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The association between obesity related health risk and fitness test results in the British Army personnel

Paul W. Sanderson[a,*], Stacy A. Clemes[a], Karl E. Friedl[b], Stuart J.H. Biddle[c]

[a] Loughborough University, School of Sport, Exercise and Health Sciences, National Centre for Sport and Exercise Medicine, UK
[b] U.S. Army Research Institute of Environmental Medicine, USA
[c] University of South Queensland, Australia

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ABSTRACT

Objective: In the British Army, fitness is assessed by a load carriage test (Annual Fitness Test, AFT) and by a three event Personal Fitness Assessment (PFA). Body composition based on body mass index (BMI) and abdominal circumference (AC) is also part of a mandatory annual assessment. This study examined the influence of BMI and AC on fitness test results within a comprehensive sample of British Army personnel.
Design: Secondary analyse were carried out on data obtained from the 2011 Defence Analytical Services and Advice (DASA) database for 50,635 soldiers (47,173 men and 3,462 women).
Methods: Comparisons using loglinear analysis were made between groups of individuals classified by body mass index as obese ($\geq$30 kg/m2) and not obese (<30 kg/m2), and further classified using combined BMI and AC for obesity-related health risks to compare "no risk" with "increased risk."
Results: Not obese or "no risk" soldiers had a significant relationship with success in the AFT ($p < 0.01$) and PFA ($p < 0.01$). Of those soldiers who attempted the AFT, 99% of men and 92% of women passed; for the PFA, 92% of men and 91% of women passed. Obese or "at risk" soldiers were more likely to fail and far less likely to take both tests ($p < 0.05$). Compared to older obese soldiers, young obese soldiers were more likely to attempt the tests.
Conclusions: We conclude that BMI and AC are useful indicators of fitness test outcome in the British Army.

1. Introduction

Regular physical activity, healthy nutrition and weight management provide extensive health, occupational and performance benefits, including physical and cognitive performance, and resistance to disease.[1,2] These relationships were already beginning to be recognized by the British Army after the Crimean War (1853–1856) and the central importance of physical training to soldier health and performance was underlined with the formation of the Royal Army Physical Training Corps. In 1946, Field Marshall Montgomery affirmed, "man is still the first weapon of war and his training is the most important consideration in the fashioning of a fighting Army".[3] Individuals in the armed forces are required to be physically fit to successfully engage in vocational activities that require high levels of occupational fitness[4] and operational fitness. High levels of cardiorespiratory and neuromuscular fitness are central to occupational fitness.[1]

Previous studies on the military have also linked physical performance with weight status, suggesting that obese personnel present high levels of risk for recruitment, retention,[4] and public perception.[5] Moreover, another study concluded that BMI was the single most important factor in predicting poor physical fitness test outcome.[6] Obesity is also linked to a reduction in cardiovascular and neuromuscular fitness[1,4] and enhanced levels of musculoskeletal disorders and injury in the military.[7] Furthermore, functional strength[1] is diminished by excessive levels of body fat. While BMI and abdominal circumference are now commonly used measures to assess obesity-related health risks, little information exists for association between these metrics and physical fitness.

The British Army is one of the few military forces that routinely assess and record both weight and abdominal circumferences in their personnel, in conjunction with standardized performance testing. The aim of this study was to examine the association between BMI-based obesity and health risk index with military

* Corresponding author.
E-mail address: P.W.Sanderson@lboro.ac.uk (P.W. Sanderson).

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physical fitness testing within a large sample of British military personnel.

2. Methods

Secondary analyses were undertaken on 2011 data produced for the British Army by the Defence Analytical Services and Advice from information captured through the Army Fitness Information Statistical Software system.[8] This information was electronically collected from units that had centralised information technology (IT) support within the Field Army and therefore did not account for individuals serving outside of centralised IT support and within training establishments. Furthermore, those serving in isolated areas or areas of heightened security were not accessible. From an original study population (n = 54,854), data were collected on 49.5% (n = 50,635, including 47,173 men and 3462 women) of the British Army (n = 102,202). This is representative of the current army population of 92% male and 8% female. Exclusion criteria were reservist status (2562), cadet or initial training status (1354), measurement error and missing data (303). Supplementary table displays the base information in respect of age, gender and fitness test outcome. This study was supported by a UK Mod grant and permission was sought and granted to publish the outcome.

Individuals were weighed to the nearest 0.1 kg using digital scales (Seca, Hamburg, Germany) wearing t-shirt and shorts, whilst height was measured to the nearest 0.1 cm, with shoes removed, using a stadiometer (Invicta, Leicestershire, England). Abdominal circumference (AC) was measured at the level of the navel (usually the smallest diameter between the costal margin and the iliac crest), using anthropometry tape. All measurements were taken in support of the Armed Forces Weight Management Policy which stipulates that all personnel are required to provide bi-annual Body Mass Index (BMI) and AC measurements.

Weight status was classified by BMI and AC using the current National Institute of Health & Clinical Excellence (NICE) guidelines[9] based on the WHO recommendations.[10] The NICE guidelines classify individuals as "overweight" at BMI 25.0–29.9 kg/m^2, and "obese" at 30.0 kg/m^2 and above. Obesity is further classified as class 1 (30–34.9 kg/m^2), class 2 (35.0–39.9 kg/m^2) and class 3 ($\geq$40.0 kg/m^2). NICE guidelines suggest that waist circumference(s) of <94 cm for men and <80 cm for women is a healthy weight status, 94–101.9 cm for men and 80–87.9 cm for women is overweight and >102 cm and >88 cm for men and women would be indicative of obesity. Using a combination of BMI and AC measurements, NICE guidelines[9] attribute a level of risk to obesity-related ill-health (particularly type 2 diabetes and coronary heart disease) to produce an obesity-related health risk (see risk matrix in Fig. 1). This risk matrix is referred to in the text as 'level of risk' (a high BMI and a large AC would increase obesity related health risk).

The Annual Fitness Test (AFT) represents the minimum maintenance standard of individual basic vocational fitness required by Army personnel[11]. This load carriage activity required participants to complete a 12.8 km loaded-march in a maximum time of 2 h, carrying a load that directly reflected the requirements of their specific combat employment groups within the army (load range 15–25 kg). Injury, illness and personal fitness could influence the test outcome and an individual's motivation to undertake the test. An individual failing to complete the test in the given time was deemed to have failed the test.

The Personal Fitness Test (PFA) is an assessment of cardiovascular fitness and muscle endurance, designed to encourage improved physical performance and the maintenance of good health. The test is split into three areas: press-ups, sit-ups, and a 2.4 km run.

The press up test was started from the lowest face-down position. The hands were kept at shoulder width position. During the movement, arms were fully extended and the torso was tensioned straight. Then the body was lowered to an elbow angle of 90°. The result of this test was expressed as the number of press-ups during 2 min. Individuals are required to meet minimum standards in each of the three areas. For example, soldiers $\leq$29 the following minimum standards apply (press-ups male = 44, female = 21, sit-ups male & female = 50, run time male = 10.30, female = 13.00). Those soldiers unable to meet the requirements would be required to (1) undergo a medical examination to clarify their medical fitness (2) if deemed medically fit, they would be required to re-take the test. Further failure would result in a period of physical conditioning to remedy the performance deficit.

In the sit up starting position the participants were lying on the floor keeping the hands to the side of the head and directing the elbows forward. The knees were flexed at an angle of 90°, legs were slightly abducted and the assistant supported the ankles. During the movement the participants lifted their upper body and touched their knees with the elbows. The result of the test was expressed as the number of sit-ups during 2 min.

The aerobic test (2.4 km run) comprises of two parts. Part 1 of the test is a warm up consisting of a walk/jog over a measured 800 m course which is to be completed in a minimum time of 4 min 50 s and a maximum time of 5 min. Part 2 of the test is a best effort run over a measured 2.4 km course and follows on immediately after Part 1.

For Statistical analyses participants were categorised according to sex, age (<30, $\geq$30 years), test outcome (pass, fail and not-taken), BMI (obese, $\geq$30 kg/m^2; not obese, <30 kg/m^2), and NICE guidelines for obesity-related health risk ('no risk'; all others above and including 'at risk'). Calculation of z-scores for each variable allowed for the identification of skewed distributions, with a score of 3.29 constituting an outlier; these scores were then replaced with a value of the mean plus 3 × the SD.[12] The reported values were expressed as the proportion of individuals within each category. Loglinear analysis was used for categorical data, where the outcome of more than two variables was required. Specific interactions between age and BMI group, age and risk group, AFT result and BMI group, AFT result and risk group, age and AFT result, PFA result and BMI group, PFA result and risk group, age and PFA result were interrogated with Chi-squared and odds ratios used to interpret the effect sizes. These analyses were conducted separately for male and female participants. Statistical significance was assessed with 95% confidence intervals. Analyses were performed using SPSS version 18, and statistical significance was set at an alpha level of 0.05.

3. Results

Data were available for 50,635 personnel, with 25,754 male and 1434 female personnel undertaking the AFT; these figures represent 54.6% and 41.4% of the male and female respective study populations. A total of 21,419 male and 2028 female soldiers did not attempt the test. Of those that attempted the test, 98.6% of male soldiers (n = 25,399) and 92% of female soldiers passed (n = 1319). Results indicate that while the number of male soldiers who failed the test is relatively small, obese male soldiers failed more than non-obese soldiers; this relationship is underlined to a greater extent within the female population (Table 2a). When AC measurement is viewed alongside BMI, and risk to obesity related health risk is assessed, those male and female soldiers categorised as 'at risk' displayed the highest levels of test failure. While 'no risk' male soldiers were more likely to attempt the test than those deemed 'at risk' (Table 2b), this did not hold true for female soldiers (where the numbers of those attempting the test was below that of those not attempting the test).

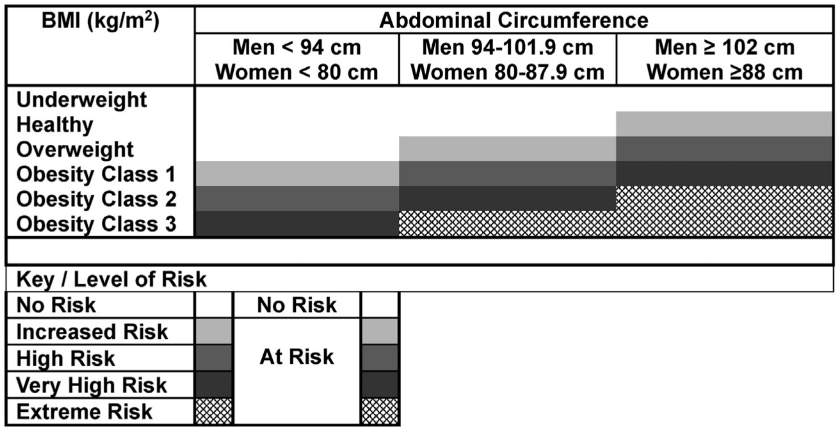


Fig. 1. BMI and abdominal circumference (risk of obesity related ill-health matrix) – based on NICE (2006) guidelines.

Table 1
AFT & PFA odds ratio for failure and attendance by BMI (obese and not-obese) and risk of obesity related ill-health (at-risk and no-risk) (NICE 2006) groups by age.

Test	Age BMI or risk group	Male				Female			
		Fail		Attend		Fail		Attend	
		Less likely to		More likely to		Less likely to		More likely to	
		OR	(95% CI)	OR	(95% CI)	OR	(95% CI)	OR	(95% CI)
AFT	>30 years – BMI ≥30	1.00		1.00		1.00		1.00	
AFT	<30 years – BMI ≥30	0.80	(0.40–1.20)	1.86	(1.74–1.98)	0.92	(−0.29 to 1.92)	1.97	(1.42–2.52)
AFT	<30 years – BMI <30	4.09	(3.78–4.39)	3.27	(3.20–3.34)	2.73	(1.81–3.65)	4.55	(4.15–4.95)
AFT	>30 years – BMI <30	4.09	(3.74–4.44)	2.02	(1.94–2.10)	3.93	(2.94–4.92)	2.48	(2.07–2.89)
AFT	>30 years – at risk	1.00		1.00		1.00		1.00	
AFT	<30 years – at risk	0.97	(0.65–1.29)	1.79	(1.71–1.87)	0.42	(−0.18 to 1.02)	2.21	(1.93–2.49)
AFT	<30 years – no risk	3.43	(3.16–3.70)	2.87	(2.82–2.92)	2.16	(1.56–2.76)	3.73	(3.50–3.96)
AFT	>30 years – no risk	4.0	(2.91–4.35)	1.9	(1.84–1.96)	1.25	(0.61–1.89)	2.29	(2.03–2.55)
PFA	>30 years – BMI ≥30	1.00		1.00		1.00		1.00	
PFA	<30 years – BMI ≥30	0.50	(0.34–0.68)	1.70	(1.59–1.81)	0.79	(0.04–1.55)	3.95	(3.45–4.45)
PFA	<30 years – BMI <30	3.96	(3.83–4.09)	3.70	(3.63–3.77)	7.92	(7.24–8.59)	6.61	(6.25–6.97)
PFA	>30 years – BMI <30	6.81	(6.66–6.96)	2.29	(2.22–2.16)	8.38	(7.66–9.10)	3.55	(3.18–3.91)
PFA	>30 years – at risk	1.00		1.00		1.00		1.00	
PFA	<30 years – at risk	0.43	(0.30–0.56)	1.74	(1.66–1.82)	0.41	(0.19–1.01)	2.58	(2.32–2.84)
PFA	<30 years – no risk	2.77	(2.65–2.89)	3.05	(3.00–3.10)	2.11	(1.51–2.71)	4.76	(4.55–4.94)
PFA	>30 years – no risk	4.69	(4.53–4.84)	2.02	(1.96–2.08)	1.23	(0.59–1.89)	2.84	(2.32–3.24)

Within each age grouping (<30 and ≥30 years) those identified as obese using BMI were more likely to fail and less likely to attempt the AFT. The results also suggested that younger soldiers (<30 years) were more likely to fail than older soldiers (≥30 years) and that obese older soldiers were least likely to attempt the test. When risk is assessed, similar trends were observed with those categorised as having the highest risk being more likely to fail. Furthermore, those older and deemed 'at risk' were the least likely to take the test (Table 1).

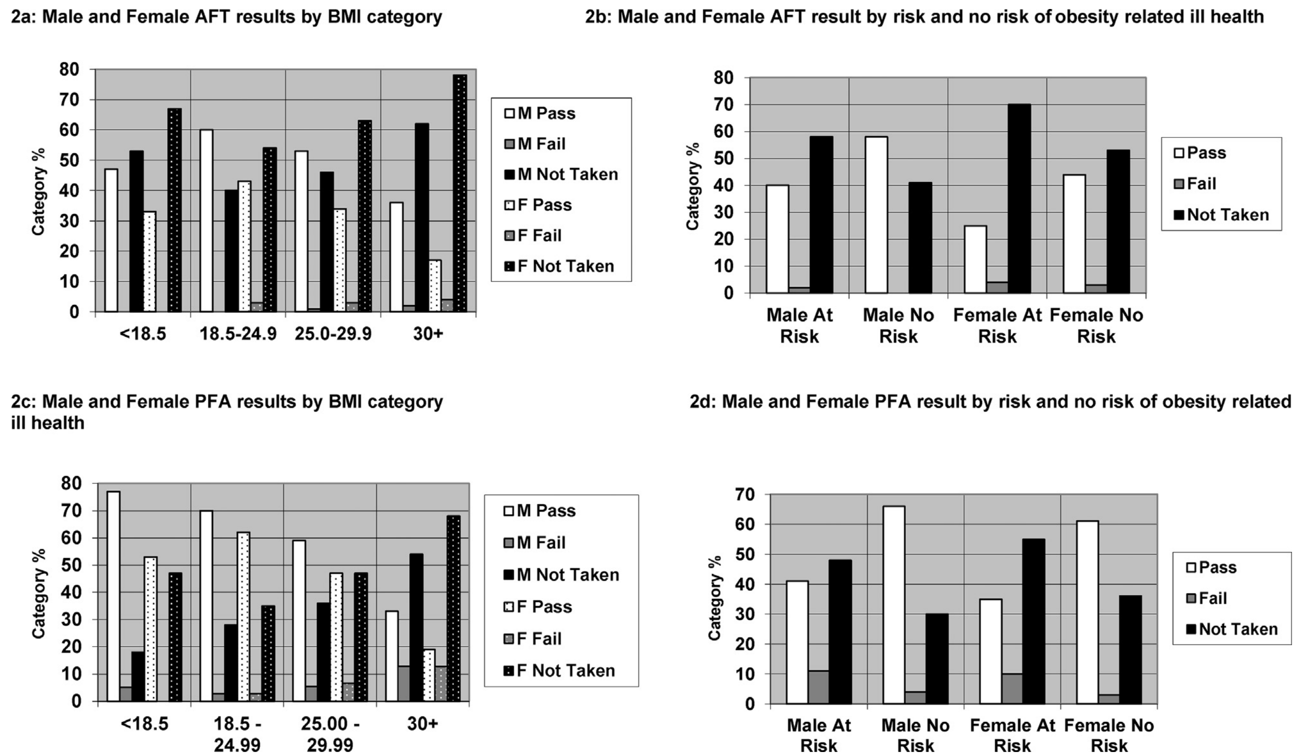
The four-way loglinear analysis produced a final significant model (χ^2 (6) = 6.62, p = 0.04) that retained the age × BMI group × gender, age × BMI group × AFT result and BMI group × gender × AFT result interactions. There were marked differences between the male and female cohorts in terms of study participants, therefore the follow-up analysis focussed on the age, AFT result and BMI group interactions. The age × BMI group interaction was significant (χ^2 (4) = 4090.86, p < 0.001), as was the age × AFT result (χ^2 (4) = 982.95, p < 0.005) and the AFT result × BMI group (χ^2 (4) = 1068.95, p < 0.001). When AC measurements were added to the BMI data and risks to obesity related ill-health were assessed, similar results were observed for the male cohort. While older 'no risk' female study participants displayed a similar likelihood of failure as their 'at risk' (referent value) counterparts, they were twice as likely to attempt the test.

The PFA was undertaken by 30,852 male and 2017 female study participants and these figures represent 65.4% and 58.3% of the male and female respective study populations. A total of 17,766 did not attempt the test. Of those that attempted the test, 91.9% male soldiers passed (n = 28407) and 91.1% of female soldiers passed (n = 1852). Regardless of gender, PFA pass and fail data suggest that in each BMI category and in the binary risk categories (no risk & at risk) the soldiers identified as obese or 'at risk' to obesity ill health are more likely to fail and less likely to attempt the test compared to their non-obese or 'no risk' counterparts (Table 2c and d).

While older (≥30 years) soldiers had better pass rates, the younger soldiers are more likely to attempt the test regardless of risk category. However, data suggest that only 41% male and 23% female soldiers categorised as obese and ≥30 years attempted the test (compared with 54% and 47% obese and <30 years, male and female respective study participants).

The four-way, loglinear analysis produced a significant final model that retained the age × gender × PFA result, age × gender × BMI group, and age × PFA result × BMI group interactions (χ^2 (8) = 16.44, p = 0.04). Understanding that there were marked differences between the male and female cohorts in terms of study participants, the follow-up analysis focussed on the age, PFA result and BMI group interactions. When obesity related health risks were assessed, the four-way analyses produced a final

Table 2
Male and female test results (AFT & PFA) by BMI category and risk and no risk of obesity related ill health.



model (age × risk group × PFA result × gender) that approached significance ($p = 0.065$). Analysis on PFA data had already established the significant male and female 2-way interactions for PFA result × risk group (male χ^2 (2) = 2401.96, $p < 0.001$, female χ^2 (2) = 219.58, $p < 0.001$). As identified in the AFT results, a suppression of effect was observed for female study participants in respect of failure rate; older non-obese female study participants had a similar likelihood of failure as their obese (referent value) counterparts (OR 1.23, 95% CI 0.59–1.89). However, these younger, non-obese female study participants were nearly 3 times more likely to attempt the test than their older obese counterparts. Results suggests male soldiers with the highest risk were least likely to attend and most likely to fail (Table 1).

4. Discussion

This paper examined the influence of weight status on fitness test results within a sample of British military personnel.

The results of this study clarify that while the failure rate is low for the load carriage test (AFT), specifically for those male soldiers with a healthy BMI or defined as overweight, the rate of failure is shown to increase markedly in the obese category. Whereas this pattern is somewhat reflected in females, at every level, higher rates of failure were observed, suggesting that combat fitness is reduced in obese female soldiers. Alternatively, for the female soldier, BMI may effectively identify over-fat women more readily than men[13] and that for weight carriage tasks the relative reduced levels of lean muscle mass support higher failure rates in obese female soldiers.[14] Further research on the topic has suggested that body composition rather than body mass is more closely associated with the metabolic demands of heavy load carriage tasks as undertaken by the military.[15]

Biomechanical studies of load carriage demonstrate that each 1 kg of added load requires an additional 10 N of force.[16] One author has suggested that due to sexual dimorphism the reaction to occupational tasks and specific strength training can result in a greater variability in muscle hypertrophy;[13] in essence the body composition of male and female soldiers could be different even if the physiological stressors are the same.[2] There is therefore a rationale for the army to target physical performance through dedicated strength training. However, unlike their male counterparts' female soldiers may not react to physical stressors with the same level of lean muscle mass development even as they gain strength, producing a different relationship between body composition and performance.

Comparable relationships were observed in the PFA; however, the level of association between failure and obesity was more apparent. Similarly, Gantt et al.[6] concluded that BMI was the single most important factor predicting failure in a military physical readiness test. A recent study on US Army personnel indicated that individuals with less body fat were more likely to perform better, compared to those with more body fat, on anaerobic and aerobic activities, as well as press-ups.[17] Additionally, BMI has a negative influence on performance tasks requiring body movement or support of the body off the ground.[18] Certainly, in the current investigation there was stark contrast between the ability to attempt and pass the PFA between those defined as 'no risk' and 'at risk' of obesity related ill-health. With those males and females categorised 'at risk' being 5 times more likely to fail than those categorised as 'no risk'. Several studies have reported a negative association between muscular endurance and body fat[19] and AC.[20] Moreover, higher waist circumference, independent of BMI, has been shown to have a negative relationship with cardiorespiratory fitness.[20]

For male and female study participants in both tests and within each age group, older and obese military personnel were more likely to fail and were less likely to attend the test(s). The association between age and obesity[21] reduced cardiorespiratory fitness[22] and general physical fitness[23] is well reported. Military studies have indicated that transition from active operational roles to more sedentary managerial employment linked to advancing age may reduce activity levels and could induce changes to body composition.[24] Nevertheless, and beyond any changes to occupational physical activity (OPA), it is well known that skeletal muscle and strength decreases with age,[25] as does maximal aerobic capacity,[26] and these changes occur in both non-trained and (to a lesser extent) trained individuals.[27] Of note, the current results indicate that only 41% of male and 23% of female soldiers categorised as obese at ≥30 years attempted the PFA and in the knowledge that 2 and 4 in every 10 male and female soldiers from these categories fail, it is highly probable failure rates would rise should all personnel attempt the tests.

5. Limitations

While there are a number of strengths to this study, including the large sample across a major organisation, there are some limitations that should be recognised. For the AFT analysis did not consider the different employment groups as separate entities and although the test was standardised the load carried was not. Whereas the use of a cross-sectional study precludes causal inferences, the large and representative (sex, age and status (officer or soldier)) military sample are contextually relevant. Given the subject population BMI data gives a somewhat crude overview[28] as BMI predicts lean mass as least as well as it predicts fat mass,[19] however, the addition of AC allows greater validity.[29]

6. Conclusion

In this large cohort of British Army personnel, across all age groups, obesity and increased risk to obesity related-ill-health were linked to higher failure and lower attendance on the PFA and the AFT. Whilst in general it would appear that the older army personnel fail less, this is a direct reflection of the low attendance rates of this group. Data suggest that due to the comparative high levels of obesity in those not attempting the physical tests, that, if attempted, overall failure rates would increase. Physical performance in the military is an occupational requirement; the results of the current study indicate physical test outcome is associated with obesity related health risk measured using both BMI and AC data. These results propose some close parallels between well-defined obesity-related health risk thresholds and the obesity thresholds that define minimum physical performance capabilities.

Practical implications

In a reducing British Army these results have wide ranging occupational and capability implications. These results suggest there are large numbers within the British Army who are not at the required level of physical fitness. Moreover, at a time of reducing military personnel the inability to clarify fitness to support occupation at the individual level will have implications on collective capacity. While fitness is a personal responsibility it would appear that for some personal choices in relation to health behaviours and physical conditioning are not commensurate with the current physical fitness test standards in the British Army.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.jsams.2018.08.003.

References

1. Fogelholm M, Malmberg J, Suni J et al. Waist circumference and BMI are independently associated with the variation of cardio-respiratory and neuromuscular fitness in young adult men. *Int J Obes* 2006; 30(6):962–969.
2. Friedl KE. Body composition and military performance – many things to many people. *J Strength Cond Res* 2012; 26:S87–S100. http://dx.doi.org/10.1519/JSC.0b013e31825ced6c.
3. Montgomery BL. The Lloyd Roberts Lecture, 1946 (a digest). *J R Army Med Corps* 1947; 88:192–194.
4. McLaughlin R, Wittert G. The obesity epidemic: implications for recruitment and retention of defence force personnel. *Obes Rev* 2009; 10(6):693–699. http://dx.doi.org/10.1111/j.1467-789X.2009.00601.x.
5. Naghii MR. The importance of body weight and weight management for military personnel. *Mil Med* 2006; 171:550–554.
6. Gantt CJ, Neely JA, Villafana IA et al. Analysis of weight and associated health consequences of the active duty staff at a major naval medical centre. *Mil Med* 2008; 173(5):434–440.
7. Cowan DN, Bedno SA, Urban N et al. Musculoskeletal injuries among overweight army trainees: incidence and health care utilization. *Occup Med* 2011; 61(4):247–252.
8. Defence Analytical Services and Advice (DASA). Health and Fitness Annual Report, DASA, Bath. 2011.
9. National Institute of Clinical Excellence (NICE) clinical guideline 43: *Obesity: guidance on the prevention, identification, assessment and management of overweight and obesity in adults and children*. London: NICE; 2006.
10. WHO. *Obesity: preventing and managing the global epidemic*. Report on a WHO Consultation. Technical Report Series 894. Geneva: WHO Press; 2000.
11. *Military Annual Training Tests and workplace induction programme* – Issue 4 – January 2012.
12. Field A. *Discovering statistics using SPSS*, 2nd ed. London, Sage, 2005. p. 78–79.
13. Friedl KE. Can you be large and not be obese? The distinction between body weight, body fat, and abdominal fat in occupational standards. *Diabetes Technol Ther* 2004; 6:732–749.
14. Scott PA, Ramabhai L. Comparison of male and female responses to carrying absolute and relative loads while on a three hour military march, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, 44. 2000, p. 161–164.
15. Lyons J, Allsop A, Bilzon J. Influences of body composition upon relative metabolic and cardiovascular demands of load carriage. *Occup Med* 2005; 55:380–384.
16. Birrell SA, Hooper RH, Haslam RA. The effect of military load carriage on ground forces. *Gait Posture* 2007; 61:1–614.
17. Friedl KE. Military application of body composition assessment technologies, in *Emerging technologies for nutritional research: potential for assessing military performance capability*, Carlson-Newberry S, Costello R, editors, Washington, DC, National Academy Press, 1997, p. 81–126.
18. Vanderburgh PM, Crowder TA. Occupational relevance and body mass bias in military physical fitness tests. *Med Sci Sports Exerc* 2008; 40(8):1538–1545.
19. Vaara JP, Kyrolainen H, Niemi J et al. Associations of maximal strength and muscular endurance test scores with cardioresiratory fitness and body composition. *J Strength Cond Res* 2012; 26(8):2078–2086.
20. Duvigneaud N, Matton L, Wijndaele K et al. Relationship of obesity with physical activity, aerobic fitness and muscle strength in Flemish adults. *J Sport Med Phys Fitness* 2008; 48(2):201–210.
21. Flegal KM, Carroll MD, Ogden CL et al. Prevalence and trends in obesity among US adults 1999–2008. *JAMA* 2010; 303(3):235–241.
22. Trappe SW, Costill DL, Vukovich MD et al. Ageing among elite distance runners: a 22 year longitudinal study. *J Appl Physiol* 1996; 80(1):285–290.
23. Santtila M, Kyrolainen H, Vasankari T et al. Physical fitness profiles in young Finnish men during the years 1975–2004. *Med Sci Sports Exerc* 2006; 38(11):1990–1994.
24. Helmhout P. *Health related fitness in the Royal Netherlands Army*. Contract No.: RTO-MP-HFM-181-P7. Utrecht; 2009.
25. Thom JM, Morse CI, Birch KM et al. Influences of muscle architecture on the torque and power-velocity characterised of young and older. *Eur J Appl Physiol* 2007; 100:613–619.
26. Heath GW, Hagberg JM, Ehsani AA et al. A physiological comparison of young and older endurance athletes. *J Appl Physiol* 1981; 51:634–640.
27. Bortz WMT, Bortz 2nd WM. How fast do we age? Exercise performance over time as a biomarker. *J Gerontol A Biol Sci Med Sci* 1996; 51:M223–M225.
28. Prentice AM, Jebb SA. Beyond body mass index. *Obes Rev* 2001; 2(3):141–147.
29. Rona RJ, Sundin J, Wood P, et al. Agreement between body mass index, waist circumference and skin fold thickness in the United Kingdom Army. *Ann Hum Biol*, 2010; Early Online 1–12.