SACN position statement on military dietary reference values for energy: supplement on submariner and military specialist data

September 2020

Background

1. This supplement provides an update to the Scientific Advisory Committee on Nutrition's (SACN) position statement on Military Dietary Reference Values (military DRVs) for energy published in 2017. New data sets were available for Royal Navy (RN) submariners undertaking maritime operational roles and military specialists (MS) undertaking arduous activity above and beyond what would be expected of regular military personnel.

2. The 2017 position statement asserted the importance of nutrition to support military physical and mental capability, as well as the health and well-being of personnel. The implications of a poorly nourished force are considerable. These include: 1) increased risk of ill health; 2) increased associated medical care costs; 3) a reduced number of military personnel available for duty due to absenteeism; 4) reduced operational readiness; and 5) decreased retention of skilled and experienced personnel. A reduction in the total number of military personnel across all three Services (that is, Army, Royal Air Force, Royal Navy) and the prevailing tempo of operational commitments, make it necessary for *all* UK military personnel to be ready and fit to deploy.

3. It is therefore imperative that measures are taken to promote optimal health and wellbeing, as well as to reverse any trends towards adverse health indicators. The nutritional quality of the food provision in the Defence setting, and the food choices of personnel, need to meet the nutrition requirements of military occupational roles. Moreover, the Ministry of Defence (MOD) requires an objective food provision and catering specification to ensure that external agencies (contract caterers) procure and cater to the standards necessary to achieve a healthier provision.

Terms of Reference for the Military Dietary Reference Values for Energy Working Group

4. The terms of reference for the Military DRVs for Energy Working Group, which developed the 2017 SACN position statement, were to:
   - provide recommendations for estimated DRVs for energy for those military occupational roles where there are evidenced requirements that are different to the estimated average requirements for UK population subgroups, as recommended by SACN in 2011
   - provide recommendations that take into account environment and relevant population descriptors such as age, body size (including consideration of body composition), levels of physical activity and sex

- consider the implications of these energy recommendations for the nutrient requirements of UK military populations – especially in terms of macronutrient requirements for high energy occupational roles.

5. In addressing these terms of reference, the position statement:
   - considered the available evidence related to the energy requirements of military personnel
   - identified evidence gaps and how these could be addressed
   - made recommendations for DRVs for energy for military personnel.

6. The position statement evaluated available evidence on the energy requirements of military personnel. It focused on evidence which would allow the approach used to determine the DRVs for energy for the general population (SACN, 2011) to be applied to the derivation of military DRVs for energy. SACN provided advice on military DRVs for a range of personnel in training and on operations where there was evidence that energy expenditures were different from the estimated average requirements (EAR) for UK population subgroups (SACN, 2011). As there was a growing evidence base to indicate that a large proportion of the UK military population would have the same energy requirements as the general UK population, these energy requirements were also included in the position statement (see Table 1; SACN 2017).

7. At the time of the 2017 position statement, no doubly labelled water (DLW) data were available to describe the rates of energy expenditure of specialist groups in the UK military, although it was noted that work to address these evidence gaps was planned. It was acknowledged that specialist groups (for example, military divers, military specialists) were likely to have higher energy requirements than the general UK population, by virtue of the physical demands or the unique requirements of their roles. Moreover, DLW data were only available for land-based, ground close combat (GCC) (for example, Royal Marines and army infantry) operational deployments (Fallowfield et al, 2014); energy requirements during maritime operations had only been estimated from non-DLW methods (see paragraph 18; SACN, 2017). Whilst maritime roles are generally less physically demanding than GCC roles, higher energy requirements than the UK civilian population may arise during this active service from the long working hours, rather than from increased physical activity per se (Fallowfield et al, 2012c; Fallowfield et al, 2013).

8. SACN agreed that once specific DLW data became available for specialist military groups, it would consider these data in a supplement to the 2017 position statement and whether the UK military DRVs required updating.

Dietary Reference Values for energy for the general UK population

9. In 2011, SACN reviewed the DRVs for energy for the general UK population (SACN, 2011) and updated the Committee on Medical Aspects of Food Policy (COMA) recommendations published in 1991 (COMA, 1991). The DRVs for energy provide a best estimate of the food energy needs of the UK population and its subgroups and presents criteria against which to judge the adequacy of food energy intakes (Department of Health, 1991). For most nutrients, the DRV is identified as the Reference Nutrient Intake (RNI), which is the intake sufficient to meet the requirements of 97.5% of people in a group. However, the RNI for dietary energy is not used as it represents an excess energy intake for the majority of the population. The DRVs for energy are defined in terms of the EAR. In adults, the EAR for energy is set at the level of energy intake required to maintain weight (that is, an energy intake which matches energy expenditure) (SACN, 2011).

10. The SACN Dietary Reference Values for energy report (SACN, 2011) adopted a "prescriptive" approach, using a Body Mass Index (BMI) of 22.5 kg/m^2, to devise energy requirements. In recognition that the UK population had a high and increasing proportion of individuals living with overweight or obesity, it set energy reference values in relation to body weights that were likely to be consistent with general health. Adoption of these prescriptive values by groups with body weights below or above such ranges would tend to encourage weight change towards the healthier, more desirable body weight range.

11. Evidence indicates that societal trends towards increasing body mass and obesity are also prevalent in the Armed Forces (Wood, 2007; Shaw et al, 2013). Unhealthy body weight and excess body fat in the military can impair physical (Kyrolainen et al, 2008) and mental fitness, negatively impact upon productivity (Kimsey et al, 2018), reduce self-reported ability to work (Bennett & Bridger, 2010), increase the likelihood of service personnel becoming 'unfit for duty' (Bridger 2003; Blacker et al, 2008), increase the risk of heat illness (Gardner et al, 1996) and directly impact upon the health and physical capability of personnel to deploy on military Exercises or Operations (Lloyd, 2017). This risk of weight-related ill-health increases with age (Sundin et al, 2011), and the relative risk of being 'unfit to deploy' due to weight-related ill health increases with increasing National Institute for Health and Care Excellence (NICE) health-risk classification (Shaw et al, 2013). The risk of sustaining a musculoskeletal injury is 15% higher in individuals living with overweight (Finkelstein et al, 2007), and increases incrementally with increasing NICE health-risk classification (National Academies of Sciences, Engineering and Medicine,

2018). Moreover, while initial (Phase-1)[1] military training on entry to the Armed Forces is associated with a reduction in body fat, this is not maintained during trade training (Phase-2) (Shaw & Fallowfield, 2013). It is hypothesised that this is most likely a consequence of a poor diet (Shaw & Fallowfield, 2013).

12. The DLW method is generally recognised as the most accurate ('gold standard') measure of free-living total energy expenditure (TEE) currently available (International Atomic Energy Agency, 2009). It provides more accurate measures of TEE than other non-calorimetric methods (for example, heart rate monitoring) (Levine, 2005). The DLW method measures the rate of carbon dioxide production, and hence TEE, in free-living volunteers. It provides a mean energy expenditure value for the measurement period (usually 4 to 21 days).

13. The provision of a mean value is a limitation of the DLW method in population groups where energy expenditure may vary markedly between days. This limitation could be addressed through simultaneous data gathering using non-calorimetric methods to assess daily physical activity level (PAL) (acknowledging the variable nature of the assumptions upon which they are based) as detailed in paragraph 15.

14. The SACN Dietary Reference Values for energy report (SACN, 2011) used a factorial approach to derive energy requirements based on the assumption that TEE is the determinant of the EAR and is equal to the product of the basal metabolic rate (BMR) and the PAL (that is, BMR x PAL). TEE values were measured in a reference population using the DLW method and divided by estimated BMR values to extract PAL values. This means that the reference populations studied by DLW were described primarily by PAL values. For the UK population, BMR values were then estimated from BMR prediction equations (the Henry equations) (Henry, 2005) using relevant anthropometric data from the population. The PAL values derived from the reference population were used to estimate TEE and EAR values for the UK population, based on the latter's predicted BMR values at "healthy" body weights. A population average value (median) for PAL, as well as the extent to which it is lower (25th percentile) or higher (75th percentile) for less or more active population groups, was also provided.

Dietary Reference Values for energy for the UK military population: approaches and methods

15. A range of methods has been used to estimate energy expenditure in UK military personnel, in training and on operations. These methods have included the DLW

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[1] Military training in the UK is divided into phases of training. Phase-1 training refers to 'initial military training', which is the first part of inducting civilians into the Armed Forces. This training continues through Phase-2 training, where recruits and officer cadets learn the knowledge and skills for their specific trade or specialism that will support their professional role within the Armed Forces.

method, physical activity diaries (PAD), task analysis questionnaires, heart rate monitoring, analysis of global position system data and analysis of accelerometer data (Fallowfield et al, 2010; Linnane et al, 2010; Dziubak et al, 2011; Fallowfield et al, 2012a; Fallowfield et al, 2012b; Fallowfield et al, 2012c; Fallowfield et al, 2013; Fallowfield et al, 2014; Shaw & Fallowfield, 2013).

16. The derivation of the military DRVs for energy (SACN, 2017) used the SACN Framework for the Evaluation of Evidence (SACN, 2012) as the basis for identifying and assessing published evidence on TEE. Only studies using the DLW method to measure TEE were considered. The available DLW dataset on military personnel was relatively small but it was considered to be specific to the populations of concern.

17. The PAL values were calculated from measures of TEE derived from DLW data (Schoeller et al, 1986; Bluck, 2008) and from the BMR calculated using the Henry equations. This approach was consistent with the methods adopted in the SACN Dietary Reference Values for energy report (SACN, 2011). However, in contrast to the "prescriptive" approach used to estimate energy reference values for the general population at healthy body weights (see paragraph 10), the calculations for military DRVs for energy were based on mean body weight and height of the actual reference population, resulting in a "reference male" and a "reference female". For the UK military reference population, the mean BMI was 23.9 kg/m^2 for men and 22.0 kg/m^2 for women.

18. The DLW dataset was skewed towards a younger age group (mean age: 22.1 years); therefore it was not representative of the whole UK military service population (age range: 16 to 60 years).[2] However, in terms of BMI and physical fitness, the dataset was considered to be representative of military service personnel in training and undertaking occupational roles with greater energy requirements than the UK civilian population. Therefore, from a risk assessment perspective, the dataset reflected the energy requirements of personnel involved in these activities.

Dietary Reference Values for energy for the UK military population – derivation

19. From the analyses undertaken on the DLW measurements, no sex differences were observed in PAL values, enabling men and women to be grouped together. Three relatively distinct groupings, with different energy requirements, were identified: Active Service, Military Training Courses A and Military Training Courses B. These groupings differed by their PAL value only; there were no differences between the anthropometric measures of the men or the women in the different groupings. For

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[2] Personnel can start their service career from 16 years of age. As a trained rank, they might serve until they are circa 40 – 45 years; officers will presently serve until they are circa 55 – 60 years.

the purpose of setting military DRVs it was assumed that the heights and body weights of personnel on future Active Service or in either of the two Military Training Courses groupings would be similar to the current volunteers. Therefore, single values for height and body weight of all male and female personnel across groups were calculated separately (that is, a reference male and a reference female).

20. BMR is age (and sex) dependent and different age bands are used to calculate predicted BMR by the Henry equation. For the dataset informing the SACN position statement on military DRVs for energy (SACN, 2017), the appropriate age bands were 18-30 years and 30-60 years. BMR calculations were initially performed using the appropriate age-related equation. However, as there was little difference in BMR values regardless of which age-specific equation was used, it was agreed to use the BMR prediction equation for the 18-30 years age group for all volunteers to provide one reference male and one reference female value across all activity groups. This allowed the TEE (and hence the EAR) for the reference male and the reference female, following either Active Service or either of the Military Training Courses groupings, to be determined from the appropriate PAL values for each of these three groupings. Thus, although EAR for energy were set by age group for the general population, in the case of military personnel it was considered appropriate to provide a combined EAR for energy for all age groups within each activity group.

21. Variation in the PAL values within the three groupings was accommodated by defining a range of PAL and EAR values: the 25th percentile, the median and the 75th percentile, with energy in MJ/day and kcal/day rounded to 2 significant figures (see Table 1). These values refer to the reference male (body weight 75.7 kg; height 1.78 m; BMR 7.34 MJ/day) and reference female (body weight 60.0 kg; height 1.65 m; BMR 5.61MJ/day) service personnel.

22. Inter-individual differences in energy expenditure were greater in active service than during training. This likely reflects the programmed nature of military training, in contrast with the dynamic and/or reactive nature of military operations. From a risk management perspective, these inter-individual differences in energy requirements should be taken into consideration when allocating rations for these activities, especially in the operational environment where the implications of poor risk management could be far more profound. Military risk managers will also need to be aware of the provisioning requirements of individuals in the 25th and 75th centiles. Furthermore, military service personnel with a BMI higher or lower than the mean may lose or gain body weight respectively, if rationing is based on these mean values.

23. It was not possible to determine the effect of environmental conditions on energy requirements per se from the available evidence base. Evidence from the general scientific literature suggests that environmental conditions, such as extremes in temperature and altitude, are likely to have modest overall effects on the energy requirements of service personnel (Garby et al, 1990; Valencia et al, 1992; Burstein

et al, 1996; Debevec et al, 2014). Observed changes in energy expenditure are likely to arise from both changes in external work depending on clothing, equipment and/or terrain (Pandolf et al, 1977) and changes in internal work as a consequence of altered thermogenesis and the impact of relative hypoxia (Westerterp-Plantenga et al, 2002; Debevec et al, 2014). Adaptation to the effects of environmental change is likely to occur with more prolonged exposure, such that the impact will be greatest in the shorter term (Corbett et al, 2014).

24. There is no direct evidence from military populations about the impact of different macronutrient sources on performance. In making recommendations about macronutrient intake at different energy requirements, SACN extrapolated from the relevant literature in other high exercise intensity settings (such as elite athletes). This provided evidence that as energy requirements increase, the proportions of macronutrients required to maintain optimum health and physical performance may change. From the evidence available it appears that a higher proportion of energy derived from carbohydrates may be associated with superior performance, particularly when sustained high-energy expenditure is required (Brooks & Mercier, 1994; Romijn et al, 1993; Vandenbogaerde & Hopkins, 2011; Hawley & Leckey, 2015; Pöchmüller et al, 2016). However, this remains a topic of active investigation.

25. Table 2 (to be read in conjunction with Table 1) presents recommended proportions of macronutrients for energy intake levels equivalent to the UK population and for the three groupings of service personnel. Level 1 recommendations are the same as for the general UK population. There is insufficient evidence to make precise recommendations for macronutrient intakes at higher levels of energy expenditure. Therefore, a range is provided for carbohydrates and total fat, with absolute protein intakes remaining constant (and hence dropping as a percentage of total energy as energy intake rises). For this purpose, total energy intake is assumed to be the same as food energy intake; it excludes energy from alcohol since alcohol is not included in provisioning. The lower limit of intake from carbohydrates is set at 50%, to reflect the current recommendation for the general UK population. The upper limit is set to reflect all additional energy being provided as carbohydrate. In practice, it is acknowledged that the proportions for operational ration packs will be determined by risk managers, due to the interaction of energy density and the weight of rations with respect to the implications for load carriage. However, SACN recommends that the proportions of energy from carbohydrate and total fat should be within the ranges provided.

26. It was specifically noted by SACN that the additional energy requirements of military personnel on active service or training should not be met, as a matter of course, through foods high in saturated fat, sugar and/or salt.

27. Micronutrient status of UK military personnel was outside the scope of the 2017 SACN position statement on military DRVs for energy. Whilst it was acknowledged that there is a paucity of micronutrient status data for UK military populations, no

evidence has been presented that indicates a poor micronutrient status per se in UK training and operational military populations. However, it cannot be excluded that there may be situations where personnel may experience temporary periods of nutritional deficiency whilst deployed on land-based operations (Fallowfield et al, 2014) and these periods may be associated with compromised micronutrient status (Fallowfield et al, 2019). As such, SACN concluded that as long as energy requirements were met and personnel consumed a predominantly healthy, balanced diet, the daily micronutrient intakes recommended for the general UK population would be adequate for UK military personnel. Recommendations for the general UK population to take supplemental folic acid (women of child bearing age) and supplemental vitamin D also apply to UK military personnel (NHS Choices).

Table 1. Estimated average requirements for the general population and the three groupings of service personnel based on physical activity level

Level	Group	PAL values[a]			Sex	EAR (MJ/day)[b]			EAR (kcal/day)[b]		
		25th percentile	Median	75th percentile		25th percentile	Median	75th percentile	25th percentile	Median	75th percentile
1	General Population	1.49	1.63	1.78	M[c]	10.9	12.0	13.1	2600	2900	3100
					F[d]	8.4	9.2	10.1	2000	2200	2400
2	Active Service	1.90	2.08	2.16	M	14.0	15.2	15.9	3300	3600	3800
					F	10.8	11.7	12.2	2600	2800	2900
3	Military Training Courses A[e]	2.15	2.32	2.44	M	15.8	17.0	17.9	3800	4100	4300
					F	12.1	13.1	13.8	2900	3100	3300
4	Military Training Courses B[f]	2.51	2.62	2.78	M	18.4	19.2	20.4	4400	4600	4900
					F	14.2	14.8	15.7	3400	3500	3800

[a] PAL = Physical Activity Level

[b] EAR = Estimated Average Requirements. Values are rounded to 2 significant figures. The values derive from calculations for the reference male and female as defined in paragraph 18.

[c] M = male [d.] F = female

[e] Included the following training groups: the Common Military Syllabus for Recruits (CMS(R)); Royal Air Force (RAF) phase-1 recruits.

[f] Included the following training groups: Common Infantry Course (CIC) – Paras and Guards; Commissioning Course for Officer Cadets (CCOC); Section Commander's Battle Course (SCBC) (army infantry soldiers phase-3 training)

Table 2. Recommended proportions of macronutrients, as a percentage of total energy intake, for the general population and the three groupings of service personnel based on physical activity level[a]. Total energy intake is assumed to be the same as food energy intake; it excludes energy from alcohol since alcohol is not included in provisioning

Group	Level	Carbohydrate (%)	Total Fat (%)	Protein (%)
UK Population	1	50	35	15
Active Service	2	50 - 55	31.5 - 35	13.5 - 15
Military Training Courses A[b]	3	50 - 60	28 - 35	12 - 15
Military Training Courses B[c]	4	50 - 65	25 - 35	10 - 15

[a] The proportions for operational ration packs will be determined by risk managers due to the interaction of energy density and the weight of rations with respect to the implications for load carriage.

[b] Included the following training groups: the Common Military Syllabus for Recruits (CMS(R)); Royal Air Force (RAF) phase-1 recruits.

[c] Included the following training groups: Common Infantry Course (CIC) – Paras and Guards; Commissioning Course for Officer Cadets (CCOC); Section Commander's Battle Course (SCBC) (army infantry soldiers phase-3 training)

Dietary Reference Values for Energy for the UK military population – maritime operations (Royal Navy submariners)

28. The maritime operations of the RN are supported by 63 surface vessels and 10 submarines. These range from the largest vessel, the aircraft carrier HMS Queen Elizabeth, to relatively small fast 'island-class' patrol boats. The physical demands of the roles performed by sailors will vary with the class and size of the vessel and its strategic purpose. The physical demands and work intensities of maritime roles, contributing to the daily rates of energy expenditure, are generally deemed to be less than those of GCC roles. However, the shift patterns associated with 'watch keeping' and the long working hours of RN sailors have previously been reported to be associated with higher energy requirements than the UK civilian population (Fallowfield et al, 2012c; Fallowfield et al, 2013).

29. The submarine environment, when deployed, is a closed environment where internal temperature and humidity are generally maintained relatively constant at approximately normal indoor working conditions. When deployed, onboard atmosphere control machinery reduces the potential effects on the crew of the external environmental conditions.

30. The mean and standard deviation (SD) daily energy expenditure of sailors undertaking general shipboard duties at sea have been estimated from PAD to be 14.2 (3.1) MJ (3389 (731) kcal) and 10.0 (1.8) MJ (2356 (440) kcal) in males and female, respectively (Fallowfield et al, 2013). These values were consistent with previous estimates of 14.2 (2.7) MJ (3391 (635) kcal) and 10.0 (2.9) MJ (2393 (700) kcal) in male and female sailors respectively, from measures undertaken during Basic Operational Sea Training (BOST) (Fallowfield et al, 2012c). However, these data were based upon energy expenditure data derived from non-DLW methods, and as such needed verification with respect to the DLW gold standard measurement approach (SACN, 2017).

31. Energy expenditure has been estimated using the DLW method and compared with self-report PAD in volunteer RN submariners (n=18) during a maritime operational patrol (Gunner et al, 2018). Submariner energy expenditure data were all from male volunteers;[3] data are not currently available for female submariners.

32. Submariners were engaged in general submarine duties, including ship controller/ command, atmosphere monitoring, communications/ radio engineer, periscope watchkeeping, sonar operator, watchkeeping, reactor panel operator, medical duties and food preparation/ chef duties. From the self-reported PAD, 40% (9.6 hours) of a 24-hour period was spent sleeping or lying in a bunk. This compares with 35% of a 24-hour period (8.4 hours) on surface ships (Fallowfield et al, 2012c; Fallowfield et al, 2013). Less than 1% of submariners' time was reported undertaking personal physical training and no time was reported for emergency activity, where emergency drills represent the most physically demanding tasks at sea.

33. Annex A presents the RN submariner energy expenditure dataset, where the measurement approach adopted for the general population has been applied (SACN, 2011). After cleaning the data set, the mean values for TEE, Physical Activity Energy Expenditure (PAEE) and PAL were 13.0 MJ/day, 3.81 MJ/day and 1.65, respectively, and the inter-individual coefficients of variation (CV) were 12.5%, 30.5% and 10.8%, respectively. The distribution of the PAL values determined from the DLW measurements (PAL_{DLW}) indicated that the submariners exhibit PAEE levels similar to the general population.

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[3] Submariner roles have been open to females as Officers since 2013 and Ratings since 2015, but females are presently underrepresented in the Service.

34. Whilst the number of volunteers analysed was small (n=18 after removing one unrealistic 'outlier' value), the PAL_{DLW} values were within the middle of the distribution of the cohort of 1000 civilians, who served as a reference for the UK DRV for energy (SACN, 2011). On this basis, it was concluded that the energy expenditure ratios for energy should not differ from those military personnel engaged in non-strenuous activities (see Annex A).

35. Societal trends towards increasing body mass and obesity are also evident in the Armed Forces (see paragraph 11). Mean BMI and percentage body fat data presented in Annex A (see Table A1) indicated that some RN submariners in the study sample had a BMI consistent with being classified as personnel living with overweight or obesity.

Dietary Reference Values for Energy for the UK military population – military specialists

36. The DRVs for energy for UK MS could not be determined for the previous position statement on military DRVs for energy (SACN, 2017). While it is not possible to be specific in this document, the MS role could be very broadly described by 3 areas of activity:
    - a land-based role involving moving over undulating ground carrying load
    - an amphibious role (AR), involving water transits, military diving and climbing
    - an urban role (UR), involving Fighting in Built Up Areas (FIBUA) drills.

37. For the land-based role, it was suggested in the position statement on military DRVs for energy (SACN, 2017) that the data collated from the Phase-3 Section Commander's Battle Course could provide an indication of the energy requirements of this component of the MS role. This would provide data of the worst-case scenario for the land-based role in terms of moving over undulating ground carrying load. This would therefore provide an upper boundary for risk assessment.

38. For the AR and UR, energy expenditure measurements for male MS were undertaken by both DLW and PAD.[4] Energy expenditure was estimated using the DLW method, and compared with self-report PAD, in volunteer MS during AR (n=18) and UR (n=16) (Gunner et al, 2020). Data were analysed by the factorial model in which energy expenditure is represented by PAL (see Annex B).

39. These analyses show that, during the AR, daily energy expenditure, as indicated by PAL values derived by the factorial analysis of DLW was comparable to that observed for Training Courses A as defined in the SACN position statement on

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[4] All roles in the UK military have been open to females since 2018. However, presently there are no females undertaking MS roles and therefore data on females are not currently available.

military DRVs for energy (SACN, 2017). However, there was a high level of variability in these data in terms of the daily rates of energy expenditure, which was evident from the indirect (for example, accelerometery and heart rate) measurement methods (see Annex B). This large day-to-day range of work rates for MS should be taken into consideration when supplying rations.

40. During the UR, daily energy expenditure was lower than during AR, and consistent with the "more active" (75th centile) individuals of the general population, as defined in the SACN 2011 DRVs for energy report. However, as with the AR role, there was evidence of a high level of day-to-day variability in terms of work rates during the UR.

Summary and conclusions

41. This supplement to the SACN 2017 position statement on military DRVs for energy considered whether the new evidence describing the energy expenditure of military personnel sub-groups would allow UK military DRVs for energy to be updated.

42. For UK service men undertaking maritime operations (RN submariners), the distribution of the PAL values determined from DLW measurements (PAL_{DLW}) indicated that the PAEE levels of RN submariners were similar to the general population.

43. The energy requirements for RN male submariners are described by the median EAR values for the general population in Table 1 (that is, 12.0 MJ/d).

44. For UK service men undertaking MS land-based roles, the position statement on military DRVs for energy (SACN, 2017) suggested that the energy requirements would be equivalent to Military Training Courses B in Table 1 (that is, 19.2 MJ/d).

45. For AR (for example, involving water transits, military diving and climbing), the distribution of the PAL_{DLW} values indicated that the PAEE levels of MS were similar to those undertaking Training Courses A (see Table 1). It should be noted that there was a high level of day-to-day variability in these data, which will require consideration when providing rations for AR.

46. The energy requirements for male MS undertaking an AR are described by the median EAR values for those undertaking Military Training Courses A in Table 1 (that is, 17.0 MJ/d).

47. For male MS undertaking UR involving FIBUA drills, the distribution of the PAL_{DLW} values indicate that the PAEE levels of MS were similar to the 75th percentile of the general population (see Table 1). It should be noted that there was a high level of day-to-day variability in the energy requirements of MS undertaking the UR, which will require consideration when supplying rations.

48. The energy requirements for male MS undertaking the UR are described by the 75th percentile EAR values for the general population in Table 1 (that is, 13.1 MJ/day).

Research recommendations

49. To improve the future assessment of energy requirements in military groups, research in the following areas is required:
    - measurement of the effect of environmental conditions on energy requirements per se for military personnel, and specifically for those military groups undertaking arduous work in extreme environments (that is altitude, temperature, humidity, terrain)
    - to better understand the day-to-day variability of military energy requirements, analysis of data from alternative measures of energy expenditure that have already been collected in military personnel, especially those which allow integrated measurements of TEE; this would enable a comparison to be made with TEE estimates from DLW measures where these have been collected in the same volunteers
    - development of new, and improvement of existing, measurement methods of energy expenditure which can be used as valid and reliable alternatives to the DLW technique
    - collection of DLW data on female military personnel, specifically those involved in submariner and MS roles, when sufficient numbers allow.

Annex A: Analysis of energy expenditure data obtained on Royal Navy submariners

Background

A1. This annex describes the analysis of measures of energy expenditure by doubly labelled water (DLW), physical activity diaries (PAD) and accelerometery. It should be considered in the context of the SACN 2017 position statement on military DRVs for energy (SACN, 2017), particularly the Annex.

Dietary Reference Values for energy

A2. The SACN Dietary Reference Values for Energy report for the UK population (SACN 2011) utilised a factorial model for evaluating energy expenditure and estimating food energy requirements from estimates of energy expenditure. This involves expressing total energy expenditure (TEE) in terms of the physical activity level (PAL) where PAL is TEE adjusted for basal metabolic rate (BMR): that is, PAL = TEE/BMR. This means that PAL is theoretically independent of factors influencing BMR (weight, height, age and sex), at least as a first approximation. Consequently, for any PAL value, TEE and hence the estimated average requirement (EAR) can be predicted for any group from estimates of the BMR.

A3. PAL values are most accurately estimated from direct measures of 24-hour TEE (for example, with the DLW method) or other measures such as a PAD or accelerometery and BMR. Such measurements in various population groups have indicated that PAL can range from less than 1.3 in immobile volunteers, to values up to 3.6-5.3 in Tour de France cyclists. In the SACN position statement on military DRVs (SACN, 2017), values were identified for the general UK population and 3 different groups of military personnel, namely:

   a. General Population

   b. Active Service

   c. Military Training Courses A, which included: the Common Military Syllabus for Recruits (CMS(R)) and; Royal Air Force (RAF) phase-1 recruits

   d. Military Training Courses B, which included: Common Infantry Course (CIC) – Paras and Guards; Commissioning Course for Officer Cadets (CCOC); and Section Commander's Battle Course (SCBC) (Army infantry soldiers phase-3 training)

A4. Median PAL values for these 4 groups were 1.63, 2.08, 2.32 and 2.62 respectively, of which the value for Military Training Courses B (2.62) was at a level of physical activity at the upper limit of what can be sustained for long periods of time.

Limitations of the factorial model

A5. In the position statement (SACN, 2017), the limitations of the factorial model were discussed in terms of the extent to which PAL values can satisfactorily categorise activity levels for population groups. One issue relating to the current submariner group that includes volunteers living with overweight and obesity is particularly relevant, namely that PAL as a measure of absolute physical activity energy expenditure (PAEE) is not independent of weight: that is a PAL value as a representation of PAEE will increase with weight or conversely the effect of a fixed amount of PAEE on PAL gets smaller as size increases. The reason is that the increase in BMR with size contributes to both the numerator and denominator in the PAL calculation, but PAEE contributes only to the numerator. In other words, to maintain a constant PAL with increasing size, PAEE would need to increase in proportion to the BMR. Thus, for a group of soldiers all carrying the same weight, the individual PAL values will tend to be lower as their size increases.

A6. While this weight dependency of PAL does not involve a large effect, there is another important complexity in the PAL–PAEE relationship which is physiological. This relates to the effect of size on both absolute strength and the consequent ease of strength-requiring tasks as well as the absolute energy cost of weight-bearing activities. These issues are quite complex and mainly involve the difficulties in relating behavioural changes in terms of activity as measured by activity diaries and especially accelerometers to both PAEE and PAL values derived from DLW values of TEE in volunteers living with overweight or obesity, compared with healthy weight volunteers. Thus, studies have shown that while similar PAL and PAEE values derived from DLW may be observed in volunteers with obesity compared with volunteers with healthy weights, accelerometer-derived activity levels on the same volunteers are lower in volunteers with obesity. This is relevant in the current data set as BMI values range from 21 to 36kg/m^2 and three measures of energy expenditure are reported (DLW, PAD and accelerometery). These issues are not relevant for deriving food energy requirement values from DLW data. However, they need to be examined in the context of determining the extent to which PAD and accelerometery data may be used as an alternative to the DLW method.

Analysis of the Doubly Labelled Water data

BMR values for the calculation of PAL from TEE

A7. There is a wide range of BMR predictive equations and different organisations choose to use different equations. The SACN Dietary Reference Values for energy report (SACN, 2011) used the Henry equations, (which predict BMR according to age, weight, height and sex) on the basis that these had been shown in independent validations to be more appropriate for predicting the BMR within the general population for all age groups and sizes than the previously used Schofield equations. It was decided to use the Henry equations to estimate BMR values in military personnel as well; that is, these BMR predictive equations together with appropriate PAL values were used to predict EAR values.

A8. Since total body water (TBW) values were available from the submariner volunteers who participated in the DLW studies, fat free mass (FFM) and fat mass (FM) could be calculated and a prediction equation for BMR, based on body composition, used. As this equation is more likely to reflect the actual individual body composition of each volunteer, it is a useful exercise to compare these BMR values with the Henry equations to provide useful information on the validity of using the Henry equations.

A9. BMR varies with both FFM and FM (Johnstone et al, 2005). FFM and FM can be calculated from TBW as FFM = 1.37 x TBW (Pace & Rathbun, 1945) and FM = weight – FFM. In this report BMR has been calculated by an equation based on FFM and FM (BMR = (0.102*FFM) + (0.024*(FM)+0.85 MJ/day) (Westerterp et al, 1995). This equation was shown in the SACN 2017 position statement on military DRVs for energy to predict mean BMR values very similar to those derived from the Henry equations.

A10. A detailed analysis of BMR predicted by the TBW data (BMR_{DLW}) and by the Henry equations (BMR_H) is shown in Table A1. Values were highly correlated (r^2 =0.934) with mean values differing by less than 1%. As previously identified in other Armed Forces personnel, where differences in the 2 BMR values occurred, these differences reflected to some extent variation in body composition. Thus, as shown in Figure A1 the ratio of the 2 predicted BMR values (BMR_H/BMR_{DLW}) fell with an increase in relative FFM (shown adjusted for height - the FFM index, (kg/height^2), which explained about one third of the variance, (r^2 = 0.33). However, given the similarity of the 2 BMR mean values, the Henry equation BMR values can be used with reasonable confidence.

Table A1. Age, weight, height, body mass index, percentage body fat, fat-free mass index, basal metabolic rate and basal metabolic rate ratios of volunteers (n=20)

Volunteer	Age (y)	Weight (kg)	Height (m)	BMI[a]	%BF[b]	FFM-Index[c]	BMR$_H$[d]	BMR $_{DLW}$ [e]	BMR$_H$/ BMR$_{DLW}$
Mean	31.5	91.4	1.8	28.6	29.4	20.0	7.94	8.00	0.99
SD	7.4	17.2	0.1	3.9	6.2	1.7	0.93	1.04	0.03
Min	21.0	60.2	1.6	20.6	18.5	16.8	6.33	6.10	0.93
Max	47.0	118.4	1.9	35.7	38.7	23.7	9.74	9.50	1.05

[a]   BMI = Body Mass Index
[b.]   %BF = Percentage Body Fat
[c.]   FFM-Index = Fat Free Mass Index (relative to the square of height)
[d,e] BMR = Basal Metabolic Rate (derived from standard Henry equations and calculated from DLW data)

Figure A1. Ratios of BMR$_H$ to BMR$_{DLW}$ as a function of height-adjusted FFM in volunteers.

BMR ratio(H/DLW) v FFMindex

$y = -0.0113x + 1.2193$
$R^2 = 0.3264$

BMR ratios (H/DLW)

FFM Index (KG/M^2)
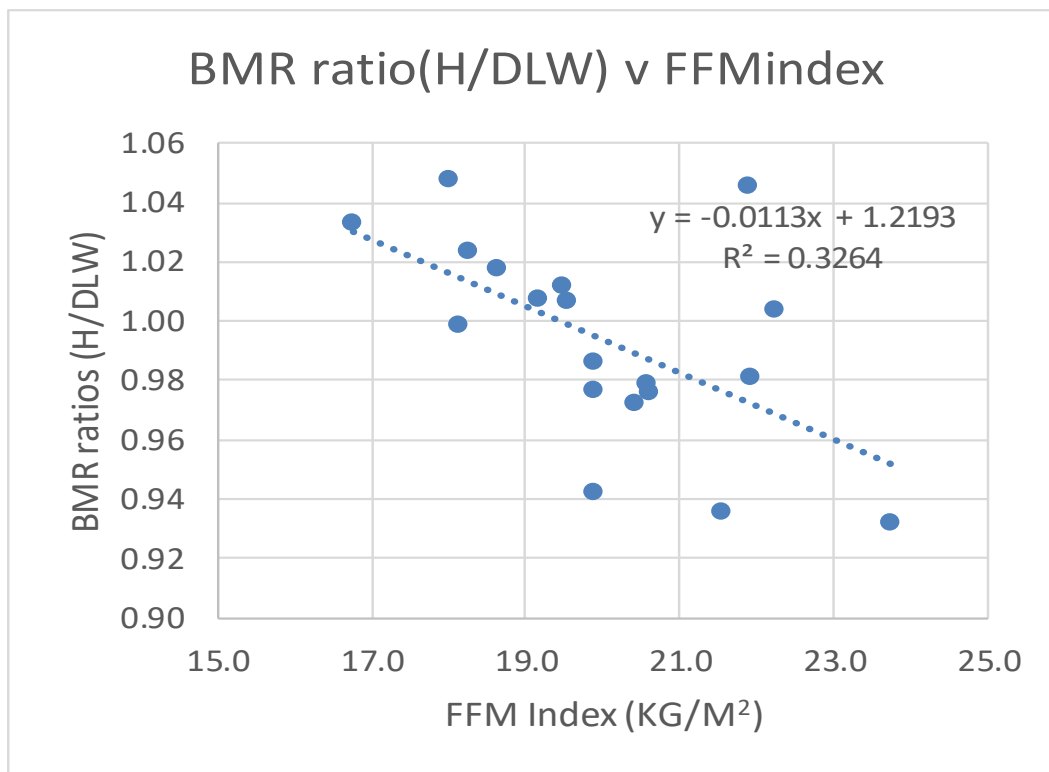
**Pre-analysis examination of rates of energy expenditure assessed by DLW and PAD: trimming of the data**

A11. Table A2 shows the rates of TEE and PAEE assessed by DLW and by PADs, expressed in each case as MJ/day and PAL values calculated from BMR estimated by the Henry equation.

A12. For the DLW measurements the range of PAL values (1.20 to 1.99) indicated low to active activity patterns. However, the lowest value (1.20), indicating a very low level of PAEE, was not compatible with the PAD PAL value for the same individual which indicated average levels of PAEE. On this basis it was concluded that the DLW data for this volunteer data was unreliable and was therefore trimmed. The next lowest value for PAL, 1.39 was associated with a PAD PAL value of 1.45 confirming low levels of PAEE in each case.

A13. For the PAD measurements, the range of PAL values (1.28 to 2.04) also indicated low to active activity patterns. The lowest value indicated very low levels of PAEE, whereas the corresponding DLW PAL value indicated average levels of PAEE. However as shown in Figure A3 (top panel), the day-to-day variation in TEE in this volunteer was low as indicated by the standard deviation (SD). This means that it is unlikely to be an erroneous value (unless the volunteer systematically misclassified activity categories). On this basis, no trimming of PAD data was performed with this volunteer, who was included in the analyses.

Table A2. Total energy expenditure assessed by doubly labelled water and physical activity diary (n=18)

Volunteers	DLW[a] data			PAD[e] data		
	TEE[b]	PAL[c]	PAEE[d]	TEE[b]	PAL[c]	PAEE[d]
Mean	13.0	1.65	3.81	13.0	1.65	5.06
SD	1.6	0.18	1.16	1.6	0.20	1.37
Min	10.1	1.39	2.30	10.3	1.28	2.25
Max	15.4	1.99	5.57	16.2	2.04	8.24
25th		1.50			1.48	
Median		1.62			1.65	
75th		1.79			1.8	

[a] DLW = Doubly Labelled Water
[b] TEE = Total Energy Expenditure
[c.] PAL = Physical Activity Level
[d.] PAEE – Physical Activity Energy Expenditure
[e] PAD = Physical Activity Diary

Figure A2. (a) Distribution of PAL$_{DLW}$ and (b) PAL$_{PAD}$ values.

(a)   (b)
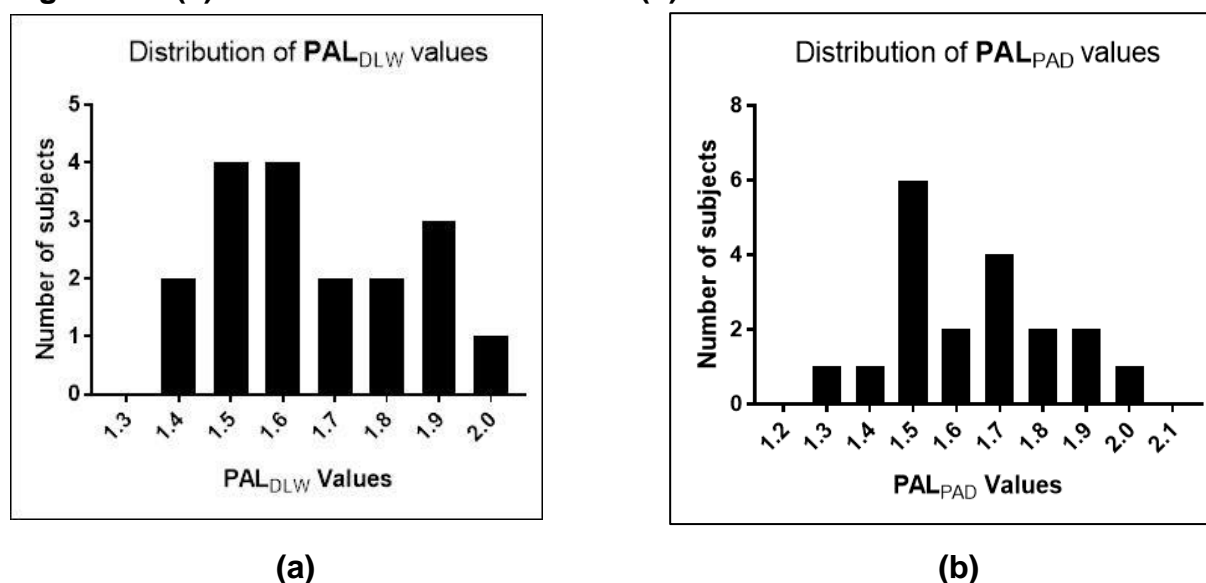
DLW rates of energy expenditure, PAL values and rates of PAEE

A14. After trimming volunteer 16, mean values for TEE, PAEE and PAL were 13.0 MJ/d, 3.81 MJ/d and 1.65 and the inter-individual coefficients of variation (CV) were 12.5%, 30.5% and 10.8%, respectively. The distribution of the PAL$_{DLW}$ values, indicated that the submariners exhibit PAEE levels similar to the general population. The distribution (see Figure A2(a)) was slightly skewed to the right, as in the general population, with values of 1.50, 1.62 and 1.79 for 25th, median and 75th percentile, respectively. These values are very similar to the general population (1.49, 1.63 & 1.78, respectively) (see Table 1, page 10). The distribution of the PAL$_{PAD}$ values (see Figure A2(b)) were also slightly skewed to the right, similar to the DLW values with very similar values of 1.48, 1.65 and 1.80 for 25th, median and 75th percentile values, respectively.

PAD rates of energy expenditure, PAL values and rates of PAEE

A15. As shown in Figure A3 (top panel), over the 10-day period of measurement mean inter-individual values of TEE, PAEE and PAL for the 19 volunteers were 13.0 MJ/day, 5.06 MJ/day and 1.65 MJ/day with CVs of 12.2%, 27.2% and 12.0% respectively. As shown in Figure A3 (bottom panel), the mean group daily TEE indicated by PAD was constant ranging from 12.6-13.7 (MJ/day) with average CVs of 14% indicating that no individual day's activity differed from the average.

Figure A3. Intra individual variation in TEE as indicated by PAD over 10 days (means and SD of 10 consecutive days of data collection (top). Daily inter-individual variation in TEE as indicated by PADs (means and SD of 19 volunteers) (bottom).
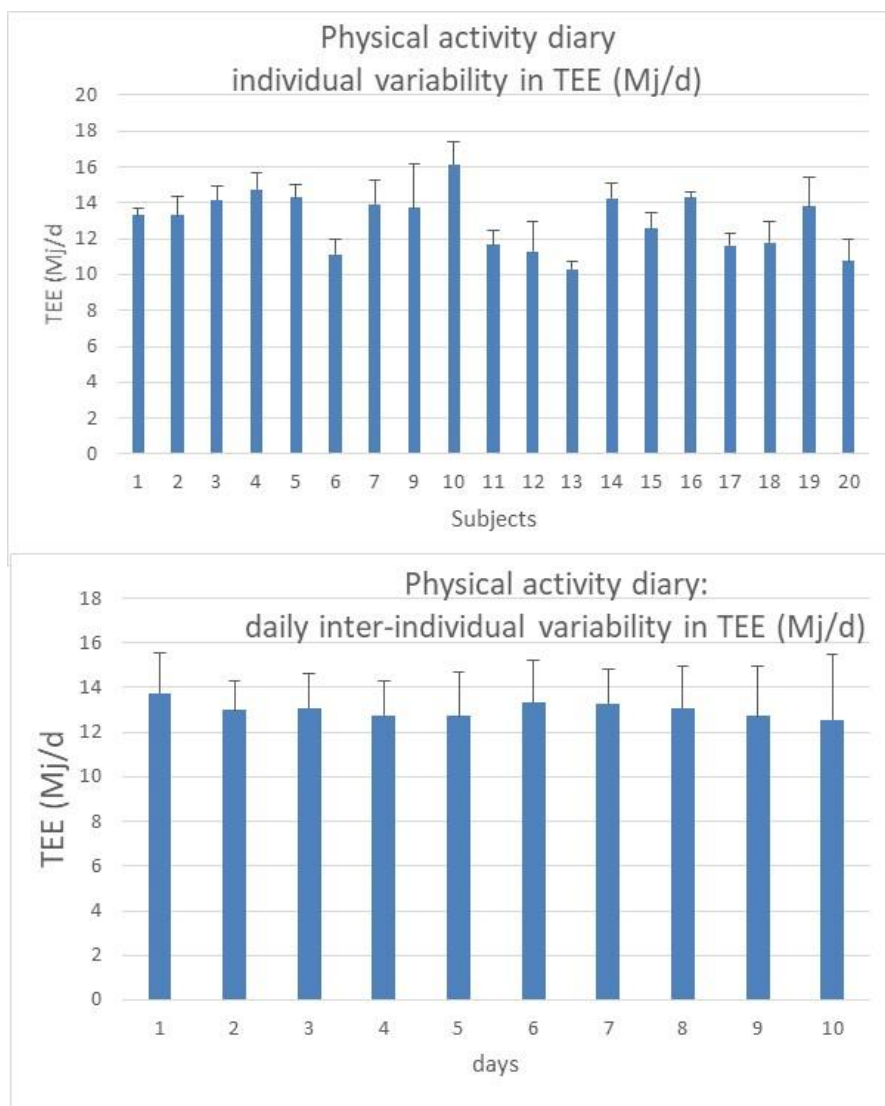

A16. Although mean and median values for DLW and PAD derived TEE and PAL values were very similar as shown in Figure A4 (left panel) the two measures were less correlated than expected from the similar mean and distribution values. Linear regressions between TEE values (top) and PAL values (bottom) show that the DLW data explained only 13% of the variance of TEE_{PAD}, and only 6% of the variance in PAL_{PAD}, with large intercepts in each case.

A17. Figure A4 (right panel) shows Bland-Altman plots of the same data as differences between the two values for TEE (top) and PAL (bottom). Since the bias values (the average of the differences) were close to zero in each case (0.1 and 0.009), the two

methods were not systematically producing different results, but individual rates of energy expenditure determined from one method were poorly predicted by the other. This was also the case for PAEE estimated by PAD or DLW. R^2 for a linear regression between the two measures was 0.008 (data not shown).

Figure A4. Relationship between energy expenditure measured by DLW and by PAD. Linear regressions between TEE (MJ/day) (top left) and PAL (bottom left). Bland Altman comparisons between TEE (MJ/day) (top right) and PAL (bottom right).
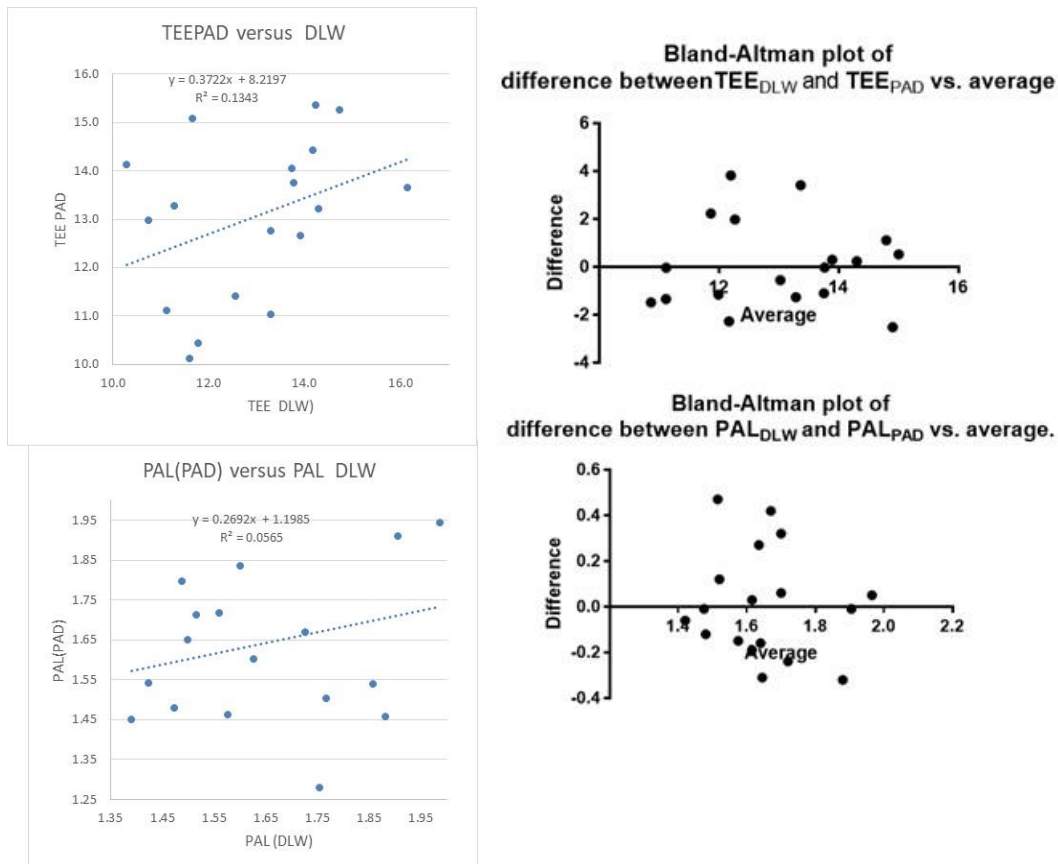
A18. As discussed above, there is evidence that in individuals with obesity, PAL is a poor measure of actual activity because the increasing cost of weight bearing exercise obscures any reduction in movement. However, as shown in Figure A5, there was little evidence that BMI influences the relationship between PAL_{DLW} and PAL_{PAD} (as indicated by their ratio) and BMI.

**Figure A5. Relationship of ratios of PAL_{DLW} to PAL_{PAD} to BMI**
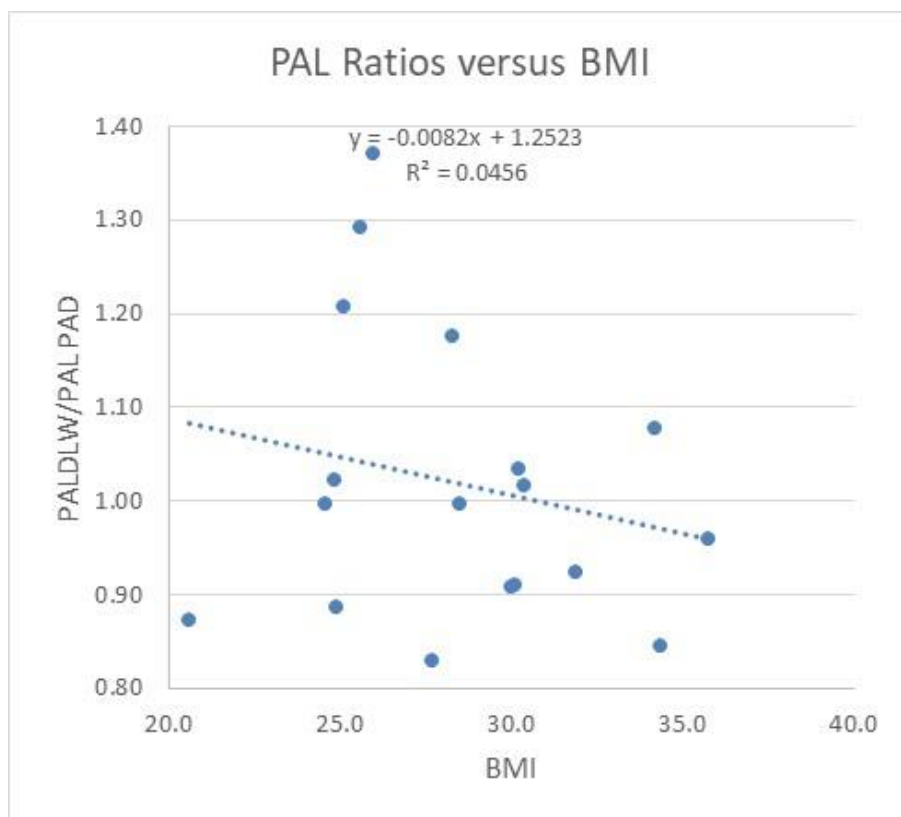
Analysis of accelerometery data

A19. Accelerometery was carried out on 15 of the volunteers over a period of 10 days (missing data for volunteers 12 and 13). Mean inter-individual 10-day values, shown below (see Figure A6 (top panel), varied over a two-fold range with CVs of daily values ranging from 10% to 38% (mean 25%) over the 10 days of measurement. Daily group mean values, shown in Figure A6 (bottom panel), differed from the daily mean values of TEE indicated by PAD (Figure A3 (bottom panel)). Although similar counts were recorded on days 1-8, counts were lower on day 9 and especially day 10 when the mean value was reduced by more than 50%. Inter-individual daily variability was high ranging from CVs of 20% to 60% (mean 31%).

A20. Figure A7 shows there was little obvious relationship between the accelerometery data and any of the DLW values (TEE, PAL or PAEE) (left panel), or PAD measures (right panel). Thus, R_2 values for the six linear regressions shown ranged from less than 1% (counts versus PAD PAEE) to 16% (counts v PAD TEE). Given that accelerometery measures movement, a relationship with the PAEE component of TEE (see Figure A7, bottom row) might be expected but none was apparent.

Figure A6. Top: Intra individual variation in TEE as indicated by accelerometery over 10 days (means and SD of 10 consecutive days of data collection). Bottom: Daily group variation in TEE as indicated by accelerometery (means and SD of 15 volunteers).
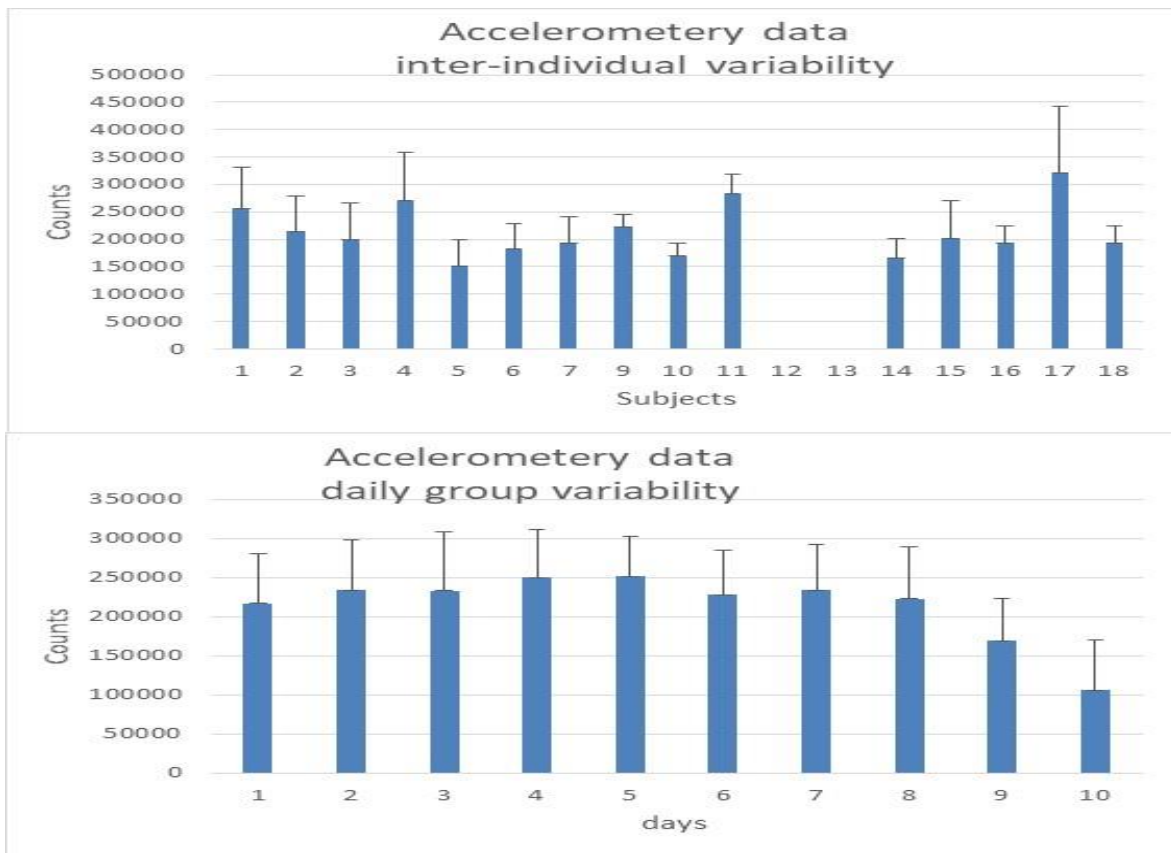
Figure A7. Left panel: accelerometery data (counts) compared with DLW data in terms of TEE (top), PAL values (middle) and PAEE (bottom). Right panel: accelerometery data (counts) compared with activity diary data in terms of TEE (top), PAL values (middle) and PAE
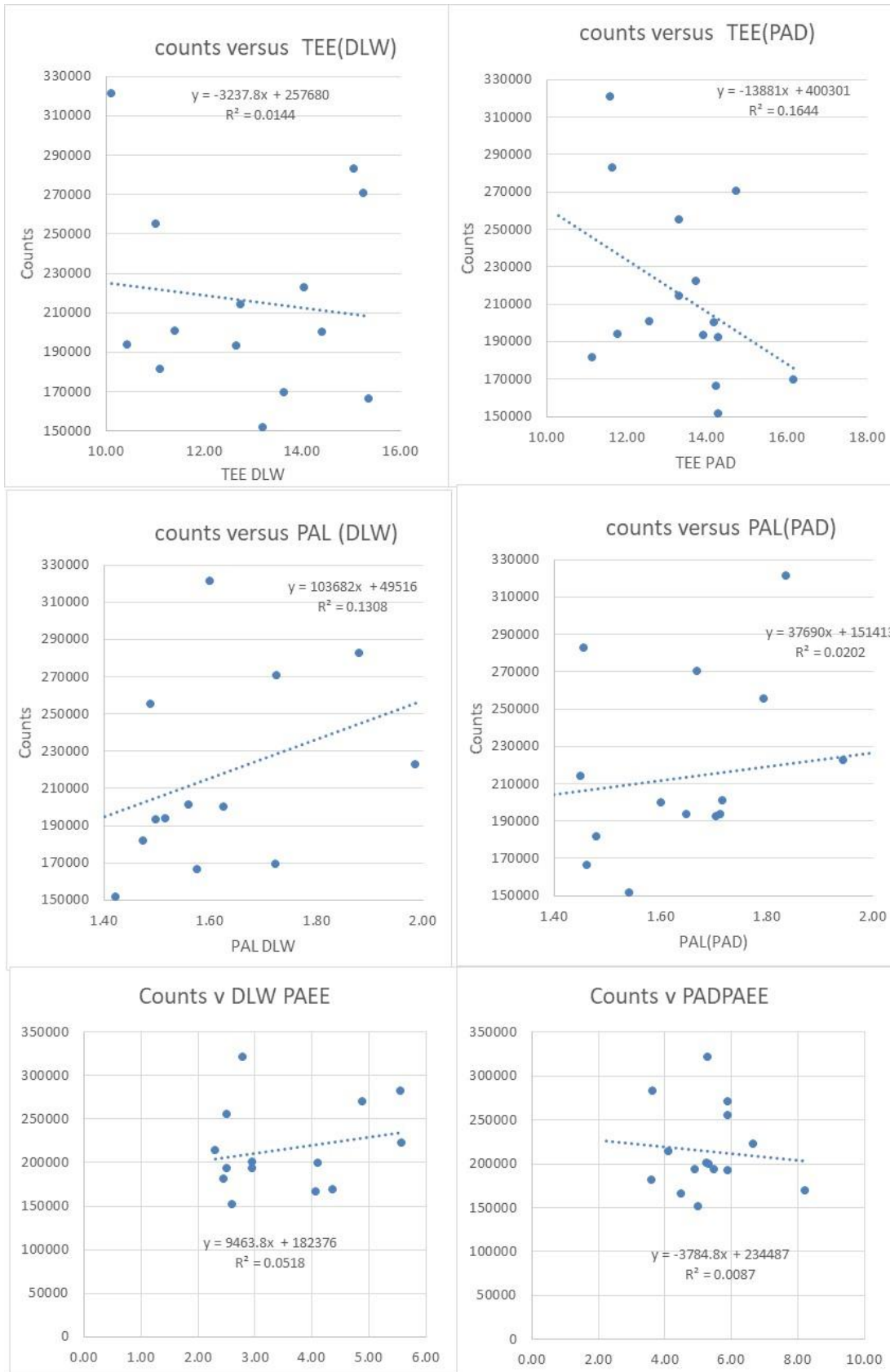
Overall conclusions

A21. The main finding of this analysis of energy expenditure of submariners is that on average, rates of TEE as indicated by PAL are the same as the general population. Whilst the number of volunteers analysed is small (n=18 after trimming one unrealistic value), it is clear from Figure A8 that PAL(DLW) values lie within the middle of the distribution of the cohort of 1000 volunteers who served as a reference for the SACN Dietary Reference Values for Energy report (SACN, 2011). On this basis EAR values for energy should not differ from those military personnel engaged in non-strenuous activities.

Figure A8. Distribution of PAL(DLW) values of submariners compared with the general population and military personnel in training and in active service. For each cohort the 25th to 75th percentile ranges are shown by the double arrows.
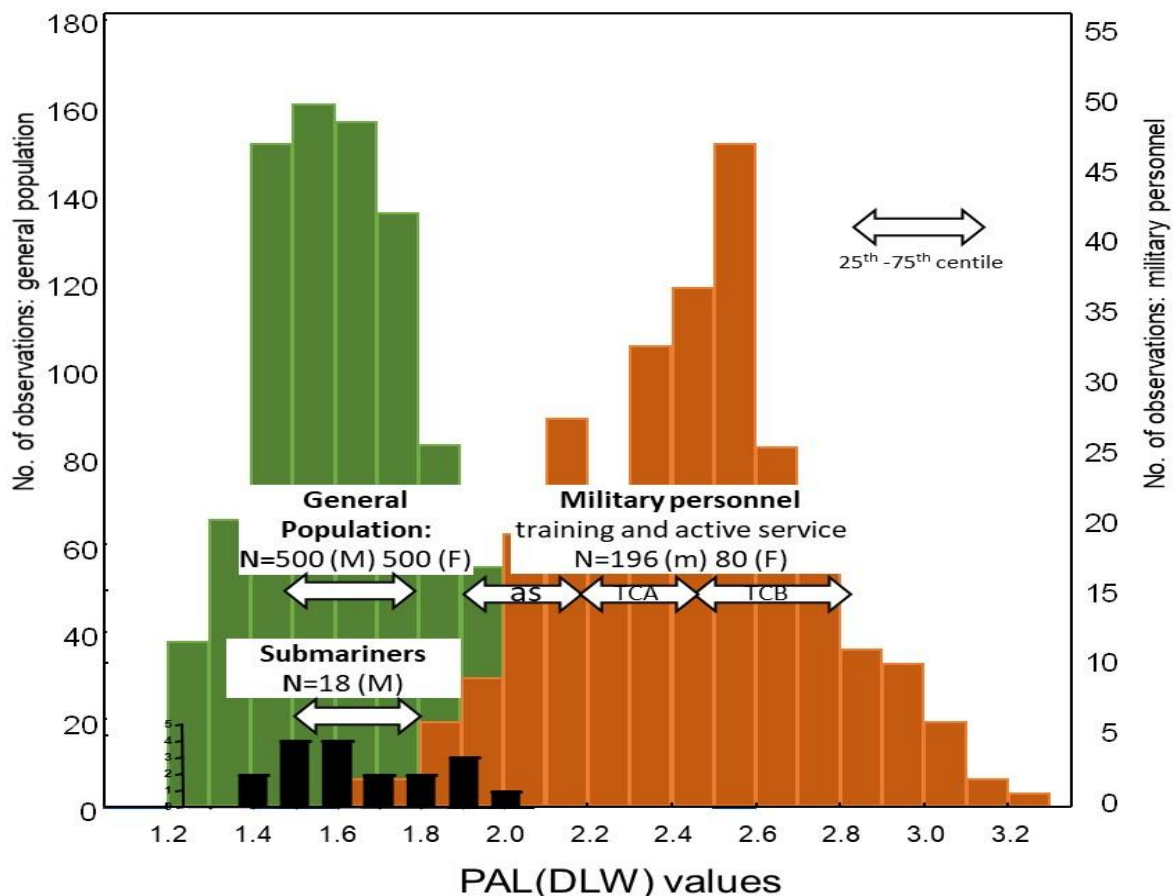

A22. Although the DLW data closely matched energy expenditure estimated from PAD, in terms of average values and distribution within the volunteers studied (see Table A2 and Figure A2), there was very little intra-individual correspondence between the two measures. The DLW values explained only 13% of the PAD TEE values and even less (5%) of the variance in the PAD PAL values (see Figure A4). As the daily intra-individual variation in PAL, as indicated by PADs over the 10 days of data collection,

was relatively small (see Figure A9 (top panel): an average CV of 7.5%), the PAD values were reproducible for individual volunteers. Also, daily mean PAD PAL values for all volunteers were remarkably similar (see Figure A9, middle) with the higher CV values (14.8%) of the daily mean values reflecting the intra-individual variability apparent in Figure A9 (top panel). This means that the PAD values indicated very similar activities from day to day over the 10 days. In contrast the accelerometery data indicated much lower activity on day 10 and lower values on day 9. Nevertheless, whatever activities were documented in the PAD, the overall summation of the equivalent energy expenditure assigned to those activities was poorly correlated to that indicated by DLW (Figure A4 and Figure A9 (bottom panel)).

A23. As for the accelerometery data, on the basis of the analysis of DLW data reported here, this is also disappointing in that it adds little either in terms of any extra insight into the overall rates of energy expenditure as indicated by the DLW data or by the PADs or into the mismatch between the PAD and DLW data.

Figure A9. (Top): Intra individual variation in PAL as indicated by PAD over 10 days (means and SD of 10 consecutive days of data collection. (Middle): Daily inter individual variation in TEE as indicated by PAD (means and SD of 20 volunteers. (Bottom): PAD PAL compared with DLW PAL.
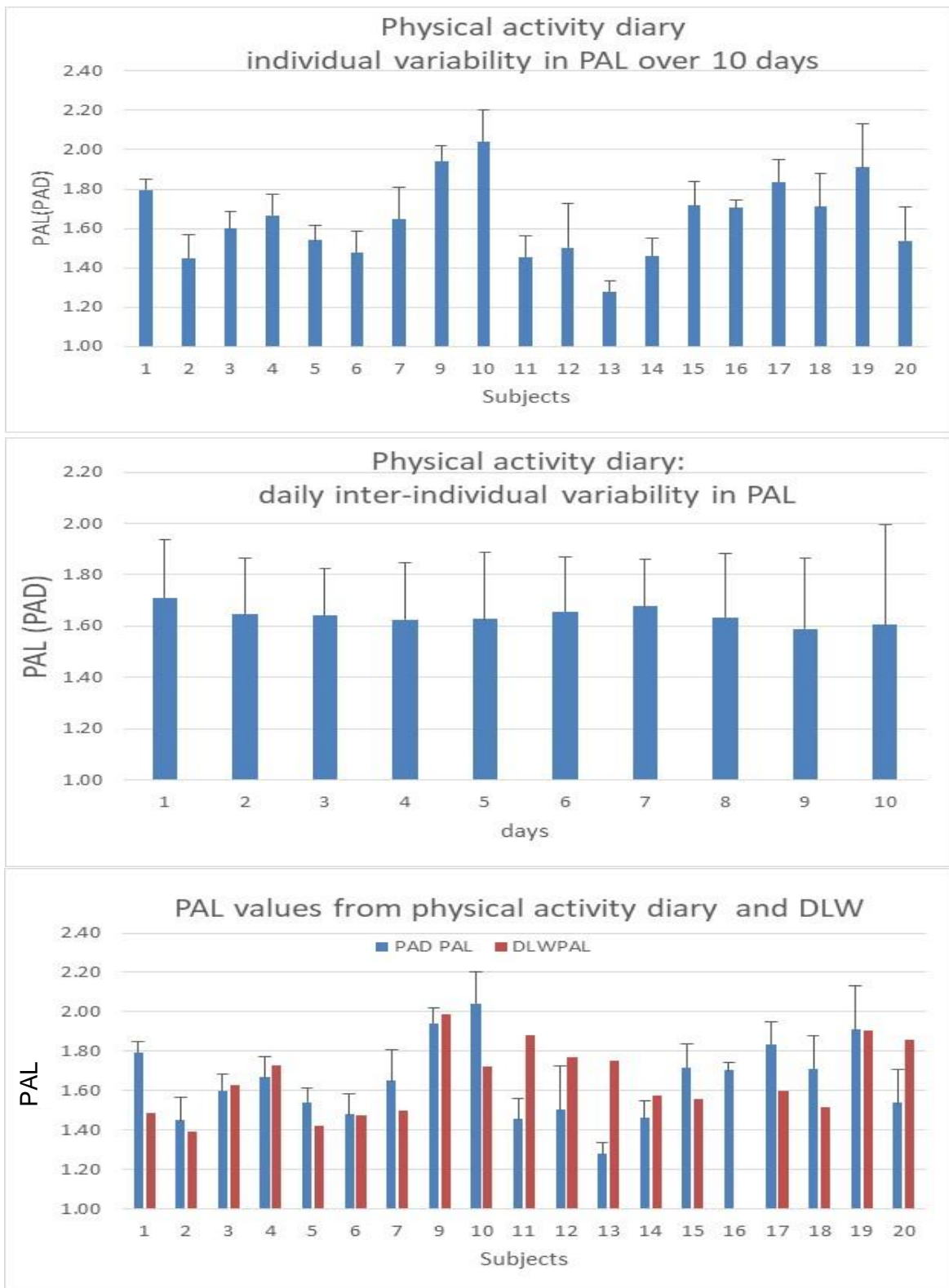
Annex B: Analysis of energy expenditure data obtained on military specialists

Background

B1.   As with Annex A, this annex describes the analysis of measures of energy expenditure by DLW, PAD and accelerometery. It should be considered in the context of the SACN 2017 position statement on military DRVs for energy (SACN, 2017).

Summary of analysis

B2.   Energy expenditure measurements for Military Specialists (MS) during 2 training periods, separated by 1 month, were undertaken in the UK by both DLW and PAD. Measurements for the Amphibious Role (AR) (that is, involving water transits, military diving and climbing), were undertaken in September 2018. Measurements for the urban role (UR) involving Fighting In Built Up Areas (FIBUA) drills were undertaken in October 2018. Data were analysed by the factorial model in which energy expenditure is represented by PAL where:

$$PAL= daily\ energy\ expenditure/\ BMR$$

B3.   PAL values were calculated with BMR values derived from the Henry prediction equations from body weights reported at the start of each DLW study. These BMR values were slightly lower than those calculated from the %FFM predicted from the DLW TBW values so that derived PAL values were 8% higher. Such differences were previously observed in volunteers with relatively high %FFM levels, namely Parachute Regiment trainees (SACN, 2017).

B4.   Twenty-four volunteers were recruited to the study, from which 17 out of 24 volunteers completed both the AR and the UR elements (19 out of 24 volunteers completed each of the AR and the UR studies). Data from one volunteer appeared anomalous with respect to TBW and was therefore excluded. This left 18 out of 24 volunteers having completed each element, and 16/24 volunteers having completed both training elements.

B5.   Mean PAL values were higher during AR (mean=2.20±0.21, n=18) than during UR (mean=1.77±0.16, n=18), and the 2 values were significantly correlated (r^2= 0.53, p=<0.002). For those with repeated measurements (n=16) PAL values were higher in AR in every case except for 1 volunteer (mean difference +29% n=16, or +31% n=15).

B6. During AR, PAL values (median and Q25-Q75 = 2.19, 2.12-2.32) were in the range identified in studies of volunteers during Common Military Syllabus for Recruits (CMSR) and Royal Air Force (RAF) Phase-1 training, identified in the SACN position statement (SACN, 2017) as Military Training Courses A (median and Q25-Q75 = 2.32, 2.15-2.44) (see Table 1, Level 3, page 10). During UR, the range of PAL values (median and Q25-Q75 = 1.75, 1.65-1.91) was similar to a more active (75th centile, PAL=1.78) population within the general population (see Table 1, Level 1, page 10)

B7. Daily PADs were completed over 10 days by 20 out of 24 volunteers during AR and 18 out of 24 during UR. PAL values were calculated for individual 10-day average rates of energy expenditure on the basis of BMR values calculated from body weights at the start of the study periods.

PAD predicted energy expenditure was 14% lower during AR, when compared with DLW-determined energy expenditure; similar differences were observed in the UR group. Thus, the difference in energy expenditure in the two periods of study determined by the PAD (+16%), underestimated the actual difference measured by DLW (29-31%). PAD were also poor predictors of individual DLW-determined energy expenditure; PAD-determined PAL values were not significantly correlated with DLW-determined PAL values during either AR or UR training periods. Thus, the PAD methodology was unable to capture the higher energy expenditure as indicated by the DLW studies during AR. The reason for this is likely a lack of specific physical activity codes relevant to the work intensity of tasks undertaken during the AR.

Initial inspection and pre-analysis preparation of the data

B8. A table of descriptive data and anthropometry (including age, weight, BMI and body fat) was supplied (see Table B1, page 33). The body fat values were obtained from skinfold thickness measurements and are therefore not directly comparable to the values of FFM shown in Table B1 (which were obtained from TBW during the DLW studies). The 24 male volunteers ranged from 24-43 years of age with BMI between 22 and 31 kg/m^2. There was no correlation between BMI and age, but BMI and waist circumference were highly correlated (r^2=0.56). Many participants in the BMI category 25 to 29.9 had relatively high percentage fat free mass (%FFM) and low percentage fat mass (%FM) for their BMI. Indeed, %FFM was similar to that of the male recruits during training examined in the SACN 2017 position statement on military DRVs for energy (overall mean %FFM = 81.5).

B9. Of the cohort of 24 males, 19 completed DLW measurement on 2 occasions a month apart, during which time 20 completed the first PAD and 18 the second PAD. The volunteer mean body weights, and ranges of values, were similar for the AR and UR cohorts. Body weights from the DLW studies were used in all calculations for body composition and BMR.

B10. TBW and FFM and %FFM were calculated. The TBW was determined as the average TBW (from regression analysis) value in moles, equivalent to N *18.015/1000 kg. This was converted to FFM as FFM = 1.37 x TBW (Pace & Rathbun, 1945), and %FFM was calculated from the body weights.

B11. On inspection of the TBW-FFM data, one pair of repeat values appeared inconsistent. There was a very low TBW and derived FFM (59.4 kg) and %FFM (72%) for AR training, which was inconsistent with the BMI (23 kg/m^2) %FFM relationship for the overall group. The value during UR training TBW-derived FFM was 15 kg higher, with only a 1.6 kg increase in body weight, and equivalent to a %FFM of 89%, which was the highest for the group. As the TEE is calculated in part from the TBW value, these inconsistent values for TBW resulted in inconsistent TEE values for this volunteer. Due to these concerns the DLW derived TEE data for this volunteer was not included in the analyses.

BMR values for the calculation of PAL from TEE

B12. As TBW values were available from the current set of MS who participated in the DLW measurements, FFM and FM could be calculated and a prediction equation for BMR based on body composition could be used, (BMR = (0.102*FFM) + (0.024*(FM)+0.85 MJ/day) (Westerterp et al, 1995). Because such an equation is more likely to reflect the actual individual body composition of each volunteer it is a useful exercise to compare such BMR values with the Henry equations since this should provide more useful information on the validity of using the Henry equations.

B13. As shown in Table B2, BMR values calculated from TBW/FFM were slightly higher than values calculated with the Henry prediction equations, as observed with several of the training cohorts, including CIC Paras and SCBC, and Active Service men examined previously (SACN, 2017), who had higher than average FFM. As a result, the ratios of BMR predicted by the Henry equations (BMR$_H$) to BMR predicted by TBW (BMR$_{TBW}$) was <1 (0.92±0.04 AR, and 0.93±0.04 UR).

B14. This analysis shows that BMR$_{DLW}$ is preferable to BMR$_H$, as discussed in the SACN (2017) position statement on military DRVs for energy (SACN, 2017). Since data on TBW was not available for all military groups examined to date, the BMR values derived from the Henry equations represented the only data which could be used for analysis by the factorial model of all DLW TEE data for military groups analysed to date.

The important question is whether these differences are likely to influence overall assessment of energy expenditure in terms of PAL values for the purposes of this report. In fact, the differences in calculated PAL values were relatively small in terms of mean values: that is, the overestimate of PAL amounted to 8%, which could be considered an acceptably small difference. In subsequent tables of this report the BMR$_H$ values have been used to calculate PAL.

Table B1. Amphibious role and Urban Role training doubly labelled water data for body weight and derived fat free mass

	Age	Weight	BMI	Body fat[a]	AR[c] DLW[d] data			UR[e] DLW data			Weight change: UR-AR	FFM[f] change: UR-AR
	(y)	(kg)	(kg.m^2)	(%)	B wt[g] kg	FFM Kg from TBW[h]	%	B wt kg	FFM Kg from TBW	%	kg	
N	24	24	24	24	19	19	19	19	19	19	17	17
Mean	33.3	87.5	26.6	19.5	87.8	70.4	80.3	87.6	70.1	80.2	0.18	0.14
SD	4.8	8.6	2.3	3.3	8.3	7.3	6.1	8.6	7.6	5.5	1.90	5.21
Min	24.0	77.3	22.0	12.8	78.4	59.4	68.4	77.8	60.3	66.3	-5.20	-7.13
Max	43.0	106	31.0	27.8	107.4	85.1	90.8	109.8	91.6	89.0	2.40	15.37
95% CI	1.9	3.43	0.9	1.3	3.7	3.3	2.74	3.9	3.4	2.5	0.90	2.48

[a] BMI = Body Mass Index
[b] Body fat values were obtained from skinfold thickness measurements
[c] AR = Amphibious Role
[d] DLW = Doubly Labelled Water
[e] UR = Urban Role
[f] FFM = Fat Free Mass
[g] B wt = Body Weight
[h] TBW = Total Body Water

Table B2. Basal metabolic rate values for Amphibious Role and Urban Role training doubly labelled water measurements

	Age	Weight	AR[a] DLW[b] data			UR[c] DLW data		
	(y)	(kg)	BMR[d]$_H$ MJ/d	BMR$_{TBW}$[e] MJ/d	Ratio	BMR$_H$ MJ/d	BMR$_{TBW}$ MJ/d	Ratio
n	24	24	23	18	18	18	18	18
Mean	33.3	87.5	7.75	8.50	0.92	7.77	8.41	0.93
SD	4.8	8.6	0.52	0.70	0.04	0.53	0.78	0.04
Min	24.0	77.3	7.01	7.67	0.86	7.03	7.48	0.84
Max	43.0	106	8.79	10.06	0.98	8.97	10.63	0.99
95% CI	1.9	3.43	0.21	0.33	0.02	0.24	0.36	0.02

[a] AR = Amphibious Role

[b] DLW = Doubly Labelled Water

[c] UR = Urban Role

[d] BMR = Basal Metabolic Rate

[e] TBW = Total Body Water

Table B3. Amphibious Role and Urban Role training total energy expenditure and physical activity level values from doubly labelled water measurements

	Age (y)	Weight (kg)	AR[a]		UR[b]		AR/UR PAL[c] ratios	
			TEE[d] DLW[e] MJ/d	PAL	TEE DLW MJ/d	PAL	All volunteers	Excluding one volunteer
n	24	24	18	18	18	18	16	15
Mean	33	87.5	17.14	2.20	13.77	1.77	1.29	1.31
SD	5	8.6	2.02	0.21	1.67	0.16	0.14	0.11
Min	24	77.3	14.05	1.78	10.60	1.51	0.94	1.13
Q25				2.12		1.65		
Median				2.19		1.75		
Q75				2.32		1.91		
Max	43	106.0	21.56	2.56	17.27	2.13	1.58	1.58
95% CI	2	3.4	0.93	0.10	0.77	0.07	0.07	0.05

[a] AR = Amphibious Role

[b] UR = Urban Role

[c] PAL = Physical Activity Level

[d] TEE = Total Energy Expenditure

[e] DLW = Doubly Labelled Water

B15. Values for TEE and PAL for the AR and UR DLW studies are shown in Table B3. For volunteers with repeat measurements in AR and UR (n=16), TEE and PAL values were higher in AR compared with UR in all volunteers except one, which was 7% lower. Excluding this volunteer, PAL values in AR were 31% higher than for UR (range 13% to 58% p=<0.00001) and the two values were significantly correlated (r^2= 0.53, p=<0.002).

B16. The range of PAL values for AR (n=18, median & Q25-Q75 = 2.19, 2.12-2.32) is within the range of PAL values observed for Training Courses A (CMSR and RAF Phase-1): that is, Median & Q25-Q75 = 2.32, 2.15-2.44 (see Table 1, Level 3, page 10). The range of PAL values for UR (Median & Q25-Q75 = 1.75, 1.65 -1.91) is similar to a more active population, (75th centile, PAL=1.78), within the general population (see Table 1, Level 1, page 10).

Physical activity diary data during Amphibious Role and Urban Role training doubly labelled water measurements

B17. The PAD were completed on each day of the 10-day DLW studies. Individual values are shown for all volunteers in AR and UR training in Figure B1. There was considerable day-to-day variation in TEE indicated by the PAD. During AR, within-volunteer 10-day coefficient of variation (CV) varied from 4.5% to 23.3%, while the between volunteer CV of 10 day mean values was 7.8%. During UR, within-volunteer 10-day CV varied from 9% to 30.5%, while the between volunteer CV of 10 day mean values was 11%. The 10-day mean values are shown in Table B3 together with PAL values and with a comparison of PAL values as measured by DLW and PAD.

B18. The 10-day mean daily energy expenditure from the PAD were only slightly higher (7% on average), for AR compared with UR. Thus, the differences between TEE for AR and UR appeared less when measured with PAD compared with DLW. In fact, in AR, DLW-PAL values were on average 16% higher compared with PAD-PAL values, and the individual values were not significantly correlated (r^2=0.18 p=0.075). However, in UR average PAL values were not significantly different as measured by the two methods, but again individual values were not significantly correlated (r^2=0.045 p=0.4). As with the DLW data the PAD AR PAL values were significantly correlated with UR PAL values (r^2=0.44, p=<0.003). Overall these results indicate that while the PAD in UR captured the mean daily pattern of physical activity for the group reasonably well, in AR, some component of the higher energy expenditure indicated by DLW was not captured as effectively by the PAD.

Table B4. Amphibious Role and Urban Role training total energy expenditure and physical activity level values from physical activity diary measurements and comparison with doubly labelled water data

	Age (y)	Weight (kg)	AR[a]		UR[b]		AR/ UR ratio	TEE[c] DLW[d] MJ/d/TEE PAD[f] MJ/d ratio	
			TEE_PAD kcal	PAL[e]	TEE_PAD kcal	PAL		AR	UR
n	24	24	20	20	18	18	18	17	15
Mean	33	87.5	14.65	1.88	13.35	1.72	1.07	1.16	0.98
SD	5	8.6	2.20	0.24	1.47	0.17	0.10	0.19	0.09
Min	24	77.3	11.26	1.36	10.53	1.50	0.91	0.80	0.81
Max	43	106.0	19.19	2.35	16.31	2.11	1.26	1.42	1.14
95% CI	2	3.4	0.96	0.10	0.68	0.08	0.05	0.09	0.05

[a] AR = Amphibious Role

[b] UR = Urban Role

[c] TEE = Total Energy Expenditure

[d] DLW = Doubly Labelled Water

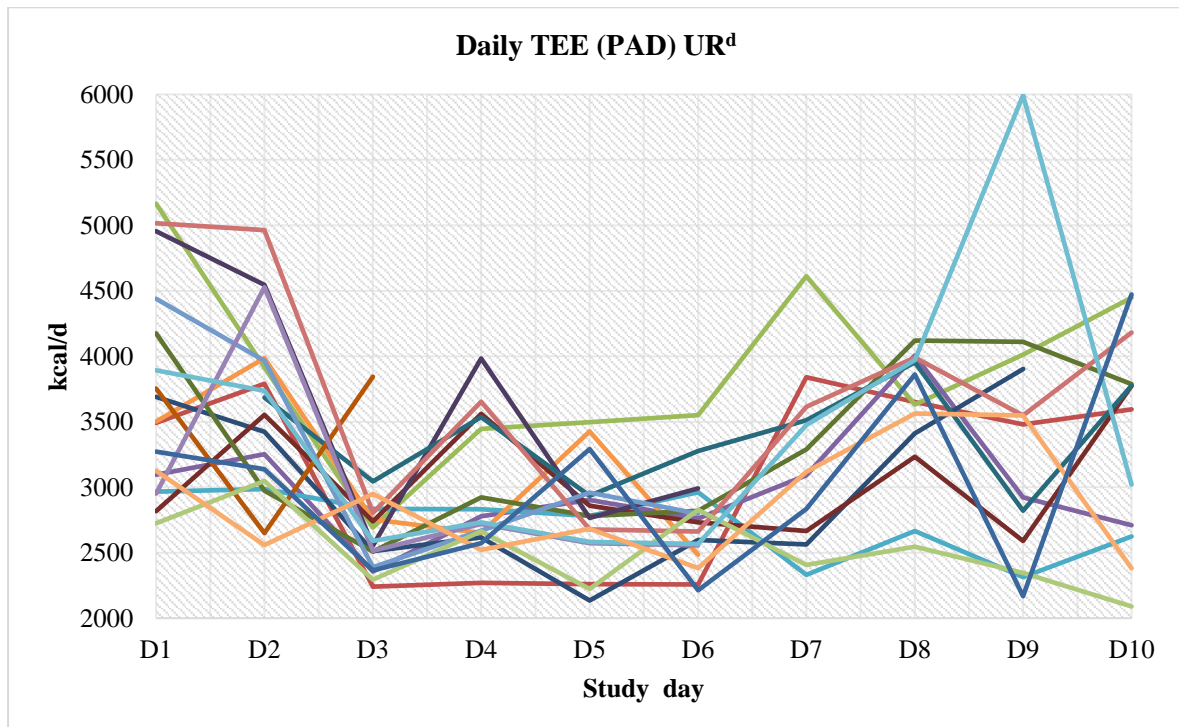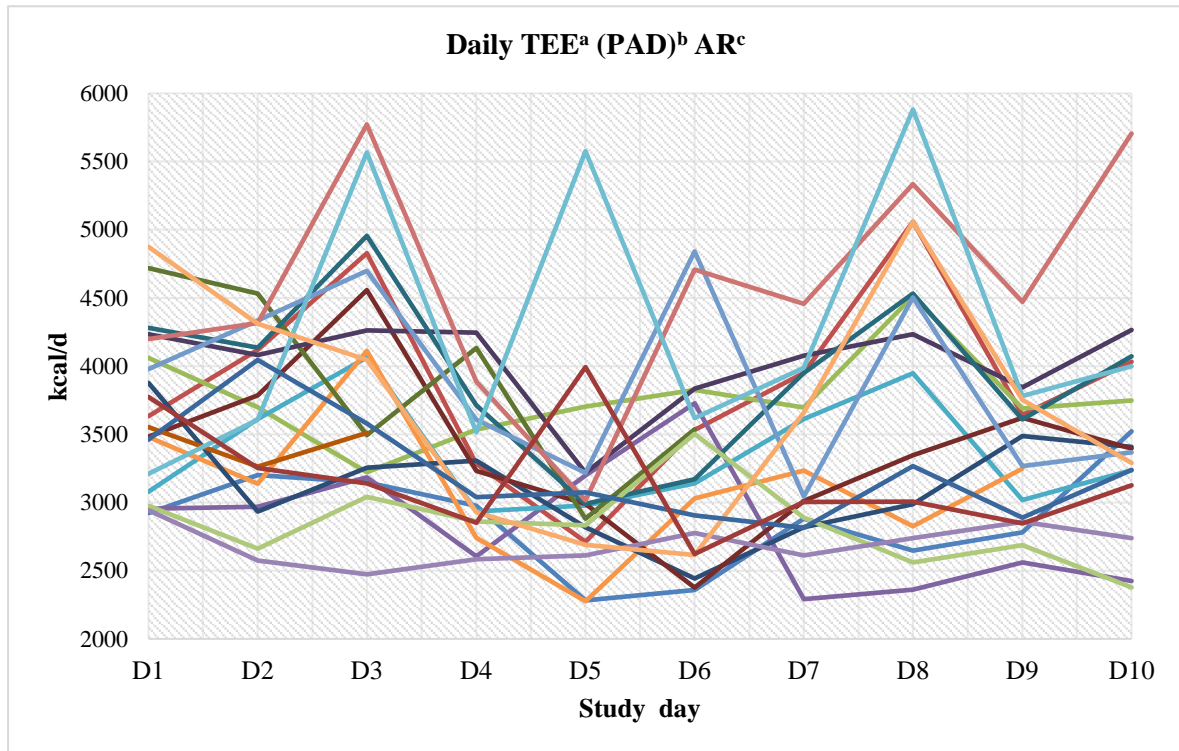[e] PAD = Physical Activity Diary

[f] PAL = Physical Activity Level

Overall conclusions

B19. The results show that, for this group of MS, energy expenditure was comparable to that observed for Training Courses A (CMSR and RAF Phase-1) as defined in the 2017 SACN position statement. This is based on PAL value derived by the factorial analysis of DLW studies during AR.

B20. During UR training, energy expenditure was lower and consistent with the "more active" 75th centile of the general population (see Table 1, Level 1, page 10).

B21. Whilst PAD indicated a level of energy expenditure which would be classified as more active in both the AR and the UR study phases, and slightly higher in AR, it is clear that the DLW methodology was unable to capture the higher energy expenditure experienced by volunteers during MS training (that is, the within variability in energy expenditure).

Figure B1. Individual daily energy expenditure amphibious role and urban role training as indicated by physical activity diaries

a TEE = Total Energy Expenditure
b PAD = Physical Activity Diary
c AR = Amphibious Role
d UR = Urban Role

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