

INTRODUCTION

The United Kingdom (UK) military has a high incidence of injuries in young (aged 16–21 years) military trainees¹⁻³. These injuries account for a high number of working days lost during initial training, and significantly contribute to training attrition^{1,2,4}. For example, training injury incidence in British Army recruits reportedly ranges between 1.2–16.2% and 5.4–26.5% in males and females, respectively¹.

Age, body mass, stature, physical fitness and previous levels of physical activity have been associated with injury risk^{1,5-10}. Female-sex, based on genetic make-up, has also been identified as an important injury risk factor during initial military training^{2,10-13}. However, female recruits are generally less physically fit at the start of training compared with males^{11,14}, such that lower entry level fitness rather than female sex *per se* may exert a greater effect in increasing injury risk¹¹. Moreover, the risk factors of stature and pre-military training physical activity may influence male and female injury risk differently¹¹.

Partitioning the effect of sex in study analyses, independent of other possible covariates with sex (e.g. muscle mass, aerobic fitness and/or stature), has not always been achieved in previous studies. This omission could mask or confound the true sex and injury relationship. Moreover, studies into injury risk only involving female volunteers preclude any comparisons by sex¹⁴⁻¹⁶. If the relative importance of risk factors is not understood, the development of interventions to strategically mitigate this injury risk would be less effective.

In the UK military, women have previously been excluded from the more physically demanding and arduous ground close combat (GCC) roles due to concerns of a potentially unacceptable level of injury risk. However, the findings of a review into this exclusion

concluded that the Ministry of Defence (MOD) should take a more positive approach towards the future inclusion of women in all military roles ¹⁷. Nevertheless, the disproportionate injury risk in females undertaking arduous military roles, and the potential for adverse impact in health and future career, must be proactively and vigorously mitigated ¹⁸.

Aims and Objectives: This study further investigated the co-factors influencing the association of sex and injury during Royal Air Force (RAF) recruit training. In the absence of women presently in GCC roles, this population provided an early opportunity to further understanding of injury risk in a mixed-sex military cohort. The analyses considered the potential confounders of aerobic fitness at the time of entry into training, anthropometric measures, life style factors and level of education attainment. This sex comparative research may be of particular importance in developing and prioritising specific injury mitigation policies and practices.

METHODS

Overview

Potential RAF recruits completed a Pre-Joining Fitness Test (PJFT) and attended the 3-day Pre-Recruit Training Course (PRTC) prior to starting Phase-1 training. The time between successfully passing the PJFT, completing the PRTC and joining Phase-1 training depended upon the operational requirement for a potential recruit's trade; recruits to high-demand trades could be fast tracked, and hence have a relatively short wait to enter training. At the time of the study, RAF Phase-1 training comprised 9 weeks. However, females and males with poor aerobic fitness (i.e. in the lowest quartile of the distribution for aerobic fitness) undertook an additional 2 weeks of physical conditioning at the start of training. Volunteers were recruited to the present study whilst attending PRTC, and continued in the study until completion of Phase-1 training.

Study Population

All potential recruits (aged 16–33 years) attending the PRTC at RAF Halton, Aylesbury, UK, between June and October 2008 were initially provided with a brief before being invited to participate in the study. Following the study brief, n=1373 (n=1136 [83%] males; n=237 [17%] females) provided written informed consent (a response rate of 93% of potential recruits attending PRTC). Among this cohort, 170 participants did not progress to start Phase-1 training during the study period, and were therefore excluded from the data analyses. In addition, there were ten participants with missing medical records, and they were also excluded. Thus, data from 1,193 recruits (990 [83%] men; 203 [17%] women) were analysed. A flowchart of the study is shown in Figure 1.

Ethical Considerations

The study was approved by the UK Ministry of Defence Research Ethics Committee (Reference Number: 0757/142; approved 08 Dec 2007), and was conducted in accordance with the ethical standards of the Declaration of Helsinki.

Primary Outcome – Any musculoskeletal injuries

The incidence of musculoskeletal injury in recruits during training was monitored in association with colleagues from the Regional Medical Centre (RMC), RAF Halton. Recruits participating in the study, who reported to the RMC, had details of their complaint coded on the Defence Medical Information Capability Programme (DMICP) system by the doctor, nurse or medical assistant according to standard RMC procedures. Injury was defined as a musculoskeletal condition causing the recruit to lose two consecutive days of physical training. The staff member categorised ‘Injury’, and detailed the week of training, on the DMICP

template. Consent to prospectively access this medical information was obtained from recruits at the start of the study.

Primary independent risk factor

Biological sex was the principal exposure in this study.

Potential confounders

Socio-demographic factors

Age and education were included. Age was considered as a continuous variable and education was defined as secondary school versus further/ higher education.

Anthropometric assessments

Height and body mass data were collated from the medical records of recruits following attestation at RAF Halton. These measures were taken using standard MOD procedures ¹⁹, during the pre-entry medical at the Armed Forces Careers Office, and reconfirmed on arrival at RAF Halton during the initial medical serial.

Life-style factors

The validated *RAF Halton Food Frequency Questionnaire* (RAFHFFQ) ²⁰ examines the lifestyle risk factors of smoking habit, alcohol consumption, previous diet and physical activity levels, as well as present diet and physical activity levels. The RAFHFFQ was completed by participants under controlled classroom conditions during a dedicated training serial scheduled into the working day of the PRTC.

Recruits were classified as never smokers, ex-smokers, or current smokers. Alcohol consumption was considered in terms of units per week, and was used as a continuous variable. Self-reported intake of milk, vegetables and fruit intakes were determined in terms of portions/day (except milk intake that was determined as ml per day). Recruits were classified as low, medium and high consumers of dairy and fruit & vegetables.

Current activity levels were assessed by the following question “*during your non-working time, how often during a normal week were you physically active for at least 20 minutes during which time you became short of breath and sweat?*”. Recruits were classified into three groups: once or less per week, 2-3 times per week, and more than 3 times per week.

Aerobic fitness test

The RAF Fitness Test (RAFFT) is a programmed component administered by RAF Physical Education Instructors during the PRTC. Data from the RAFFT provided an indication of the physical fitness of potential RAF recruits at the start of training. The RAFFT comprises three parts: the Multi-Stage Fitness Test (MSFT); sit-ups test; and press-ups test. The MSFT was undertaken in the gymnasium with recruits wearing shorts, t-shirt and training shoes. The MSFT is a 20 m shuttle running test that has been shown to be a good predictor of maximum oxygen uptake per kilogram body mass (i.e. $VO_2\text{max}$)²¹, where maximum oxygen uptake (aerobic fitness) has previously been associated with training success and injury incidence in a similar population of Phase-1 recruits²². Following the MSFT, recruits performed the maximum number of sit-ups in 60 s and the maximum number of press-ups in 60 s.

Statistical Analyses

Descriptive statistics of potential confounders by sex were examined using means (standard deviation [SD]) or medians (interquartile range [IQR]) for quantitative measures, and frequency (percentage) for categorical variables. Comparisons between groups were made using Students *t* and Mann Whitney U tests (as appropriate) for continuous variables, and χ^2 test for categorical variables.

An assumption of linearity for continuous variables (using fractional polynomials or linear splines) was assessed²³ and an interaction term between sex and each potential confounders was tested.

To address potential bias and increase power in these analyses, multiple imputation of missing data was used^{24,25}. Twenty imputed datasets were generated, and combined coefficient estimates across these datasets were determined using Rubin's Rules²⁶.

To assess associations between sex and injury, a preliminary unadjusted analysis by sex was used to select potential confounders for inclusion in the multivariate model (using $P < 0.10$ as the criterion for statistical significance). Risk ratios (RR) and the corresponding 95% confidence intervals (CI) were calculated, using generalised linear models using a log link, Poisson family and robust error variances²⁷. Five cumulative models were used.

To assess the relative importance of each individual factor in the fully adjusted model, a ranking based on "goodness of fit", using Nagelkerke R^2 value, was used^{28,29}. Nagelkerke R^2 numerically expresses the percentage of variability attributed to a factor. Variable importance ranking was calculated by comparing the change in the Nagelkerke R^2 value after dropping the factor of interest from the fully adjusted model. Due to "pseudo" R^2 value being affected by

the distribution of the risk factors, in this study we used this value only to assess the change in model fit rather than focus on the value *per se*.

All calculations were performed using Stata statistical software version 13.1 (StataCorp, College Station, Texas, USA) and R statistical software, version 3.4.2 (R Foundation for Statistical Computing, Vienna, Austria). Nagelkerke R² was performed using the Nagelkerke R² function from the 'fmsb' package. A P value of <0.05 was used for statistical qualification.

RESULTS

The median (IQR) age of RAF Phase-1 recruits was 19 years (range 18-22 years). Male recruits represented 83% of the study sample, and were younger, taller, and heavier, had lower education attainment and were more physically fit than their female counterparts. With regards to lifestyle and dietary habits, male recruits reported higher alcohol and lower fruit and vegetables consumption compared with female recruits. Descriptive statistics of potential risk factors by sex are presented in Table 1.

A total of 372 (31.1%) recruits (27.6% males; 48.8% females) presented at least one injury over the course of the (9 or 11 week) training period (23.4% of recruits presented 2 or more injuries). With regards to the time of occurrence of injury during the training programme, the frequency of injury peaked during the first two weeks of training (41% in women and men). There was a statistically significant difference with regards to sex in the proportion of recruits who presented any injury (Table 2). Injuries involving lower limbs accounted for 75% of all injuries (74% of male injuries; 79% of female injuries). The knee was the most frequent injury site followed by the foot in males and the pelvis-femur side injury followed by knees in females (Table 2).

In both male and female recruits, higher injury risk was associated with poorer aerobic fitness (i.e. lower VO₂max values), lower counts for press-ups and sit-ups, lower education attainment, and increasing smoking habit. Taller stature, higher physical activity frequency, and moderate current fruit and vegetable intakes were associated with lower injury risk compared with lower intakes in males (see supplementary Table S1).

Table 3 presents the significant factors from the unadjusted and adjusted models for males and females in combination. Female recruits had a greater risk of injury during training than male recruits (RR=1.77; 95%CI: 1.49 to 2.10) in the unadjusted model. After stature (height) was added to an education-adjusted model, injury risk for females compared with males decreased by 35% (RR=1.47; 95%CI: 1.16 to 1.87). However, when RAFFT was included in the model, females were less likely to experience injuries during training than males (RR=0.59; 95%CI: 0.42 to 0.83), where VO₂max was the principal confounder.

Importance ranking of each individual factor in the fully adjusted model is shown in Figure 2. VO₂max was ranked the most important risk factor of injury, followed by sex, smoking habit, height, and education with a 26%, 10%, 9%, 9% and 8% reduction on R² value, respectively.

The percentage of injured recruits by VO₂max tertile groups and sex is reported in Table 4. Women in the highest VO₂max category experienced less injuries compared with the rest of the VO₂max categories in both men and women. In contrast, men classified in the lowest VO₂max group experienced more injuries than their male and female counterparts in the other groups.

DISCUSSION

This study investigated co-factors influencing the effect of sex on injury risk during RAF recruit training. Understanding the relative importance of potential confounders of this relationship would assist in the implementation and prioritisation of injury risk mitigation strategies. Specifically, this study evaluated whether female recruits *per se* were at increased risk of injury relative to male recruits once confounders were controlled for in the analyses. Consistent with previous work, this study showed that the risk of suffering an injury among recruits was twice as high for females compared with males ^{2,10-13}. This study further highlighted the importance of developing aerobic fitness and strength in mitigating training injury risk in *both* females and males.

Whilst the levels of injury occurrence might appear compared with civilian populations engaged in regular physical training, injury occurrence in the present study was similar to data reported previously for United States (US) and UK recruits engaged in military training programmes of similar duration ^{1,15,30}. There was no effect of recruit age or body mass index (BMI) on injury risk.

Sex has previously been shown to be a risk factor for injury in military training programmes, with female recruits being at significantly greater risk compared with male recruits ^{1,10,30-34}. Similar to the present study, Bell *et al.* ³¹ reported a two-fold greater injury risk with female sex, when fitness was not taken into account. However, consistent with the present study, previous research has not found female-sex to be an independent risk factor, where the sex and injury risk relationship appeared to be explained by poorer aerobic fitness ^{1,31,34}.

Our findings are consistent with previous studies that have demonstrated differences in aerobic fitness (VO_2max) between males and females^{11,14,35}. The key determinants for sex differences in VO_2max , apart from lower haemoglobin concentrations, are mainly due to women having a higher percentage body fat and being shorter in stature³⁶, and this is particularly important when VO_2max is presented as a relative value to body mass or based on fixed fitness task. In the present study, women with the highest VO_2max experienced fewer injuries compared with the remaining male and female recruits. Possible explanations for this may be due to physiological differences underpinning the sex-physical fitness-injury risk relationship, higher absolute value of VO_2max of fit female recruits compared with their male counterparts, and/or differences on other performance factors as for example motivation and efficiency.

In addition, consistent with previous studies,³⁷ the female recruits in the present study were shorter than the males. Indeed, shorter stature was found to be a risk factor for injury in male RAF recruits in the univariate regression model. Shorter trainees would struggle to keep pace with their taller counterparts during group marching activities – unless stride length was rigorously controlled. Short stature could contribute to over-extending in stride length, which increases injury risk^{38,39}. Another suggestion for the sex difference in injury risk arises from the structure of the female pelvis, which appears to be more susceptible to overuse and over extension injury, especially when fatigued². During group training activities, women are more likely to be working at a higher relative exercise intensity, by virtue of a lower aerobic fitness, and as such will start to fatigue earlier than male recruits. In a non-fatigued state, tensile stress through the pelvic bone is neutralised by the surrounding musculature. However, when fatigued, there is a decline in the ability to neutralise the compressive forces⁴⁰, which it is asserted would increase injury risk when marching, running or carrying load. Indeed, per

number of recruits in training, female recruits had nearly a five-fold greater number of injuries of the pelvis/femur (19%), compared with male recruits (4%).

Data from this study support earlier findings where military trainees with poorer fitness were more susceptible to injury^{8,11,33,41,42}. Injured male and female recruits had lower aerobic fitness (relative to MSFT performance), and lower counts for press-ups and sit-ups completed in 60 s. This variation in fitness status between injured and non-injured recruits is an important point as many tasks in military training (and particularly during initial Phase-1 training) are group-based. Team working is an important capability to develop, but does necessitate groups of trainees of varying levels of fitness and mixed physical abilities undertaking physical work at the same absolute rate. As a consequence, individuals with a lower level of cardiovascular and musculoskeletal fitness will experience greater physical and physiological strain for any given task.

Pre-RAF training physical activity frequency was lower in injured male recruits compared with non-injured recruits. The effects of weight-bearing physical activity during growth (i.e. childhood and early adolescence) may be as important as those benefits gained from activity undertaken immediately prior to commencing military training. Increased weight-bearing activity during childhood and adolescence has been associated with an increase in measures of bone mineralisation⁴³⁻⁴⁶, and therefore would reduce the risk of later fracture. One study has shown a relationship between physical activity at school and present bone mineral density (BMD), but this was not shown to be associated with lower fracture rate⁴⁷.

Strengths and potential limitations

This study has presented a model for injury risk in male and female RAF recruits undertaking a relatively short (9 or 11 week) initial military programme. Previous studies have similarly

identified sex, physical fitness, and smoking habit as injury risk factors. However, this study presents a model that combines these risk factors with further lifestyle variables including dietary quality (specifically fruit and vegetable intake), habitual physical activity and educational attainment (see supplementary Table S2).

Variable importance based on model “goodness of fit” for each injury risk factor was assessed, where VO₂max was identified as the most important risk factor, followed by sex, smoking and stature. Moreover, a more sophisticated understanding of the interrelationship of sex, stature and physical fitness has also been elucidated. As such, evidence from this study will inform more effective targeting of interventions to mitigate injury risk.

Limitations of the study should be noted. Data on other potential confounders, such as recruit BMD and body composition as percentage of body fat were not available in this study. Missing information included unreported injuries; there may be injury reporting bias where women are more likely to report lower extremity musculoskeletal injuries than men⁴⁸. This implies that the injury diagnosis in men may have been underreported compared with women in this study. This could also explain the higher risk of injury in women when physical fitness was not taken into account. But this latter limitation is endemic of all such research undertaken in the military training environment.

Conclusions

In conclusion, poor physical fitness was the most important risk factor for injury during RAF training, followed by sex, smoking habit and height. This is a positive observation, as physical fitness is a highly modifiable risk factor. Moreover, women with greater aerobic fitness were less likely to suffer a musculoskeletal injury than their male and female counterparts. Indeed, this study supports that recruits who were more physically active pre-military training, of taller stature, with moderate/good quality diets, were less likely to experience injury during training. Thus, evidence from this study should inform tailored initial training by placing recruits into ability groups with similar relative aerobic fitness, and taking into account recruit's body composition. Healthy lifestyle education to mitigate injury risk – targeting diet and smoking – should also be prioritised for military trainees. As long as physical training is prioritised and recruit streaming based on aerobic fitness is carefully managed, this study supports a 'sex free' (and therefore legally defensible) policy for military physical fitness training.

TABLES

Table 1. Descriptive statistics of recruits at week 1 according to female and male sex

Table 2. Distribution of injuries by anatomical site and female and male sex

Table 3. Adjusted injury risk in RAF recruits

Table 4. Injury risk by VO₂max tertiles and female and male sex

Table S1. Unadjusted injury risk in RAF recruits by sex

Table S2. Adjusted injury risk in RAF recruits

FIGURES

Figure 1. A flow diagram of recruits included and excluded for the analysis

Figure 2. Relative importance value expressed using partial Nagelkerke's partial R² values

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