Nutrition and Physical Activity during British Army Officer Cadet Training: Part 1 - Energy Balance and Energy Availability

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Running Title: Energy Balance and Availability in Officer Cadet Training

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Abstract

Military training is characterised by high daily energy expenditures (EE) which are difficult to match with energy intake (EI) potentially resulting in negative energy balance (EB) and low energy availability (EA). The aim of this study was to quantify EB and EA during British Army Officer Cadet (OC) training. Thirteen (seven women) OCs (mean ± SD: age 24 ± 3 years) volunteered to participate. EB and EA were estimated from EI (weighing of food and food diaries) and EE (doubly-labelled water) measured in three periods of training; nine days on-camp (CAMP), a five-day field exercise (FEX) and a nine-day mixture of both (MIX). Variables were compared by condition and gender with a repeated measures ANOVA. Negative EB was greatest during FEX (-2197 ± 455 kcal·d^{-1}) compared with CAMP (-692 ± 506 kcal·d^{-1}; $p<0.001$) and MIX (-1280 ± 309 kcal·d^{-1}; $p<0.001$). EA was greatest in CAMP (23 ± 10 kcal·d^{-1}) compared with FEX (1 ± 16 kcal·d^{-1}; $p=0.002$) and MIX (10 ± 7 kcal·d^{-1}; $p=0.003$), with no apparent difference between FEX and MIX ($p=0.071$). Irrespective of condition, there were no apparent differences between gender in EB ($p=0.375$) or EA ($p=0.385$). These data can be used to inform evidenced-based strategies to manage EA and EB during military training and enhance the health and performance of military personnel.

Key Words: Military, Energy Expenditure, Energy Intake

INTRODUCTION

British Army Officer Cadets (OCs) undertake the 44-week Commissioning Course (CC) at the Royal Military Academy Sandhurst (RMAS), consisting of periods of training in-camp and field exercises. The course, which is necessarily arduous, consists of a typical mixture of military work and training and as such consists of intermittent periods of moderate-to-high intensity exercise and periods of prolonged low intensity exercise (Henning et al., 2011; Tharion et al., 2005; Wilkinson et al., 2008). During the CC, it has previously been documented that male and female OCs have energy expenditures (EE) of 4898 ± 430 and 3822 ± 478 kcal·d^{-1}, respectively (Bilzon et al., 2006). This EE is comparable to military work and training in other settings, for example EE has been reported to be 6851 kcal·d^{-1} during an operational exercise and 5480 kcal·d^{-1} when training in camp (Margolis et al., 2014). In comparison with in-camp training, field environments typically elicit greater EE due to the abundance of ambulatory activities, carrying external load, long work days and restricted sleep (Tharion et al., 2005). During periods of training in the field, EE is often difficult to match with energy intake (EI) as food supply and the time to eat or prepare meals are often limited (Margolis et al., 2014; Margolis et al., 2013; Nindl et al., 2007). A mismatch between EI and EE can result in (a) positive or negative energy balance (EB) , which is calculated as total EI minus total EE, and/or (b) reduced (or low) energy availability (EA), which is calculated as total EI minus exercise EE (EEE; or physical activity) expressed relative to fat free mass (FFM), and represents the energy remaining for other metabolic processes to ensure optimal physiological function (Mountjoy et al., 2018).

Negative EB is associated with reductions in physical performance during military training and operations (Murphy et al., 2018). Predictions derived from a meta-regression indicated that a total EB of -8162 kcal could be endured for a 7-day operation (negative EB of -1166 kcal·d^{-1}) with little decrease in performance and that for longer-duration operations (7 to 64 days), total negative EB should be limited to between -5686 to -19109 kcal for a zero to small (2%) decline in lower-body power and strength performance (Murphy et al., 2018). Although the measurement of EB provides a useful construct to consider the overall regulation of human body mass, it also has conceptual limitations, particularly the assumption that all physiological systems are functioning at an optimal level. This simplification is pertinent when an energy-deficient organism may reduce basal metabolism in an attempt to restore balance, albeit with a suppression of non-immediately essential physiological functions (Stubbs et al., 2004). Taken together, the concept of EA may be a more useful model for longitudinal adaptation to training as it is closer to an “input” to the body’s physiological systems (Loucks et al., 2011). In an athletic population, reduced EA (30 - 45 kcal·kg $\mathrm{FFM}^{-1}\cdot\mathrm{d}^{-1}$) has been associated with increased risk of impaired physiological functions and physical performance (Loucks et al., 2011). Reduced EA has been shown to increase risk of bone stress injuries in both men and women (Papageorgiou et al., 2017), increase risk of menstrual disorders and infertility in women (Loucks et al., 2011), and reduce testosterone levels in men (Burke, Close, et al., 2018; Hackney, 2020). Low EA (≤ 30 kcal·kg $\mathrm{FFM}^{-1}\cdot\mathrm{d}^{-1}$) limits the amount of energy used for thermoregulation, growth, cellular maintenance and reproduction in favour of the more crucial physiological mechanisms that are necessary for survival, with implications for health and performance (Mountjoy et al., 2018). Although EA hasn’t previously been quantified in military training, a comprehensive review by O'Leary et al. (2020) demonstrated that large energy deficits during military training are likely to disturb endocrine and metabolic function, menstrual function, bone health, immune function, gastrointestinal health, iron status, mood, and physical and cognitive performance.

The importance of quantifying both EB and EA, with a view to protecting the health and performance of athletes, is being increasingly recognised (Ackerman et al., 2018; Papageorgiou et al., 2017). However, research in military settings is limited. Therefore, the aims of this study are to 1) investigate the EB and EA across three contextually different periods of the CC and 2) investigate the EB and EA of male and female OCs undertaking the CC at RMAS.

METHODS

The general approach to this study was to measure dietary intake during three contextually different periods of the CC:

Period 1 (Junior Term, CC Week 9): Nine days training in camp (CAMP). The OCs undertook classroom-based work, rifle and combat drills and instructor-led physical training. Meals were either hot food from a dining hall, field container meals or packed lunch on the shooting ranges.

Period 2 (Intermediate Term, CC Week 22): Five days on a defensive field exercise (FEX) consisting of constant low-to-moderate activity, digging, and limited sleep. Meals were supplied in 24-hour ration packs and self-selected non-perishable items, and eating was *ad libitum*.

Period 3 (Senior Term, CC Week 34): Nine days of mixed camp and field-based training (MIX). Participants undertook training akin to that in CAMP for three days and six days on field exercise, conducting public order training. On camp meals were provided in a dining hall and during the field exercise meals were from a field-based kitchen.

In all conditions, participants were permitted to supplement their nutritional intake with their own personal items of food and drink.

Participants

Twenty Officer Cadets from RMAS volunteered for each of the conditions (total of 26 individuals). Fifteen participants who successfully completed all data collection periods were included in the study. Two participants (one man and one woman) were excluded from FEX due to injury, therefore 13 participants (six men: 24 ± 1 years, 1.78 ± 0.07 m, 82.1 ± 8.3 kg, and seven women: 22 ± 2 years, 1.69 ± 0.03 m, 70.2 ± 4.2 kg) were included in the final data analysis. Participants were provided with a verbal and written brief on the requirements of the study, in the absence of any uniformed staff, and offered the opportunity to ask questions before providing informed written consent. Ethical approval was granted by the Ministry of Defence Research Ethics Committee (protocol number 780/MoDREC/16).

Anthropometry

Height (SECA, Birmingham, UK) and body mass (Fitbit Aria, CA, USA) were measured at the beginning of each data collection period, before lunch, wearing minimal clothing (shorts and t-shirt, with no shoes) where possible. Fat mass was calculated from total body water determined from Doubly Labelled Water (DLW) as described previously by Schoeller et al. (1980) and FFM was calculated as the difference between body mass and fat mass (Wishart, 2011).

Energy Expenditure

Free-living EE during the data collection periods was determined using the DLW technique over each data collection period. On the evening prior to the start of data collection, baseline urine samples were collected. Following the collection of baseline urine, participants drank a single bolus dose of doubly labelled water ($^2H_2{}^{18}O$) containing 174 $mg \cdot kg^{-1}$ body weight deuterium oxide (Cambridge Isotope Laboratories Inc., MA, USA) and 70 $mg \cdot kg^{-1}$ body weight 18-Oxygen (Sercon Ltd, Crewe, Cheshire, UK). Following administration of DLW, urine samples were collected each day for nine consecutive days, avoiding the first void of the day. Urine samples were kept refrigerated until they arrived at the Medical Research Council (MRC) Elsie Widdowson Laboratory where they were frozen at -20°C until later analysis using isotope ratio mass spectrometry. The rate of carbon dioxide production was determined using the multi-point method of Schoeller et al. (1986) and converted to EE using the energy equivalent of CO_2 (Elia & Livesey, 1988), assuming a respiratory quotient of 0.85.

Energy Intake

Dietary intake of all core meals was primarily measured through researcher-led dietary weighing and food diaries as a secondary source when researchers were not present with participants. In CAMP and MIX, dietary weighing was conducted by researchers placed at three locations in the dining hall and field kitchen; the hot plate, salad bar and dessert stand. When participants entered the dining hall they were provided with a tray marked with their participant number. At the hot plate, a ‘protein portion’ was served by dining hall staff, which was subsequently weighed. The participants were then permitted to self-select all other items, which were each individually weighed. Upon finishing, all discards, including any wrappers from sauces, food and drinks, were weighed. Participants were provided with food diaries on a daily basis to record all food eaten per day, and a small zip-lock bag to contain wrappers from any food consumed. Participants were also asked to record the time of day the food was eaten, the brand, the location (e.g. dining hall, shooting range etc.) and the portion size. During FEX, OCs were required to store all ration pack wrappers and any additional food item wrappers in zip-lock bags, with the day and time eaten, written on the wrapper. All wrappers were collected each day by researchers and discards were weighed. The dietary intake of each participant was analysed using nutritional analysis software (Nutritics, Nutritics LTD, Ireland) to calculate energy intake.

Energy Balance

Energy Balance was quantified over the three data collection periods during each term (CAMP, FEX, MIX) where EE was subtracted from EI. During FEX, despite EE being measured over nine days, EI was only measured over the exercise period (five days) and therefore it must be noted that EB was an average of five days during camp training and five days of field exercise.

Energy Availability

Energy availability was calculated by subtracting average daily EEE from the average daily EI, relative to FFM (Loucks et al., 2011), shown in Equation 1, where EEE was calculated from the total daily EE minus estimated basal metabolic rate (BMR) (Henry, 2007) and the thermogenic effect of food, which was set at 10 % of EI. Energy availability was categorised as optimal EA (> 45 kcal·kg FFM^{-1}·d^{-1}), reduced EA (45 < 30 kcal·kg FFM^{-1}·d^{-1}) or low EA (< 30 kcal·kg FFM^{-1}·d^{-}1).

$$EA = \frac{(EI - EEE)}{FFM}$$

Equation 1: Calculation of energy availability (EA) from energy intake (EI) minus exercise energy expenditure (EEE) relative to fat free mass (FFM).

Data Analysis

Results are expressed as mean ± one standard deviation or 95% confidence intervals (CI) as stated. Statistical analysis was conducted using Statistical Package for the Social Sciences (SPSS; IBM SPSS version 23 for Windows, IBM Corporation, Chicago, IL). Statistical significance and evidence for rejection of the null hypothesis was set at an alpha level of < 0.05. Descriptive statistics were used to assess assumptions of the data for chosen analysis procedures, and normality was confirmed using Shapiro-Wilk tests for dependent variables. Homogeneity of variances was confirmed using Levene's test. A two-way repeated measures analysis of variance (ANOVA) with reported effect size (partial eta squared [η^2_p]) was used to evaluate differences in EE, EI, EB and EA between men and women across the three conditions (CAMP, FEX, MIX). Significant main effects were analysed with Bonferroni *post hoc* adjustments to determine the location of the pairwise differences. Interpretation of Cohen's d was used as follows: ≤ 0.2 trivial effect, 0.21 to 0.50 small effect, 0.51 to 0.80 moderate effect and ≥ 0.8 a large effect (Cohen, 1988).

RESULTS

Energy Intake

Table 1 presents a summary of the EI, EE, EB and EA for the three measurement periods by gender.

For EI, there was a main effect of condition ($F_{(2,10)}=19.688$, $p<0.001$, $\eta^2_p=0.797$), irrespective of gender, where EI was greater during CAMP than FEX (mean difference [95% CIs]: 981 [591, 1371], $p<0.001$, $d=1.522$) and MIX (837 [458, 1217], $p=0.001$, $d=1.334$); however, data did not support a difference between FEX and MIX ($p=0.338$, $d=-0.227$). Men had higher EI compared with women ($F_{(1,5)}=8.821$,

$p=0.013$, $\eta^2_p=0.445$), irrespective of condition, but no interaction effect of gender and condition was apparent ($F_{(2,10)}=0.792$, $p=0.480$, $\eta^2_p=0.137$).

Energy Expenditure

For EE, there was a main effect of condition ($F_{(2,10)}=34.068$, $p<0.001$, $\eta^2_p=0.872$) irrespective of gender, where EE was higher during FEX than CAMP (mean difference [95% CIs]: 558 [351, 765], $p<0.001$, $d=1.628$) and MIX (765 [486, 1045], $p<0.001$, $d=1.652$), and greater in CAMP than MIX (208 [31, 384], $p=0.025$, $d=0.711$). Men had higher EE compared with women ($F_{(1,5)}=21.978$, $p=0.005$, $\eta^2_p=0.815$), irrespective of condition, but with no interaction effect between gender and condition ($F_{(2,10)}=2.549$, $p=0.102$, $\eta^2_p=0.188$).

Energy balance

Average EB appeared different between conditions ($F_{(1.04,5.18)}=48.805$, $p=0.001$, $\eta^2_p=0.907$) irrespective of gender, where participants were in a greater negative EB in FEX compared with CAMP (mean difference [95% CIs]: -1497 [-1123, -1871], $p<0.001$, $d=3.171$) and MIX (-909 [-615, -1204], $p<0.001$, $d=2.408$), and in a greater negative EB in MIX compared with CAMP (-588 [-919, -257], $p=0.007$, $d=1.402$; Figure 1). There was no difference apparent in EB between genders, irrespective of condition ($F_{(1,5)}=0.946$, $p=0.375$, $\eta^2_p=0.159$) nor an interaction effect ($F_{(2,10)}=0.172$, $p=0.844$, $\eta^2_p=0.033$).

INSERT FIGURE 1 HERE

Figure 2 shows total EB (average daily EB x duration) during CAMP (-6231 ± 4555 kcal), FEX (-10984 ± 2273 kcal) and MIX (-11560 ± 2898). Despite the smallest negative EB being measured in CAMP, observationally it had the largest range between participants (CAMP: -16969 to 255; FEX: -13417 to -5190; MIX (-15558 to -5941 kcal).

INSERT FIGURE 2 HERE

Energy Availability

During CAMP, 69% of participants were in low EA (four women and five men; Figure 3), and 31% of participants were in reduced EA with none considered optimal. During FEX and MIX, 92% of participants were in low EA, one woman and one man were in reduced EA during FEX and MIX, respectively. There was an effect of condition on average EA ($F_{(2,10)}$=12.107, p=0.002, η^2_p=0.708), irrespective of gender, where participants had higher EA in CAMP compared with FEX (mean difference [95% CIs]: 23 [10, 35], p=0.002, d=1.11) and MIX (13 [5, 20], p=0.003, d=1.039) but FEX and MIX appeared similar (p=0.214, d=0.071; Table 1). There was no difference in EA between genders, irrespective of condition ($F_{(1,5)}$=0.904, p=0.385, η^2_p=0.153), nor an apparent interaction effect ($F_{(2,10)}$=0.660, p=0.538, η^2_p=0.117).

INSERT FIGURE 3 HERE

DISCUSSION

The present study is the first to characterise the EB and EA of men and women in three contextually different military training settings. All three periods of military training resulted in negative EB and low EA, which were similar between men and women. Quantifying the magnitude of negative EB and low EA can be used to inform military populations on the potential risks and detrimental effects on health and performance in contextually different settings. These risks and detrimental effects include decrements in physical performance and training time loss due to increased injury rates.

The negative EB demonstrated in the present study was in keeping with previous military research and was likely caused by prolonged low intensity work and intermittent periods of moderate-to-high intensity activity over 16 to 22 hours of training per day (Henning et al., 2011; Tharion et al., 2005; Wilkinson et al., 2008). Similarly, average EE during the data collection periods in the present study was similar to those previously reported during other British Army training courses; 4732 ± 700 kcal·d^{-1} (Wilkinson et al., 2008), 3633 ± 359 kcal·d^{-1} (Blacker et al., 2009), 5094 ± 471 kcal·d^{-1} (Richmond et al., 2014). During field exercises, time to eat is often limited and it is common for soldiers to “field strip” their rations to increase available packing space and limit the amount of weight carried (Pasiakos

& Margolis, 2017), choosing to keep specific items based on personal preference. Whilst this is done to try to decrease physical burden of carrying load mass, this may in turn reduce EI. In these instances, EI is unlikely to match EE, as demonstrated by Margolis et al. (2014), where Norwegian soldiers expended up to 6800 kcal·d^{-1} (measured via DLW) during a 3-day arctic military exercise, but ate approximately 3400 kcal·d^{-1} (measured via dietary weighing), equating to only 50% of the energy required to maintain EB. During FEX in the present study, the operations performed meant participants undertook low-to-moderate continuous physical activity over the 5-day period combined with substantial sleep deprivation. These factors, as well as stripping their rations, collectively contributed to the negative EB observed.

A meta-regression performed by Murphy et al. (2018) explored the changes in physical performance in relation to study duration (daily EB x duration) during military operations. It was suggested that limiting total EB to above or between -5686 to -19,109 kcal across an entire operation (between 7 to 64 days) would keep potential loss of performance to a minimum (Murphy et al., 2018). In the present study, participants' mean net energy deficit was ~11000 kcal in FEX and ~11500 in MIX which, falling within the above range, would have projected no more than a 2% decline in performance. However, the predictions made by Murphy et al. (2018) were only based on nine studies, and should be interpreted with caution.

In the present study OCs were, on average, in low EA during all data collection periods, though it is noted that EA in FEX and MIX was significantly lower than CAMP. Low EA could pose a risk of compromised physiological function and physical performance (Loucks et al., 2011). Research attention on EA has been prevalent in athletes with few studies investigating EA in the military setting. Mullie et al. (2019) examined EA in 21 male soldiers during a six-month Special Forces training course consisting of theoretical lessons, field training, tactical exercises, parachuting, and shooting exercises. On average, the soldiers were in a low EA (mean; range: 17; 1 to 44 kcal·kg FFM^{-1}·d^{-1}) as well as a negative EB of -704 ± 824 kcal·d^{-1}, similar to that of CAMP and MIX in the present study but a higher

EA than that seen during FEX. In US Army soldiers, McAdam et al. (2018) determined the EI and EE of OCs using dietary logs and activity monitors. Their data suggested that average EEE was high in comparison to research concerning sporting populations, at approximately 1461 ± 286 kcal·kg FFM^{-1}·d^{-1}. Although EA was not reported, when retrospectively estimated, it indicated that participants would have been in a low EA of approximately 17 kcal·kg FFM^{-1}·d^{-1}. Similar to military training, high EEE has been reported in endurance sports alongside reduced and low EA from the high volume of required training. For example, previous research investigating swimmers and Tour de France cyclists found EEE to be 1230 ± 82 kcal·d^{-1} and 3561 kcal·d^{-1}, respectively, equating to 18 and 6 ± 3 kcal·kg FFM^{-1}·d^{-1} across multiple days (Schaal et al., 2017; Vogt et al., 2005). In the present study, during FEX, EEE was demonstrated to be almost double (3300 kcal·d^{-1}) that reported in US Army recruits by McAdam et al. (2018) and similar to that of the Tour de France cyclists, but without the same nutritional replenishment afforded to elite athletes, explaining the low EA observed.

Optimal EA for healthy physiological function is reported to be ≥ 45 kcal·kg FFM^{-1}·d^{-1} (Loucks et al., 2011). As described previously, low (≤ 30 kcal·kg FFM^{-1}·d^{-1}) and reduced (30 to 45 kcal·kg FFM^{-1}·d^{-1}) EA have been associated with increased risk of impaired physiological functions and/or physical performance (Loucks et al., 2011), increased risk of menstrual disorders and infertility in women (Loucks et al., 2011), reduced testosterone levels in men (Burke, Close, et al., 2018) and increased risk of bone stress injuries due to decreased bone resorption in both men and women (Papageorgiou et al., 2017). Further, low EA can result in the amount of energy used for thermoregulation, growth, cellular maintenance and reproduction to be reduced for physiological mechanisms that are more crucial for survival, with subsequent health and performance impairments with possible implications for long-term health (Mountjoy et al., 2018). As no measures were obtained in the present study that could help identify mechanistic impacts of low EA, it is unknown to what degree OCs were affected. Previous work within the same cohort has demonstrated that weekly injury incidence over the three terms during the CC were 4.1 ± 1.8, 2.9 ± 2.5 and 2.5 ± 2.4%, respectively, which was demonstrated to be more likely during high-moderate training load (Powell et al., [Under Review]), which may suggest that there could be a relationship with low EA, however this would need further exploration. Previous research however, has demonstrated disturbed endocrine function (increased cortisol and decreased testosterone and luteinising hormone) after seven days of field exercise whilst soldiers were in negative EB (Hamarsland et al., 2018; Kyrolainen et al., 2008), as well as decreased markers of bone transformation and increased markers of bone reabsorption after eight weeks of military training in male soldiers when in an energy deficit (Hughes et al., 2014). Therefore, it is likely that prolonged continuation of these training exposures, particularly FEX and MIX, would have negative consequences, however further research is required to investigate the effect of low EA on physiological functions and physical performance in military settings.

There has been a greater volume of research in women on the potentially negative health consequences from energy deficit from athletic pursuits than in men (Burke, Close, et al., 2018; Hackney, 2020). The resultant collective term for the three key impacts of energy insufficiency — low bone mineral density, eating disorder, infertility — in women is the Female Athletic Triad which, when coupled with impacts observed in both sexes as well as the recognition of other health and performance implications beyond the aforementioned three, has culminated in the clinical term “Relative Energy Deficiency in Sports” (RED-S) (Mountjoy et al., 2014). The aforementioned emphasis has meant that the reference values for reduced- and low- EA have been determined from data in women; however, it is unclear if the reference values may differ from women, as men may be more metabolically robust against short-term energy reductions than women (Koehler et al., 2016). Although studies of low EA in male athletes are more rare, it seems that the prevalence of low EA occurs in similar sports as for women athletes (Mountjoy et al., 2014), including weight-sensitive sports, where leanness and/or body mass are important factors for performance or eligibility (*e.g.*, long-distance running, road cycling, boxing and wrestling) (Sundgot-Borgen et al., 2013). Although the present study demonstrated no sex differences in EA during any condition, it should be noted that low

EA in men may adversely affect different processes than women (Ackerman et al., 2018; Hackney, 2020). Furthermore, specific thresholds exist at which either physiological functions or performance can be impaired, therefore there is likely to be a large degree of within- and between- participant variability (Williams et al., 2014), limiting interpretation without measuring possible downstream effects alongside EA, which was not possible in the present study.

Within military environments, where direct measures of EI and/or EE cannot be easily made, clinical screening tools can be used for the detection of low EA such as the low EA in females questionnaire (Melin et al., 2014), the RED-S clinical assessment tool (Mountjoy et al., 2018) or the cumulative risk assessment tool which are validated methods to identify the risk of low EA in athlete cohorts (Logue et al., 2019). Although these assessments include some degree of error, they are considered a cost- and time- effective tool to identify those who would benefit from a more detailed EA assessment (Burke, Lundy, et al., 2018); their utility in a military setting should be explored.

Despite the recent abundance of research investigating EA in athletes, there are still no clear guidelines on measurement of EA in military environments, including the time-frame of the assessment and techniques used to measure each of the components of EA (Burke, Lundy, et al., 2018). The measurement of EEE has been shown to contribute a significant error to the calculation of EA (Burke, Lundy, et al., 2018) due to the lack of consensus on what constitutes exercise in a free-living environment, especially within the military where prolonged periods of light-to-moderate intensity exercise are often the contributing factors to the high total daily EE (Margolis et al., 2013; Nindl et al., 2007). A limitation of the present study was that despite EE being measured using DLW over nine days during FEX, EI was only measured over the exercise period and therefore EB was an average of five days during camp training and five days of field exercise. Therefore, during FEX, EB and EI may have been underestimated. Therefore, further investigation of EI and EEE in military personnel paired with biochemical, clinical, and endocrine measures are warranted to understand the impact of low EA on health and performance.

CONCLUSION

The present study is the first to report EB and EA in men and women in a free-living military setting. The high EE and low EI resulted in negative EB and low EA which was exacerbated during the FEX period, which could be detrimental to health and physical performance. There was no difference in EB and EA between men and women, which is consistent with research in athletes. Further investigation is required to assess possible physiological influences of low EA in both male and female military personnel and other occupations that operate in arduous condition for prolonged periods of time, as well as a need to develop gold-standard guidelines for the measurement techniques and duration to quantify EA. Further research is warranted to explore whether an acute period of low EA would be detrimental to soldiers' health or how to best counteract this occurrence in a field environment.

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Tables

Table 1: Energy intake, expenditure, balance and availability during periods of camp training (CAMP), field exercise (FEX) and combined camp and field training (MIX)

	CAMP		**FEX**		**MIX**	
	Men	Women	Men	Women	Men	Women
EI (kcal·d^{-1})*†	3846 ± 1068	3172 ± 524	3071 ± 732	2015 ± 477	3037 ± 412	2311 ± 108
EE (kcal·d^{-1})*,**	4264 ± 581	3714 ± 132	5361 ± 539	4420 ± 391	4371 ± 579	3546 ± 163
EB (kcal·d^{-1})*†**	-868 ± 572	-542 ± 442	-2289 ± 264	-2104 ± 603	-1334 ± 377	-1235 ± 245
EA (kcal·kgFFM·d^{-1})*†	21 ± 11	25 ± 10	-5 ± 6	5 ± 22	12 ± 10	10 ± 5

* significant difference between CAMP and FEX, † significant difference between CAMP and MIX, ** significant difference between FEX and MIX, $p < 0.05$.

List of Figures

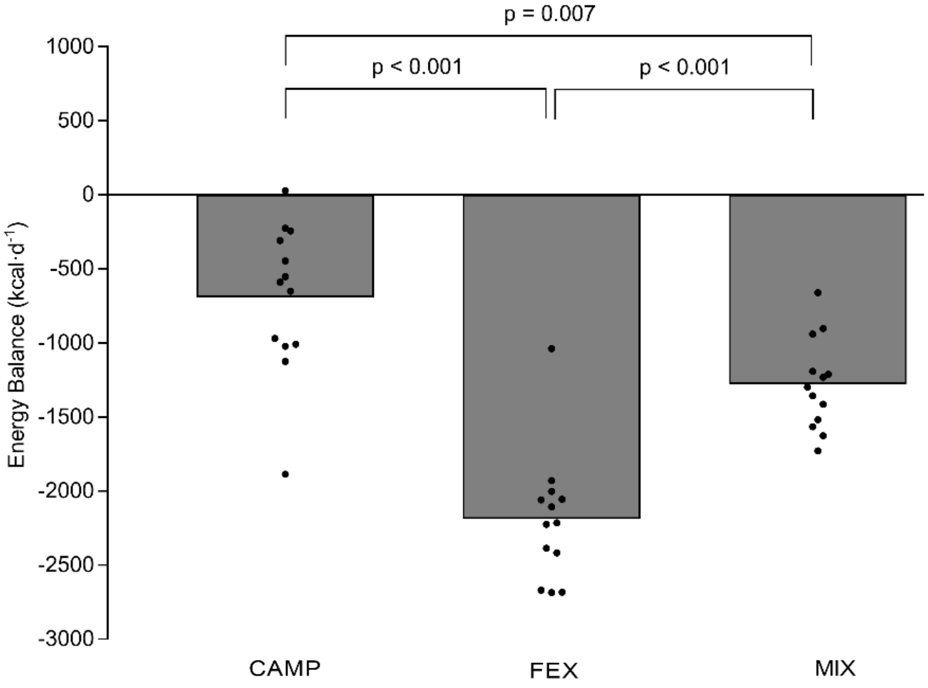

Figure 1: Average energy balance during nine days camp training (CAMP), five days field exercise (FEX) and a combination of 9 days of camp and field training (MIX) with individual data points overlaid

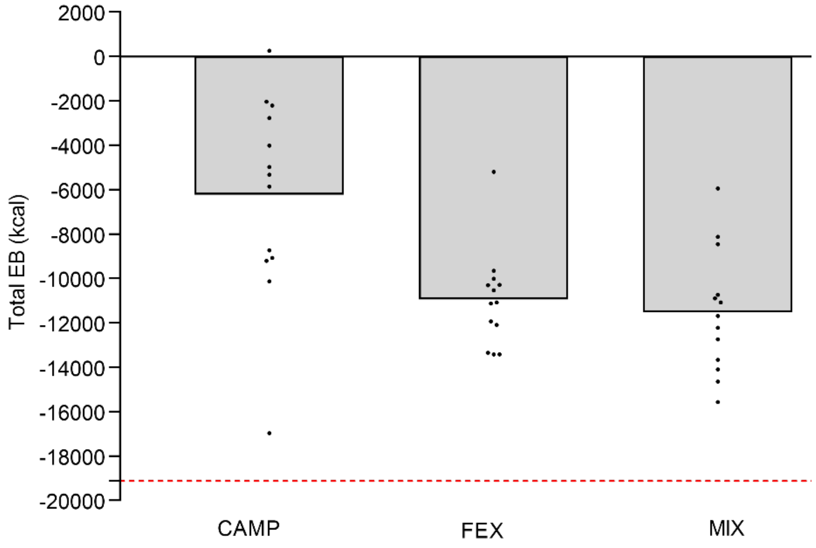

Figure 2: Average and individual total Energy Balance (EB; average daily EB x duration) during nine days camp training (CAMP), five days field exercise (FEX) and nine days combined camp and field based training (MIX)

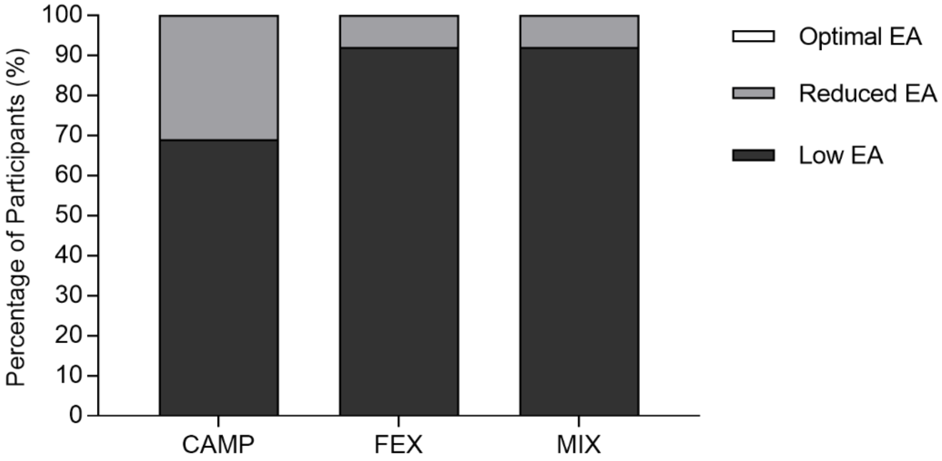

Figure 3: Percentage of participants in optimal Energy Availability (EA; ≥ 45 kcal·kg FFM^{-1}·d^{-1}), reduced EA (30 - 45 kcal·kg FFM^{-1}·d^{-1}) and low EA (≤ 30 kcal·kg FFM^{-1}·d^{-1}) for camp (CAMP), field based training (FEX) and combined camp and field training (MIX)