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# Energy Expenditure in the Backcountry

**Mandy Pojha**
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## Abstract

The study of energy economics, known as energetics, has played a key role in shaping human ecology, evolution, and performance (Leonard & Ulijaszek, 2002). Research on energetics gives insight into how humans interact with their environment and how differences in body shape and size can impact that interaction. This understanding is particularly insightful for humans living in the backcountry for extended periods of time. Selecting food types and amounts to meet high-energy demands in the backcountry setting is a challenge, because energy demand models have primarily been based on lab studies that, in hindsight, appear to routinely underestimate energy demands on backcountry expeditions.

This study examined Total Daily Energy Expenditure (TDEE) as it pertains to two to three week periods of time spent backcountry hiking, rock climbing, and skiing/camping in a winter environment. Total Daily Energy Expenditure is calculated by totaling the energy spent on basal metabolic rate, activity, thermoregulation, and Thermic Effect of Food (TEF). In total 59 participants were tested on courses with the National Outdoor Leadership School. Information from the study has been instrumental in informing the ration and nutrition practices at NOLS, as well as providing insight into other outdoor programs and backcountry users.

**Keywords:** *energetics, energy use, nutrition, backcountry travel, backcountry nutrition, physiology*

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## Introduction

A number of studies have been conducted assessing how humans allocate energy by examining subsistence strategies, growth and repair, reproductive output, thermoregulatory demands, mobility patterns, and human brain-size evolution (Durnin, 1990; Roberts, Heyman, Evans, Fuss, Tsay, & Young, 1991; Haggarty et al., 1994; Leonard & Robertson, 1994; Aiello & Wheeler, 1995; Panter-Brick, 1996a, b; Leonard & Ulijaszek, 2002).

Furthermore, body shape and size have been implicated as factors impacting the cost of both thermoregulation and activity (Ruff, 1991, 1994; Tikuisis, Moroz, Vallerand, & Martineau, 2000; Steudel-Numbers, 2006; Tilkens, Wall-Scheffler, Weaver, & Steudel-Numbers, 2007; Holliday & Hilton, 2010). This large body of work has examined the impact of individual environmental and morphological factors on human energy expenditure in the laboratory as well as indoor environments. But little research has been conducted on the comprehensive impact that environmental and morphological factors have on Total Daily Energy Expenditure among human populations living in a variety of natural environments (Askew, 2009). Thus, the field of outdoor education also lacks information on ration planning and food consideration for extended backcountry trips. Research specific to backcountry expeditions tends to focus on high altitude expeditions or short-duration climbs of large peaks. Limited within the field is an understanding of nutrition needs and adaptations for spending extended time in a backcountry environment (Hesterberg & Johnson, 2013).

## Methods

NOLS is a nonprofit outdoor education program that was founded in 1965. NOLS offers students the chance to live in the wilderness for an extended period of time, anywhere from two weeks to four months, while learning a variety of outdoor skills. NOLS has core curriculum that is taught on every expedition, including technical skills, leadership, risk management, and environmental studies. The ultimate goal is to train students to become independent wilderness travelers and leaders. NOLS has supplied field rations on expeditions for over five million user days, making it the premier ration provider in the world for recreational trips. Under the current ration system, NOLS uses a pounds-per-person/per-day formula to determine how much food should go on expeditions. While there is not a specific meal plan for most courses, the system allows students to create meals based on preference, time, and caloric needs. The average ration is 1.6 lbs per person/day for a hiking course, and up to 2.2 lbs per person/day for a winter course. Calorie averages are around 1,000 kilocalories per one pound of food (Howley Ryan, 2008). While this system has stood the test of time, little research has been done to understand the balance of calorie consumption and energy expenditure pertaining to this ration.

### Participants

The 59 subjects (40 males, 19 females, ages 18–30 years), participating in this study took part in four semester-long courses. Two of the courses (*n*=25) were in the spring/summer semester that lasted for three months and the other two (*n*=28) were in the fall/winter semester that lasted four months. Six subjects took part in the pilot study that was conducted during the summer of 2010 (Table 1.1).

**Table 1.1**

*The NOLS Courses that Took Part in this Study with their Corresponding Dates and Climates*

| Course | Semester | Activities | Course Duration |
|---|---|---|---|
| WSS 1 | Spring/Summer | Hiking & Climbing | 6/2/11 – 8/10/11 |
| WSS 2 | Spring/Summer | Hiking & Climbing | 6/4/11 – 8/12/11 |
| FSR 5 | Fall/Winter | Hiking & Winter | 9/4/11 – 12/3/11 |
| FSR 8 | Fall/Winter | Hiking & Winter | 9/8/11 – 12/10/11 |
| Pilot | Summer | Hiking & Climbing | 7/1/10 – 8/4/10 |

This subject pool was advantageous for two reasons. First, NOLS students were highly active and highly motivated to participate in data collection throughout their course. This made them ideal for both representing physically active populations and managing the logistics and time commitment necessary for this study. Second, the semester-long courses allowed for students to be tested during two separate activity types. Subjects taking part in the spring/summer semester were exposed to wilderness hiking and rock climbing for a month each. Subjects taking part in the fall/winter semester were exposed to wilderness hiking and winter ski travel for a month each. This means that two data sets were collected from each student: one during their hiking section, and a second during a more extreme activity, either climbing (hot climate) or ski travel (cold climate) depending on the course in which they participated. The students selected their NOLS course voluntarily prior to knowledge of the study, but all students agreed to the study upon arrival.

### Methods

Each participant underwent two phases of testing for a total of seven metrics. Many of these tests were completed multiple times and multiple days, resulting in a tremendous amount of data recorded for each student. The data in Table 1.2 and Table 1.3 represent summary versions of the data, while entire descriptions can be found in Appendix I.

Table 1.4 gives a visual representation of data collection in conjunction with the remainder of the semester. Field testing sections were on average 5 to 7 days of the section.

**Table 1.2**

*PHASE 1–Pre/Post Lab Testing*

| These data were collected three times throughout the semester long course: before the course began (Pre-Course Lab), in between the different climate regimes (Mid-Course Lab) and at the end of the course (Post-Course Lab). | |
|---|---|
| **Test** | **Method** |
| Resting Metabolic Rate | Portable respirometry unit (Cosmed K4b2, Chicago, IL, USA) following Gayda et al. (2010) |
| Heart Rate Calibration | Subjects wore both the portable respirometry unit and a heart rate strap during calibrations so that metabolic rate and heart rate were collected simultaneously |
| Anthropometric and bioelectrical impedance measurements. | Utilized the Tanita Ironman Scale (reliability is +/- 5% as compared to gold standard DEXA scan). |

**Table 1.3**

*PHASE 2–Field Energy and Activity Testing*

| These data were collected for five-day periods, twice during each semester course. Each course had one testing period during a hiking section and one testing period during either a climbing or winter section. | |
|---|---|
| **Test** | **Method** |
| Acti-Trainer Heart Rate Monitor | Measures minute-by-minute heart rate as well as 3-axis accelerometry data to count steps. |
| Doubly Labeled Water | Eight Subjects were given an oral dose of DLW (116.08-122.62g; 10% $H_2^{18}O$, 6% $^2H_2O$). Urine samples were taken before and after the administration (and kept cold). |
| Food Diary | Exact food types and quantities that were consumed throughout the day. |
| Activity Diary & Temperature Recordings | Taken by NOLS Instructors |

**Table 1.4**

*Activities and Timing Measured*

| Pre-Course Lab Testing | Hiking Acclimation | Hiking Field Testing | Subjects Finish Section | Mid-Course Lab Testing | Climb/Ski Acclimation | Climb/Ski Field Testing | Subjects Finish Section | Post-Course Lab Testing |
|---|---|---|---|---|---|---|---|---|
| RMR, HR Calibration, Anthropo-metrics | 2 weeks | Energy and Activity Assessment | 1-2 weeks | RMR, HR Calibration, Anthropo-metrics | 2 weeks | Energy and Activity Assessment | 1-2 weeks | RMR, HR Calibration, Anthropo-metrics |

Finally, the locations of the testing sites are pertinent in regard to climate and altitude. The majority of the testing took place in Lander, Wyoming, at 1,600 meters. The two mountain locations (Wind River and Absaroka) have elevations ranging from 2,000–3,000 meters. The climbing locations include City of Rocks at 2,000 meters and Devil's Tower at 1,500 meters. The river base of Vernal, UT is at 1,600 meters. Table 1.5 provides additional information about each location and Table 1.6 provides insight to temperatures in these locations.


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In total, data collection ranged from July of 2010 through December of 2011. Results are discussed in the subsequent section.

### Table 1. 5

*Locations of the Different Data Collection for Each Course*

| *Course* | *Pre-Course Lab Testing* | *Hiking* | *Mid-Course Lab Testing* | *Climbing* | *Ski Travel* | *Post-Course Lab Testing* | Sample Size |
|---|---|---|---|---|---|---|---|
| WSS 1 | Lander, WY | Absaroka Range, WY | Lander, WY | City of Rocks, ID | – | Vernal, UT | 13 |
| WSS 2 | Vernal, UT | Absaroka Range, WY | Lander, WY | Devil's Tower, ID | – | Lander, WY | 11 |
| FSR 5 | Lander, WY | Wind River Range, WY | Lander, WY | – | Absaroka Range, WY | Lander, WY | 12 |
| FSR 8 | Lander, WY | Wind River Range, WY | Lander, WY | – | Absaroka Range, WY | Lander, WY | 14 |
| Pilot | Lander, WY | Wind River Range, WY | – | – | – | Lander, WY | 6 |

### Table 1.6

*The Minimum, Maximum, and Mean Temperatures (°C) for the Energy and Activity Assessment Data Battery for Each Climate*

| *Course* | *Hiking* | | | *Climbing* | | |
|---|---|---|---|---|---|---|
| | *Minimum* | *Maximum* | *Mean* | *Minimum* | *Maximum* | *Mean* |
| WSS 1 | 1.2 | 42.1 | 15.6 | 15.1 | 45.1 | 23.3 |
| WSS 2 | 0.3 | 39.2 | 13.5 | 15.4 | 46.7 | 23.5 |
| | | | | | | |
| | *Hiking* | | | *Winter* | | |
| | *Minimum* | *Maximum* | *Mean* | *Minimum* | *Maximum* | *Mean* |
| FSR 5 | -2.1 | 30.3 | 6.2 | -17.45 | 17.0 | -4.9 |
| FSR 8 | 0 | 41.4 | 14.0 | -26.8 | 14.8 | -9.4 |
| | | | | | | |
| | *Hiking* | | | | | |
| | *Minimum* | *Maximum* | *Mean* | | | |
| Pilot | -3.3 | 25 | 12.8 | | | |

## Results and Discussion

The focus of this study was to understand the relationship between food and exercise in the wilderness environment. Crucial to this research goal was a better understanding of Total Daily Energy Expenditure (TDEE). Data in Table 2.1 represents the various methods that were used to determine TDEE. The Doubly Labeled Water (DLW) applied to only the 11 participants selected for this invasive testing. Additionally, the Flex-HR is based on heart rate monitors for all participants, the Factorial Method is a predictive model that has been used previously, and the Allocation Model is a new predictive model designed by this study (reliability remaining untested).

**Table 2.1**

*Summary of the Total Daily Energy Expenditure for Each Subject in Hiking, Climbing, and Winter Sections as Measured by the Doubly Labeled Water Method, Flex-HR Method, the Allocation Model, and the Factorial Method*

## The Allocation Model for Predicting Human Total Daily Energy Expenditure

| Section | Subject | DLW TDEE (kCal day$^{-}$) | Flex-HR TDEE (kCal day$^{-}$) | Allocation Model TDEE (kCal day) | Factorial Method TDEE (kCal day) |
|---|---|---|---|---|---|
| Hiking | NS1-12 | 4264 | 5427 | 3280 | 3156 |
| | NS2-1 | 2837 | 2814 | 3217 | 2591 |
| | FS5-12 | 2593 | 3949 | 2595 | 2196 |
| | FS8-10 | 3597 | 3138 | 3118 | 2839 |
| | Pilot 1 | 3340 | 3729 | 3675 | 2286 |
| | Pilot 3 | 3641 | 4031 | 3537 | 2644 |
| | Pilot 4 | 4313 | 4889 | 4276 | 2839 |
| Climbing | NS1-12 | 3790 | 5668 | 3629 | 3093 |
| | NS2-1 | 2838 | 3651 | 2154 | 2027 |
| Winter | FS5-1 | 4517 | 9155 | 5090 | 3031 |
| Skiing | FS8-10 | 4137 | 4678 | 5687 | 3261 |

The Allocation Model is designed to better predict human Total Daily Energy Expenditure over a range of physical activity levels and in any given climate. This model consists of metabolic cost terms for basal metabolic rate (BMR), activity, thermoregulation, and the thermic effect of food (TEF).

*Total Daily Energy Expenditure= BMR + Activity + Thermoregulation + TEF*

The Allocation Model was used to calculate metabolic costs on a day-by-day basis as well as a daily mean for the entire data collection period. As demonstrated in Figure 2.1, the Allocation Model produced daily Total Daily Energy Expenditure with a mean of 3242$\pm$517 kcal day for the hiking ($N$=52), 2704$\pm$396 kcal day$^{-1}$ for climbing ($N$=21) and 5200$\pm$802 kcal day for the winter travel (N=22). Figure 2.2 also provides the numerical values of range and mean for the various courses.

Beyond the TDEE, it is imperative to understand the breakdown of energy expenditure between BMR, activity, thermoregulation and TEF for the different sections during the entire data collection period. These understandings greatly improve the ability to predict caloric needs in the future. Table 2.3 summarizes the percentage each cost comprises of the Total Daily Energy Expenditure budget for the three different activities and Table 2.4 summarizes the minimum, maximum and mean metabolic cost of each component, by course.


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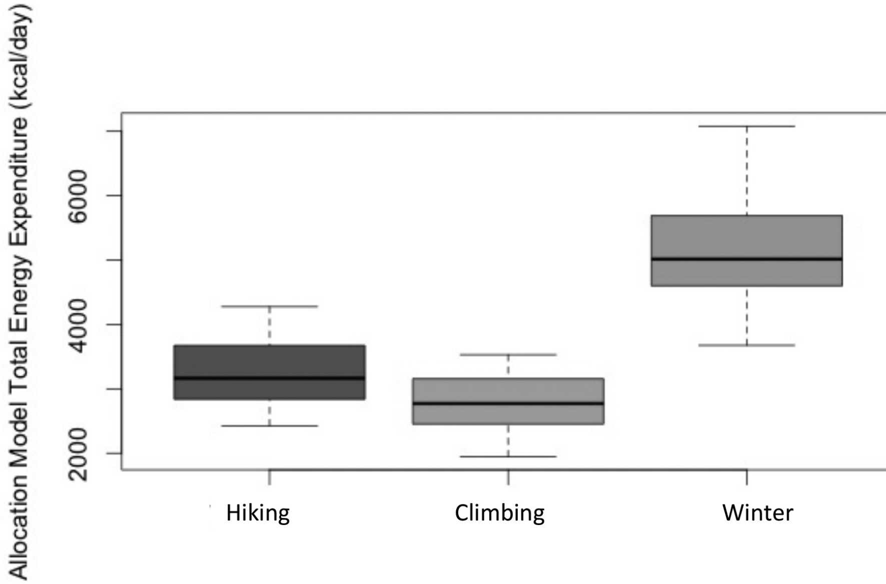


***Figure 2.1.*** Summary of daily TDEEs for the entire data collection period as calculated from the Allocation Model for hiking, climbing, and winter environments. TDEEs range from 2,439–4,276 kCal day for the hiking, 1947-3629 kCal day for climbing, and 3,965–7,080 kcal day for winter

**Table 2.2**

*A Summary of the Mean Daily Total Daily Energy Expenditure Values over the Entire Data Collection Period as Calculated by the Allocation Mode**

| Course | Climate | TDEE Range (kCal day) | Mean TDEE (kCal day) |
|---|---|---|---|
| WSS1 | Temperate | 2483-3530 | 3031±302 |
| WSS1 | Hot | 2397-3629 | 2928±339 |
| WSS2 | Temperate | 3208-4219 | 3789±266 |
| WSS2 | Hot | 1947-2965 | 2480±314 |
| FSR5 | Temperate | 2439-3497 | 2817±272 |
| FSR5 | Cold | 3965-5407 | 4595±449 |
| FSR8 | Temperate | 2469-3951 | 3063±431 |
| FSR8 | Cold | 4405-7080 | 5678±754 |
| Pilot | Temperate | 3537-4276 | 3908±283 |

*The Range and Mean Values are Provided for the Climates Experienced by Each Course

**Table 2.3**

*Summary of the Allocation Model Metabolic Cost Breakdown for Each TDEE Component: BMR, Activity, Thermoregulation and TEF for Temperate, Hot, and Cold Climates**

| Skill Type | BMR | Activity | Thermoregulation | TEF |
|---|---|---|---|---|
| *Hiking* | 52.1% (1662) | 24.4% (780) | 15.5% (494) | 8.0% (254) |
| *Climbing* | 62.3% (1690) | 17.2% (465) | 11.3% (306) | 9.2% (250) |
| *Winter* | 31.7% (1680) | 43.7% 2316) | 19.2% (1018) | 5.3% (282) |

*The percentage of TDEE each component makes up and it corresponding mean cost (kcal day) are reported.

The most notable difference in allocation breakdown between the course types is the proportion of Total Daily Energy Expenditure that is made up by activity cost, as demonstrated in Figure 2.2. Activity comprises 36±3.6% of energy expenditure for winter ski courses compared to 21±4.7% and 14±4.3% in hiking and climbing sections respectively. Surprisingly, the percentage that thermoregulation comprises of the total energy budget is similar between the climates: 13±4.4%, 9±1.3%, and 16±4.8% for hiking, climbing, and winter environments, respectively.

Though the analyses presented earlier demonstrated that there is an increased energy expenditure associated with cold climates for each component of the total energy budget (Table 2.4), it is attributable to the high activity levels more than the cold temperatures. Winter courses involve a great deal of ski travel, shoveling, and using physical activity to stay warm. An additional study of a less active winter environment would provide additional insight to hypothesized increases to thermoregulation costs.

### Total Daily Energy Expenditure Discussion

The NOLS population was used for this study for many reasons, but one of the most compelling was that we were able to observe one student in two separate environments, hiking and either climbing or winter ski environment. Analysis of the flex-HR results revealed that there was no significant difference between the hiking and climbing energy expenditure. However, subjects taking part in winter sections experienced significantly higher Total Daily Energy Expenditure than what they experienced in hiking sections. This mirrors studies done on indigenous populations that found increased metabolic rates associated with cold climates (Leonard et al., 2002, 2005; Snodgrass et al., 2005, 2006, 2008).

The energy expenditure due to activity and thermoregulation were each significantly higher in the winter section than in both the hiking and climbing sections. And the expenditure due to activity and thermoregulation in tem-

**Table 2.4**

*Summary of the Allocation Model Metabolic Cost Breakdown for Each TDEE Component: BMR, Activity, Thermoregulation, and TEF for Each Course**

| Section | | BMR (kCal day) | Activity (kCal day) | Thermoregulation (kCal day) | TEF (kCal day) |
|---|---|---|---|---|---|
| *WSS1 Hiking* | *Minimum* | 1292 | 534 | 402 | 183 |
| | *Maximum* | 2115 | 733 | 563 | 314 |
| | *Mean* | 1731 | 609 | 480 | 252 |
| *WSS1 Climbing* | | | | | |
| | *Minimum* | 1427 | 394 | 272 | 131 |
| | *Maximum* | 2108 | 942 | 353 | 386 |
| | *Mean* | 1768 | 569 | 318 | 282 |
| *WSS2 Hiking* | *Minimum* | 1339 | 958 | 331 | 147 |
| | *Maximum* | 1887 | 1355 | 640 | 338 |
| | *Mean* | 1633 | 1122 | 461 | 262 |
| *WSS2 Climbing* | | | | | |
| | *Minimum* | 1348 | 174 | 242 | 124 |
| | *Maximum* | 1844 | 674 | 369 | 346 |
| | *Mean* | 1612 | 361 | 293 | 218 |
| *FSR5 Hiking* | *Minimum* | 1386 | 470 | 310 | 67 |
| | *Maximum* | 2134 | 666 | 562 | 353 |
| | *Mean* | 1665 | 527 | 423 | 240 |
| *FSR5 Winter* | *Minimum* | 1408 | 1686 | 346 | 181 |
| | *Maximum* | 2030 | 2407 | 1448 | 444 |
| | *Mean* | 1700 | 1953 | 920 | 290 |
| *FSR8 Hiking* | *Minimum* | 1345 | 625 | 279 | 86 |
| | *Maximum* | 2273 | 1020 | 525 | 432 |
| | *Mean* | 1687 | 747 | 425 | 236 |
| *FSR8 Winter* | *Minimum* | 1372 | 2196 | 562 | 195 |
| | *Maximum* | 2161 | 3697 | 1525 | 453 |
| | *Mean* | 1660 | 2678 | 1117 | 274 |
| *Pilot-Hiking* | *Minimum* | 1334 | 903 | 646 | 272 |
| | *Maximum* | 1695 | 1258 | 1089 | 389 |
| | *Mean* | 1500 | 1143 | 950 | 323 |

perate hiking sections were significantly higher than in hot climate climbing sections. There was no significant difference between hiking and climbing in the expenditure due to the thermic effect of food. However, in winter ski environments, the cost due to TEF was significantly higher than in hiking sections, but not in climbing sections.

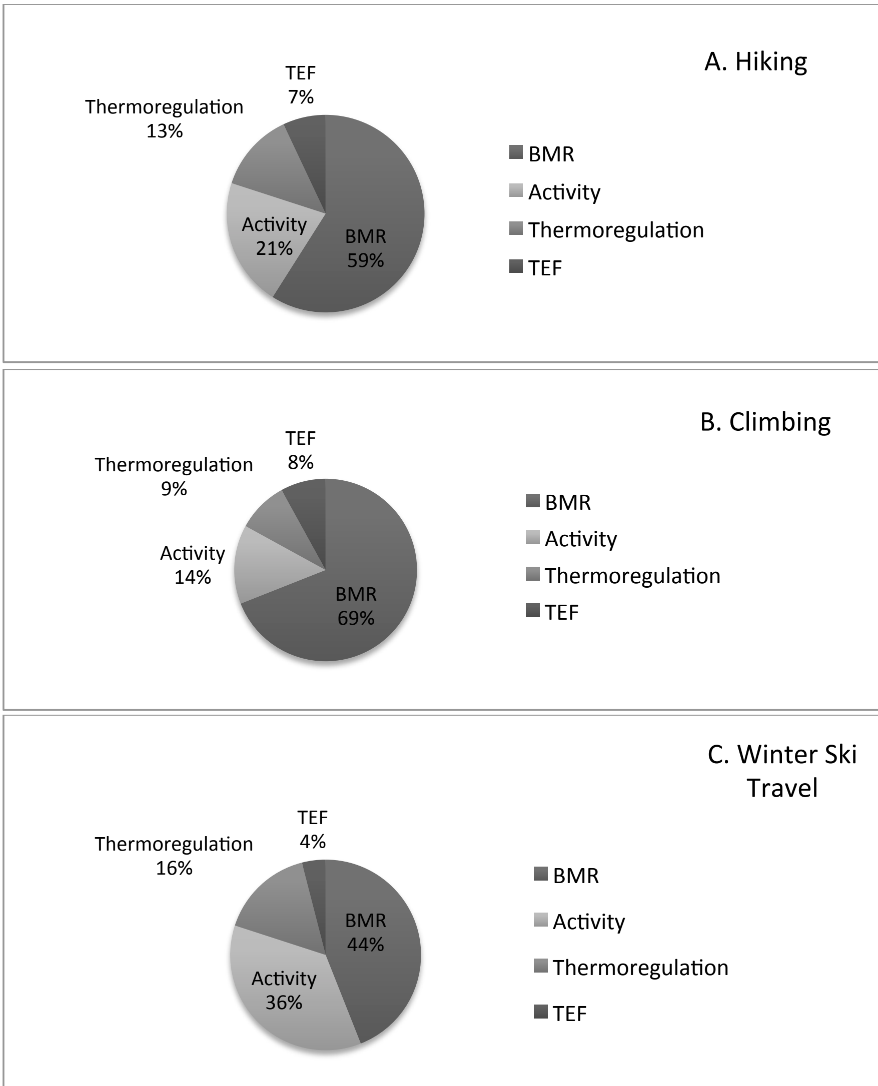


***Figure 2.2.*** The percentage that BMR, activity, thermoregulation and TEF comprise of TDEE for the different sections A) Hiking, B) Climbing and C) Winter during the entire data collection period. Basal metabolic rate makes up over half of the Total Daily Energy Expenditure budget in both hiking and climbing sections. On the winter section, activity takes up a larger proportion of the energy expenditure budget compared to hiking and climbing.


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## Food Intake Discussion

The data collected from the food logs was varied in quality and comprehensiveness. NOLS is seeking additional research opportunities to explore the specifics of a likely caloric deficit on courses. Based on the work of this study, it appears to be very challenging to provide participants with enough food to meet their energy expenditure needs on high-activity days, particularly when constrained by the weight of food contributing to the difficulty of travel (ie on their back or in a sled). There may be physiological boundaries as well: there are limitations to the intake and digestion of food beyond the normal food intake each person is used to, leading to an energy deficit condition called over-exertion malnutrition (Askew, 2009).

## Conclusions and Plans for Future Study

The results presented here demonstrate the differences in energy expenditure and its components between hiking, climbing, and winter ski travel. It is apparent that individuals traveling in the backcountry are expending a large number of calories to fulfill the physical requirements of the environment. Once again, those averages were 3,242 calories for hiking, ($N$=52), 2,704 calories for climbing ($N$=21) and 5,200 calories for winter ($N$=22).

In general, NOLS estimates that one pound of dry ration equates to 1,000 calories of prepared food. This would mean that over five pounds of food would be required to reach calorie equilibrium for the average NOLS winter course. As of now, carrying 2.5 pounds of food per person/per day is the top end for maintaining a pack weight that can be transported from one camp to another.

The reality of high caloric expenditure coupled with the challenges of carrying more food leaves expeditions struggling to balance the economics of energy. Below are five suggestions for all backcountry users.

**Use calories and pounds for planning.** Instead of just buying random food for a trip, backcountry users should calculate estimated calorie needs for the trip and buy food accordingly. Even though it is unlikely anyone can carry and eat 8,000+ calories for a really challenging day, it will help recreationalists know what their bodies are enduring in the backcountry and ensure they do not overload their pack weight

**Eat all the food.** Although it seems foolish, often individuals and programs return from the mountains having carried unutilized calories the entire time. The best bet for minimizing calorie deficit is to actually eat the food participants are carrying throughout the trip.

**Consume energy before and during exercise**. During long days on the trail, rock, or snow, the body needs constant nourishment. Eating every 60–90 minutes is the best practice for not having a noticeable drop in glucose and glycogen levels.

**Carry less, get more**. Of the three macronutrients, fat has the most caloric value at nine calories per gram as opposed to four calories per gram for protein and carbohydrates. When weight is a concern, packing foods with fat means the same weight of food will actually provide more calories.

**Eat a snack immediately following exercise.** Recent research suggests an anabolic window of 20–40 minutes postexercise in which cells are most open to tissue repair (Aragon & Schoenfeld, 2013). A snack with a 4:1 ratio of carbohydrates to protein is considered the ideal ratio, with examples including cheese and crackers, peanut butter and bread, or fruit and nuts.

Subsequent studies should identify more accurate ways to understand food consumption and the daily balance of energy intake and output. Studies could also expand to include more activity types such as paddling and biking. Additional work to validate The Allocation Model is needed in order to accept the model's predictive qualities and gain an understanding of its validity and reliability.

## Appendix I

## Testing Methods Explained

### Anthropometrics and Body Composition

Several external anatomical measurements were collected following Lohman et al. (1988) (Table A.1). These measurements were collected using a standard cloth measuring tape in millimeters and large calipers. Body mass, percent body fat and muscle mass were collected using a bioelectrical impedance scale, Tanita BC-558 Ironman Segmental Body Composition Monitor (Tanita Corporation, Arlington Heights, IL, USA).

### Resting Metabolic Rate (RMR) and Heart Rate Calibrations

Resting metabolic rates were collected from each subject using a portable respirometry unit (Cosmed K4b2, Chicago, IL, USA) following Gayda et al. (2010). This system measures oxygen consumption and carbon dioxide production using a breath-by-breath analysis. RMR measurements were taken early 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, and rested 15–20 minutes before measurements were taken. Measurements were then taken for 6–8 minutes with the last four minutes of the measurement averaged to determine RMR.

Heart rate calibrations, used to calculate Total Daily Energy Expenditure from heart rate using the Flex-HR Method, were also performed using a portable respirometry unit (Cosmed K4b2, Chicago, IL, USA) following Gayda et al. (2010). Subjects wore both the portable respirometry unit and a heart rate strap during calibrations so that metabolic rate and heart rate were collected simultaneously. This provided the data to determine the relationship between heart rate and metabolic rate (kcal day) at a variety of exercise intensities. Data

**Table A.1**

*Anthropometric Measurements Collected*

| *Measurement* | *Definition* |
|---|---|
| Neck + Head length | Taken from the C-7 spinous process to the skull apex |
| Head circumference | Taken from glabella to opisthocranion |
| Neck length | Taken from the junction of the neck and shoulder to the mastoid process |
| Neck circumference | Taken from the length mid-point of the neck |
| Total arm length | Acromion to dactylion |
| Upper arm length | Acromion to olecranon |
| Lower arm length | Radion to stylion |
| Hand length | Stylion to dactylion |
| Upper arm circumference | Taken at the length mid-point of the upper arm |
| Forearm circumference | Taken at the length mid-point of the forearm |
| Wrist circumference | Taken just distal to the styloid process |
| Chest breadth | Males – nipple/fourth rib level, females – just below the bust |
| Chest depth | Males – nipple/fourth rib level, females – just below the bust |
| Chest circumference | Males – nipple/fourth rib level, females – just below the bust |
| Bi-iliac | Taken from the most lateral distance between the left and right tubercles |
| Bi-asis | Distance between the left and right anterior superior iliac spines |
| Total leg length | Greater trochanter to floor |
| Upper leg length | The lateral cord from the greater trochanter to tibia |
| Low leg length | Tibia to the tip of lateral malleolus |
| Foot length | Heel to toe |
| Proximalthigh circumference | Taken at the junction of the thigh and pelvis |
| Mid-thigh circumference | Taken at the length mid-point thigh |
| Distal thigh circumference | Taken just above the knee |
| Calf circumference | Taken at the maximal circumference of the calf |
| Ankle circumference | Taken just above the lateral malleolus |

collected for resting metabolic rates were averaged (kcal day$^{-}$) for the last four minutes of the RMR measurement. This was done for the precourse, mid-course, and postcourse resting metabolic rate measurements.

To execute the Flex-HR method, the flex-point and the linear relationship, calibration equation, between energy expenditure and heart rate at different exercise intensity levels were first determined. The flex-point was determined to be the mean of the highest heart rate at rest and the lowest heart rate during exercise. To determine the calibration equation for heart rates above the flex-point, the heart rates were plotted against their corresponding energy expenditure and the linear relationship determined.

### In Field Energy Expenditure and Activity Measurements

**Flex-Heart Rate Method.** ActiTrainer heart rate monitors (ActiGraph, Pensacola, FL, USA) were used to collect heart rate data (Crouter, Churilla, & Basset, 2006). The ActiTrainer collected a minute-by-minute average heart rate and those data were stored in the unit's internal memory and later downloaded for analysis and TDEE calculations. This device also collected the number of steps, 3-axis accelerometry data, date, and time. Subjects wore a combination ActiTrainer data recorder and heart rate strap for 6–11 days depending on the course (Table A.2).

### Table A.2

*Dates during which Subjects Took Part in the Energy and Activity Assessment Data Collection Battery that Included the Subjects Wearing the ActiTrainer Heart Rate Monitors, Doubly Labeled Water Sample Collection, Temperature Data Collection and the Subjects Filling Out the Activity and Food Logs*

| *Course* | *Hiking* | *Climbing* | *Winter* |
|---|---|---|---|
| WSS 1 | 6/24/11 – 7/4/11 | 7/20/11 – 7/25/11 | – |
| WSS 2 | 8/1/11 – 8/10/11 | 7/10/11 – 7/15/11 | – |
| FSR 5 | 9/14/11 – 9/20/11 | – | 11/23/11 – 11/29/11 |
| FSR 8 | 9/25/11 – 10/2/11 | – | 12/1/11 – 12/7/11 |
| Pilot | 7/25/10 – 7/30/10 | – | – |

Subjects wore the data recorder either on an elastic belt around the waist or attached to the heart rate monitor chest strap. Subjects were asked to wear the ActiTrainer during all waking hours, and, if they felt comfortable, to wear the unit while sleeping. Subjects were also asked to remove the heart rate monitor unit when submersed in water.

Heart rate data were downloaded from the ActiTrainers and then converted to .csv files using the ActiGraph software (ActiGraph, Pensacola, FL, USA) for each Energy and Activity Assessment Battery of each subject. Missing data or erroneous heart rates (any heart rates above 200 or below 40) and their corresponding times were deleted. For those subjects who did not wear heart rate monitors while sleeping, resting heart rate (and, therefore, resting metabolic rate) was inserted during sleeping hours. The calibration equations and RMRs from the data collection battery after the Energy and Activity Assessment Battery of each climate were used. Heart rates below the flex-point were assigned the resting metabolic rate. All heart rates above the flex-point, indicating activity, were run through the calibration equations to calculate Total Daily Energy Expenditure. These metabolic rates were then used to extrapolate a full 24-hour total metabolic rate. Daily energy expenditures were calculated for each subject within each climate regime.

**Doubly Labeled Water Method**. Total Daily Energy Expenditure (kcal day) was measured using the doubly labeled water (DLW) method which is a very precise measure of Total Daily Energy Expenditure. Eight subjects took part in the DLW validation portion of this study. Three of these subjects were measured twice, once in the hiking section and once in the climbing or winter ski section. Two subjects were measured once, one in the hiking section and the other in the winter ski section. The other three subjects took part in the pilot study, which took place during a backcountry rock climbing section. Subjects were given an oral dose of DLW (116.08-122.62g; 10% $H_2{}^{18}O$, 6% $^2H_2O$). Dose bottles were rinsed with bottled water twice that was also consumed by subjects to ensure the full dose of this radioisotope was administered. Urine samples were collected prior to the DLW dose, 6–8 hours after the dose and then every other day for the duration of the Energy and Activity Assessment Battery. Urine samples were collected in clean, dry wax coated paper cups. Four 2ml cryovials (Sarstedt) were filled at each urine sample collection. Vials were labeled with the date, time and subject specific information. Vials were then placed in two waterproof plastic bags and kept cold in a small soft-pack cooler using either pack snow or mountain river water during the hiking sections. In the climbing section, bagged vials were kept in a large cooler filled with ice. During the winter section, bagged vials were kept in a waterproof bag left exposed to the adequate freezing ambient temperatures (average -9.4°C). Once samples were taken out of the field, they were placed in a -80°C freezer at Washington University in St. Louis for long-term storage.

Doubly labeled water samples from five subjects in the main study were analyzed using the Picarro Cavity Ring-Down Spectroscopy system (Sunnyvale, CA, USA) at Hunter College in New York. DLW samples from the three pilot study subjects were analyzed with gas-isotope mass spectroscopy at the Baylor College of Medicine, under the direction of Dr. William Wong.

**Activity, food and clothing diaries.** Subjects were asked to keep self-reported activity and food diaries for the duration of the Energy and Activity Assessment Battery. Subjects reported activity type (hiking, walking, climbing, cross country skiing, digging snow, etc.), distance or duration of activity and backpack weight during reported activity. Subjects reported type and quantity of food. Collapsible measuring cups were provided to aid measuring accuracy, though many subjects opted not to use these and instead estimated food amounts. Subjects also documented all of the clothing they took with them while in the field.

Activity diaries kept by subjects were transcribed into a database. Each day was entered separately to include the activity and its corresponding distance and duration. All distances and elevations were converted to meters. Data from the food logs were also transcribed into a database on a day-by-day basis. Kilocalories were calculated and assigned to each food entry using the *NOLS Cookery* (Pearson, 2004), *NOLS Backcountry Cooking* (Pearson & Kuntz, 2008), *NOLS Backcountry Nutrition* (Howley Ryan, 2008), and the official USDA National Nutrient Database for Standard Reference (USDA 2012). Kilocalories were summed for each day along with total carbohydrates, dietary fiber, sugar, protein, total fat, trans fat, and saturated fat. The average for each subject was calculated for the Energy and Activity Assessment Battery of each climate.

**Temperature data.** Temperature was measured using the Extech RHT10 Humidity and Temperature USB Data-logger (Extech Industries, Nashua, NH, USA). Two subjects each carried one data-logger in an outside pocket of their backpacks for the duration of the Energy and Activity Assessment Battery. This device measured and recorded temperature and humidity on a minute-by-minute basis, which was later downloaded for analysis.

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