British Journal of Nutrition (2014), **112**, 821–829 doi:10.1017/S0007114514001524

British Journal of Nutrition

Energy expenditure, nutritional status, body composition and physical fitness of Royal Marines during a 6-month operational deployment in Afghanistan

Joanne L. Fallowfield[1]*, Simon K. Delves[1], Neil E. Hill[2,3], Rosalyn Cobley[1], Pieter Brown[1], Susan A. Lanham-New[4], Gary Frost[3], Stephen J. Brett[3], Kevin G. Murphy[3], Scott J. Montain[5], Christopher Nicholson[1], Michael Stacey[2], Christian Ardley[2], Anneliese Shaw[1], Conor Bentley[6], Duncan R. Wilson[2] and Adrian J. Allsopp[1]

[1]*Institute of Naval Medicine, Alverstoke, Hampshire PO12 2DL, UK*
[2]*Royal Centre for Defence Medicine, Birmingham, UK*
[3]*Imperial College London, London, UK*
[4]*Department of Nutrition and Metabolism, Faculty of Health and Medical Sciences, University of Surrey, Guildford, Surrey, UK*
[5]*U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760, USA*
[6]*University Hospitals Birmingham NHS Foundation Trust, Queen Elizabeth Hospital, Birmingham, UK*

(Submitted 15 October 2013 – Final revision received 26 April 2014 – Accepted 22 May 2014 – First published online 9 July 2014)

Abstract

Understanding the nutritional demands on serving military personnel is critical to inform training schedules and dietary provision. Troops deployed to Afghanistan face austere living and working environments. Observations from the military and those reported in the British and US media indicated possible physical degradation of personnel deployed to Afghanistan. Therefore, the present study aimed to investigate the changes in body composition and nutritional status of military personnel deployed to Afghanistan and how these were related to physical fitness. In a cohort of British Royal Marines (n 249) deployed to Afghanistan for 6 months, body size and body composition were estimated from body mass, height, girth and skinfold measurements. Energy intake (EI) was estimated from food diaries and energy expenditure measured using the doubly labelled water method in a representative subgroup. Strength and aerobic fitness were assessed. The mean body mass of volunteers decreased over the first half of the deployment ($-4·6$ (SD 3·7) %), predominately reflecting fat loss. Body mass partially recovered (mean $+2·2$ (SD 2·9) %) between the mid- and post-deployment periods ($P<0·05$). Daily EI (mean 10 590 (SD 3339) kJ) was significantly lower than the estimated daily energy expenditure (mean 15 167 (SD 1883) kJ) measured in a subgroup of volunteers. However, despite the body mass loss, aerobic fitness and strength were well maintained. Nutritional provision for British military personnel in Afghanistan appeared sufficient to maintain physical capability and micronutrient status, but providing appropriate nutrition in harsh operational environments must remain a priority.

Key words: **Nutrition: Military: Body composition: Energy expenditure**

Nutrition is a key determinant of health, well-being and physical capability[1]. The operational capability of military personnel is determined by their physical fitness, ability to respond to external stimuli including local environmental conditions, and dietary intake and by the quality of their rest/recovery after bouts of arduous work[2]. Thus, nutrition is fundamental to operational capability, as well as to the health and well-being of personnel; the provision of sufficient nutrition to maintain the physical and mental performance of soldiers is a major factor in the success of military operations[2].

British and American Armed Forces were first deployed in numbers to Afghanistan in 2001. Despite significant improvements, forward operating bases (FOB) and patrol bases (PB) remain austere living and working environments. Soldiers patrolling on foot in Afghanistan frequently carry loads in excess of 50 kg (including body armour, weapons and backpack), often in temperatures greater than 40°C for up to 12 h a day. During such patrols, soldiers may be required to sprint, cross ditches, climb compound walls, fire weapons, and lift and evacuate casualties, increasing daily energy

Abbreviations: DEE, daily energy expenditure; DLW, doubly labelled water; EI, energy intake; FFM, fat-free mass; FM, fat mass; FOB, forward operating bases; MCR, Multi-Climate Ration; ORP, Operational Ration Packs; PAL, physical activity levels; PB, patrol bases; R&R, rest and recuperation.

* **Corresponding author:** Dr J. L. Fallowfield, fax +44 2392 504823, email joanne.fallowfield258@mod.uk

expenditure (DEE). Such conditions place severe physical and nutritional demands on soldiers.

On operations, if a field kitchen and fresh food are not available, UK military personnel subsist on Operational Ration Packs (ORP). The basic unit of the ORP is the Multi-Climate Ration (MCR), which is provided in thirty-eight different menu variants and is designed to sustain a soldier for 24 h[2]. The energy provision (across all variants) of the MCR is 17 146 kJ, which includes 651 g of carbohydrate, 130 g of protein and 92 g of fat. This is provided in the form of a breakfast, a main meal and a pudding, snacks (trail mix, boiled sweets, energy bars and biscuits), soup, and drinks (tea, coffee, chocolate, and orange or lemon). All the meals are packaged in aluminium foil laminate packets that can be immersed in hot water (boil-in-the-bag) to cook on hexamine stoves or can be eaten cold. The 10-man ORP is designed to feed ten men for a 24 h period and is provided in five menu variants. The energy provision and actual nutrient quality, as well as the day-to-day variety, of the food prepared from the 10-man ORP are very much dependent on the skill of the military field chef and how the basic components of the ration (which can be combined with fresh rations when available) are made into meals to sustain military personnel.

Anecdotal observations of possible physical degradation of personnel stationed at the more austere FOB and PB were reported in the British and US media[3–5]. Therefore, the present study aimed to prospectively evaluate changes in body composition, food intake and energy intake (EI), energy expenditure and physical fitness in a large cohort of personnel during a 6-month deployment to Afghanistan to inform future training schedules and nutritional provision.

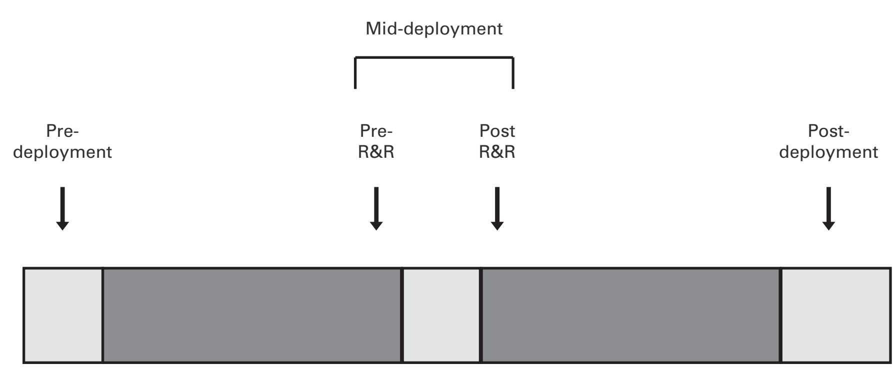
Methods

Study design

This was a within-subject, repeated-measures study. Volunteers' anthropometric (body mass, body height and body composition) measures were recorded and dietary intake and physical capability were assessed in the UK pre-deployment (March 2010) and post-deployment (October 2010). Anthropometric measures and dietary intake were also evaluated in Camp Bastion before and after 14 d of mid-tour leave (rest and recuperation (R&R); June–August 2010). Mean time from pre- to mid-deployment was 121 (SD 18) d (range: 90–153 d) and that from mid- to post-deployment was 86 (SD 19) d (range: 55–125 d). A schematic representation of the study design is shown in Fig. 1. The present study was conducted according to the guidelines laid down in the Declaration of Helsinki, and all procedures involving human volunteers were approved by the Ministry of Defence Research Ethics Committee (090/GEN/09). Written informed consent was obtained from all volunteers.

Research participants

A unit of approximately 750 Royal Marines was approached to take part in the study. The study sample was limited to those in camp during the pre-deployment measurement period.



Measurements	UK	Afghanistan	UK		Afghanistan	Cyprus	UK
Physical fitness: MSFT, sit-up test and press-up test (*n* 34 matched volunteers)	•						•
Physical fitness: hand-grip and static lift strength (*n* 63 matched volunteers)	•		•	•		•	
Anthropometry (*n* 105 matched volunteers)	•		•	•		•	
Blood sample (*n* 98 matched volunteers)							
Dietary intake (*n* 40 matched volunteers pre *v*. mid)	•	•			•		•
Energy expenditure (DLW *n* 18; PAL *n* 63)		•			•		

Fig. 1. Schematic representation of the study design for measurements taken at pre-, mid- and post-deployment in military volunteers. Measurements in military volunteers (*n* 249) were taken at four time points: pre-deployment (UK); pre-rest and recuperation (R&R; Afghanistan); post-R&R (Afghanistan); post-deployment (Cyprus and UK). Measurements of physical fitness (hand grip and static lift strength) and anthropometry (body mass, height, skinfolds and body girths) were taken at four time points; the multi-stage fitness test (MSFT), sit-up test and press-up test were carried out at only pre- and post-deployment. Dietary intake (food record card) and health history and nutritional supplements questionnaires were administered at pre-, mid- and post-deployment. Energy expenditure was estimated in subgroups of volunteers (by the doubly labelled water (DLW) method and Task Analysis Questionnaire) during the military deployment. PAL, physical activity levels.

However, it was confirmed following recruitment that the study sample was representative of the deploying unit in terms of age, military experience and rank structure through comparison with the unit demographics – and specifically through comparison with the rank distribution across the unit. All participants were at least 18 years old at deployment, operationally fit and medically healthy. A cohort of 249 volunteers was recruited (i.e. 139 Marines, ninety Non-Commissioned Officers, ten Officers, and ten Other).

Procedures

Anthropometric assessment. Pre-deployment anthropometric measures were recorded in the UK, mid-deployment measures were recorded at Camp Bastion, Afghanistan, and post-deployment measures were recorded at RAF Akrotiri, Cyprus, as volunteers returned to the UK. Thus, the anthropometric parameters of volunteers were measured within 7 d of leaving the frontline. Body mass (Seca scales; accuracy 0·1 kg), height (Invicta stadiometer; accuracy 0·1 cm; Invicta Plastics Ltd) and body composition as assessed by skinfolds (eight sites) and circumferential girths (six sites) were measured as described in the Anthropometric Standardisation Reference Manual[6]. Body mass measurements were standardised with volunteers being measured in a fasted state in the morning wearing underwear/lightweight sports shorts. To minimise error variance in the anthropometric assessment, body girth and skinfold measurements were controlled and standardised between investigators taking the measurements by locating specific measurement sites relative to stable anatomical features, where the distance from the anatomical landmark was standardised between measurements. BMI was calculated from body mass (kg) and height (m). Body fat percentage was estimated using the method of Durnin & Womersley[7].

Dietary intake assessment. The dietary intake of volunteers, where the mainstay of provision was from the MCR, was recorded over representative 4 d periods at pre-, mid- and post-deployment using a bespoke food diary developed from the Ministry of Defence (MOD) food record card[8]. The food record card is summarised in Appendix 1 (available online). The post-deployment data set was limited (*n* 38) by the departure of volunteers on leave immediately on returning to the UK. The most robust comparison for evaluating the effect of deployment *per se* on dietary intake, therefore, was between pre- and mid-deployment (i.e. before mid-deployment leave) measurement periods. There was movement of personnel between bases during the deployment, making determination of the effects of specific location on dietary intake difficult. However, it was possible to identify a subset of volunteers stationed solely at either Camp Bastion or a FOB between pre- and mid-deployment measurement periods. In the subgroup of volunteers participating in the energy expenditure measurement sessions, dietary intake was assessed over a 7 d period. Pre- and post-deployment measurements were taken in the UK and mid-deployment measurements at the FOB, PB and the main operating base at Camp Bastion. The accuracy of the self-reported diet records was assessed by applying the James & Schofield[9] human energy requirement equation for BMR calculation.

Nutritional analysis of food diaries. Dietary intake data were analysed using an analysis package (WinDiets; Robert Gordon University) and assessed in relation to normative data[10] and published military and exercise science literature[1,11].

Micronutrient status assessment. At pre-, mid- and post-deployment, blood samples were drawn, and serum was extracted from a 10 ml aliquot, frozen at -20°C *in situ* and subsequently stored at -80°C until the measurement of micronutrient concentrations (Nutritional Sciences Laboratory, University of Surrey, Guildford, Surrey, UK). The trace elements Cu, Mg, Se and Zn were selected to provide a general profile of nutritional status. Specifically in relation to the research participants and the field context of the present study, these trace elements perform important metabolic functions associated with bone and muscle health (Mg, Cu and Se), immune function (Mg and Zn), enzyme activity (Mg and Cu) and antioxidant function (Zn and Se)[12–19]. Concentrations in serum samples were determined by inductively coupled plasma MS (Thermo X1 ICP-MS; Thermo Electron Corporation); the concentrations of Cu, Zn and Mg were measured in standard mode, whereas the concentration of Se was measured in collision cell mode with kinetic energy discrimination and He:H_2 as the cell gas. The samples and calibration standards were diluted using 0·5 % (v/v) nitric acid containing an internal standard, and the calibration standards were prepared with bovine calf serum to correct for sample matrix effects. Internal quality control samples were analysed alongside the samples, and analysis was carried out only if the values of the internal quality control samples were within the stated ranges. The methods used are documented in standard operating procedures and the work is accredited by Clinical Pathology Accreditation (UK). The serum concentrations of ferritin were measured using standard immunoassay techniques on an Abbott Architect i2000SR analyser (Abbott Diagnostics).

Operational energy expenditure assessment. Energy expenditure was measured during the deployment at a time when the operational tempo was most representative of a summer deployment to Afghanistan. Energy expenditure was estimated in a subgroup (*n* 18) of volunteers over a representative 7 d period of military operations using a Task Analysis Questionnaire (which included details of the intensity and duration of physical activities) and military-specific physical activity levels (PAL) and measured in the same subgroup using the doubly labelled water (DLW) method, as described by Schoeller *et al.*[20]. Urine samples were analysed by the United States Army Research Institute of Environmental Medicine. Data reported are the mean estimated DEE over the 7 d sampling period. Dietary intake was also assessed in this subgroup over the same 7 d[8]. Estimated DEE data (from PAL data) and daily EI data were partitioned for this subgroup into patrolling (almost entirely on foot) and non-patrolling days; military patrolling with load is deemed to be the most arduous occupational task of deployed frontline personnel. The estimated DEE (from PAL data) was also

https://doi.org/10.1017/S0007114514001524 Published online by Cambridge University Press

Table 1. Body mass and body fat percentage of volunteers at pre-, mid- and post-deployment

(Matched data for three measurement points, mean values and standard deviations)

	Body mass (n 105) (kg)		Body fat percentage (n 85)	
	Mean	SD	Mean	SD
Pre-deployment	82·4	9·1	17·2	4·9
Mid-deployment	78·5*	8·0	15·9*	4·6
Post-deployment	80·9†	8·3	16·0	4·2

* Mean values were significantly different from the pre-deployment value ($P<0·05$).
† Mean value was significantly different from the mid-deployment value ($P<0·05$).

determined over 4 d periods in an additional sixty-three volunteers, undertaking operational frontline duties, for comparison with the DLW subgroup.

Physiological fitness assessment. The physiological fitness test battery included the following tests: the multistage fitness test[21] to estimate VO_{2max}; press-up test (maximum number of military standard repetitions completed in 2 min) as an assessment of upper body strength; sit-up test (maximum number of military standard repetitions completed in 2 min) as an assessment of core muscular endurance; hand-grip strength assessment (Takei Hand Grip Dynamometer, Model 5401, Cranlea) of both dominant and non-dominant hands (i.e. in a standing position, arm positioned down the side of the body holding the dynamometer perpendicular to the ground, volunteers squeezed the hand grip to exert a maximal, isometric force, performing three repetitions of the exercise each separated by 30 s rest, where the highest value was recorded); a static lift strength assessment (Takei Isometric Dynamometer, Model 5402, Cranlea) (i.e. from the dead lift position, volunteers exerted a maximal, isometric force in the leg, buttock and back muscles, performing three repetitions of the exercise each separated by 30 s rest, where the highest value was recorded).

Statistical analyses

Statistical analyses were carried out using the statistical package SPSS (version 20.0.1; IBM). Data were checked for normality using the Kolmogorov–Smirnov test. Parametric and non-parametric data are presented as means and standard deviations or medians and interquartile ranges, respectively. Differences between pre-, mid- and post-deployment measurements were investigated using ANOVA, with Bonferroni correction as appropriate. Data that were not normally distributed were evaluated using the Friedman test with *post hoc* evaluation by the Wilcoxon matched-pairs test, with Bonferroni correction as appropriate. P values $<0·05$ were considered significant.

Results

Research participants

In total, 249 volunteers provided data (mean: age 28 (SD 7) years; height 1·79 (SD 0·06) m; body mass 82·8 (SD 9·1) kg; body fat percentage 17·3 (SD 4·5) %). Operational constraints prevented many volunteers from providing complete data at all time points. Furthermore, two volunteers were killed in action and nine were injured and returned to the UK before study completion. The challenges of tracking volunteers during an operational deployment between the UK and Afghanistan resulted in a subgroup of 153 volunteers being assessed before mid-tour leave at mid-deployment (in Camp Bastion, Afghanistan) and 100 volunteers on return to Afghanistan following R&R leave. Post-deployment measurements were taken in 176 volunteers in two stages: the most time critical (anthropometric measures and blood draw) were taken in Cyprus, during the return transit to the UK (October 2010), and the others (physical fitness and dietary intake assessments) within 14 d of volunteers returning to the UK. Matched data were available at all time points for 105 volunteers, and these data were used to analyse changes in body mass, BMI and body composition. Data were excluded from analyses if a volunteer was not assessed at pre-, mid- and post-deployment. The physical characteristics of volunteers are given in Tables 1 and 2.

Body mass, BMI and body composition

The mean body mass of volunteers decreased by 3·9 (SD 3·2) kg between pre- and mid-deployment measurement periods (mean 4·6 (SD 3·7) % loss in body mass; $P<0·05$) and increased by 2·4 (SD 2·2) kg between mid- and post-deployment measurement periods (i.e. mean 2·2 (SD 2·9) % increase in body mass) (Table 1). The mean BMI pre-deployment was 25·9 (SD 2·3) kg/m^2; this decreased to 24·8 (SD 2·1) kg/m^2 at mid-deployment and recovered to 25·5 (SD 2·1) kg/m^2 post-deployment ($P<0·05$). The mean body fat percentage of volunteers decreased from 17·2 (SD 4·9) % pre-deployment to 15·9 (SD 4·6) % at mid-deployment ($P<0·05$) and 16·0 (SD 4·2) % post-deployment ($P<0·05$). During the first half of the deployment, mean fat mass (FM) decreased by 1·7 (SD 2·0) kg ($P<0·05$) and mean fat-free mass (FFM) decreased by 1·9 (SD 1·9) kg ($P<0·05$). During the second half of the deployment, mean FM increased by 0·5 (SD 1·3) kg ($P<0·05$) and mean FFM increased by 2·1 (SD 1·8) kg ($P<0·05$).

In a subsample for which data collected at pre-deployment, before and after mid-deployment (R&R) leave, and post-deployment (n 75) were available, mean body mass increased

Table 2. Body mass and body fat percentage of volunteers at pre-deployment, pre-rest and recuperation (R&R), post-R&R, post-deployment

(Matched data for four measurement points, mean values and standard deviations)

	Body mass (n 75) (kg)		Body fat percentage (n 64)	
	Mean	SD	Mean	SD
Pre-deployment	81·1	8·8	16·6	4·8
Pre-R&R	77·8*	7·7	15·6*	4·6
Post-R&R	79·6†	8·2	16·2†	4·4
Post-deployment	80·1	8·0	15·6‡	4·1

* Mean values were significantly different from the pre-deployment value ($P<0·05$).
† Mean values were significantly different from the pre-R&R value ($P<0·05$).
‡ Mean value was significantly different from the post-R&R value ($P<0·05$).

https://doi.org/10.1017/S0007114514001524 Published online by Cambridge University Press

Table 3. Self-reported energy and macronutrient intake data of volunteers at pre-, mid- and post-deployment

(Mean values and standard deviations)

	Energy (kJ)		CHO (%)		Fat (%)		Protein (%)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Total pre-deployment (*n* 202)	12 690	3414	46	7	35	6	16	3
Total mid-deployment (*n* 80)	10 590	3339	48	8	34	7	17	3
Total post-deployment (*n* 38)	11 234	3548	43	7	35	6	17	5
MDRV (UK)*	11 757		60		25		15	
MDRV (Op)*	16 736		60		25		15	

CHO, carbohydrate; MDRV (UK), Military Dietary Reference Value for personnel serving in the UK; MDRV (Op), Military Dietary Reference Value for personnel serving on overseas operations.
* Based on current best available evidence[11].

by 1·8 (SD 1·6) kg during R&R leave, equivalent to a 46 % regain in body mass ($P<0·05$; Table 2), associated with a 0·8 (SD 1·3) kg increase in mean FM ($P<0·05$) and a 1·0 (SD 1·4) kg increase in mean FFM ($P<0·05$). Similar changes in body mass and body composition values observed in these paired data sets were also observed when all unpaired data were analysed.

Dietary intake

Breakfast was the most frequently missed meal unless there was a morning patrol. Breakfast food items at a FOB/PB included baked beans, bacon grill, powdered egg, tinned sausages, spam, porridge and pancakes. During the day, if patrolling, volunteers would consume snack items from the MCR (e.g. trail mix, sweets, energy bars and biscuits). Indeed, snacking was a widespread, accepted (and deemed necessary), eating behaviour, where snack items provided a relatively light (from a load carriage perspective) source of energy and nutrients. Occasionally, main meal pouches from the MCR would be taken on patrol if it were anticipated that volunteers might stay out on the ground for an extended period. If remaining at the FOB/PB, volunteers might prefer a main meal option from the MCR or 10-man ORP, supplemented with fresh rations when available. Dinner was the most frequently attended meal, with the evening meal providing an important opportunity to refuel, as well as being socially important for volunteers.

The dietary intakes of all volunteers at pre-, mid- and post-deployment are given in Table 3. The mean EI pre-deployment (12 690 (SD 3414) kJ) and post-deployment (11 234 (SD 3548) kJ) was generally consistent with the recommended dietary reference values for UK in-barrack (non-operational) energy requirements[11], though macronutrient intake included less carbohydrate than reported optimal (Table 3)[1]. The mean EI of volunteers at mid-deployment was 10 590 (SD 3339) kJ, which was lower than the pre-deployment EI ($P<0·05$). However, the percentages of macronutrient intake at mid-deployment were similar to the pre-deployment intake. Comparing the EI and macronutrient intake of personnel stationed either at Camp Bastion or at the more austere FOB indicated reductions in total EI and fat and protein intakes of personnel stationed at the FOB (Fig. 2), though this did not result in statistically significant differences in changes in body mass or composition between these relatively small subgroups (Table 4). The mean serum concentrations of micronutrients remained within the normal ranges across the 6-month deployment, albeit at the lower end of the normal ranges (Table 5). Nevertheless, volunteers reported the use of a number of dietary supplements while deployed, most notably protein bars and/or protein powders and carbohydrate energy drinks.

Energy expenditure and energy balance

The mean DEE of a subgroup (*n* 18) of volunteers undertaking normal operational duties measured by the DLW method was 15 171 (SD 1883) kJ, with a maximum DEE of 19 615 kJ and a minimum DEE of 11 795 kJ.

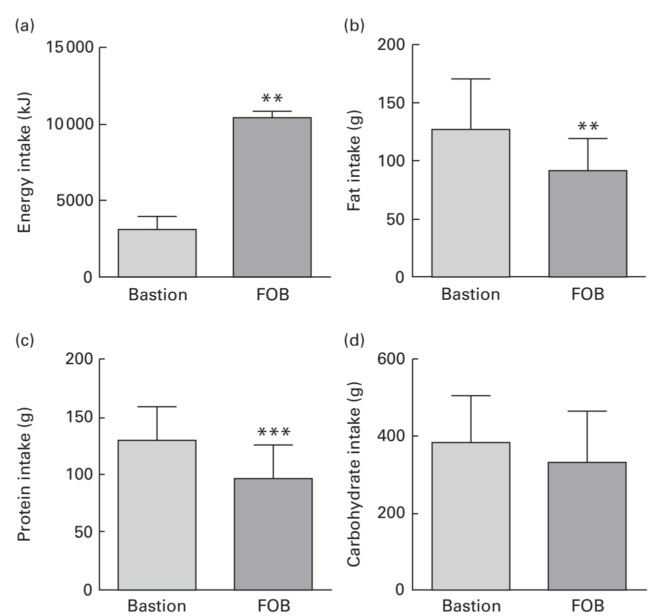


Fig. 2. Comparison of energy and macronutrient intakes reported by Royal Marines stationed at Camp Bastion or forward operating bases (FOB). Average daily (a) energy, (b) fat, (c) protein and (d) carbohydrate intakes of Royal Marines stationed at Camp Bastion (*n* 16) or FOB (*n* 48) at mid-deployment. Values are means, with standard deviations represented by vertical bars. Mean values were significantly different from that of Royal Marines stationed at Camp Bastion: ** $P<0·01$; *** $P<0·001$ (unpaired *t* test).

British Journal of Nutrition

Table 4. Difference between pre- and mid-deployment body mass, fat-free mass, body fat percentage and BMI data of volunteers stationed at Camp Bastion or a forward operating base/patrol base (FOB/PB)

(Mean values and standard deviations)

	Camp Bastion (*n* 10)		FOB/PB (*n* 28)		
	Mean	SD	Mean	SD	*P*
ΔBody mass (kg)	−4·6	4·1	−3·7	3·2	0·48
ΔFat-free mass (kg)	−1·3	2·3	−1·8	1·8	0·50
ΔBody fat percentage	−2·6	2·7	−1·4	1·9	0·15
ΔBMI (kg/m^2)	−1·4	1·4	−1·1	1·0	0·43

Energy balance in this subgroup was also investigated on a daily basis between patrolling and non-patrolling days over the representative observation period. Based on an analysis of daily PAL data – to provide greater clarity with respect to daily differences in comparison with mean DLW data – the energy expenditure on patrolling days was 17 475 (SD 2782) kJ, compared with 14 460 (SD 2071) kJ on non-patrolling days ($P<0·05$). The types of activities undertaken by volunteers on non-patrolling days would include sentry duty, Quick Reaction Force duty, patrol briefs, mission-specific administration, personal administration (e.g. cleaning kit), general duties for maintaining the FOB/PB, personal training, or recreational activities (e.g. reading or watching digital video disc). The corresponding mean daily EI on these days were 9180 (SD 2636) and 8765 (SD 2565) kJ, respectively. All physical activities – including military occupational work, personal physical training and routine administration – were reported in the Task Analysis Questionnaire, and these data informed the interpretation of the energy balance data.

The DLW and PAL subgroup data obtained from eighteen volunteers were used to validate the use of the PAL method in this specific military context, which was then applied to a larger subgroup of sixty-three volunteers (method comparison: PAL method 15564 (SD 2439; CI 14439, 16694) kJ; DLW method 15172 (SD 1883; CI 14301, 16041) kJ; limits of agreement 2·2 %, systematic bias ± random error of 24·9 %). The mean estimated DEE (from PAL data) for this larger group was 15 439 (SD 2996) kJ (minimum 11 581 kJ; maximum 24 836 kJ). The estimated mean EI of this group was 11 075 (SD 3297) kJ (minimum 5803 kJ; maximum 17 836 kJ). Comparison between the two methods[22] revealed the mean daily metabolic rate determined from the DLW measurements (i.e. mean DLW energy expenditure/estimated BMR) to be 2·0 PAL and that determined from the PAL method to similarly be 2·0 PAL.

Physical fitness

The matched data sample for physical fitness measures was smaller than that for other measures due to the challenges of scheduling fitness tests before and after deployment and in a war zone. The data indicate that aerobic fitness was well maintained throughout the 6-month deployment and that performance in measures of strength improved ($P<0·05$; Table 6).

Discussion

The present study investigated changes in body mass, body composition, food intake, energy expenditure and physical fitness of Royal Marines serving on combat operations in Afghanistan. Despite the rigours of operational deployment and the arduous work environment, Royal Marines assessed in the present study were able to maintain physical fitness. Although moderate weight loss did occur, anecdotal concerns[3–5] about possible physical degradation of personnel stationed at the more austere FOB and PB have not been substantiated. This was a challenging study, undertaken in an austere and dangerous environment that presented significant difficulties to basic research and involved collaboration between UK and US military research institutes. Volunteers were often located in isolated PB and had to be tracked during transits between the UK, Afghanistan and Cyprus over an 8-month period (March–November 2010).

Data obtained from US soldiers indicated that hot-dry deployments to the Middle East could result in changes in body mass and composition that may influence physical fitness. Sharp *et al.*[23] reported a 1·9 % decrease in body mass, increased body fat, decreased FFM, and decreased peak rate of oxygen uptake in US infantry soldiers following a 9-month deployment to Afghanistan. Lester *et al.*[24] also reported an increase in body fat and decreased aerobic performance in US combat arms soldiers following a 13-month deployment to Iraq. However, importantly these studies collected only pre- and post-deployment data, and in the study carried out by Sharp *et al.*[23], there were significant delays (from 5 to 209 d) between

Table 5. Micronutrient status of volunteers at pre-, mid- and post-deployment (matched data)

(Mean values, standard deviations and ranges)

	Mg (*n* 98) (μmol/l)		Zn (*n* 98) (μmol/l)		Cu (*n* 98) (μmol/l)		Se (*n* 98) (μmol/l)		Ferritin (*n* 95) (μg/l)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-deployment	0·80	0·06	15·41	2·81	14·03	1·90	1·14	0·12	105·0	72·4
Mid-deployment	0·80	0·06	16·09	2·73	14·06	1·94	1·06*	0·15	85·2*	53·7
Post-deployment	0·79*	0·05	14·34*†	2·11	14·00	1·90	1·15†	0·13	82·2*	49·4
Normal range	0·65–1·00		11–24		11–120		0·89–1·65		20–300	

* Mean values were significantly different from the pre-deployment value ($P<0·05$).
† Mean values were significantly different from the mid-deployment value ($P<0·05$).

https://doi.org/10.1017/S0007114514001524 Published online by Cambridge University Press

Table 6. Physical fitness data of volunteers obtained at pre-, mid- and post-deployment
(Mean values and standard deviations)

	Absolute VO_{2max} (litres/min)		Estimated VO_{2max} (*n* 34) (ml/kg per min)		Press-ups (*n* 35) (count)		Sit-ups (*n* 35) (count)		Hand grip (*n* 63) (kg force): Dominant hand		Hand grip (*n* 63) (kg force): Non-dominant hand		Static lift (*n* 61) (kg)	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-deployment	4·3	0·5	53·1	4·0	77	20	77	13	50·9	7·0	50·3	6·4	138·3	18·8
Mid-deployment	–		–		–		–		52·7	6·5	50·0	6·6	140·5	19·3
Post-deployment	4·1	0·9	52·7	4·1	85	17	80	15	53·6	6·4	51·6*	6·6	145·2	20·9

* Mean value was significantly different from the mid-deployment value ($P < 0·05$).

personnel returning to the USA and post-deployment measurements. These issues will have introduced errors in interpreting deployment-related body mass changes because, as shown in the present study, body mass recovers rapidly towards pre-deployment levels after just 2 weeks of mid-tour R&R leave. Thus, delays in obtaining post-deployment measurement data will lead to an underestimation of the weight loss.

No such studies with British military personnel have been published in the scientific literature. Previous studies have not undertaken mid-deployment measurements, which appear crucial for fully understanding the pattern of changes in body mass and body composition in deployed military personnel, as observed in the present study. The reduction in body mass between pre- and mid-deployment periods in volunteers was 3·9 kg (5 %), and the average gain in body mass between mid- and post-deployment periods was 2·4 kg (3 %). Volunteers tended to lose body fat and FFM during the first half of the tour and to gain FFM during the second half of the tour, while FM continued to decrease. This indicates that volunteers adapted to the work and living demands of their frontline role, a contention supported by the tendency for strength to increase. The mid-deployment leave period, during which volunteers return home for R&R, appears critical to preserving body mass, FM and FFM over the tour. During this 14 d period, volunteers regained nearly half of the body mass lost during the first half of the deployment. There was potential bias within the sample population; the research participants, by self-selecting, may have been biased towards those with a greater interest in their physical fitness and dietary habits and possibly may not fully reflect the nutritional habits of the unit or the UK military as a whole. This potential limitation was countered by recruiting a third of this specific deploying population, as well as ensuring representation in terms of age, military experience and rank.

VO_{2max} can provide an index of a specific population's aerobic fitness. Pre- and post-deployment VO_{2max} levels were similar in the subset of Royal Marines assessed, indicating that aerobic fitness was well maintained. Strength, as assessed from static lift and hand-grip strength assessments, tended to increase in volunteers during the 6-month deployment. Volunteers assessed in present the study continued to participate in physical training during the deployment (albeit at reduced levels relative to pre-deployment training), which may explain their preserved physical conditioning. Furthermore, the mode of physical training possible at FOB and PB was strength and muscle endurance-focused, as opposed to aerobic training. Observations from the present study would support the earlier contention of Friedl[25], who suggested that body mass losses closer to 10 % would be typically required before physical performance was reduced.

This is the first study to assess the DEE of UK military personnel undertaking frontline operational duties. Previously, the mean DEE of US special operations soldiers (measured using the DLW method) during a 28 d field training exercise receiving the US Ready-to-Eat Meal ration was found to be 14 811 (SD 753) kJ/d[26]. Similarly, US soldiers performing military physical training activities in warm weather for twelve consecutive days were found to have a mean DEE of 16 472 (SD 665) kJ/d and a reported mean energy deficit of 3866 (SD 971) kJ/d[27]. The mean DEE of UK soldiers undertaking the 15-week Section Commanders' Battle Course was 19 636 (SD 1774) kJ/d in week 9 of training and 21 313 (SD 1971) kJ/d during the final week of the Course[28]. Soldiers lost 5·1 (SD 2·6) kg of mean body mass over this 8-week period, mainly in the form of FM, which equated to an estimated energy deficit of 2694 kJ/d. The theoretical energy deficit, as determined from the difference between DEE and estimated energy provision from Army catering, was 5607 kJ/d.

In the present study, the DEE of volunteers undertaking normal operational duties was 15 171 (SD 1883) kJ as estimated using the DLW method, and similar levels were estimated using PAL data in this subgroup, as well as in a larger (*n* 63) group of Royal Marines. DEE was higher on patrolling days than on non-patrolling days, but there was no difference between self-reported EI. The self-reported EI of volunteers varied considerably from day to day during the observation period. For example, the estimated daily EI of one Royal Marine from the main study sample varied between 6573 and 16 351 kJ during the mid-deployment observation period.

Self-reported EI and fat and protein intakes were significantly lower in Royal Marines based in the FOB than in those based in Camp Bastion. These data indicate that personnel undertaking operations at forward locations may experience periods of significant daily energy deficit. These results indicated that location was an important determinant of food intake during operational deployment and that it was not simply that deployment *per se* alters energy homeostasis.

Whilst high ambient temperature may play a part in reducing overall food intake and EI in those stationed at the FOB, this is unlikely to be the whole story. Other factors such as menu fatigue and stress may also play an important role in the reduced food intake observed in those personnel based at the more austere forward positions.

The mean EI:BMR ratio for the entire cohort was 1·40 (SD 0·34; median 1·37), which indicates probable under-reporting of dietary intake[29], though this would still be considered acceptable from a nutritional science perspective[9]. The EI:BMR ratio was lower in the FOB and PB locations than in Camp Bastion, and it probably reflects the extremely difficult living and working environments on the frontline. However, even when FOB data were corrected to account for this estimated under-reporting, the FOB-based Royal Marines were found to still consume less energy and less fat than Camp Bastion-based Royal Marines.

Further partitioning of data between patrolling and non-patrolling days, and between Camp Bastion- and FOB- or PB-based volunteers, provided tentative data regarding the energy balance of Royal Marines. Further investigation was undertaken by calculating the energy equivalents of changes in FFM and FM, according to the methods of Westerterp *et al.*[30]. Assuming an energy cost of 6 MJ/kg for FFM loss and 35 MJ/kg for FM loss, a loss of 1·7 kg FM and a loss of 1·9 kg FFM between the pre- and mid-deployment periods (121 d) would equate to a net energy deficit of approximately 70·9 MJ. An increase of 0·5 kg of FM and 2·1 kg of FFM between the mid- and post-deployment periods (86 d) would equate to a net energy gain of approximately 30·1 MJ. These data would represent an energy deficit of approximately 0·6 MJ/d between pre- and mid-deployment periods and an energy gain of 0·4 MJ/d between mid- and post-deployment periods.

It should be noted that the energy expenditure and dietary intake data represent snap shot data, as they were collected at fixed time points during the 6-month deployment. This may partly explain the discrepancy between the large calculated energy deficit and the relatively modest changes in body mass observed. Periods of high energy expenditure were probably balanced by periods of lower energy expenditure when volunteers ate sufficient food to meet or exceed their energy expenditure. Nevertheless, these data indicate that deployed soldiers may experience periods of a temporary loss in appetite and some degree of energy deficit while on operations. Loss of appetite is likely to arise as a consequence of both the psychological and physiological stresses of the frontline and the prevailing operational tempo, as well as the heat and arduous living conditions experienced by deployed soldiers on a daily basis[31]. Accepting these limitations of snap shot dietary intake data, and the discrepancy between the large calculated energy deficit and the modest changes in body mass and body composition, absolute EI data must be treated with caution. However, these data did provide important practical insights with respect to dietary behaviour and food group choices – providing information on dietary quality – from frontline ration feeding.

In conclusion, this is the first study to evaluate the effects of military deployment on the nutrition of UK infantry personnel assigned to a 6-month deployment to a hot-dry, hostile theatre of military operations. The body mass and body composition of frontline soldiers changed significantly during the deployment to Afghanistan, where body mass decreased during the deployment. This decrease was associated with a progressive reduction in FM, while FFM initially decreased before increasing during the second half of the deployment. EI and expenditure data indicated that military personnel might experience temporary periods of energy deficit, particularly in frontline positions. However, importantly these changes did not appear to significantly affect physical performance or micronutrient status. Current nutritional provision for British military personnel in Afghanistan therefore appears sufficient to maintain physical status. Nevertheless, ensuring adequate provision of food in harsh operational environments must remain an operational priority. The present study also demonstrated the importance of mid-deployment leave to ameliorate such changes, which are probably due to an EI deficit on the frontline. Even though these data were gathered from an intensive study of a British military unit, they have broader applicability, as many countries have forces deployed in similar environments in an intense light infantry operational mode under similar operational circumstances. Thus, these data and observations have broader applicability. Providing adequate nutrition to frontline military personnel must remain a major priority for military operations.

Supplementary material

To view supplementary material for this article, please visit http://dx.doi.org/10.1017/S0007114514001524

Acknowledgements

The authors thank the Command and volunteers from the Royal Marines as well as LAND Forces HQ and the UK Permanent Joint Head Quarters for their support.

The present study was funded by the United Kingdom Ministry of Defence. Stable isotopes were provided by the US Army Research Institute of Environmental Medicine. Chemical analysis of the stable isotopes was carried out by the Pennington Biomedical Research Center, Baton Rouge, LA, USA. The study was supported by the National Institute for Health Research (NIHR) Biomedical Research Centres based at Imperial College Healthcare NHS Trust and Imperial College London (S. J. B., K. G. M. and G. F.). The views expressed are those of the authors and do not necessarily reflect those of the UK Government, the MOD, the NHS, the NIHR, or the Department of Health.

The authors' contributions are as follows: J. L. F. and N. E. H. contributed to the study design, data collection, data analysis, data interpretation and manuscript preparation; S. K. D. contributed to the study design, data collection, data analysis and data interpretation; R. C. contributed to the method development, data collection and data analysis; P. B. contributed to the method development and data collection; S. A. L.-N. designed the study, interpreted the data and contributed to the preparation of the manuscript; G. F., S. J. B. and K. G. M. interpreted the data and contributed to the preparation of the manuscript; S. J. M. analysed the data, prepared the manuscript, and provided essential materials; C. N., M. S. and C. A. collected the data; A. S. collected, analysed and interpreted the data; C. B. analysed and interpreted the data; D. R. W. and A. J. A. designed the study, interpreted the data and prepared the manuscript.

None of the authors has any conflicts of interest to declare.

References

1. American College of Sports Medicine, American Dietetic Association, and Dieticians of Canada (2000) Joint position statement: nutrition and athletic performance. American College of Sports Medicine, American Dietetic Association, and Dieticians of Canada. *Med Sci Sports Exerc* **32**, 2130–2145.
2. Hill N, Fallowfield JL, Price S, *et al.* (2011) Military nutrition: maintaining health and rebuilding injured tissue. *Phil Trans R Soc Lond B Biol Sci* **366**, 231 − 240.
3. Crick A (2009) 'The War Store'. The Sun. http://www.thesun.co.uk/sol/homepage/news/campaigns/our_boys/2615997/ARMY-mum-Rhiannon-Manning-builds-home-war-store.html (accessed April 2013)
4. Kiley S (2010) 'Soldiers went hungry on the battlefield'. The Times. http://www.timesonline.co.uk/tol/news/world/afghanistan/article7146334.ece (accessed April 2011)
5. Madhani A (2007) 'Field rations failing soldiers'. Chicago Tribune. http://www.chicagotribune.com/chi-070325mre-story,0,6799228.story (accessed April 2013)
6. Lohman TG, Roche AF & Martorell R (1998) *Anthropometric Standardisation Reference Manual*. Champaign, IL: Human Kinetics.
7. Durnin JV & Womersley J (1974) Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. *Br J Nutr* **32**, 77 − 97.
8. Davey T, Delves SK, Allsopp AJ, *et al.* (2010) Validation of a bespoke food record card as a method of recording dietary intake in Royal Marine recruits. *Proc Nutr Soc* **69**, E64.
9. James WPT & Schofield EC (1990) *Human Energy Requirements: A Manual for Planners and Nutritionists*. New York, NY: Oxford University Press.
10. Committee on Medical Aspects of Food Policy (1991) *Dietary Reference Values for Food Energy and Nutrients for the United Kingdom: Report of the Panel on Dietary Reference Values of the Committee on Medical Aspects of Food Policy. Volume 41 of Report on Health and Social Subjects*. London: HMSO.
11. Casey A (2008) *Military Dietary Reference Values*. Farnborough: QinetiQ Ltd.
12. Musso CG (2009) Magnesium metabolism in health and disease. *Int Urol Nephrol* **41**, 357–362.
13. Wachnik A (2006) The physiological role of copper and the problems of copper nutritional deficiency. *Nahrung* **32**, 755–765.
14. Bray TM & Bettger WJ (1990) The physiological role of zinc as an antioxidant. *Free Radic Biol Med* **3**, 281–291.
15. Tapiero H, Townsend DM & Tew KD (2003) The antioxidant role of selenium and seleno-compounds. *Biomed Pharmacother* **57**, 134–144.
16. Prasad AS (1998) Zinc and immunity. *Mol Cell Biochem* **188**, 63–69.
17. Hie M, Iitsuka N, Otsuka T, *et al.* (2011) Zinc deficiency decreases osteoblasts and osteoclasts associated with the reduced expression of Runx2 and RANK. *Bone* **49**, 1152–1159.
18. Nagata M, Kayanoma M, Takahashi T, *et al.* (2011) Marginal zinc deficiency in pregnant rats impairs bone matrix formation and bone mineralization in their neonates. *Biol Trace Elem Res* **142**, 190–199.
19. Sun JY, Wang JF, Zi NT, *et al.* (2011) Effects of zinc supplementation and deficiency on bone metabolism and related gene expression in rat. *Biol Trace Elem Res* **143**, 394–402.
20. Schoeller DA, Ravussin E, Schutz Y, *et al.* (1986) Energy expenditure by doubly labeled water: validation in humans and proposed calculation. *Am J Physiol* **250**, R823–R830.
21. Brewer J, Ramsbottom R & Williams C (1988) A progressive shuttle run test for the prediction of maximum oxygen uptake. *Br J Sports Med* **22**, 141–144.
22. Westerterp KR (2001) Limits to sustainable human metabolic rate. *J Exp Biol* **204**, 3183–3187.
23. Sharp MA, Knapik JJ, Walker LA, *et al.* (2008) Physical fitness and body composition after a 9-month deployment to Afghanistan. *Med Sci Sports Exerc* **40**, 1687–1692.
24. Lester ME, Knapik JJ, Catrambone D, *et al.* (2010) Effect of a 13-month deployment to Iraq on physical fitness and body composition. *Mil Med* **175**, 417–423.
25. Friedl KE (1995) *Not Eating Enough: A Report of the Committee on Military Nutrition Research, Food and Nutrition Board, Institute of Medicine*. Washington, DC: National Academy Press.
26. DeLany JP, Schoeller DA, Hoyt RW, *et al.* (1989) Field use of D2 18O to measure energy expenditure of soldiers at different energy intakes. *J Appl Physiol* **67**, 1922–1929.
27. Burstein R, Coward AW, Askew WE, *et al.* (1996) Energy expenditure variations in soldiers performing military activities under cold and hot climate conditions. *Mil Med* **161**, 750–754.
28. Richmond VL, Horner FE, Wilkinson DM, *et al.* (2010) Energy balance during the British Army section commanders' battle course. *Med Sci Sports Exerc* **42**, S202–S203.
29. Goldberg GR, Black AE, Jebb SA, *et al.* (1991) Critical evaluation of energy intake data using fundamental principles of energy physiology: 1. Derivation of cut-off limits to identify under-recording. *Eur J Clin Nutr* **45**, 569–581.
30. Westerterp KR, Donkers JH, Fredrix EW, *et al.* (1995) Energy intake, physical activity and body weight: a simulation model. *Br J Nutr* **73**, 337–347.
31. Booth C, Coad R & Roberts W (2002) The nutritional, physiological and psychological status of a group of British sappers after 23 days of adventure training in the hot wet tropics. DSTO-RR-0243 Report, Victoria, Australia.