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Total energy intake and self-selected macronutrient distribution during wildland fire suppression

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**TOTAL ENERGY INTAKE AND
SELF-SELECTED MACRONUTRIENT DISTRIBUTION
DURING WILDLAND FIRE SUPPRESSION**

by

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presented in partial fulfillment of the requirements for the degree of:

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Total energy intake and self-selected macronutrient distribution during wildland fire suppression

Chairperson: Brent Ruby, Ph.D.

Introduction: Wildland firefighters (WLFF) are required to work long hours in extreme environments resulting in high daily rates of total energy expenditure (TEE). Increasing the number of eating episodes throughout the shift and/or providing rations that promote convenient feeding has shown augmented self-selected work output, as has regular carbohydrate (CHO) consumption. It remains unclear how current WLFF feeding strategies compare to more frequent nutrient delivery. Our study's aim was to determine the self-selected field total energy intake (TEI), composition, and patterns of WLFF feeding during wildland fire suppression shifts.

Methods: 86 WLFF (16 female, 70 male; 27.5 ± 6.4 yrs) deployed to fire incidents across the United States throughout the 2018 fire season. Pre- and post-shift food inventories were collected at basecamp and provided item-specific nutrient content (calories [kcal], CHO, fat, protein). Work shift consumption (TEI, feeding frequency, episodic composition) was monitored in real-time by field researchers on fireline via observational data capture using mobile tablets. Shift work output was determined via actigraph accelerometry.

Results: WLFF work shift length averaged 14.0 ± 1.1 hr, with a TEI of 6.3 ± 2.5 MJ (1494 ± 592 kcal) (51 ± 10 , 37 ± 9 , $13 \pm 4\%$ for CHO, fat, and protein, respectively). WLFF averaged 4.3 ± 1.6 eating episodes (1.4 ± 1.3 MJ [345 ± 306 kcal] and 44 ± 38 g CHO \cdot episode $^{-1}$). WLFF who consumed >20 kcal \cdot kg $^{-1}$ averaged less sedentary activity than those consuming <16 kcal \cdot kg $^{-1}$.

Conclusion: The present work shift TEI approximates 33% of previously-determined WLFF TEE and demonstrates that WLFF consumption patterns using current rations may not deliver adequate nutrients for the occupational demands. Future work should elucidate the impact of work shift provisions on overall patterns of self-selected work output.

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I: INTRODUCTION

Throughout a fire season, wildland firefighters (WLFF) are exposed to a myriad of mental and physical challenges, including extended work shifts of up to 24 hr in adverse conditions (e.g., high ambient and radiant heat, acute altitude, low humidity), compromised dietary intake, smoke inhalation, and sleep deprivation (1–4). When deployed to a fire incident, WLFF establish base camps often comprised of homogenous catered meals, crowded living conditions (i.e., tent lodging), and noisy gasoline generators. The hardships of any assigned incident greatly depend on the fire intensity and size as well as geographic location and respective environmental conditions.

Common work duties often include brush removal, digging, hiking steep and rough/uneven terrain, sawyering (chainsaw work), and construction of fire-lines (2–4), all of which have been shown to require an average total energy expenditure (TEE) of roughly 6200 kcal/d (~26 MJ/d) (3). Although high-protein diets have been historically promoted for individuals performing large amounts of work (5), previous research has established that diets largely consisting of carbohydrates (CHO) are preferable to optimization of total work output by those engaged in demanding work or intense physical training (1,5–12).

Because of the laborious physical requirements, it is crucial for WLFF to maintain adequate energy consumption throughout the workday while also providing sufficient satisfaction to sustain consumption patterns for the entire fire season. Dietary provisions for fire crews with catering support consist of catered breakfast and dinner of unlimited proportions and a sack lunch to be consumed throughout the work shift. Many WLFF crews and individuals supplement provided meals with convenient foods such as dehydrated meats, dried fruit and nut mixes, energy bars, and sports drinks, some of which may not always be available due to cost, fire location, or policy restrictions. Undertaking shifts without supplemental foods can potentially result in acute and/or

chronic negative energy balance, consequently leading to premature fatigue. Such outcomes can limit overall work output and may ultimately jeopardize individual and crew safety.

From both a safety and performance perspective, it is imperative for the WLFF community to have a clear comprehension of the occupation's physiological demands. Research nutritional records have indicated a reduced total CHO intake in fire camps due to the self-selection of foodstuffs comprised of dietary fat and protein quantities greater than those recommended for arduous work (1). In addition to the specific composition and types of foods consumed, it has been demonstrated that the timing of consumption is essential to the maintenance of steady work output as well as the prevention of gastrointestinal discomfort (13–17). Moreover, previous literature has detailed the benefits of supplemental feeding, particularly that of CHO, during long-duration activity (>2 hr) and individuals' subsequently improved completion of physical work (5,6,9,13–32). Characterization of an advantageous macronutrient distribution and beneficial feeding habits may explicate the effects of diet on performance, thereby helping WLFF achieve optimal work output and minimize undue safety risk.

Study problems

Work shift provisions for WLFF currently include an isocaloric sack lunch of approximately 5.4-8.4 MJ (1300-2000 kcal); however, it is not well-established if this adequately provides the required amount of consumable energy to maintain work through extended shifts (≤ 24 hr) of fire suppression. Furthermore, habitual work shift consumption of WLFF has never been established, and, as such, there are several purposes of the current study:

1. Establish average caloric and macronutrient composition (CHO, fat, protein) of all work shift foods at beginning and end of work shift
2. Determine average caloric/macronutrient intake and distribution throughout shift

3. Outline average number of and time between feeding episodes within work shift
4. Evaluate average caloric/macronutrient intake and distribution per feeding episode
5. Describe periodic (e.g., hourly, percent of shift length) average caloric/macronutrient intake and distribution for all foods consumed during work shift
6. Determine average activity of WLFF throughout work shift
7. Assess potential relationships between consumed foods and activity output during work shift

Research hypotheses

Null: There will be no difference between observed work shift consumption and previously recommended guidelines.

Null: There will be no difference between previously determined and observed work shift activity counts.

Null: There will be no difference between observed energy intake and expenditure during work shift.

Study significance

It is important to ensure that WLFF are regularly consuming adequate fuel – quantity and quality (i.e., appropriate macronutrient proportions) – to safely and effectively perform daily labor duties. We therefore hope that the current study can provide a concise description of the currently available provisions and applied feeding habits, as well as measures of efficacy at providing sufficient energy as required by position duties and tasks. Additionally, our study will provide valuable information for WLFF and those in similar extended-shift occupations in regard to feeding strategies to support optimal work output.

Study rationale

Previous literature regarding the WLFF community has outlined the total energy expenditure of arduous fire suppression and the effects of supplemental feeding on overall work output. It is therefore reasonable to determine what provisions are currently available to WLFF as well as the average WLFF's self-selected feeding habits. We will then be able to compare our findings to those from previous WLFF energy intake and preferential consumption literature. A supplementary goal of our study will be to evaluate potential associations between habitual feeding and activity output throughout an average WLFF work shift.

Limitations

- Daily meal consumption tasks may be inconsistent as job tasks will vary depending on fire activity and regional conditions
- Data collection of self-selected feeding (sack lunch and supplemental provisions) away from base camp will require subjects to be followed by member of study team throughout work shift, potentially leading to unnatural feeding practices
- Subjects may consume foods that had not been inventoried prior to leaving base camp that morning (e.g., if given additional food from co-worker)
- All subjects will be from various WLFF crew types that have access to meal support via a third-party catering service (i.e., no subjects will be recruited from crews without external meal support)

Delimitations

- Observational data will be collected in field setting while WLFF are deployed to fires across western U.S. during 2018 fire season

- Subjects of both sexes and with varying amount of fire suppression experience will be selected from fire crews of all types
- Subject sack lunch and supplemental provisions will be inventoried via photograph and manual data capture prior to leaving base camp each morning and again upon return to base camp at end of shift
- Subject food consumption will be monitored by member(s) of study team for entirety of work shift (eliminate recall bias)

Key terms

<u>Abbreviation</u>	<u>Term</u>	<u>Definition</u>
CHO	Carbohydrate	Macronutrient substrate utilized as glycolytic fuel to produce usable energy in the form of ATP
	episode	Period of observed feeding during which no more than ten minutes elapsed between items consumed
FI _{Pre}	Food inventory before work shift	Daily catalogue of foods from all sources taken from base camp by WLFF to be consumed during work shift
FI _{Post}	Food inventory after work shift	Daily catalogue of foods from all sources brought back to base camp by WLFF at end of work shift
kcal	Kilocalorie	Amount of heat required to raise the temperature of 1000 g of water 1 degree (C); unit used to express heating value of foods and to measure metabolic rate
TEE	Total energy expenditure	Sum of energy expended during rest and activity; typically measured over a 24-h period and expressed in kcal or kJ
TEI	Total energy intake	Sum of energy consumed during rest and activity; typically measured over a 24-h period and expressed in kcal or kJ
WLFF	Wildland firefighter	Firefighter who suppresses fires in wilderness areas, such as mountains and backcountry

II: REVIEW OF LITERATURE

Energy expenditure

Wildland firefighters (WLFF) perform arduous duties including brush removal, chainsawing, hiking rough terrain with a heavy (≤ 20 -kg) load, and fire-line digging, often in adverse environmental conditions (acute altitude, high heat, low humidity) (2–4). Depending on the work being done and over what duration, labor duties can either prioritize long-term endurance or short-term productivity (33), both of which are required during wildfire suppression. Metabolic equivalents (METs), expressions of work performed in relation to an individual's basal metabolic rate (BMR), are often utilized to measure work output and determine the absolute intensity of specific performance tasks, whereas other measures (e.g., rating of perceived exertion, percentage of maximal heart rate) can be used to establish an activity's relative intensity (33). Although rigorous, energy-intensive efforts are periodically necessary, there is greater demand for sustained endurance throughout extended fire suppression shifts.

Total energy expenditure (TEE) of wildfire suppression greatly depends on fire conditions (intensity, size, location), assigned duties, and self-selected intensity of work output. Examining seventeen WLFF (8 male, 9 female) from three interagency hotshot crews (IHCs), Ruby and colleagues measured TEE for five days by calculating three components – BMR, energy expenditure of physical activity, thermogenic effect of dietary intake – via doubly-labeled water methodology (3). As it is impractical to directly measure BMR in the field, total body water (TBW) was used to predict BMR using an equation previously elucidated by Cunningham et al. (34) ($[21.6 \cdot (TBW/0.73)] + 370$). Despite greater absolute TEE in male subjects compared to female counterparts, there were no significant differences in TEE relative to BMR or body weight. Results

also exhibited a high mean TEE of 2868-6214 kcal/d (12.9-26.2 MJ/d), equating to approximately 2.5-3.0 times the average BMR.

To distinguish the effects of WLFF's self-selected work activity on TEE, Cuddy et al. (35) similarly monitored fifteen IHC participants (12 male, 3 female) during three days of fire suppression. Prior to deployment each morning, subjects were equipped with a physiological and activity monitor to measure heart rate, physical activity (≤ 99 , 100-1499, and ≥ 1500 activity counts for sedentary, light, and moderate/vigorous activity, respectively), and TEE for the duration of each work shift. Work performed throughout the shifts consisted of sedentary ($49 \pm 8\%$), light ($39 \pm 6\%$), and moderate-vigorous ($12 \pm 2\%$) activities, eliciting a mean heart rate of 112 ± 13 beats/min. Subjects produced a daily TEE of 19.1 ± 3.9 MJ/d and a three-day average TEE of 2946-5811 kcal/d, both of which are in accordance with previously described TEE of wildland fire suppression (17.5 ± 6.9 MJ/d and 2868-6214 kcal/d, respectively) (3).

More recently, Robertson et al. (36) monitored the energy expenditure and consumption habits of Canadian FireRangers ($n = 21$) during the 2014 fire season. Heart rate variability was employed to determine intensity (kcal/min; METs (37)) relative to deployment type – initial attack (16 ± 2.6 ; 11.3 ± 1.6), project fire (14 ± 4.9 ; 9.9 ± 3.2), fire base (11 ± 4.1 ; 8.1 ± 3.4). Subsequent analyses revealed a negative energy balance (kcal/d) across all deployment types (-780 ± 1006.3 , -1063 ± 1499.0 , -409 ± 851.9 , respectively), suggesting insufficient overall fuel intake and thereby negatively affecting occupational performance. Moreover, a negative energy balance while at base camp indicates scant recovery, which may further hinder WLFF work capacity and crew safety.

Field nutrition: macronutrient composition

Dietary provisions for WLFF deployed to large, supported incidents traditionally consist of bookend meals (breakfast, dinner) of unlimited proportions and an isocaloric (1500-2000 kcal)

sack lunch to be consumed throughout the work shift. Many WLFF crews and individuals supplement provided meals with convenient foods such as dehydrated meats, dried fruit and nut mixes, energy bars, and sports drinks, some of which may not always be available due to cost, fire location, and policy restrictions. Undertaking shifts without supplemental foods can potentially result in acute and/or chronic negative energy balance, consequently leading to premature fatigue, which may ultimately limit overall work output and jeopardize individual and crew safety. From both a safety and performance perspective, it is imperative for the WLFF community to have a clear comprehension of the physiological demands of the occupation.

Occupational tasks necessitate that WLFF consume a sufficient quantity of fuel throughout the workday to ensure meeting energy demands while also providing an adequate degree of satisfaction. Furthermore, maintenance of body weight and energy balance is essential for peak performance throughout the fire season. Although high-protein diets have been historically promoted for individuals performing large amounts of work (5), previous research has established that diets largely consisting of carbohydrates (CHO) are favorable to optimization of total work output by those engaged in demanding work or intense physical training (1,5–12).

Regular consumption of supplemental CHO has been shown to enhance work output, particularly during the latter half of the work shift (38,39). In two separate counter-balanced crossover studies, WLFF ($n = 29$; $n = 20$) consumed either CHO (160 kcal/hr and 40 g/hr, respectively) or placebo every hour in addition to the conventional sack lunch. CHO cohorts displayed increases in work rate (241 ± 56 kcal/hr and $64,172 \pm 30,501$ counts/hr, respectively) compared to placebo groups (202 ± 47 and $47,528 \pm 26,541$ counts/hr, respectively). These findings suggest that consumption of auxiliary CHO elicits greater work output and that self-selected work rate is thus augmented by heightened CHO intake.

In addition to establishing inadequate energy balance in WLFF, Robertson and colleagues (36) found deficient substrate intake across all deployment types. WLFF were asked to photograph and dictate serving information of all foods ingested throughout work shifts and results exhibited deviations from guidelines (27) for macronutrient distribution (CHO: 27-37% [low]; fat: 39-50% [high]; protein: 22-25% [adequate]) and consumption relative to body weight (2.8-3.5 g/kg CHO and 1.8-2.5 g/kg protein). Insufficient CHO intake was most importantly detected as it is paramount for sustaining work during high- (5) and low-intensity (40) efforts, both of which are known to occur during fire suppression labor.

Field nutrition: feeding strategy

In addition to the specific composition and types of foods consumed, it has been demonstrated that the timing of consumption is essential to the maintenance of steady work output as well as the prevention of gastrointestinal discomfort (13–17). Furthermore, previous literature has detailed the benefits of supplemental feeding, particularly that of CHO, during long-duration activity (>2 hr) and individuals' subsequently improved completion of physical work (5,6,9,13–31). Although prior studies have sought to investigate the effects of liquid CHO utilization on various performance metrics, most trials have been conducted in well-trained subjects and lasted no more than 4 hours; however, not all WLFF are elite athletes and work shifts are markedly longer than the aforementioned testing duration.

As CHO consumption has been shown to attenuate some of the challenges of extended physical work, Cuddy and colleagues (41) monitored occupational performance of WLFF (n = 76) with actigraphy units throughout shift for three fire seasons. Subjects' self-selected work output was shown to increase due to both supplemental CHO consumption and regularly-timed feedings. During shifts, subjects ingested either supplemental CHO or placebo in addition to standard sack

lunch (first two seasons) or were regularly given shift food items of ~150-400 kcal in place of the sack lunch (third season). Comparisons made via crossover study design showed greater average activity counts, especially in the shift's terminal hours, as well as a continuous deterioration of work output and self-selected work rate in the absence of regular CHO consumption.

An analogous study by Montain et al. (42) compared the consumption habits of two different provisions, meals real-to-eat (MRE) and first strike ration (FSR), during two consecutive work shifts in twenty-eight WLFF (28 male, 6 female). MREs consist largely of an entrée and other complimentary items, whereas contents within FSRs are more convenient for on-the-go consumption. Work output was measured with an actigraphy device and was shown to have been higher with FSR than MRE ($507,833 \pm 129,310$ and $443,095 \pm 142,208$ activity counts/shift, respectively). Also observed was a greater total number of feeding episodes with FSR than MRE (8.2 ± 1.3 and 7.6 ± 1.1 episodes/2 d), indicating a relationship between number and frequency of feedings and work output amid extended shifts.

III: METHODOLOGY

Research design

Our descriptive study is intending to determine the meal intake and consumption habits of WLFF and was conducted via direct field observation. Each day, a member of the study team was paired with a WLFF (1:1) and assigned to inventory all foods taken on and brought back from shift, as well as to monitor the subject's feeding habits throughout the shift. WLFF subjects wore physical activity monitors in work shirt pocket to compile individual activity count data throughout work shift.

Research setting

All data collection occurred in fire suppression setting. Food inventories and were conducted at WLFF base camp, while all self-selected consumption and activity data was collected in the field while on work shift (i.e., away from base camp).

Subjects

Individuals who had been deployed to fires across the western United States throughout the 2018 fire season were eligible for participation in our study. 125 subjects of both sexes and from various WLFF crew types were originally recruited by volunteer self-selection. Prior to study participation, subject anthropometric (height, body weight) and demographic data (age, location, sex) was documented. If, on the day of study participation, subject did not complete a full work shift (i.e., reassigned), consume all meals provided per current catering contract, or have all foods consumed during shift captured in mobile tablet and nutritional analysis program, they were excluded from subsequent analysis. Such exclusions resulted in a final sample size (n) of 86 WLFF subjects.

Data collection

A complete inventory of all work shift food items was conducted via photo and manual data capture (43–46) prior to departure from base camp (pre-shift food inventory, FI_{Pre}) and upon return from work shift (post-shift food inventory, FI_{Post}). Caloric and macronutrient profiles of all foods from both pre- and post-shift food inventories were then catalogued in Food Processor Nutrition Analysis Software 11.1 (ESHA Research, Salem, OR) for subsequent consideration.

One subject was paired with one study team member for day of monitoring. Each day, study team members observed and recorded subjects' feeding habits in real time throughout the entire work shift. Collected data – foods items consumed, amount of each item consumed, and respective time of item consumption – was documented in mobile tablet by study team member throughout work shift. Nutritional information for FI_{Pre} and FI_{Post} items was then matched with observed foods, enabling determination of caloric and macronutrient profiles of all individual items as well as average intake and distribution throughout shift and per feeding episode. For analysis purposes, we termed a “feeding episode” as a period during which consumption of all foods occurred with no more than ten minutes elapsed between items.

Physical activity monitor output was compiled, analyzed as counts/min, and differentiated by varying levels of intensity.

Statistical procedures

Comparison of FI_{Pre} and FI_{Post} provided assessment of foods consumed during work shift. Average intake and distribution of calories and macronutrients throughout shift was expressed for all foods consumed during work shift. Self-selected consumption habits were expressed as number of feeding episodes per work shift, time between feeding episodes, and average caloric and macronutrient intake per feeding episode. All descriptive data are presented as mean ± standard

deviation. T-tests were performed to examine sex-based differences among feeding and activity measures. A one-way analysis of variance (ANOVA) was used to explore differences in work shift activity, feeding episodes, caloric intake per kilogram body weight, and other behavioral and consumption metrics. Statistical significance was indicated by p-values less than 0.05.

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Title: Total energy intake and self-selected macronutrient distribution during wildland fire suppression

Short title: Wildland firefighter total energy intake

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Introduction: Wildland firefighters (WLFF) work long hours in extreme environments resulting in high daily total energy expenditure (TEE). Increasing work shift eating episodes and/or providing rations that promote convenient feeding has shown augmented self-selected work output, as has regular carbohydrate (CHO) consumption. It remains unclear how current WLFF feeding strategies compare to more frequent nutrient delivery. Our study's aim was to determine WLFFs' self-selected field total energy intake (TEI), composition, and patterns feeding during wildland fire suppression shifts.

Methods: 86 WLFF (16 female, 70 male; 27.5 ± 6.4 yr) deployed to fire incidents across the United States throughout the 2018 fire season. Pre- and post-shift food inventories collected at basecamp provided item-specific nutrient content (calories [kcal], CHO, fat, protein). Work shift consumption (TEI, feeding frequency, episodic composition) was monitored in real-time by field researchers on fireline via observational data capture using mobile tablets. Shift work output was determined via actigraph accelerometry.

Results: Work shift length averaged 14.0 ± 1.1 hr, with a TEI of 6.3 ± 2.5 MJ (1494 ± 592 kcal) (51 ± 10 , 37 ± 9 , $13 \pm 4\%$ for CHO, fat, and protein, respectively). WLFF averaged 4.3 ± 1.6 eating episodes (1.4 ± 1.3 MJ [345 ± 306 kcal] and 44 ± 38 g CHO·episode⁻¹). WLFF who consumed >20 kcal·kg⁻¹ averaged less sedentary activity than those consuming <16 kcal·kg⁻¹.

Conclusions: The present work shift TEI approximates 33% of previously-determined WLFF TEE and demonstrates that current WLFF consumption patterns may not deliver adequate nutrients for the occupational demands.

Keywords: carbohydrate, field study, occupational physiology, performance monitoring, wildland firefighting

Introduction

Wildland firefighters (WLFF) are regularly exposed to a myriad of environmental and physical demands, including extended work shifts (≤ 24 hr) in adverse conditions (heat, altitude, and low humidity), compromised diet, and sleep deprivation (1–4). The hardships of a fire assignment depend on the fire intensity, geographic location, and respective ambient conditions. Using the doubly labeled water methodology, our laboratory determined the total energy expenditure (TEE) of the WLFF to be 11.4–26.2 MJ·d⁻¹ (2719–6260 kcal·d⁻¹) (1). Fifteen years later, we reported similar TEE values, ranging from 12.3–25.5 MJ·d⁻¹ (2946–6083 kcal·d⁻¹) (19.1 ± 3.9 MJ·d⁻¹ [4556 ± 943 kcal·d⁻¹]) for WLFF (4), demonstrating the consistent and arduous nature of the WLFF profession.

Despite former promotion of high-protein intake for individuals performing large amounts of work, it has more recently been established that diets primarily consisting of carbohydrates (CHO) are advantageous to optimize total work output by those engaged in arduous occupational or physical training (5–8). Previously reported nutritional records suggest that WLFFs' total CHO intake in fire camps may be inadequate due to the self-selection of foodstuffs containing dietary fat and protein quantities greater than those recommended for arduous work (1). Moreover, the timing of intake has shown improved maintenance of steady work output and prevention of gastrointestinal discomfort (9–13). Supplemental feedings during long-duration exercise (>2 hr) have consistently demonstrated increased ability to complete physical work (7–26), a notion later confirmed by auxiliary feeding interventions that elicited improved work output during the latter work shift hours (27). Additionally, our laboratory demonstrated significant muscle glycogen preservation in males and females when regularly supplied carbohydrates during a 10 hr exercise trial (25). Montain et al (28) further indicated enhanced work performance via supplemental

consumption by way of augmented episodic frequency using a redesigned military ration system (First Strike Ration).

Occupational requirements of the WLFF necessitate foods that meet energy demands and impart adequate satisfaction to sustain consumption patterns for the entirety of single work shifts and fire season duration, typically extending from April to October. Current WLFF work shift provisions are comprised of a sack lunch of approximately 5.4–8.4 MJ (1300–2000 kcal) (29); however, it is not well-established if this provides sufficient energy to maintain required work efforts. Furthermore, it remains uncertain if current sack lunch provisions promote apposite feeding frequency. The aims of the present study, therefore, were to ascertain the average caloric and macronutrient (CHO, fat, protein) intake and distribution of all work shift foods, as well as WLFF feeding behavior and corresponding work output throughout extended fire suppression shifts.

Methods

Subjects

Individuals deployed to twelve different wildland fire incidents across six regions of the western United States during the 2018 fire season were eligible for study participation. On the basis of their fire assignments, subjects were recruited and enrolled by volunteer self-selection the night prior to the observation work shift. Prospective participants must have had at least one complete day's work on the fire incident prior to study involvement to ensure sufficient consumption of fire camp and line meals. Subjects provided written, informed consent approved by the University of Montana Institutional Review Board before participation in the study, after which subject data (anthropometric: height, body weight; demographic: age, sex, location) was documented.

Work shift food inventory

A complete inventory of all work shift food items was conducted via manual and photographic data capture (30–33) before leaving base camp (pre-shift food inventory, FI_{pre}) and upon return from work shift (post-shift food inventory, FI_{post}). Caloric and macronutrient profiles of all FI_{pre} and FI_{post} foods were then catalogued in Food Processor Nutrition Analysis Software 11.1 (ESHA Research, Salem, OR) for subsequent evaluation. Prior to departure from camp, FI_{pre} food items were also entered into mobile tablet for ensuing work shift observation.

Field consumption

All study team members had been previously employed as WLFF and were therefore well-suited to monitor subject field behavior with minimal influence or interruption. Each day, one research team member was assigned to a WLFF (1:1) and utilized a mobile tablet inventory approach to surveil and record subjects' feeding habits (food items consumed, amount and corresponding time of respective item intake) in real-time throughout work shift, thus minimizing the potential for self-report or recall bias (34–40). Nutritional information for FI_{pre} and FI_{post} items was then aligned with observed foods and respective timestamps, enabling chronologic determination of caloric and macronutrient profiles of all individually consumed items as well as average intake and distribution throughout shift and per feeding episode. For analytical purposes, a “feeding episode” was defined as any work shift period during which intake of all foods occurred with no more than ten minutes elapsed between items consumed.

Actigraphy

Actical actigraphy units (MiniMitter, Bend, OR) were utilized to determine participant total body activity and movement while on shift. Monitors were distributed to subjects on the morning of observation and, to protect from damage and ensure stable positioning, secured on a white foam

core square that was later placed in left chest pocket of subjects' Nomex fire shirt. Unit placement was standardized for all data collection due to WLFFs' frequent upper body use to perform daily job duties, thus providing the greatest likely capture of work performed (27,28,41). In accordance with previous studies, per-minute activity counts were subsequently classified into three distinct ranges (sedentary [≤ 99 counts \cdot min $^{-1}$], light [100-1499 counts \cdot min $^{-1}$], and moderate/vigorous [≥ 1500 counts \cdot min $^{-1}$]), allowing for ensuing analysis of various work shift intensities (27,28). For ensuing comparative intake analysis, work shift consumption was examined in relation to subject body mass (kcal \cdot kg $^{-1}$) and divided into subcategories (low, <16 ; medium, 16-20; and high, >20).

Statistics

125 subjects of both sexes and from various WLFF crew types volunteered for work shift observation. If, on the day of study participation, subjects did not complete a full work shift due to reassignment or spiking, consume all meals provided per current catering contract, or have all foods consumed during shift captured in both FI_{pre}/FI_{post} and mobile tablet (i.e., data loss), they were excluded from further analysis. Such exclusions resulted in a final subject pool (N) of 86 WLFF subjects for dietary and feeding assessment. Actigraphy examination necessitated additional exclusions due to data loss, yielding 74 WLFF subjects for subsequent analyses of work shift activity.

All descriptive data are presented as mean \pm SD. Independent t-tests were performed to examine sex-based differences among feeding and activity measures. A one-way analysis of variance (ANOVA) was used to explore differences in work shift activity, feeding episodes, caloric intake per kilogram body weight, and other behavioral and consumption metrics. Statistical significance is indicated by p-values less than 0.05.

Results

Subjects

Among all subjects (27.5 ± 6.4 yr), there was an observed difference in height and body weight between females and males ($p < 0.05$) (table 1).

Work shift feeding

Average WLFF work shift duration was 14 ± 1.1 hr with a TEI of 6.3 ± 2.5 MJ (1494 ± 592 kcal) (51 ± 10 , 37 ± 9 , $13 \pm 4\%$ for CHO, fat, and protein, respectively). TEI for breakfast and dinner was similarly quantified (3.7 ± 1.5 and 5.7 ± 2.3 MJ [893 ± 353 and 1356 ± 560 kcal], respectively), resulting in an estimated TEI of 15.7 ± 6.3 MJ·d⁻¹ (3743 ± 1505 kcal·d⁻¹). Total caloric intake was lowest and greatest during the first and third quintiles of the work shift, respectively ($p < 0.05$). Conversely, average energy intake was shown to steadily rise throughout the work shift (figure 3), during which eating episodes ranged from 2 to 9.

Females exhibited a greater carbohydrate intake, both as a percent of total caloric intake and per kilogram body weight, as well as a consistently lesser protein intake their male counterparts (table 2). Although no relationship was determined ($p = 0.0506$), males undertook less feeding episodes than did females throughout the work shift, during which there was a greater intake of calories, fat, and protein per episode (table 3).

Actigraphy

For 74 of the 86 total subjects, an average of 689 ± 73 minutes of activity were noted throughout the work shift. Overall work shift activity averaged 220 ± 168 counts·min⁻¹ and was composed of 63 ± 17 , 33 ± 17 , and $4 \pm 5\%$ sedentary, light, and moderate/vigorous intensity, respectively. Activity counts exhibited a nearly 50% decrease from the first to third quintiles of the work shift, before slightly increasing over the latter quintiles (figure 3), likely representing the

ingress/egress hike to/from the fireline. Episodic feeding frequency did not generate any interactions with work shift activity ($p > 0.05$). There was a noted difference in the amount of moderate/vigorous activity performed (41 ± 32 vs 24 ± 31 counts \cdot min $^{-1}$ and 6 ± 4 vs $4 \pm 5\%$ for females and males, respectively; $p < 0.05$); however, there were no differences seen between the sexes' output of sedentary or light intensity work.

Observed caloric intake per kilogram body weight (kcal \cdot kg $^{-1}$) was stratified into groups of equal proportion (< 16 , $16-20$, and > 20 kcal \cdot kg $^{-1}$, respectively) for further analysis. Although kcal \cdot kg $^{-1}$ and work shift activity counts were not statistically associated, subsequent contrast of work intensity did elicit a relationship ($p < 0.05$). WLFF who consumed greater than 20 kcal \cdot kg $^{-1}$ spent more of their individual work shifts (percent, total minutes) performing light (100-1499 counts \cdot min $^{-1}$) intensity work than sedentary (≤ 99 counts \cdot min $^{-1}$) activity (table 4). There were no observed interactions between kcal \cdot kg $^{-1}$ and moderate/vigorous (≥ 1500 counts \cdot min $^{-1}$) intensity work among any of the groups. There was an observed difference between work shift feeding episode count per group (< 16 and > 20 kcal \cdot kg $^{-1}$, respectively; $p < 0.05$).

Discussion

WLFF are routinely subjected to unfavorable and potentially injurious conditions (rough terrain, acute altitude, low humidity, high ambient and radiant heat (42–44)) during extended work shifts. Ingress hikes to the fireline have demonstrated the greatest metabolic demand during fire suppression shifts (45), which often emphasize greater need for long-term endurance rather than high-intensity efforts (46). Previous base camp nutritional records have evinced greater-than-advised fat and protein consumption (1), despite recent promotion of diets rich in CHO for those performing great amounts of labor (5–8). Coker et al (47) recently indicated diminished health measurements incurred in WLFF over the duration of the fire season, namely increased total

cholesterol and low-density lipoprotein, as well as elevated total body and visceral fat. Intrahepatic lipid was also noted to trend upward at season's end, despite the lack of significant difference. While these maladaptations cannot be fully attributed to deficient nutrient and fuel delivery throughout the fire season, they may suggest ramifications of the seasonal lifestyle alterations and arduous occupational demands of WLFF.

Improved feeding occurrence has also demonstrated efficacy in minimizing gastrointestinal distress while maintaining steady work output over training or work periods of two-plus hours (7–26), and our laboratory has illustrated preservation of muscle glycogen via regular carbohydrate ingestion during prolonged exercise (25). Ancillary work shift feedings have also demonstrated enhanced occupational performance, especially in a shift's latter hours (27,28). Despite heightened caloric and macronutrient consumption as a result of increased frequency of eating (figure 2), 64% of all 86 subjects were observed to have fed between 2 and 4 times throughout the work shift (figure 1). This is in contrast to previously reported data resulting from manipulation of feeding frequency by Cuddy et al (27). Furthermore, Montain et al (28) demonstrated a similar number of eating episodes (8.2 ± 1.3 and 7.6 ± 1.1) for different sack lunch provisions (First Strike Rations and Meals Ready-to-Eat [MRE], respectively) during a two-day ration intervention among actively-deployed WLFF. Sex-based feeding differences (tables 2, 3) are also in line with previous findings from our laboratory (1). Discrepancies between observed feeding episodes may stem from fire activity and corresponding shift duties or food item-specific packaging and can have a direct effect on self-selected feeding behaviors. It is imperative that WLFF and those in comparable prolonged performance occupations (e.g., military personnel) have reliable access to appropriate shift provisions to ensure acceptable work output and minimize safety risk.

WLFF work tasks require foods that provide sufficient energy for the duration of the shift. The peak total consumption observed during the middle of the shift likely indicates the typical “lunching hour” that may be practiced by some crews. Although average caloric intake was noted to steadily increase over the course of the work shift (figure 3), fat and protein constituted a greater percentage of the overall composition as the shift progressed (figure 4). Accordingly, the majority of the work shift was spent performing sedentary or light activity (figure 5), which is comparable to previous findings from our laboratory that demonstrate increased work demands associated with in- and egress hikes to/from fireline in the final hours of the shift (4,45). Actigraphy data from studies by Cuddy et al (27) and Montain et al (28), however, exhibited higher work rates (335 ± 218 and 338 ± 83 counts \cdot min $^{-1}$, respectively) compared to values in the present study (220 ± 168 counts \cdot min $^{-1}$).

Although it has not previously been intimated if shift rations currently provide adequate energy to maintain required work efforts or promote optimal feeding incidence, contemporary WLFF work shift provisions include an isocaloric sack lunch (29) that is often supplemented with more favorable/preferred food items. Roughly 78% of WLFF subjects were noted to have consumed accessory food items (i.e., those not provided in caterer-provided sack lunch), which ultimately accounted for 32% of those subjects’ respective work shift calories. As United States Forest Service WLFF crews are typically deployed in fourteen-day increments throughout a nearly six-month season, reliance on external fuel sources may elicit greater occurrence of negative energy balance if somehow unavailable (e.g., financial, geographical limitations). Similarly, lack of dietary diversity may also discourage appropriate work shift feeding, consequently resulting in threats to seasonal energy balance preservation. Current standard fire orders highlight the importance of “fireline group and personal safety” and the need to “fight fire aggressively, having

provided for safety first” (48), and these data suggest that more aggressive fire suppression operations likely demand improved coordination of feeding frequency and diverse provision availability.

This is the first study to appraise the free-living (i.e., sans intervention) feeding habits of WLFF during unscripted fire suppression work shifts. The techniques employed to monitor subject behavior did not rely on individual recall or self-report, as has historically been a hindrance of dietary and nutritional data collection (34–40), thus imparting improved reporting accuracy. Although researchers following WLFF throughout their shift may have engendered unnatural feeding behavior, all members of the study team previously worked as fireline personnel and were thus befitting to minimize interruption of WLFF habitual feeding and activity. The greatest limitation, therefore, is likely the inconsistency of specific work shift tasks due to varying fire activity and conditions, which is inherent to the WLFF position. Results indicate that work shift TEI provides roughly 33% of the previously determined TEE (1,4). These data also suggest that the current feeding practices and rations may not provide sufficient fuel consummate with WLFF labor assignments. Present data provide an apparent association between relative energy intake ($\text{kcal}\cdot\text{kg}^{-1}$) and self-selected work activity. Moreover, work shift feeding episodes were shown to influence relative consumption ($\text{kcal}\cdot\text{kg}^{-1}$), although no relationship was observed between feeding frequency and work output, perhaps due to insufficient statistical power within our subject pool. Future studies should therefore seek to determine optimal nutrition delivery and ideal dietary diversity to sustain appropriate intake for the duration of the fire season. Further explication of the influences of work shift provisions on overall patterns of self-selected work output should also lead to development of optimal work shift rationing to encourage requisite consumption.

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Figure legends

Figure 1. Observed feeding episodes during wildland fire suppression shift; N = 86.

Figure 2. Caloric consumption (A) and macronutrient distribution (B-D) relative to eating episodes during wildland fire suppression shifts.

Figure 3. Average caloric consumption and activity during wildland fire suppression shifts.

a: $p < 0.05$ vs 20% work shift; b: $p < 0.05$ vs 40% work shift; c: $p < 0.05$ vs 60% work shift;

d: $p < 0.05$ vs 80% work shift.

Figure 4. Wildland fire suppression work shift macronutrient composition.

Figure 5. Wildland fire suppression work shift intensity composition (% total activity);

S = sedentary (≤ 99 counts \cdot min $^{-1}$), L = light (100-1499 counts \cdot min $^{-1}$);

M/V = moderate/vigorous (≥ 1500 counts \cdot min $^{-1}$).

Figures

Figure 1

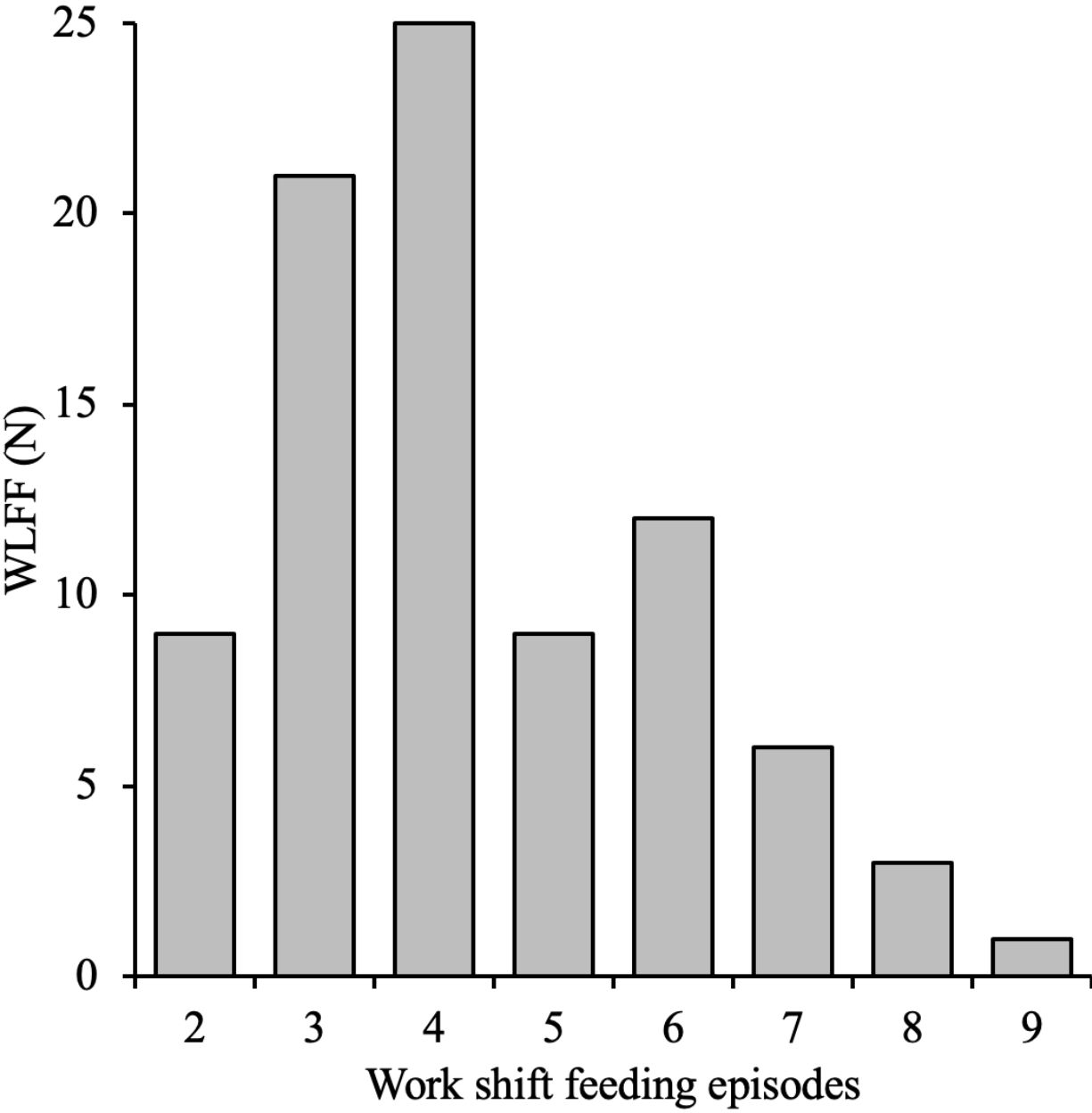


Figure 2

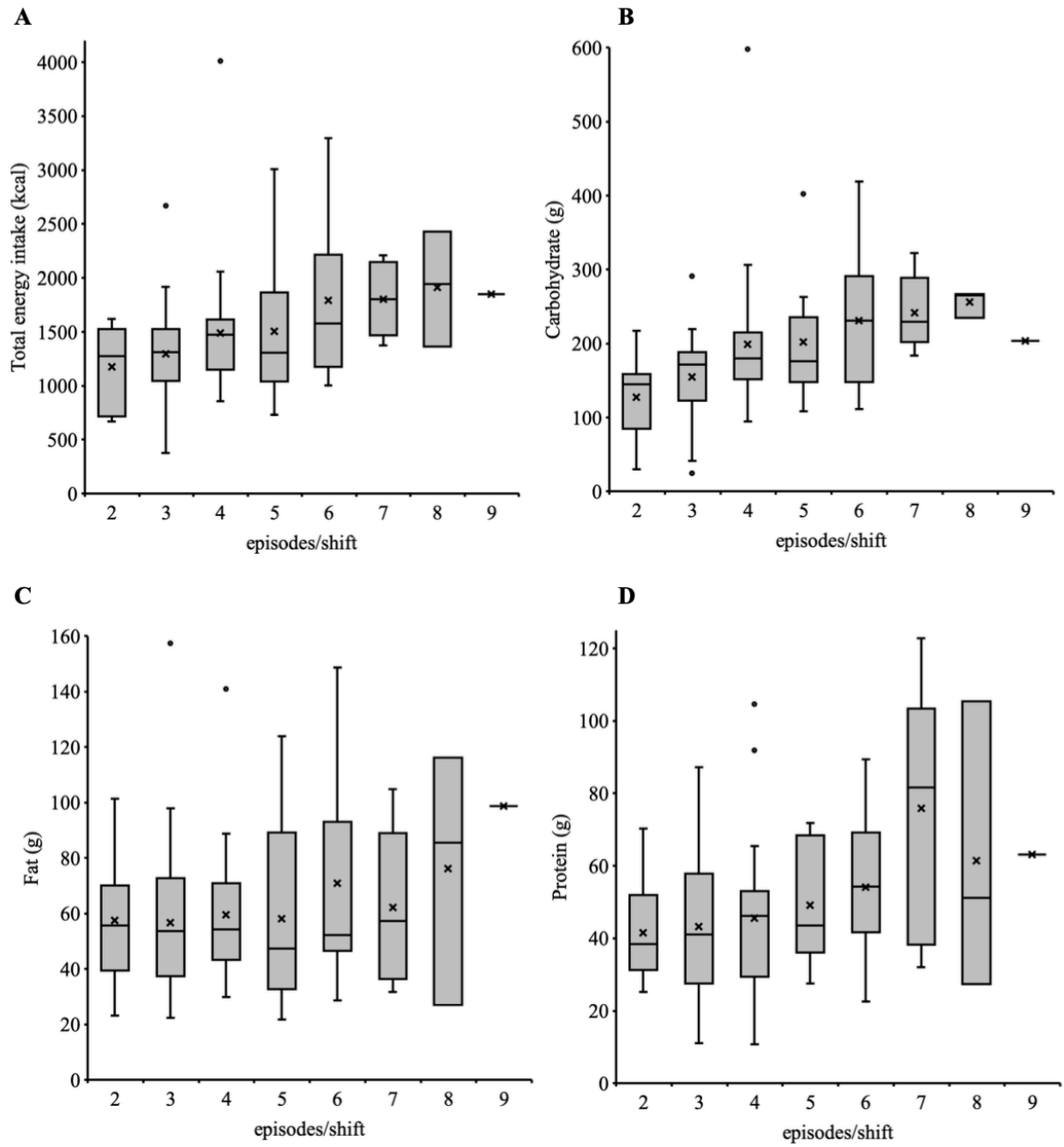


Figure 3

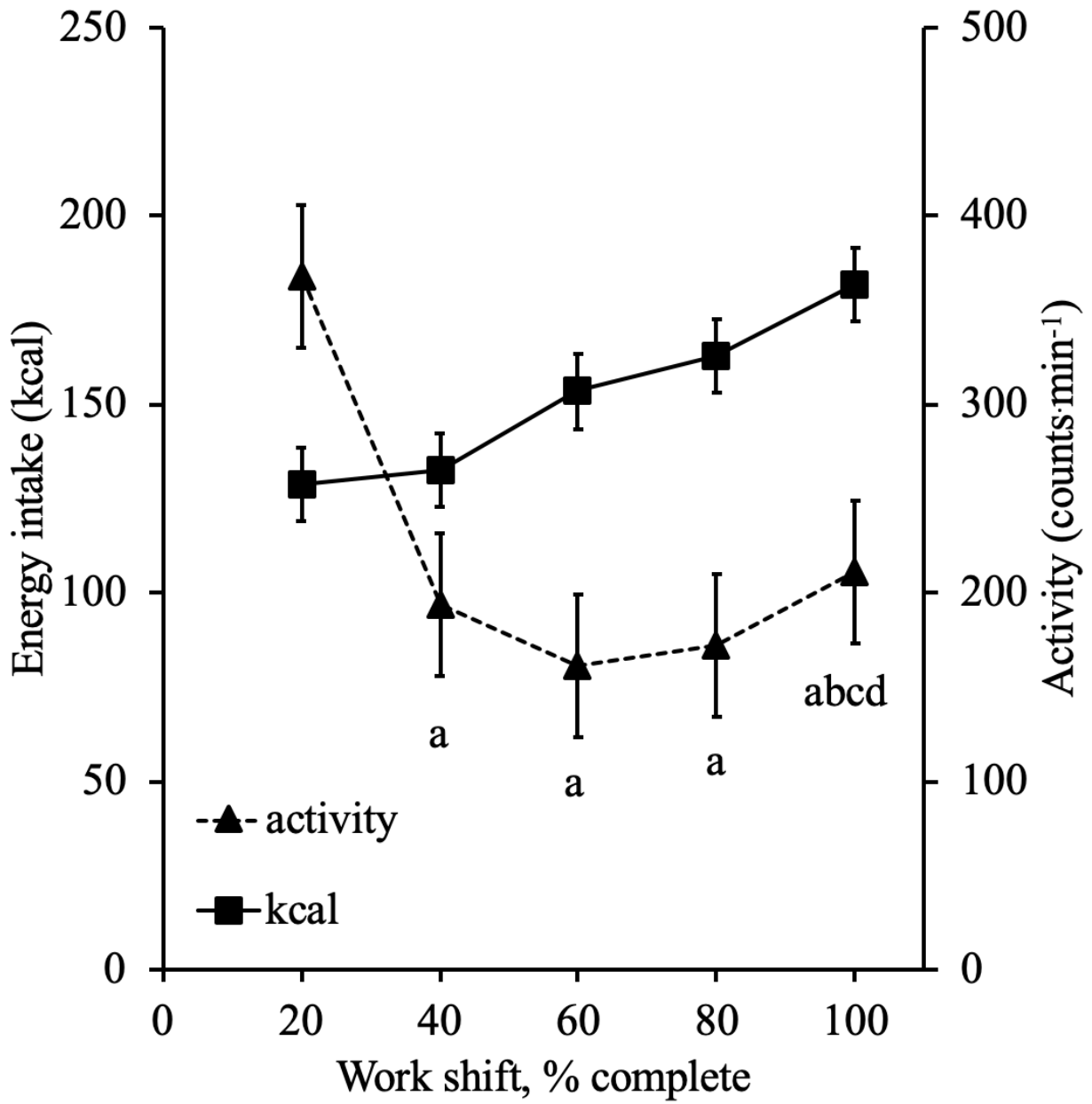


Figure 4

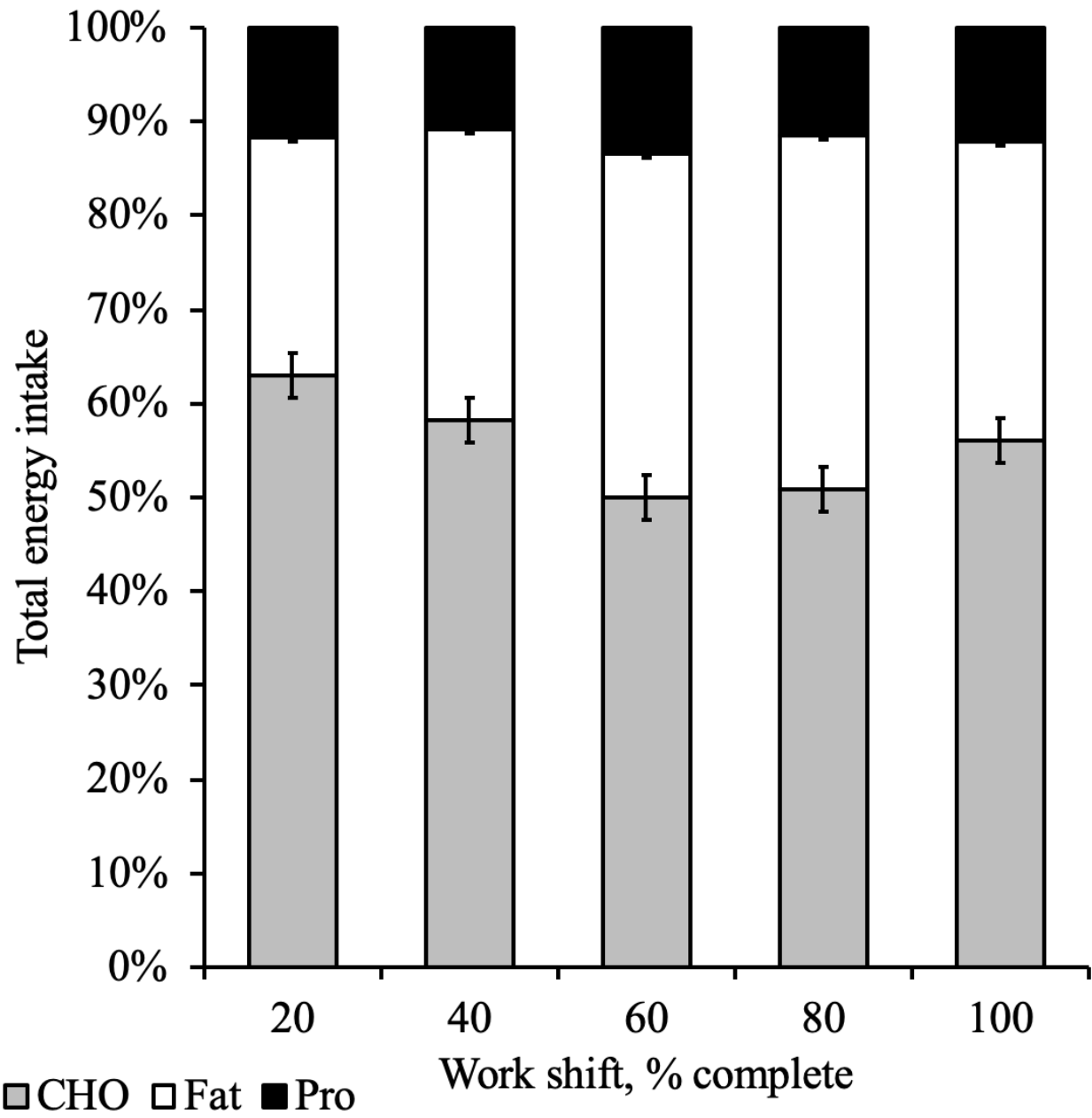


Figure 5

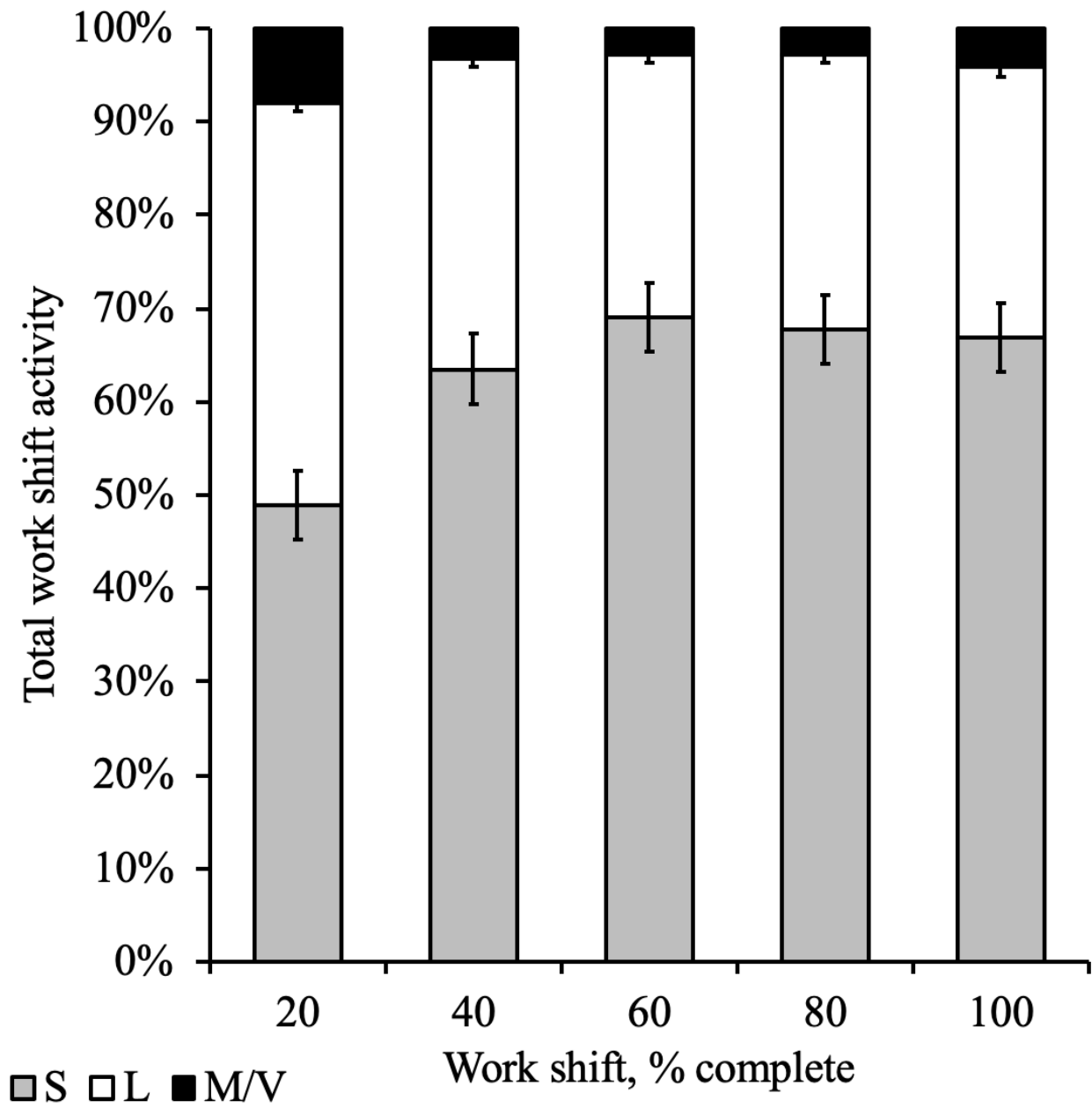


Table 1. WLFF subject and work shift demographics.

	<i>Overall</i>	<i>Female</i>	<i>Male</i>
Subject (n)	86	16	70
Age (yr)	27.5 ± 6.4	25.8 ± 5.1	27.9 ± 6.6
Height (cm)	178.7 ± 9	166.2 ± 6.8	181.6 ± 6.7 *
Weight (kg)	81.3 ± 15.9	63.5 ± 7.9	85.4 ± 14.4 *
Shift			
Duration (hr)	14 ± 1.1	14.2 ± 0.6	14 ± 1.2
Start time	06:16 ± 35 min		
End time	20:17 ± 51 min		

* p <0.05 vs female.

Table 2. Total energy intake and macronutrient distribution during wildland fire suppression shifts.

	<i>Overall</i>	<i>Female (n=16)</i>	<i>Male (n=70)</i>
Calories (kcal)	1494.3 ± 592.1	1392 ± 412	1517.7 ± 626.1
kg ⁻¹ BW	190.6 ± 7.9	22.1 ± 6.7	18.3 ± 8
Carbohydrates (g)	190.6 ± 84	195.8 ± 61.8	189.4 ± 88.6
kg ⁻¹ BW	2.4 ± 1.1	3.1 ± 1.1	2.3 ± 1.1 *
% kcal	51 ± 10	57 ± 10	50 ± 10 *
Fat (g)	61.3 ± 29.9	55 ± 26.4	62.8 ± 30.6
kg ⁻¹ BW	0.8 ± 0.4	0.9 ± 0.4	0.8 ± 0.4
% kcal	37 ± 8	35 ± 10	37 ± 9
Protein (g)	49 ± 22.2	38.3 ± 14.2	51.5 ± 23 *
kg ⁻¹ BW	0.6 ± 0.3	0.6 ± 0.2	0.6 ± 0.3
% kcal	13 ± 4	11 ± 4	14 ± 4 *

* p <0.05 vs female.

Table 3. Episodic consumption and distribution during wildland fire suppression shifts.

	<i>Overall</i>	<i>Female (n=16)</i>	<i>Male (n=70)</i>
Observed feeding episodes	4.3 ± 1.6	5.1 ± 2.1	4.2 ± 1.5
Interval between episodes (min)	117 ± 76	126 ± 47	133 ± 50
Calories (kcal)	344.5 ± 306.6	275 ± 193.7	363.8 ± 328.9 *
Carbohydrates (g)	43.9 ± 38	38.7 ± 26.8	45.4 ± 40.5
Fat (g)	14.1 ± 16.1	10.8 ± 11.3	15 ± 17 *
Protein (g)	11.3 ± 13.3	7.6 ± 7.7	12.3 ± 14.4 *

* p <0.05 vs female.

Table 4. Total energy intake relative to body mass ($\text{kcal}\cdot\text{kg}^{-1}$) and the differences in self-selected work output distribution.

	$<16 \text{ kcal}\cdot\text{kg}^{-1}$	$16-20 \text{ kcal}\cdot\text{kg}^{-1}$	$>20 \text{ kcal}\cdot\text{kg}^{-1}$
Average activity (counts/min)	196 ± 150	220 ± 192	246 ± 165
Sedentary (min)	463 ± 77	446 ± 129	388 ± 150 *
Sedentary (%)	68 ± 11	66 ± 18	56 ± 20 *
Light (min)	195 ± 82	205 ± 116	284 ± 153 *
Light (%)	28 ± 11	30 ± 17	40 ± 20 *
Moderate/vigorous (mins)	28 ± 30	28 ± 37	28 ± 29
Moderate/vigorous (%)	4 ± 5	4 ± 6	4 ± 4

* $p < 0.05$ vs $<16 \text{ kcal}\cdot\text{kg}^{-1}$.