healthy volunteers (37 males and 16 females, aged 18–31 years) took part in four 12–16 week-long outdoor education courses operated by NOLS. They were US citizens, all of whom were un-acclimatized to high-altitude at the start of their course. Individual ancestry data were not collected. The Institutional Review Board of Washington University, St. Louis (IRB protocol 201104106) approved this study, and subjects gave informed consent prior to participating.

2.2 | Field settings

NOLS is a US-based nonprofit outdoor education program that offers its students the opportunity to live in the wilderness for an extended period of time. The core curriculum includes outdoor survival skills, leadership, risk management, and environmental studies. Two of the courses in this study, course names NS1 and NS2, took place during spring and summer for 12 weeks. The other two courses, course names FS5 and FS8, were in fall and winter for 16 weeks (Table 1). Students in NS1 and NS2 experienced temperate and hot climates. The hot climate portion was not included in this analysis since it did not take place at high altitude. Students in FS5 and FS8 experienced temperate and cold climates. NS1, NS2, FS5, and FS8 are four separate courses; there was no subject overlap from one course to another. Temperate climate exposures lasted five weeks, and cold climate exposures lasted four weeks. The locations and altitudes for the temperate and cold climates are provided in Table 1.

Body composition measurements were collected before (1st Measurement) and after (2nd Measurement) exposure to each climate. These measurements were taken at the NOLS headquarters in Lander, WY (1633 m altitude). The In-Field Energy Assessment (IEA) was performed while subjects were in the field for each climate. During the IEA, total energy expenditure (TEE), and dietary intake were measured.

The typical schedule for a NOLS course begins with students arriving in Lander, WY, several days before they embark on their backcountry experience. Students use this time to prepare gear and rations and meet their course-mates and instructors. It was during this time that the 1st Measurement of body composition was performed. Students then left for the first section of their course. Subjects were exposed to their in-field conditions for 2 weeks to allow for acclimatization. After this 2-week period, the IEA was performed and lasted 6–11 days (Table 1). Once the IEA was complete, subjects finished the first section of their course and returned to Lander, WY, for 2 days to change gear and replenish rations. During this time the 2nd Measurement of body composition was performed. This procedure schedule was followed for each of the climates.

During these courses, subjects took part in rigorous physical activities in which laborious days were followed by rest days. Subjects carried 2 weeks' worth of rations during their courses, and NOLS provided planned re-rations at two-week intervals. During the temperate climate sections of all four courses, subjects took part in extensive daily hiking and beginner mountaineering. Subjects would hike a mean of 7.3 ± 4.0 km day^{-1}. They carried all of their equipment and food during these hikes, often ending each day setting up a new campsite. During the cold climate sections of FS5 and FS8, subjects would cross-country ski or snow-shoe with their equipment and food for a mean of 5.7 ± 4.2 km day^{-1}, frequently ending each day camping at a new location. Subjects had to shovel snow a mean of 1.0 ± 1.7 h day^{-1} in order to set up camp.

2.3 | Anthropometric and body composition measurements

Body mass, muscle mass, fat mass, and percent body fat were measured using a Tanita BC-558 Ironman Segmental Body Composition Monitor bioelectrical impedance scale (Tanita Corporation, Arington Heights, IL). The athletic setting was chosen for these measurements due to the increased fitness achieved throughout courses and to maintain measurement consistency. The Tanita equations are unpublished.

TABLE 1 NOLS course summary including number of subjects, mean temperature, location, altitude, and duration of IEA (in-field energy assessment)

Course	*N*	Climate	Mean temp. (°C)	IEA location	Altitude (m)	IEA duration (days)
NS1	14	Temperate	15.6	Absaroka Mountain Range, WY	3205	11
NS2	11	Temperate	13.5	Absaroka Mountain Range, WY	3205	11
FS5	14	Temperate	13.8	Wind River Range, WY	3658	7
		Cold	−4.9	Absaroka Mountain Range, WY	3205	7
FS8	14	Temperate	14.2	Wind River Range, WY	3658	8
		Cold	−9.4	Absaroka Mountain Range, WY	3205	7

Measurements were taken on subjects in the morning before they consumed their first meal of the day.

2.4 | Temperature measurements

Temperature was measured using an Extech RHT10 Humidity and Temperature USB Data-logger (Extech Industries, Nashua, NH, USA) carried by the course instructors, attached to the outside of their backpacks. The device was brought into the tents with the backpacks each night. This device measured and recorded temperature and humidity on a minute-by-minute basis. Temperature data were downloaded using the Extech software (Extech Industries, Nashua, NH, USA). High, low, and mean temperatures were calculated for each day as well as averaged across the IEA (Table 1).

2.5 | Energy expenditure measurements

Resting metabolic rates (RMR) were collected from each subject using a portable respirometry unit (Cosmed K4b2, Chicago, IL, USA) following standard practice (Gayda et al., 2010). This system measures oxygen consumption and carbon dioxide production using a breath-by-breath analysis. RMR measurements were performed in the morning before subjects had their first meal. Subjects were in a supine position on foam pads placed on the floor in a temperature-controlled room. They rested 15–20 min before measurements were taken. Measurements lasted 6–8 min with the last four minutes of the measurement averaged to determine RMR.

TEE was measured among subjects using the Flex-Heart Rate method (Flex-HR) based on in-field heart-rate data collected using an ActiTrainer (Actigraph, Pensacola, FL, USA) heart rate monitor. This device was worn continuously during the IEA. Equations were calculated from a set of calibration measurements performed for each subject to convert heart rate to metabolic rate. For the calibration measurements, heart rate (bpm) and metabolic rate (kcal min^{-1}) were recorded simultaneously using a portable respirometry unit (Cosmed K4b2, Chicago, IL, USA) while subjects stood, walked (1, 1.5, 2 m s^{-1}), and ran (2, 2.5, 3 m s^{-1}) for 5 min at each speed on a treadmill. Calibration measurements were conducted before and after climate exposure.

To calculate the Flex-HR equations, the Flex-HR flex-point was determined for each subject as the mean of the highest heart rate at rest and the lowest heart rate during exercise following Leonard (2003). All in-field HR measurements below this flex-point were assigned the RMR. TEE for all in-field HR measurements above this flex-point, indicating activity, were calculated as the least-squares regression line for heart rate and energy expenditure. Missing in-field heart rate data were filled in using averaged heart rate values calculated from the available data for each day. A mean of 5.6 ± 1.9% heart rate data points was missing per subject per day. To account for changes in fitness throughout the course, only equations calculated from the calibration closest in time to the relevant IEA (temperate or cold) were used to implement the Flex-HR method. For example, the calibration measurements conducted at the end, not the beginning, of the temperate climate were used to estimate temperate climate TEE.

2.6 | Dietary intake

Subjects kept a daily diet log recording type and amount of food–collapsible measuring cups were provided to aid measuring accuracy. These logs were transcribed into Microsoft© Excel© for Mac 2010. Typical backcountry recipes were broken down into separate ingredients using *NOLS Cookery* (Pearson, 2004), *NOLS Backcountry Cooking* (Pearson & Kuntz, 2008), and *NOLS Backcountry Nutrition* (Howley, 2008). The official USDA National Nutrient Database for Standard Reference was used to assign nutritional values and protein, carbohydrate, and fat content for the foods consumed (USDA, 2012). Calories and macronutrients were summed for each subject for each day during the IEA. Subjects with blank or incomplete diet logs ($N = 9$) were removed, resulting in 44 subjects included in the macronutrient analysis.

2.7 | Statistical analysis

Figures were generated using Microsoft© Excel© for Mac 2010. Linear regressions and Students' *t* tests were performed using IBM© SPSS© Version 21. Males and females were analyzed separately and together for all analyses. Linear regressions were used to determine the relationship between initial body composition and the change in composition experienced while subjects were in the field. Repeated *t* tests were used to analyze composition differences within each subject. One sample binomial Clopper–Pearson and Jeffreys tests were used to determine the relationship between macronutrient (carbohydrates, protein, and fat) intake and muscle mass catabolism. Results were considered significant at the $p = .05$ level.

3 | RESULTS

For this study, it was hypothesized that initial body composition would influence body composition changes experienced by individuals participating in high levels of physical activity in high altitude temperate and cold climates. Specifically, it was expected that individuals with greater body fat

TABLE 2 Summary of female subjects' measurements

Climate	N	TEE (kcal day^{-1})	Dietary intake (kcal day^{-1})	Protein intake (g day^{-1})	Carbohydrate intake (g day^{-1})	Fat intake (g day^{-1})	Variables	1st measure	2nd measure	p values
Temperate	16	2884 ± 496	2238 ± 240	75.2 ± 11.5	290.7 ± 34.8	108.0 ± 19.1				
							HT (cm)	168.2 ± 0.1	–	
							BM (kg)	68.8 ± 9.3	67.7 ± 8.9	0.03
							Fat%	23.7 ± 6.0	21.7 ± 6.5	0.08
							FM (kg)	16.8 ± 6.4	15.2 ± 6.4	0.04
							MM (kg)	49.4 ± 3.5	49.9 ± 3.4	0.48
Cold	6	3837 ± 1176	2439 ± 384	74.0 ± 9.2	268.5 ± 15.0	96.3 ± 14.3				
							HT (cm)	170.0 ± 0.04	–	
							BM (kg)	70.1 ± 7.1	68.0 ± 8.7	0.04
							Fat%	24.9 ± 5.3	21.8 ± 5.7	0.02
							FM (kg)	17.8 ± 5.6	15.2 ± 6.1	0.48
							MM (kg)	49.7 ± 2.8	50.3 ± 3.3	0.01

The six subjects that took part in the cold climate also took part in the temperate climate. Results were considered significant at $p < .05$. TEE is total energy expenditure, HT is height, BM is body mass, FM is fat mass, and MM is muscle mass.

percentages would experience greater fat mass loss but reduced muscle mass loss compared to individuals with a lower initial body fat percentage. Furthermore, the effect of dietary macronutrient content on body composition changed was analyzed.

3.1 | Total energy expenditure and dietary intake

As measured by the Flex-HR Method in temperate climates, females expended a mean daily TEE of 2884 ± 496 kcal day^{-1} and a mean dietary intake of 2238 ± 240 kcal day^{-1} while males expended 3848 ± 783 kcal day^{-1} and consumed 2525 ± 119 kcal day^{-1}. In cold climates, females expended 3837 ± 1176 kcal day^{-1} and consumed 2439± kcal day^{-1} while males expended 5113 ± 1660 kcal day^{-1} and consumed 3095 ± 319 kcal day^{-1}. Subjects consumed roughly 1000 kcal day^{-1} fewer than they expended in temperate climates and consumed almost 2000 kcal day^{-1} fewer than they expended in cold climates.

3.2 | Body mass

In temperate climates males lost 2.8 ± 2.9 kg ($p < .001$) and females lost 1.1 ± 1.7 kg ($p = .027$). Similarly, males and females both lost body mass in the cold climate, 2.3 ± 1.1 kg ($p < .001$) and 2.1 ± 1.7 kg ($p = .04$), respectively. The mean values for anthropometrics and body composition data are in Table 2 for females and Table 3 for males.

3.3 | Body fat percentage and fat mass

In temperate climates, males lost 1.9 ± 2.4 kg ($p < .001$) and females lost 1.6 ± 2.7 kg of their fat mass ($p = .04$); 6 of 16 females (37.5%) and 18 of the 37 males (48.6%) reached a body fat percentage within the essential fat range. In cold climates, females tended to lose more than males, 2.6 ± 1.5 and 0.8 ± 1.9 kg, respectively; however, neither were significant ($p > .08$). Three of six female subjects (50%) and eight of 22 male subjects (42.1%) reached a body fat percentage within the essential fat range.

Individuals with a greater 1st measurement of body fat lost significantly more fat mass in both temperate ($p = .02$, $r^2 = 0.10$) (Figure 1A) and cold climates ($p = .029$, $r^2 = 0.19$) (Figure 1B). There was no significant relationship between initial body fat and fat mass lost among females ($p > .52$) for either climate. However, males with a high initial body fat lost significantly more body fat in the temperate climate ($p < .001$). There was not a similarly significant relationship in the cold climate ($p = .62$).

3.4 | Muscle mass

In temperate climates, females tended to gain muscle mass, 0.5 ± 2.54 kg, though not to a significant degree ($p = .48$).

TABLE 3 Summary of male subjects' measurements

Climate	*N*	TEE (kcal day^{-1})	Dietary intake (kcal day^{-1})	Protein intake (g day^{-1})	Carbohydrate intake (g day^{-1})	Fat intake (g day^{-1})	Variables	1st measure	2nd measure	*p* values
Temperate	37	3848 ± 783	2525 ± 119	86.6 ± 10.3	323.3 ± 43.0	122.7 ± 16.3				
							HT (cm)	181.8 ± 0.1	–	
							BM (kg)	77.4 ± 12.9	74.6 ± 11.5	<0.001
							Fat%	10.0 ± 5.3	9.0 ± 4.1	<0.001
							FM (kg)	8.9 ± 6.1	7.1 ± 4.6	<0.001
							MM (kg)	65.0 ± 7.8	64.1 ± 6.6	0.06
Cold	22	5113 ± 1660	3095 ± 319	94.6 ± 16.2	330.5 ± 57.5	131.1 ± 23.8				
							HT (cm)	181.1 ± 0.1	–	
							BM (kg)	77.6 ± 10.9	75.3 ± 10.2	<0.001
							Fat%	10.4 ± 3.9	9.6 ± 4.0	0.22
							FM (kg)	8.3 ± 4.3	7.5 ± 4.0	0.08
							MM (kg)	65.9 ± 7.5	64.4 ± 7.4	0.003

The 22 subjects that took part in the cold climate also took part in the temperate climate. Results were considered significant $p < .05$. TEE is total energy expenditure, HT is height, BM is body mass, FM is fat mass, and MM is muscle mass

Males tended to lose muscle mass, 0.9 ± 2.8 kg, which approached significance ($p = .06$). However, subjects with a low 1st Measurement of body fat percentage lost significantly more muscle mass than those with a higher initial body fat percentage (Figure 2A) ($p = .019$, $r^2 = 0.105$). In cold climates, females gained a significant amount of muscle mass, 0.6 ± 1.7 kg ($p = .01$), and males lost a significant amount of muscle mass, 1.5 ± 1.8 ($p = .003$). Subjects with a low 1st Measurement of body fat percentage lost significantly more muscle mass than those with high initial body fat percentages ($p = .013$, $r^2 = 0.241$) (Figure 2B). There is no significant relationship between initial body fat and muscle mass loss for either climate when the sexes are analyzed separately ($p > .1$).

3.5 | Macronutrient content and effect on body composition

Overall, in the temperate climate the dietary composition was 47% carbohydrates, 12% protein, and 41% fat. In the cold climate the dietary composition was 46% carbohydrate, 13% protein, and 41% fat (Table 4). There was no significant difference in macronutrient content between climates among males or females (Paired *t* test, $p > .3$ for all cases). There was no significant relationship between protein intake, which has been shown to reduce muscle catabolism, and changes in muscle mass in either climate for either sex ($p > .25$) (Figure 3A,B). The same was also true for carbohydrate and fat intake (carbohydrates: $p > .41$; fat: $p > .39$).

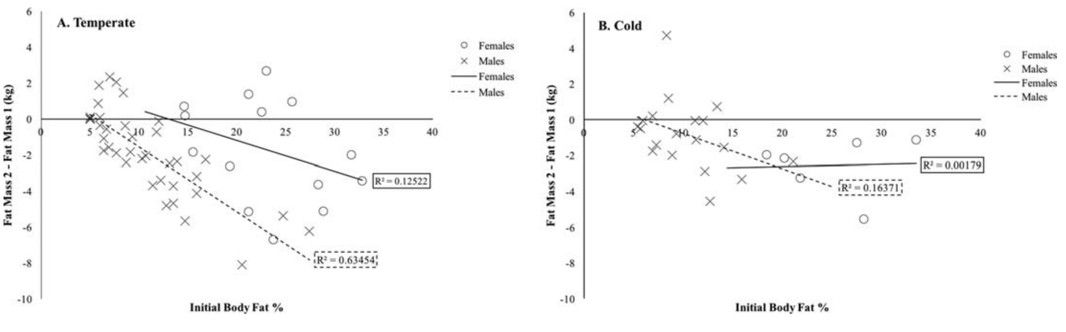

FIGURE 1 **A, B** Relationship between initial body fat percentage and fat mass lost in (**A**) temperate and (**B**) cold climates. Individuals with greater initial body fat percentage lost significantly more fat mass during their high altitude excursions in both climates. Females: ○ and Males: ×.

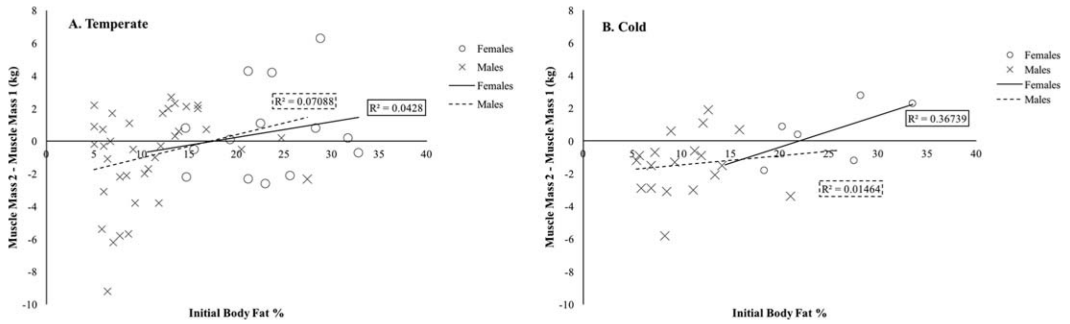

FIGURE 2 **A**, **B** Relationship between initial body fat percentage and muscle mass lost in (**A**) temperate and (**B**) cold climates. Individuals with higher initial body fat percentage lost significantly less muscle mass during their high altitude excursions. Females: ○ and Males: ×

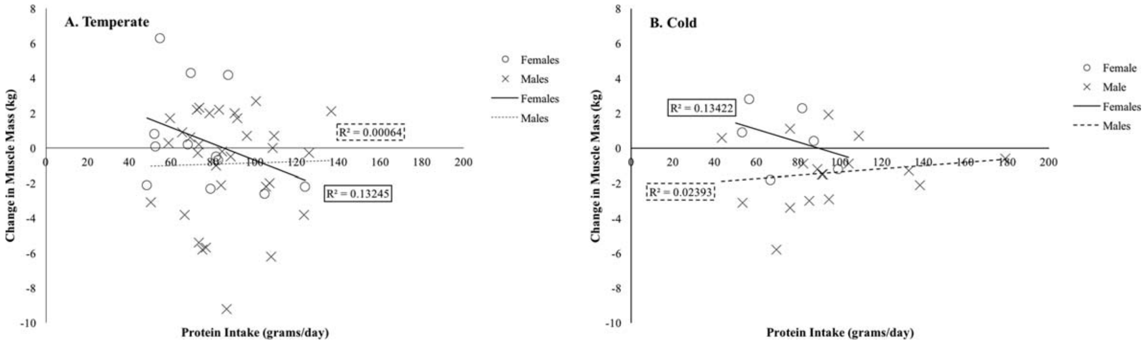

FIGURE 3 **A**, **B** Relationship between protein intake and muscle mass loss in (**A**) temperate and (**B**) cold climates. Females: ○ and Males: ×. Individuals who consumed more dietary protein did not experience reduced muscle mass catabolism, $p > .25$ in temperate and $p > .48$ in cold for both males and females

4 | DISCUSSION

This study analyzed how initial body composition influenced body composition changes during a period of a negative energy balance due to high activity levels in high altitude temperate and cold climates. NOLS subjects took part in prolonged endurance activities almost daily for several weeks. Given the known increase in protein catabolism within 24 h of endurance exercise (Koopman et al., 2004; Kumar et al., 2009; Tipton et al., 1996), these subjects were at a greater risk of catabolizing muscle mass. Subjects experienced an energy deficit of more than 1000 kcal day^{-1} in the temperate climates, and 2000 kcal day^{-1} in cold climates. Deficits of this magnitude required the NOLS students to utilize their own bodily energy stores to maintain their high levels of energy expenditure. At least 37% of NOLS students reached essential fat levels, requiring them to utilize stored protein for energy.

Overall, females tended to gain muscle mass but lose fat mass in both climates, whereas males tended to lose both. Furthermore, individuals with low initial body fat percentages lost significantly more muscle mass than those with high initial body fat percentages. These results suggest that possessing a higher body fat percentage might spare muscle mass catabolism during long periods of negative energy balance at high altitudes, which supports previous research that indicated a possible protective effect of body fat (Reynolds et al., 1999; Zaccagni et al., 2014).

TABLE 4 Summary of the body mass, total energy expenditure (TEE), caloric intake, and macronutrient content results for female and male subjects in temperate and cold high altitude environments

Climate	Sex	N	Body mass (kg)	TEE (kcal day^{-1})	Caloric intake (kcal day^{-1})	Carbohydrates (g day^{-1})	Protein (g day^{-1})	Fat (g day^{-1})
Temperate	Male	32	75.7	3822	2695	323.3	86.6	122.7
	Female	12	67.9	3081	2388	290.7	75.2	108.0
Cold	Male	17	75.7	4787	2880	330.5	94.6	131.1
	Female	6	67.7	3880	2287	268.5	74.0	96.3

Nutrition in a negative energy balance can play a critical role. In cold climates, subjects had the ability to carry perishable items such as meat, cheese, and eggs and preserve them in the snow. Access to a regular supply of fresh food with higher protein content, as opposed to the typical dry rations consumed during the temperate climate, vastly alters the macronutrient profile. A diet with protein levels exceeding the recommended daily allowance has been shown to mitigate muscle loss and promote muscle repair in individuals experiencing a negative energy balance (Carbone et al., 2012; Farnsworth et al., 2003; Fisher, Yagaloff, & Burn, 1999; Kayser, 1992; Koopman et al., 2004; Layman et al., 2003; Rodriguez & Garlick, 2007; Skov et al., 1999). However, even with potential greater access to a diet higher in protein, subjects did not eat significantly more protein and still experienced muscle mass loss in cold climates.

High altitude impacts metabolism and appetite beyond just higher energy expenditure, it can also lead to a decreased appetite (Westerterp et al., 2000; Westerterp-Plantenga, Westerterp, Rubbens, Verwegen, Richelet, & Gardette, 1999). One explanation for this is the broken link between hunger and the desire to eat, thought to be due to the elevated concentration of leptin observed at high altitudes (Westerterp, 2001; Westerterp et al., 1992). High levels of leptin, a satiety mediator, would reduce the feeling of hunger in an individual even if his or her body were in need of sustenance, perpetuating the negative energy balance (Tschop et al., 1998; Westerterp, 2001). Furthermore, there was no relationship between any of the dietary macronutrient levels and fat-free mass loss, suggesting that, in the face of such a large negative energy balance, macronutrient content, even protein levels, cannot protect against muscle mass loss.

These results demonstrate the need to assess initial body composition, an important factor that is often overlooked when planning diet rations for long-term backcountry forays. Traditional ration planning focuses on the number of individuals and each individual's body mass (Howley, 2008). However, one ration plan does not fit all. Individuals with a low body fat percentage are at greater risk for muscle mass catabolism as they will more quickly reach the lower limit of healthy body fat levels, and their physical performance will suffer (Carbone et al., 2012; Kayser, 1994). However, few ration plans take into account this individual variation in initial body composition, and, therefore, variation in nutritional needs. Ration plans should address this issue and provide recommended provisions based on body composition.

The present study has limitations. First, the use of a bioelectrical impedance scale is not the ideal method for measuring body composition due to changes in whole body hydration, particularly at high altitudes (Fulco et al., 1992). Steps were taken to reduce the impact of whole body hydration on measurements, such as collecting data in the morning before subjects ate or drank. Furthermore, all body composition measurements were taken at the same altitude (1633 m) in Lander, WY. Second, the two altitudes covered in this study were not the exact same, there was a difference of 400 m, which makes it difficult to assess the direct effect climate had on body composition changes. Finally, the sample of females in this study was much smaller than that of males. It is likely that with a greater sample size of women some of the trends seen in this study would have approached statistical significance. But, given the constraints of the NOLS curriculum and tendency for NOLS to have a higher male enrollment, these issues could not be avoided.

5 | CONCLUSION

This study reinforces the observed patterns of body mass loss at high altitude through fat and muscle mass loss. This study also establishes the relationship between initial body fat percentage and muscle mass loss, demonstrating the need for more individualized provision planning to mitigate potential muscle mass catabolism during high altitude excursions. Finally, changes in dietary macronutrient content, though high levels of protein have been shown to mitigate muscle mass loss, will not impact body composition changes in the face of a significant negative energy balance.

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