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14. ABSTRACT

The purpose of this investigation was to assess the predictive potential of variables collected duirng the Australian Defence Force Recruit Training (n=19,769; 7,692 [28-day reservists course]; 12,077 [80-day standard]. The 28-day incurred 17.6% injury rate, 1 stress fracture, 5.2% attrition, 30.0% fitness test failure. The 80-day: 34.3% injury rate, 44 stress fractures, 5.0% attrition, 12.1% fitness test failure. Separate models were derived to predict injuries, attrition, and failure to pass the final physical fitness test. Areas under the receiver operating characteristic curves (AUCs) for course-specific predictive models were relatively low (ranging from 0.51 to 0.69) consistent with "failed" to "poor" predictive accuracy. Course-combined models performed somewhat better, with two models having AUCs of 0.70 and 0.78; considered "fair" predictive accuracy. Although overall predictive accuracy was poor, accuracy was imporved in the models that included course length (28 vs. 80 day) as a predictor; suggesting the potential for using duration of training as a proxy for physical activity dosage to help predict injury and physical fitness.

15. SUBJECT TERMS

Military, Army, recruit training, prediciton accuracy, injury rates, attrition rates, physical fitness test, modelling, training duration

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USARIEM TECHNICAL REPORT T16-6

PREDICTIVE MODELS TO ESTIMATE PROBABILITIES OF INJURIES, POOR PHYSICAL FITNESS, AND ATTRITION OUTCOMES IN AUSTRALIAN DEFENCE FORCE ARMY RECRUIT TRAINING

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DISCLAIMER

The opinions or assertions contained herein are the private views of the author(s) and are not to be construed as official or as reflecting the views of the Army or the Department of Defense. The Investigators have adhered to the policies for protection of human subjects as prescribed in Army Regulation 70-25, and the research was conducted in adherence with the provisions of 32 CFR Part 219. This study was funded under ATO/Task Area R.MRM.2010.01. This article is approved for public release; distribution is unlimited.

EXECUTIVE SUMMARY

The purpose of the investigation was to assess the predictive potential of available variables collected at or near the beginning of training for the purpose of identifying individual recruits with high risk for training injuries and adverse training outcomes. The Australian Defence Force data set contained injury and physical fitness outcomes for 19,769 recruits receiving basic military training from 2006 to 2011: 7,692 in the 28-day course for reserve soldiers; 12,077 in the standard 80-day course for full time soldiers. The data set also contained demographic and other baseline variables that were used to estimate individual probabilities for occurrence of injuries, attrition, and poor physical fitness at final testing. Average recruit age was 22.2 $\pm$ 6.1 years; 89.9% of the recruits were male. Incidence of at least one injury during training was 17.6% in the 28-day course and 34.3% in the 80-day course. Incidence for injuries was higher for women (43.3%) than men (26.0%). There were only 45 stress fractures recorded, with an overall incidence of 0.2%; all but one of these occurred with recruits in the 80-day course. Attrition rates were 5.2% in the 28-day course and 5.0% in the 80-day course. The rates for failure to pass the final battery of physical fitness tests were 30.0% in the 28-day course and 12.1% in the 80-day course. Separate models were derived to predict injuries, attrition for any reason, and failure to pass any element of the final physical fitness test battery. Areas under the receiver operating characteristic curves (AUCs) for course-specific predictive models were relatively low -- ranging from 0.51 to 0.69 -- consistent with "failed" to "poor" predictive accuracy. Course-combined models performed somewhat better, with two models having AUCs of 0.70 and 0.78: considered "fair" predictive accuracy. Although overall predictive accuracy was poor, accuracy was

improved in the models that included course length (28 vs. 80 day) as a predictor; this suggests the potential for using duration of training as a proxy for physical activity dosage to help predict injury and physical fitness.

INTRODUCTION AND BACKGROUND

Musculoskeletal injuries received during initial entry/basic combat training and poor physical fitness performance are leading causes of attrition and delayed military recruit graduation. Injuries, delayed graduation, and attrition increase military training costs and result in a lower level of total force readiness and availability for deployment.[1-3] Developing predictive models with sufficient accuracy to predict who may become injured, who may fail physical fitness tests, or who may fail to graduate from training, remains an unmet goal.[4]

Unlike the U.S. Army, the Australian Defence Force (ADF) conducts its entire basic recruit training at one site. Training at a single site provides the opportunity to collect injury and performance data in a more consistent and reliable fashion because there are fewer personnel conducting fitness assessments and coding injuries. This arrangement also increases the likelihood of training program standardization. At this one site, the ADF offers a 28-day reservist training course for army reserve soldiers and an 80-day basic recruit training course for full time soldiers. The availability of a large data set collected at a single site with relatively standardized training and testing presented the opportunity to assess predictive potential in the available variables collected at or near the beginning of training, for the purpose of identifying individual recruits with high risk for adverse training outcomes.

Recruit Training Injuries

The purpose of basic combat training (BCT) is to prepare recruits for the rigors of military life, which requires a high level of physical fitness. While pursuing a higher fitness level, recruits often become injured. Therefore, an important challenge during BCT lies in minimizing injures while maximizing performance. Over the past 30 years, median injury incidence (% trainees with at least one injury requiring medical care) for women (55%) during U.S. Army BCT has been about twice that for men (28%).[5,6] These data indicate that musculoskeletal injuries remain endemic among recruits in BCT despite systematic investigation for over 35 years.[7] The most common types of injuries during BCT are overuse injuries, strains, sprains, and stress fractures.[8] Studies of U.S. Army BCT at Ft. Jackson, SC demonstrated that, among recruits who entered training, 19% failed to complete training with their peers, 15% failed the U.S. Army Physical Fitness Test (APFT) and 29% suffered an overuse injury.[9-11] These high rates of injury are associated with high attrition rates (nearly 1 in 5 military recruits), which have adverse effects on the number of deployable soldiers and rising medical costs.

During 1987 to 1991, lower limbs were the most frequent site of injury, accounting for 40% of all reported injuries, and 51% of restricted duties.[13] In 1999,[12] 59% of recruits in the Australian Defence Force (ADF) Army Common Recruit Training course (ACRT) were discharged as “medically unfit”. A lower limb injury was sustained in 21% of the recruits with tibial stress fractures or periostitis accounting for 36% of these injuries. Injured recruits were 10 times less likely to complete recruit training. Supporting these findings, the Defence Health Status Report[14] also identified the lower limbs to be the body location to suffer the highest number of reported injuries, over 31%, attributing to more than 50% of working days lost. An injury review of the ADF's Army Recruit Training Centre / 1st Recruit Training Battalion (ARTC / 1RTB) over the period Jan 2002 to Dec 2005, identified that 78% of the six most common injuries occurred in the lower Limbs.[15]

Although the ADF Health Status Report[14] identified physical training and walking as the two key known activities to cause injury in the overall Force, the most common activities noted as causing injuries specifically in Army recruits at ARTC / 1RTB were running (21.3%), marching (14.4%) and walking (7.0%), with the two highest mechanisms of injury being overuse (33.4%) and overexertion (12.4%).

A 2002 study[16] predicting Australian Regular Army Recruits' risk of injury and attrition found that a low score of 3.5 on the 20m shuttle run test, indicating low cardiovascular fitness, was associated with 14.2 times the risk of injury compared with a high score of 13.5. The remaining two components of the physical fitness assessment (push-ups and sit-ups) were poor predictors of injury.[17]

In one 2006 study, researchers employed analytic methods including test item clusters to predict the negative training outcomes of fitness test failure, overuse injuries and attrition in U.S. Army BCT.[11] These multivariate models suggested that negative training outcome probabilities as high as 91% might be estimated for individual recruits, given positive results for predictive test clusters. Moderate probability shifts were seen with the single tests identified to predict BCT attrition for both men and women. No useful model for predicting overuse injuries in women was derived from the methods employed in that study.

Investigators found in a study conducted jointly by USARIEM and the Israeli Defense Forces that actual soldier participation in walking/running/marching and calisthenics was less than planned (60-80%), while standing was significantly greater (160-210%) than planned.[18] In a study conducted by U.S. Army Center for Health Promotion and Preventive Medicine,[19] the number of daily steps for recruits in different companies at the same Basic Combat Training installation varied greatly. The U.S. Army has several training sites/bases which have contributed to a lack of uniformity in exactly how recruits are training over the 8-9 weeks of BCT. In the U.S. Military it has been a challenge to draw conclusions about injury or performance from physical activity due to lack of standardized training across bases or companies at the same site.

Current ADF Recruit Training

The ADF conducts all Army recruit training at one location: the ADF Army Recruit Training Centre (ARTC) Kapooka Military Area (KMA), located in Wagga Wagga, NSW. Two courses were conducted during the 2006-2011 period: a 28-day reservist and 80-day basic recruit training course. In the shorter reservist training course, the length of each training day was greater than in the 80-day course. Army officer training is held at the Australian Defence Force Academy and the Royal Military College with both institutions collocated in Canberra.

The ADF's Defence Injury Prevention Program

Throughout 2006-2011, the ADF's Defence Injury Prevention Program (DIPP) provided a framework that enabled unit level ownership and control of the injury prevention process. An integral part of the DIPP was its injury surveillance tool which captured data on injuries received during both the 28-day and 80-day recruit training at ARTC. The ADF data set included recruit injury data (type, location, activity during injury, action, severity and mechanism cause), performance data (pre, initial, mid and post fitness tests), and start/completion dates. These injury data were collected by physiotherapists and physical training instructors who closely monitored the program delivery and medical care for those sustaining injuries.

The primary purpose of the current study was to determine the best-fit analytic models for predicting injury, attrition, and failure to pass the final physical fitness test based on available predictor variables and common statistical methods. Secondary purposes were: 1) to quantify the additional predictive accuracy in models using course type (short vs. long) as a proxy predictor for exercise dose; 2) to examine the sensitivity-specificity tradeoff observed by setting varying cut scores for estimated probability of relevant outcomes to dichotomize high vs. low risk; and 3) to present results including coordinate points for receiver operating characteristic curves that will enable direct comparisons of predictive accuracy at any given probability cut score for the derived models.

METHODS

Data Set Procurement

Per a signed agreement with the Defence Science and Technology Organisation (DSTO) and with ethical approval from the Australian Defence Human Research Ethics Committee, the ADF's Defence Injury Prevention Program (DIPP) sent to USARIEM a retrospective, anonymous data set containing 22,085 recruits from courses conducted over the years 2006 to 2011. See Appendix A for the corresponding inter-agency cooperation documents: Cooperative Research and Development Agreement for Material Transfer, Transfer Agreement for Existing Specimens or Data and Data Transfer Agreement.

The ADF data set included army recruit training injury data (type, location, activity during injury, action, severity and mechanism cause), performance data (initial, mid- and post-course fitness tests), and course start/completion dates. The data set also included basic anthropometric variables (height, weight, age) and course-specific variables such as course number and military unit of assignment.

Data Preparation

Researchers at USARIEM imported and cleaned the ADF raw data in Statistical Analysis Software (SAS), version 9.1 (Cary, NC) to enable data aggregation. Two separate comma-separated value files, containing demographic and injury data, respectively, were imported into the SAS software package. The two data sets were merged by matching on unique common identifiers. All date, character and numeric variable lengths, formats and properties were standardized. Data were deleted for all trainees in courses #202512 (n=478) and #202513 (n=172). These courses were from year 2006 with incomplete data, and were not intended for this analysis. Data were also deleted for all entries assigned to the Training Support Company (n=1,666), given that these individuals were mostly those who were recycled through training because of injuries or other difficulties during initial training attempts or were staff members posted to assist in the training process. This left a total sample size for analysis of n=19,769 with only 2 courses represented: #20543 (28-day course, n=7,692) and #20549 (80-day course, n=12,077).

The resulting data set was cleaned to eliminate impossible or unlikely values that appeared to be data entry errors. Values outside the ranges of accession standards (age 17 to 60 years, height $\geq$ 152 cm, weight 42 to 150 kg, or body mass index [BMI] 18.5 to 32.9) were changed to missing values.

Detailed DIPP data specifications were reduced and collapsed to aggregated data categories. Appendix B displays how the DIPP data categories were collapsed. Injury categories were not mutually exclusive, but were defined by clinically sensible groupings of original injury types. Aggregated data specifications were further given index (numeric) values to enable inferential statistical analyses. Repeated values from each subject, due to multiple injuries, were reduced to one. These procedures produced a person-level analytical data set. Therefore, any recruit with an indication of an injury in any injury category may have experienced one or more injuries of that type.

ADF Physical Fitness Performance Tests and Standards

Sit-ups and Push-ups were employed for both initial and final fitness assessments. The ADF employed the 20m shuttle run for the initial fitness assessment. The 2.4 km run was utilized in the final fitness assessment. Minimum passing standards are listed in Table 1.

Table 1. Minimal Passing Standards for ADF Basic Recruit Physical Fitness Performance Tests *(15)

Initial Fitness Assessment Pass Mark			
	Push-ups (repetitions)	Sit-ups (repetitions)	Shuttle Run Score (Level)
Males	15	45	7.5
Females	8	45	7.5
Final Fitness Assessment Pass Mark			
	Push-ups (repetitions)	Sit-ups (repetitions)	2.4 km Run
Males	35	70	11:18 min
Females	18	70	13:30 min

* DI(A) PERS 148-2 Army Physical Conditioning Assessment System of 13 Oct 09

The 20m Shuttle test: Each level of the Shuttle Run / Beep Test was composed of a number of 20 meter sprints or shuttles. As the test progressed, the time allowed for each shuttle was reduced, so recruits were required to increase their running speed to complete the shuttle in the time allowed for each successive level. The test began at a speed just above a quick walking pace and increased to a full running speed by the time level 7.5 (the minimum passing standard) was reached. To reach level 7.5 the test involved 56 shuttles (1120 meters), and took approximately 6.5 minutes.

The Sit-up Test: The correct sit-up technique was as follows: 1) to start, knees were flexed to 90 degrees and feet were either flat or with heels on the ground; feet could be either held or anchored; 2) arms were kept straight with the palms of hands on top of the thighs; the chin was held as close to the chest as comfortable; 3) to sit-up, hands were kept in contact with the top of the thigh until wrists came to the top of knee caps; when wrists reached this position, recruits lowered to the start position; this action was to be completed within 3 seconds and counted as one sit-up. Each sit-up commenced on the command 'up' at an audio cadence of 1 sit-up every 3 seconds for a maximum of 100 sit-ups over a 5 minute period. The test was ceased if the recruit could no longer keep cadence with the audio recording, could not complete the sit-up as directed, was told to cease by the instructor due to a safety concern, or on volition fatigue.

The Push-up test: 1) to start, toes were on the ground, feet together or shoulder width apart and palms flat; back was straight; head could either face forward or down; arms were in the locked position; 2) to reach the down position, the body was kept straight and elbows were flexed to a 90 degree angle; then the body was pushed back to the full arm lock position -- this was one push-up; 3) recruits were allowed to rest in either the full arm lock position or in the down position; 4) time limit was 2 minutes to complete the required number of push-ups. The test was ceased if the recruit could could not complete the push-up as directed, was told to cease by the instructor due to a safety concern, two minutes had expired, or on volition fatigue.

The 2.4 km Run: Recruits ran or walked until they covered the entire 2.4 km course. The course was conducted on a flat path with minimal undulating terrain. Time to complete the course was the measured outcome.

Data Analysis

Descriptive statistics were computed to characterize demographic and performance attributes of recruits in the 2 courses, and to quantify incidence rates for injuries, attrition, and failure to pass the final physical fitness test battery. Predictive models were developed for all targeted outcomes for each course separately, given that the 28-day course for reservists differed in important ways from the standard 80-day course. Models were also created for all outcomes using data from both courses combined, which allowed adding course type (duration) as an additional potential predictor variable. There were 8 predictor variables available in the data set for the course-specific models that were available at or near the beginning of training: age, gender, height, weight, BMI, and initial shuttle run, sit-ups, and push-ups. When models were created using both courses combined, course type became a 9th potential predictor variable. Given that the initial physical fitness tests tended to be assessed with recruits stopping upon attaining minimum passing standards, these tests were also assessed for predictive value after transformation to dichotomous pass/fail variables. Predicted outcomes in the models were: any injury, overuse injury, stress fracture, neuromuscular injury, traumatic injury, attrition, and failure to pass the final physical fitness test battery. A recruit was considered to have failed the final battery of physical fitness tests if minimal passing standards were not met for one or more of the three individual tests.

Univariate analyses served as initial filters to determine whether potential predictor variables available at or near the beginning of training could discriminate between groups of recruits with vs. without the outcomes of interest. These analyses were performed using unpaired t-tests for continuous predictor variables and Chi-square tests for gender. Alpha levels for these initial univariate tests were relaxed to 0.20 to protect preferentially against Type II error.

Binary logistic regression analyses were then used to filter the sets of potential predictor variables further and to derive multivariate models that eliminated redundant or substantially correlated predictors, or any predictors that did not contribute meaningfully to the multivariate prediction. Potential predictors that yielded p-values < 0.20 from the t-tests and Chi-square tests were entered into the logistic regression analyses using a Forward conditional stepwise procedure. Probability levels were set to 0.05 for entry and 0.10 for removal from the models. Logits for each recruit were computed from the final logistic regression equations and subsequently transformed into estimated probabilities of respective outcomes for every individual in the data set, using the inherent transformation algorithm in the analytic software. These estimated probabilities for the outcomes, combined with observed occurrences or non-occurrences for injury and performance outcomes, were then used to construct receiver operating characteristic (ROC) curves. Areas under the curves (AUCs) were computed to provide a general indication of prognostic performance for the models. A minimum AUC of 0.70 was expected for a model to have minimally acceptable predictive accuracy.[20, 21]

Discriminant function analyses (DFAs) were performed to construct potential alternative models for injuries and poor performance. Estimated probabilities of injury and performance outcomes were also computed based on the derived discriminant functions. ROC curves were constructed for these DFA-derived probability distributions as described above.

In order to illustrate one approach to dichotomization, model-based probability of each outcome was dichotomized into higher vs. lower probability using tables of coordinate points for the ROC curves and the Youden Index.[22] Predictive performance of each model dichotomized with the Youden Index was then characterized by calculation of sensitivity, specificity, positive and negative predictive values, and positive and negative likelihood ratios. These predictive accuracy statistics were computed from 2 x 2 contingency tables containing frequency counts expressing numbers of recruits with true positive test results, false positive test results, true negative test results, and false negative test results. Tables of coordinate points for the ROC curves were then modified slightly for presentation in this technical report to display sensitivity and specificity (instead of 1-specificity), plus positive and negative likelihood ratios. The tables also include Youden's Index values for intuitive comparison of sensitivity vs. specificity tradeoffs involved with selecting varying threshold values for dichotomization. IBM SPSS version 20 was used for all statistical analyses.

RESULTS

The analyzed data set contained injury and performance outcomes for 19,769 recruits: 7,692 in the 28-day course for reservists (87.0% men); 12,077 in the standard 80-day course (91.8% men). For both courses combined, average recruit age was 22.2 $\pm$ 6.1 years; 89.9% of the recruits were men. Although the incidence of any type of injury during training was 27.8% in both courses combined, the proportion injured at least once in the 28-day course (17.6%) was significantly lower ($p<0.001$) than in the 80-day course (34.3%). Accounting for exposure time however, the any-type incidence rates were 2.29 initial injuries per person-year in the 28-day course and 1.56 per person-year in the 80-day course. Women overall had a higher any-type injury incidence (43.3%) than men (26.0%) in both courses combined ($p<0.001$); this held true even when exposure time was accounted for: 1.97 injuries per person-year for women and 1.19 injuries per person-year for men in both courses combined. When all-type injury incidence was stratified by both course and gender, 31.0% of women were injured in the 28-day course (4.05 injuries per person-year) whereas 15.5% of men were injured in the 28-day course (2.03 injuries per person-year). By contrast, 55.7% of women experienced at least one injury of some type in the 80-day course (2.54 injuries per person-year) whereas 32.4% of men were injured in the 80-day course (1.48 injuries per person-year). There were only 45 stress fractures recorded (13 in women; 32 in men), with an overall incidence of 0.2%; all but one of these occurred with recruits in the 80-day course, and all but one of these injuries was a lower extremity stress fracture.

Attrition rates were not significantly different in the two courses: 5.2% in the 28-day course and 5.0% in the 80-day course (p=0.660). Rates for failure to pass the final battery of basic fitness assessments (BFA) were significantly higher (p<0.001) in the 28-day course (30.0%) compared to the 80-day course (12.1%). Detailed descriptive statistics are presented in Table 2.

Table 2. Descriptive statistics for demographic, performance, and injury variables

	28-day Reservist Course		80-day Standard Course	
	Women	Men	Women	Men
*Age (yr)	25.3 ± 7.4 (n=1001)	24.1 ± 7.4 (n=6686)	20.7 ± 4.8 (n=990)	21.0 ± 4.7 (n=11085)
*Height (cm)	166.2 ± 6.7 (n=789)	179.0 ± 7.2 (n=5444)	165.4 ± 6.2 (n=845)	178.8 ± 7.0 (n=9129)
*Weight (kg)	63.1 ± 8.1 (n=810)	78.5 ± 10.8 (n=5549)	63.3 ± 8.5 (n=864)	78.1 ± 11.3 (n=9371)
*Body Mass Index (kg/m^2)	22.9 ± 2.4 (n=787)	24.5 ± 2.9 (n=5407)	23.1 ± 2.6 (n=840)	24.4 ± 3.1 (n=9099)
*Initial Push-ups (repetitions)	8.3 ± 2.3 (n=535)	15.0 ± 1.0 (n=3906)	8.6 ± 2.7 (n=596)	15.0 ± 0.9 (n=6413)
*Initial Push-ups Failure (No., %)	52 (9.7%) (n=535)	63 (0.9%) (n=2784)	50 (8.4%) (n=596)	82 (1.3%) (n=6413)
*Initial Sit-ups (repetitions)	44.8 ± 3.2 (n=542)	45.0 ± 1.6 (n=3907)	45.4 ± 6.0 (n=607)	45.2 ± 2.7 (n=6412)
*Initial Sit-ups Failure (No., %)	14 (2.6%) (n=542)	21 (0.5%) (n=3907)	15 (2.5%) (n=607)	33 (0.5%) (n=6412)
*Initial Shuttle Run (level)	7.3 ± 0.7 (n=542)	7.5 ± 0.3 (n=3911)	7.3 ± 0.9 (n=608)	7.5 ± 0.2 (n=6414)
*Initial Shuttle Run Failure (No., %)	100 (18.5%) (n=542)	80 (2.0%) (n=3911)	105 (17.3%) (n=608)	83 (1.3%) (n=6414)

Table 2 (continued). Descriptive statistics

	28-day Reservist Course		80-day Standard Course	
	Women	Men	Women	Men
Final Push-ups (repetitions)	25.2 ± 9.9	43.2 ± 12.2	27.0 ± 8.1	46.5 ± 11.8
	(n=431)	(n=3302)	(n=513)	(n=5942)
Final Sit-ups (repetitions)	91.6 ± 17.2	94.9 ± 12.4	96.6 ± 9.5	97.6 ± 7.7
	(n=439)	(n=3322)	(n=515)	(n=5953)
Final 2.4 km run (min)	11.7 ± 0.9	10.3 ± 0.9	11.5 ± 0.7	9.9 ± 0.8
	(n=395)	(n=3111)	(n=495)	(n=5794)
†Any Injury (No., %)	311 (31.0%)	1040 (15.5%)	551 (55.7%)	3587 (32.4%)
	(n=1002)	(n=6690)	(n=990)	(n=11087)
†Overuse Injury (No., %)	181 (18.1%)	550 (8.2%)	454 (45.9%)	2337 (21.1%)
	(n=1002)	(n=6690)	(n=990)	(n=11087)
†Stress Fracture (No., %)	0 (0%)	1 (0.0%)	13 (1.3%)	31 (0.3%)
	(n=1002)	(n=6690)	(n=990)	(n=11087)
†Neuromuscular Injury (No., %)	290 (28.9%)	880 (13.2%)	494 (49.9%)	3152 (28.4%)
	(n=1002)	(n=6690)	(n=990)	(n=11087)
†Traumatic Injury (No., %)	109 (10.9%)	409 (6.1%)	256 (25.6%)	1598 (14.4%)
	(n=1002)	(n=6690)	(n=990)	(n=11087)
†Attrition (No., %)	27 (7.9%)	51 (4.4%)	27 (4.5%)	198 (5.0%)
	(n=341)	(n=1148)	(n=599)	(n=3945)
†Failure Final BFA Battery (No., %)	112 (28.0%)	953 (30.2%)	44 (8.9%)	716 (12.4%)
	(n=400)	(n=3152)	(n=497)	(n=5797)

Results are presented as mean +/- SD for continuous-scale variables; number (% of total) for dichotomous outcomes (injuries, attrition, and failure on final test battery). Percent of total values for attrition and failure on final test battery may be underestimates due to missing values. *Potential predictor variables. †Outcome variables for predictive models. BFA = Basic Fitness Assessment.

Models derived with logistic regression and discriminant function analyses retained essentially the same sets of predictor variables, and resulting ROC curves were very similar – with AUCs differing by no more than 5% between model derivation methods. Where there were differences, the logistic regression models generally performed slightly better. Therefore, results of the logistic regression analyses are presented below.

Course-Specific Predictive Models

When predictive models were created for each course separately, the models retained from 1 to 6 predictors, with AUCs for associated ROC curves ranging from 0.51 (predicting attrition in the 80-day course) to 0.69 (predicting stress fracture in the 80-day course). All models were statistically significant with omnibus tests of coefficients $\leq$ 0.028. All models showed acceptable goodness of fit with Hosmer-Lemeshow tests being all non-significant. However, the Nagelkerke R^2 values were quite low, ranging from 0.008 to 0.101. Retained predictors, pseudo-R^2 values, and AUCs are presented in Table 3, with corresponding predictive equations in Table 4. Prognostic accuracy profiles for each course-specific model are presented in Table 5 using cut scores determined with the maximum Youden index.

Table 3. Retained predictors and associated areas under the ROC curves for models created separately for each course

Course	Outcome	Retained Predictors	Nagelkerke R^2	AUC
28-day	Any Injury	Gender, Age, Init-SU, Init-shuttle (failure)	0.060	0.625
80-day	Any Injury	Gender, Age, BMI, Init-SU, Init-shuttle (failure)	0.051	0.598
28-day	Overuse Injury	Gender, Age, Init-SU, Init-shuttle (failure)	0.050	0.634
80-day	Overuse Injury	Gender, Age, BMI, Init-shuttle (failure)	0.062	0.611
28-day	Stress Fracture	(No model: only 1 stress fracture)	------	------
80-day	Stress Fracture	Ht, Age, Init-shuttle	0.047	0.685
28-day	Neuromuscular Injury	Gender, Age, Init-SU, Init-shuttle (failure)	0.067	0.638
80-day	Neuromuscular Injury	Gender, Age, BMI, Init-shuttle (failure)	0.048	0.597
28-day	Traumatic Injury	Gender, Age	0.020	0.589
80-day	Traumatic Injury	Gender, Age, BMI, Init-SU (failure), Init-shuttle (failure)	0.020	0.568
28-day	Attrition	Age	0.020	0.580
80-day	Attrition	Init-PU	0.008	0.514
28-day	Failure Final BFA Battery	Age, Wt, Init-PU (failure), Init-SU (failure), Init-shuttle (failure)	0.101	0.643
80-day	Failure Final BFA Battery	Ht, Wt, Init-PU (failure), Init-SU (failure), Init-shuttle (failure)	0.067	0.644

AUC = area under the ROC curve; Init-PU = push-up repetitions obtained upon arrival at basic training site; Init-SU = sit-up repetitions obtained upon arrival at basic training site; Init-shuttle = shuttle run level obtained upon arrival at basic training site; Ht = height in cm; Wt = weight in kg; BMI = Body Mass Index in kg/m^2; BFA = Basic Fitness Assessment; (failure) = dichotomized pass/fail version of predictor variable.

Table 4. Predictive equations for models created separately for each course

Course	Outcome	Equation
28-day	Any Injury	Z = -3.805 +.928(Gender) + .034(Age) +.049(Init-SU) -.593(Init-shuttle (failure))
80-day	Any Injury	Z = -1.877 +.871(Gender) + .044(Age) + .031(BMI) +.020(Init-SU) – 1.070(Init-shuttle (failure))
28-day	Overuse Injury	Z = -5.031 +.739(Gender) + .035(Age) + .064(Init-SU) - .845(Init-shuttle (failure))
80-day	Overuse Injury	Z = -1.621 + 1.032(Gender) + .046(Age) + .030(BMI) – 1.106(Init-shuttle (failure))
28-day	Stress Fracture	(No model: only 1 stress fracture)
80-day	Stress Fracture	Z = 6.184 - .042(Ht) + .077(Age) - .763(Init-shuttle)
28-day	Neuromuscular Injury	Z = -3.911 + 1.018(Gender) + .035(Age) + .046(Initial SU) - .637 (Init-shuttle (failure))
80-day	Neuromuscular Injury	Z = -1.247 + .841(Gender) + .046(Age) + .027(BMI) - .957 (Init-shuttle (failure))
28-day	Traumatic Injury	Z = -3.087 + .642(Gender) + .028(Age)
80-day	Traumatic Injury	Z = -1.460 + .602(Gender) + .021(Age) + .032(BMI) - .746(Init-SU (failure)) - .533(Init-shuttle (failure))
28-day	Attrition	Z = -3.943 + .040(Age)
80-day	Attrition	Z = -4.825 + .077(Init- PU)
28-day	Failure Final BFA Battery	Z = 2.263 + .024(Age) + .035(Wt) – 1.578(Init-PU (failure)) - 3.549(Init-SU (failure)) – 1.441(Init-shuttle (failure))
80-day	Failure Final BFA Battery	Z = -8.775 + .033(Ht) + .025(Wt) + .032(Init-SU) – 1.455(Init-PU (failure)) – 1.048(Init-shuttle (failure))

Z = logit from the logistic regression equation. Logits were converted to probabilities of corresponding outcomes. Gender was coded 0 for female, 1 for male. Ht = height in cm; Wt = weight in kg; BMI = Body Mass Index in kg/m^2; Init-PU = push-up repetitions obtained upon arrival at basic training site; Init-SU = sit-up repetitions obtained upon arrival at basic training site; Init-shuttle = shuttle run level obtained upon arrival at basic training site; (failure) = dichotomized pass/fail version of predictor variable. BFA (failure) variables were coded 0 for passing; 1 for failure.

Table 5. Prognostic accuracy profiles for models created separately for each course, with cut scores determined by probabilities of the outcome associated with maximum Youden index values

Course	Model	Cut score	Sn	Sp	PLR	NLR	PPV	NPV
28-day	Any Injury	≥ 21.8%	0.507	0.689	1.68	0.71	0.333	0.827
80-day	Any Injury	≥ 45.2%	0.354	0.792	1.70	0.82	0.565	0.617
28-day	Overuse Injury	≥ 11.6%	0.540	0.679	1.68	0.68	0.194	0.912
80-day	Overuse Injury	≥ 30.7%	0.380	0.798	1.88	0.78	0.439	0.755
28-day	Stress Fracture	---	---	---	---	---	---	---
80-day	Stress Fracture	≥ 0.55%	0.606	0.737	2.31	0.53	0.012	0.997
28-day	Neuromuscular Injury	≥ 19.4%	0.483	0.738	1.85	0.70	0.312	0.853
80-day	Neuromuscular Injury	≥ 40.1%	0.362	0.786	1.69	0.81	0.515	0.663
28-day	Traumatic Injury	≥ 8.2%	0.558	0.591	1.36	0.75	0.090	0.949
80-day	Traumatic Injury	≥ 18.9%	0.490	0.620	1.29	0.82	0.237	0.834
28-day	Attrition	≥ 5.5%	0.487	0.690	1.57	0.74	0.080	0.961
80-day	Attrition	≥ 1.8%	0.922	0.114	1.04	0.68	0.024	0.984
28-day	Failure Final BFA Battery	≥ 31.1%	0.496	0.737	1.89	0.68	0.439	0.779
80-day	Failure Final BFA Battery	≥ 12.7%	0.527	0.689	1.69	0.69	0.190	0.913

Cut scores are in units of probability of the outcome, as transformed from logits computed from the logistic regression models. Sn = Sensitivity; Sp = Specificity; PLR = Positive Likelihood Ratio; NLR = Negative Likelihood Ratio; PPV = Positive Predictive Value; NPV = Negative Predictive Value; BFA = Basic Fitness Assessment.

Predictive Models Including Course Type/Duration as a Predictor

When predictive models were created using data from both courses combined, the models retained from 2 to 7 predictors, with AUCs for associated ROC curves ranging from 0.59 (predicting attrition) to 0.78 (predicting stress fracture). Course type was retained as a predictor in all models except for attrition. All models were statistically significant with omnibus tests of coefficients ≤ 0.001. All models showed acceptable goodness of fit with Hosmer-Lemeshow tests being all non-significant. Here too, Nagelkerke R^2 values were relatively small. However, performance was generally better than with course-specific models, with Nagelkerke R^2 values ranging from 0.015 to 0.137, and two models (stress fracture prediction AUC = 0.78; failure of final physical fitness test battery prediction AUC = 0.70) in the "fair" category of prognostic accuracy.[20, 21] Retained predictors and AUCs are presented in Table 6, with corresponding predictive equations in Table 7. Prognostic accuracy profiles for each course-combined model are presented in Table 8 using outcome probability cut scores determined with the maximum Youden index. Improvements in model performance when course type was added as a crude surrogate for exercise dose are illustrated in the ROC curves representing prediction of stress fractures with course type (Figure 1) vs. without course type (Figure 2) as a predictor. A modified table of coordinate points for the ROC curve in Figure 1 is given in Appendix C.

Table 6. Retained predictors and associated areas under the ROC curves for models created from both courses combined

Outcome	Retained Predictors	Nagelkerke R^2	AUC
Any Injury	Gender, Age, BMI, Init-SU, Init-Shuttle (failure), Course#	0.107	0.661
Overuse Injury	Gender, Age, BMI, Init-SU, Init-Shuttle (failure), Course#	0.113	0.677
Stress Fracture	Ht, Init-Shuttle, Course#	0.098	0.779
Neuromuscular Injury	Gender, Age, BMI, Init-SU, Init-shuttle (failure), Course#	0.106	0.663
Traumatic Injury	Gender, BMI, Init-SU, Init-shuttle, Init-SU (failure), Course#	0.052	0.627
Attrition	Age, Init-shuttle (failure)	0.015	0.586
Failure Final BFA Battery	Ht, Wt, Age, Init-PU(failure), Init-SU(failure), Init-Shuttle (failure), Course#	0.137	0.703

AUC = area under the ROC curve; Init-PU = push-up repetitions obtained upon arrival at basic training site; Init-SU = sit-up repetitions obtained upon arrival at basic training site; Init-shuttle = shuttle run level obtained upon arrival at basic training site; Ht = height in cm; Wt = weight in kg; BMI = Body Mass Index in kg/m^2; BFA = Basic Fitness Assessment; (failure) = dichotomized pass/fail version of predictor variable.

Table 7. Predictive equations for models created from both courses combined

Outcome	Equation
Any Injury	Z = -2.137 + .908(Gender) + .037(Age) + .025(Init-SU) - .840(Init-shuttle (failure)) - 1.143(Course#)
Overuse Injury	Z = -2.500 + .929(Gender) + .040(Age) + .021(Init-SU) + .021(Init-shuttle (failure)) - 1.322(Course#)
Stress Fracture	Z = 7.964 - .044(Ht) - .722(Init-shuttle) - 15.963(Course#)
Neuromuscular Injury	Z = -2.161 +.925(Gender) +.039(Age) + .026(BMI) + .021 (Init-SU) - .819(Init-shuttle (failure)) - 1.160(Course#)
Traumatic Injury	Z = -1.057 + .650(Gender) + .044(BMI) + .032 (Init-SU) - .291(Init-shuttle) - .764(Init-SU(failure)) - .896 (Course#)
Attrition	Z = -3.637 + .038(Age) - .769(Init-shuttle (failure))
Failure Final BFA Battery	Z = -2.790 + .010(Ht) + .031(Wt) + .016(Age) - 1.463 (Init-PU(failure)) - 1.363(Init-SU(failure)) - 1.104(Init-shuttle(failure)) + 1.115 (Course#)

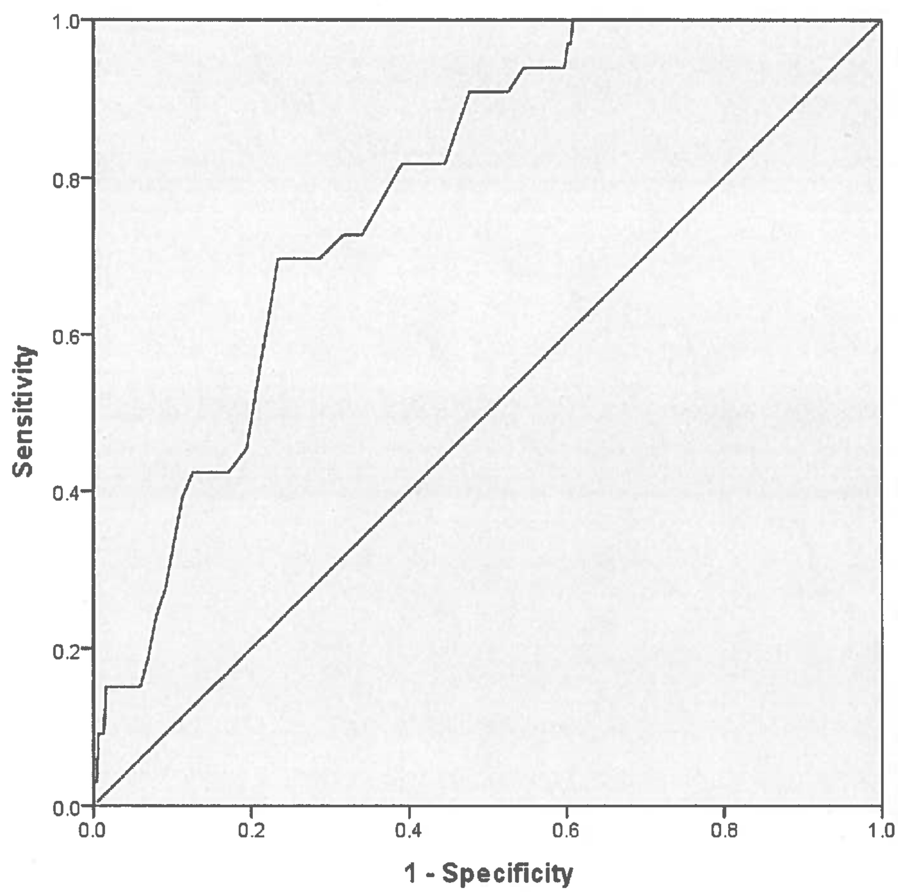
Z = logit from the logistic regression equation. Logits were converted to probabilities of corresponding outcomes. Gender was coded 0 for female, 1 for male. Ht = height in cm; Wt = weight in kg; BMI = Body Mass Index in kg/m2; Init-PU = push-up repetitions obtained upon arrival at basic training site; Init-SU = sit-up repetitions obtained upon arrival at basic training site; Init-shuttle = shuttle run level obtained upon arrival at basic training site; (failure) = dichotomized pass/fail version of predictor variable. BFA (failure) variables were coded 0 for passing; 1 for failure. Course# for 28-day course = 204543; Course# for 80-day course = 204549.

Table 8. Prognostic accuracy profiles for models created from both courses combined, with cut scores determined by probabilities of the outcome associated with maximum Youden index values

Model	Cut score	Sn	Sp	PLR	NLR	PPV	NPV
Any Injury	≥ 35.2%	0.771	0.461	1.43	0.50	0.441	0.784
Overuse Injury	≥ 23.6%	0.710	0.541	1.54	0.54	0.315	0.862
Stress Fracture	≥ 0.52%	0.697	0.766	2.98	0.40	0.010	0.999
Neuromuscular Injury	≥ 31.5%	0.736	0.497	1.46	0.53	0.400	0.805
Traumatic Injury	≥ 15.7%	0.737	0.454	1.35	0.58	0.203	0.902
Attrition	≥ 3.4%	0.362	0.801	1.82	0.80	0.055	0.975
Failure Final BFA Battery	≥ 21.1%	0.573	0.729	2.11	0.59	0.322	0.883

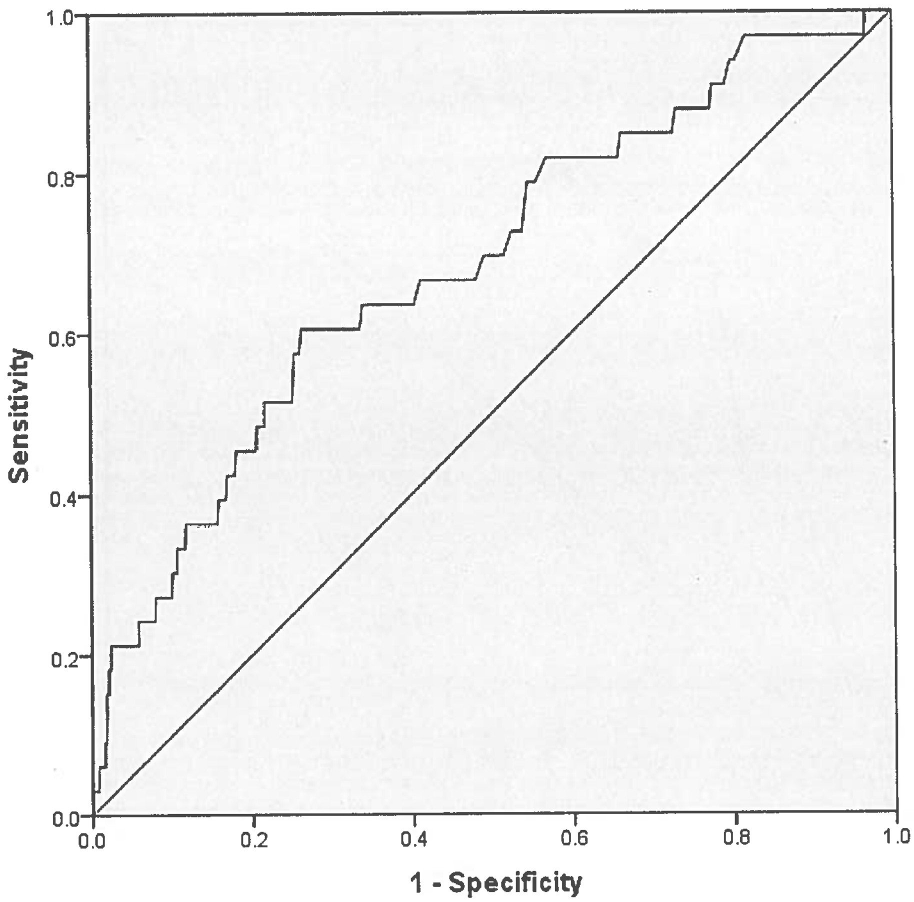
Cut scores are in units of probability of the outcome, as transformed from logits computed from the logistic regression models. Sn = Sensitivity; Sp = Specificity; PLR = Positive Likelihood Ratio; NLR = Negative Likelihood Ratio; PPV = Positive Predictive Value; NPV = Negative Predictive Value. BFA = Basic Fitness Assessment.

Figure 1. Receiver operating characteristic curve for probability of stress fracture, using one model for both courses combined and including course type as a predictor.



Area under the curve = 0.779

Figure 2. Receiver operating characteristic curve for probability of stress fracture, using model derived from the 80-day course separately (course type excluded as potential predictor).



Area under the curve = 0.685

DISCUSSION

Predictive models were derived using common statistical methods for injury, attrition, and failure of physical performance assessment outcomes of interest in the study. Retained predictors for the injury models were consistent with earlier work identifying gender,[3, 7, 23-25] height,[23, 25] and initial fitness levels[23, 26, 27] to be predictive of injuries incurred during training.

None of the models performed with good or excellent predictive accuracy, commonly defined as AUC values >.80 and > .90, respectively.[20, 21] The course-specific models performed poorly, with AUC values from the ROC curves mostly within ranges interpreted to represent predictive failure (AUC .50 to .60) or poor discriminative prediction (AUC .60 to .70).[20, 21] However, two models created with data from both courses combined, allowing for inclusion of course type/duration as a predictor in the models, performed somewhat better: in the minimally acceptable or "fair" discrimination range (AUC .70 to .80).[20, 21] Overall, predictive accuracy as reflected in AUC values was consistent with previous work. For example, George et al[28] found an AUC of 0.64 for a logistic regression model used to predict first episode of low back pain in Soldiers undergoing combat medic training. Moran et al[29] reported an AUC of .765 for a pragmatic 5-predictor logistic regression model to predict stress fractures in female recruits during basic training. However, those authors were able to obtain an AUC of .907 with an unwieldy 20-predictor model for the same outcome; none of the models in this current study had AUCs this high.

Although there were many ways in which the nature of training differed between the courses, the cumulative volume of physical activity and exercise dose was obviously greater in the 80-day course than in the 28-day course. Improvement in predictive performance for the combined-course models suggests that predictive models should capture exercise dose if possible in order to yield levels of predictive accuracy that would make them useful for identifying recruits at high vs. low risk for adverse training outcomes. As a surrogate for exercise dose, course type/duration (short vs. long) was retained as a predictor in every model derived from both courses combined, except for the model predicting attrition which was essentially the same in both courses.

The failure rate for the final battery of Basic Fitness Assessments (BFA) was higher (30.0%) in the 28-day course than in the 80-day course (12.1%). As mentioned in the previous paragraph, this may also be attributed to the cumulative volume of training (physical activity and exercise dose). Perhaps 28 days (4 weeks) at present dose/exposure is not as adequate to improve fitness levels as 80 days (11+ weeks). Most exercise training programs recommend 12 weeks to achieve noticeable changes in aerobic, muscular strength and endurance fitness components. The BFA failure rate was high in the 28-day course in comparison to U.S. Military APFT failure rates of about 15%.[10] Unfortunately, it is unknown as to whether the failure rates seen in this data set are within typical ranges as the ADF does not routinely keep data on this outcome. Attrition rates for both genders in both courses were lower than corresponding BFA failure rates. A recruit may fail one or more of the final three (push-ups, sit-up, run) performance tests without attriting from training. Recruits failing the BFA can receive an “incomplete” but are required to pass all elements of the BFA at the end of their Initial Employment Training/Specialist Corps Training which is the next stop after ACRT and before their first duty assignment.

Selection of cut scores to distinguish between recruits estimated to have high vs. low risk for adverse outcomes must be made deliberately, with a view toward protecting either against falsely identifying a recruit as high-risk (a false positive prediction) or protecting against falsely identifying a recruit as low-risk (a false negative prediction). Cut scores yielding high sensitivity and high negative predictive values protect preferentially against false negatives: relatively few recruits would be falsely identified as low-risk. Alternately, cut scores yielding high specificity and high positive predictive values protect preferentially against false positives: relatively few recruits would be falsely identified as high-risk.

Predictive or diagnostic models typically demonstrate a sensitivity-specificity tradeoff: selecting a cut score yielding high sensitivity will yield relatively low specificity, and vice-versa.[30] This tradeoff was evident in the models derived in this study. The tradeoff is illustrated in the paragraphs below with selections of varying cut scores for the stress fracture model derived from both courses combined.

If the goal is to minimize false negatives we might select a minimum sensitivity of .90, whereby only 1 in 10 recruits who suffered a stress fracture during training would have been falsely identified as low-risk. In order for the stress fracture model to perform with a sensitivity of at least .90 we would select a probability cut score of .0037 -- which would categorize any recruit with an estimated probability from the model of .37% or greater to be at high risk for stress fracture (Appendix C, cut point #225, p.C-2). This is the highest cut score yielding a sensitivity value ≥ .90 (actually .91). However, with a cut score of .0037 the specificity is only .52 – such that about half of recruits who did not develop a stress fracture would have been falsely identified as high-risk at the beginning of training. Given the very low incidence of stress fractures, these results demonstrate a relatively low rate of false negatives among those who did experience a stress fracture (3/33 = 9.1%) and also a very low false negative rate among all those who were estimated to have a low risk of stress fracture according to the model (3/5224 < 0.1%). Frequency counts and prognostic accuracy indices with a probability cut score of .0037 are presented in Table 9.

Table 9. Crosstabulation with prognostic accuracy profile for combined-course stress fracture prediction model using a cut score with high sensitivity: > .37% probability = high risk

	Stress Fracture (n = 33*)	**No Stress Fracture (n = 9,988)**
Estimated High Risk (n = 4,797)	30 True Positives	4,767 False Positives
Estimated Low Risk (n = 5,224)	3 False Negatives	5,221 True Negatives

Sensitivity = .909

Specificity = .523

Positive Predictive Value = .006

Negative Predictive Value = .999

Positive Likelihood Ratio = 1.905

Negative Likelihood Ratio = .174

* Note that only 33 of 45 stress fractures are accounted for in this contingency table. This is because the other 12 recruits who had a stress fracture were missing data for either height or initial shuttle score or both (predictors in the model) and thus could not be classified according to probability of the outcome as calculated by the model.

If instead the goal is to minimize false positives, one might seek a cut score with high specificity. Illustrating again with the combined course stress fracture model, a cut score of .0070 (Appendix C, cut point #280, p.C-2) yields a specificity of .92, but provides a very low sensitivity of .24. This would protect relatively well against false positives among those who do not experience stress fractures, but at the cost of a high false negative rate among those who did. Here, selecting for high specificity did yield the expected low false positive rate among those who had no stress fracture during training (798/9988 = 7.9%). However, given the very low incidence of stress fractures, the false positive rate among all recruits estimated to have high risk for stress fractures was very high (798/806 = 99.0%) – making a prediction of high stress fracture risk untrustworthy in spite of the relatively high specificity. Frequency counts and prognostic accuracy indices with a probability cut score of .0070 are presented in Table 10.

Table 10. Crosstabulation with prognostic accuracy profile for combined-course stress fracture prediction model using a cut score with high specificity: ≥ .70% probability = high risk

	Stress Fracture (n = 33*)	**No Stress Fracture (n = 9,988)**
Estimated High Risk (n = 806)	8 True Positives	798 False Positives
Estimated Low Risk (n = 9,215)	25 False Negatives	9,190 True Negatives

Sensitivity = .242

Specificity = .920

Positive Predictive Value = .010

Negative Predictive Value = .997

Positive Likelihood Ratio = 3.034

Negative Likelihood Ratio = .823

* Note that only 33 of 45 stress fractures are accounted for in this contingency table. This is because the other 12 recruits who had a stress fracture were missing data for either height or initial shuttle score or both (predictors in the model) and thus could not be classified according to probability of the outcome as calculated by the model.

Results from this study are likely influenced by multiple important limitations. Although extensive efforts were made to capture injury data, it is possible that some recruits failed to report injuries. Individual recruits who are highly motivated to graduate from basic training may conceal injuries that will surface in subsequent training. Future studies may be able to capture more complete injury data by following recruits for injuries that are reported early in training subsequent to basic military training. Many potential predictors of interest were not available in the ADF data set. Previous research has shown that injuries with military training are related to additional risk factors not considered in these analyses such as prior injuries,[26] smoking status,[26, 27] race/ethnicity,[25, 31, 32] self-reports of physical activity levels prior to training,[26, 33, 34] exercise dose,[26, 35-37] joint flexibility,[3826, 38, 39] age of running shoe,[40, 41] and individual biomechanical attributes.[27, 42-44] Likewise, known risk factors for attrition such as physical or sexual abuse[2] and mental health history[2] were not available for analysis in this study. Predictive accuracy of the models may have improved meaningfully if these additional variables had been available. Future prospective studies to derive predictive models should include the full spectrum of known and suspected risk factors for negative training outcomes.

Results from this study suggest that inclusion of exercise dose in predictive models may yield higher levels of predictive accuracy. Furthermore, measurement or estimation of biomechanical attributes of recruits (where feasible) should be included in future predictive models, because inclusion of biomechanical variables has been shown to improve prediction of injuries in military training.[27] It is possible that complex modeling methods exploring nonlinear relationships among injuries, poor physical fitness, exercise dose, and individual biomechanical factors may yield greater prognostic accuracy than can be obtained with common statistical procedures as employed in this study.

CONCLUSIONS

Models predicting probability of injury included known risk factors as predictors: gender, age, height, weight, and initial fitness test scores. Models predicting probability of BFA failure and attrition included age, height, weight, and initial fitness test scores as predictors. The models performed with levels of prognostic accuracy (defined by areas under receiver-operating characteristic curves) considered failing to poor when derived for each course separately, but some models performed with fair predictive accuracy when course type (considered a surrogate for exercise dose) was included in the course-combined models. Predictive performance of the models was limited due to absence of data for other known risk factors. All of the models exhibited a sensitivity-specificity tradeoff, illustrating the imperative for deliberate selection of cut scores to distinguish low-risk from high-risk recruits, depending on policy considerations.

RECOMMENDATIONS

Future studies to derive predictive models should be planned prospectively to include the full spectrum of known and suspected risk factors for negative training outcomes. To the extent possible, future models should include as potential predictors exercise dose and measurements (or estimations) of biomechanical attributes of recruits. More complex models including nonlinear methods currently under development should be used to analyze the same data analyzed in this study in order to compare prognostic accuracy obtained with the two modeling approaches.

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Appendix A. Study/Data Approval Documentation

DEPARTMENT OF THE ARMY
U.S. ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE
KANSAS STREET
BUILDING 42
NATICK, MA 01760-5007

REPLY TO ATTENTION OF

MCMR-EMR-BP 1 June 2010

MEMORANDUM THRU Bradley Nindl, Ph.D., Principal Investigator, Military Performance Division, USARIEM

FOR THE RECORD

SUBJECT: Data from Defence Science and Technology Organisation, Australian Defence Forces transferred to L3 Corporation by USARIEM

1. With concurrence from the U.S. Technical Project Officer, this data transfer is permitted under the terms of Australian Defence Forces Data Exchange Agreement, N-04-AT-5859, to which USARIEM is a signatory.

2. This retrospective data was collected from 2004-2007 by the Defence Science and Technology Organisation, the civilian agency of the Australian Defence Forces.

3. This performance and injury data contains no link to personal identifiers.

4. The data will be used by L3 Corporation in the development of the Department of Defense Training, Overuse injury and Performance Model.

5. Approval is given for USARIEM to transfer this data to L3 Corporation.

Kevin N. Keenan
COL, MC
Commanding

CF:
Edward J. Zambraski, Ph.D., Division Chief, MPD

COOPERATIVE RESEARCH AND DEVELOPMENT AGREEMENT
FOR MATERIAL TRANSFER

This Agreement is entered into under the authority of the Technology Transfer Act of 1986, 15 U.S. Code Section 3710a, as amended. The parties of this Agreement are: L3 Communications, Inc. (Recipient) and U.S. Army Research Institute of Environmental Medicine (USARIEM) (Provider).

With respect to Provider furnishing the following research materials: De-identified, retrospective data received from the Defence Science and Technology Organisation (DSTO), Australian Defence Forces transferred by USARIEM to L3 Communications, Inc., the parties agree as follows:

1. Recipient agrees that the Materials and/or Information will be used for the following research purposes only: Development and provision of a Training, Overusing Injury and Performance (TOP) prediction tool for the Department of Defense. The Materials and/or Information shall not be sold, offered for sale, used for commercial purposes, or be furnished to any other party without advance written approval from the Provider's official signing this Agreement or from another official to whom the authority has been delegated, and any use or furnishing of Material shall be subject to the restrictions and obligations imposed by this Agreement. If the materials and/or information are to be used for human subject research, the Recipient must submit to the Provider a copy of the Recipient's IRB approval letter for use of the materials/information. In such case, the Recipient will not have access to any personal identifying information on study subjects. All data sent by Provider will be either coded, de-identified data with the link remaining at the Provider institution, or completely anonymous data with no existing link. If it is determined that Recipient will need access to identifying information, an amendment to this Agreement will need to be made granting access to such information. Additionally, the protocol and consent form will need to be adjusted accordingly.

2. The purpose of this Agreement is the provision of the Materials and Information; No further collaboration is contemplated. Any intellectual property rights to the Materials in existence prior to this Agreement, or potential rights, such as issued patents, patent applications or invention disclosures are retained by the Provider. The party entitled to ownership under U.S. patent law shall own any invention patentable under U.S. patent law, which is conceived or first reduced to practice under the Agreement. Any invention arising under this Agreement is subject to the retention by the U.S. Government of a nonexclusive, irrevocable, paid-up license to practice, or have practiced, the invention throughout the world by or on behalf of the U.S. Government.

3. The parties shall maintain in confidence all Information relating to these Materials and shall not disclose Information to others without specific written permission, in

advance, unless required to by law. In any event, the parties agree to promptly communicate any third party request for Information.

4. When the Materials or Information are no longer being used for research purposes, in accordance with this Agreement, all Materials will be destroyed with notice to DTSO. All maintenance and calibration costs for materials will be borne by recipient while the materials are in recipient's possession. Materials that become non-repairable will be replaced in kind by recipient, as directed in writing by the provider.

5. Recipient agrees to report in a timely manner the results of data use in the provision of the TOP model.

6. The Materials are provided as a service to the research community. They are provided without warranty of merchantability or fitness for a particular purpose or any other warranty, express or implied. No indemnification for any damages is intended or provided for under this Agreement. Each party shall be responsible for any damages it incurs as a result of its activities under this Agreement.

7. Recipient shall accept full responsibility for the safety and security of the Research Project and assure that the Research Project will be performed in accordance with all Federal, State and local laws, rules and regulations. Where applicable, each party agrees to abide by all laws, rules, and regulations governing biological select agents and toxins.

8. The non-Federal party to this Agreement agrees to make no claim or inference regarding this Agreement, the Materials or its products, which implies governmental endorsement or recommendation.

9. The construction, validity, performance, and effect of this Agreement shall be governed for all purposes by the laws applicable to the United States Government.

10. The obligation of the parties to transfer technology to one or more other parties, provide technical information and reports to one or more other parties, and otherwise perform under this Agreement are contingent upon compliance with applicable United States export control laws and regulations. The transfer of certain technical data and commodities may require a license from a cognizant agency of the United States Government or written assurances by the Parties that the Parties shall not export technical data, computer software, or certain commodities to specified foreign countries without prior approval of an appropriate agency of the United States Government. The Parties do not, alone or collectively, represent that a license shall not be required, nor that, if required, it shall be issued. In addition, if applicable, parties to this agreement will comply with 42 CFR section 72 entailing Interstate Shipment of Etiologic Agents.

11. The Provider may terminate this Agreement unilaterally at any time by giving the Recipient written notice. This Agreement is effective as of the last date of signature of all authorized officials of the parties and shall be effective

for 5 years. If the Department of Defense contract for the TOP model is canceled or L3 no longer needs to maintain the dataset to maintain the predictive model, the provided dataset will be destroyed, and certification of destruction provided to DSTO. The person signing this Agreement on behalf of the Recipient represents that he/she has the authority to bind the Recipient to the terms of this Agreement.

12. This Agreement may be executed in one or more counterparts by the parties by signature of a person having authority to bind the party, which may be by facsimile signature, each of which when executed and delivered by facsimile transmission, mail, or email delivery, will be an original and all of which will constitute but one and the same Agreement.

For: L3 Communications, Inc.

(Signature)
WEIXIN SHEN
(Typed Name)
Program Manager
(Title)
09/14/2010
Date

Recipient Point of Contact

(Signature)

(Typed Name)

For: USARIEM

Gaston P. Bathalon
Colonel, Army Medical Specialist Corps
Commanding
2 MARCH 2011
Date

USARIEM Point of Contact

Bradley Nindl, PH.D.
Military Performance Division

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U.S. Army Research Institute of Environmental Medicine
Human Use Review Committee

TRANSFER AGREEMENT for EXISTING SPECIMENS OR DATA

Principal Investigator Providing Specimens or Data:

Principal Investigator(s): Mark Jaffrey, Ph.D.
Institution: Defence Science and Technology Organisation, Department of Defence, Commonwealth of Australia
Address: 506 Lorimer Street, Fishermans Bend, VIC, 3127, AUSTRALIA
OHRP Federal Wide Assurance (FWA) or DOD Assurance: N/A
IRB Contact: LT COL Rosemary Landy, ADHREC Executive Secretary, Ph +61262663807

Investigator Transferring Specimens or Data:

Investigator(s): Bradley Nindl, Ph.D., (508) 233-5382
Institution: U.S. Army Research Institute of Environmental Medicine (USARIEM)
42 Kansas Street, Natick, MA 01740
DoD Assurance: DOD A20107
IRB Contact/Phone No: Cory Baker-Fulco, Human Protections Administrator, (508) 233-4803

Investigator Receiving Specimens or Data:

Investigator(s): WEIXIN SHEN
Institution: L3 Communications, Inc. (L3)
Address: 3394 CARMEL MOUNTAIN ROAD, SANDIEGO, CA 92121
Contact Information:

To ensure the greatest level of privacy for the persons whose specimens or data are being used in the research study noted below, the investigators agree to the following:

- The data or specimens were not obtained specifically for the proposed project.
- The proposed research will be conducted within the terms of their FWA or DOD assurances as applicable for both parties.
- All data will be de-identified at the source location by the Australian Defence Force (ADF) Army Recruit Training Centre (ARTC) personnel before transfer to the providing investigator.
- The providing investigator will not, under any circumstances, provide links to identifiers of coded specimens or data used in this study.
- The receiving investigator will not, under any circumstances, request or accept private or linking identifiers for the specimens or data used in this study.
- Where identifiers might inadvertently be included with specimens or data, the receiving institution agrees to immediately notify the providing institution and return the identified specimens or data to them as soon as is reasonably possible.
- As de-identified data is being provided pertaining to several thousand recruits, there is no opportunity for identifying individuals.
- The receiving investigator will ensure any hard copy data is stored securely in locked cabinets, with electronic records being contained within password protected files.

- These variables will be utilized only for the development and provision of a Training, Overusing Injury and Performance (TOP) prediction tool to identify those individuals at risk of becoming injured or performing poorly during basic recruit combat training. No individual's data will be reported and only pooled data will be utilized for predictive purposes in order to develop a predictive model.

- L3 will not disclose, release, reveal, show, sell, rent, lease, loan or otherwise grant access to the detailed data to anyone not covered by this agreement. Access to these data will be limited to a minimum number of individuals necessary to achieve the purpose of developing the predictive TOP model and to those individuals on a need-to-know basis. The data will not be used to establish a system of records.

- L3 may retain file(s) and/or any derivative file(s) indefinitely, or until one of the following occurs: The DOD contract is canceled; L3 no longer needs to maintain the dataset to maintain the predictive model. At which time one of these events occur, the provided dataset will be destroyed, and certification of destruction provided to DSTO.

- L3 cannot use the data for marketing or commercial purposes.

This agreement applies to the following protocol:

Originating Institution's Protocol No and Title: TBA 2012/37663 ADHREC/OUT/2010/AF6185869

USARIEM will transfer all data to L3 Communications, Inc.; no data will be retained at USARIEM.

L3 Project: TOP Predictive Model Development

Description of Specimens and/or Data:

Retrospective datasets from the Australian Defence Force's Army Recruit Training Centre (ARTC), containing de-identified soldiers' injury and physical activity histories from the time during their initial recruit training course. This will include information sourced from the ARTC Defence Injury Prevention Program (DIPP) along with physical activity information (course content and structure) from past course records. Additional dataset variables will include basic anthropometrics (height, weight, age) and physical fitness performance tests conducted during the courses.

Signature of Providing Investigator: Original signed Date: 3/12/10 (3 DEC 2010)
Mark Jaffrey, Defence Science and Technology Organisation, Department of Defence

Signature of Transferring Investigator: [signature] Date: 15 SEP 2010
Bradley Nindl, U.S. Army Research Institute of Environmental Medicine (USARIEM)

Signature of Recipient Investigator: [signature] Date: 09/14/2010

Appendix B. DIPP Data Categories Collapsed for Analysis

<u>Collapsed Injury Severity Categories</u>
Missing
No Further Treatment Required
Mild (1-3 further treatments)
Moderate (4-6 further treatments)
Severe (7+ treatments/referred to hospital/emergency)

<u>Collapsed Diagnosis List Categories</u>
Any Injury
Overuse Injury
Stress Fracture
Neuromuscular Injury
Traumatic Injury

<u>Collapsed Venue List Categories</u>
Combat training related
Fitness training related
Sports related
Recreational related
Transportation related
other
unknown
unspecified
Missing

<u>Collapsed General Activity Categories</u>
Trade Training
Physical Training
Military Skills
Normal Duties
Sport Event
Sport Training
Adventure training
Battle-related
Travel
Other
Unsure

<u>Collapsed Action Categories</u>
Menial Tasks
Soldiering/Combat Task
Fitness Task
Recreational Task

Body Positions
Not Applicable
Other Action
Missing

Collapsed Mechanism Cause Categories

Contact
Chemical
Complications - Medical
Exposure
Falling
Mechanical Force
Neglect
Other
Overuse/exertion
Thermal Mechanism
Threat to Breathing
Transport
Unspecified
Missing

Appendix C. Prognostic Indexes for Model Predicting Stress Fractures from Both Courses Combined, Associated with Coordinate Points from Receiver Operating Characteristic Curve

Sampled to every 5th coordinate point

With highlighted cut scores of probability ≥ .0037 (Sensitivity ≥ .90) and probability ≥ .0070 (Specificity ≥ .90)

Cut Point #	Positive if Probability of Outcome Greater Than or Equal To	Sensitivity	Specificity	Positive Likelihood Ratio	Negative Likelihood Ratio	Youden's Index
1	0.00000	1.000	0.000			0.000
5	.00000	1.000	.000			.000
10	.00000	1.000	.002			.002
15	.00000	1.000	.008			.008
20	.00000	1.000	.030			.030
25	.00000	1.000	.086			.086
30	.00000	1.000	.138			.138
35	.00000	1.000	.222			.222
40	.00000	1.000	.263			.263
45	.00000	1.000	.263			.263
50	.00000	1.000	.298			.298
55	.00000	1.000	.324			.324
60	.00000	1.000	.329			.329
65	.00000	1.000	.343			.343
70	.00000	1.000	.347			.347
75	.00000	1.000	.359			.359
80	.00000	1.000	.365			.365
85	.00000	1.000	.367			.367
90	.00000	1.000	.368			.368
95	.00000	1.000	.371			.371
100	.00000	1.000	.375			.375
105	.00000	1.000	.376			.376
110	.00000	1.000	.379			.379
115	.00000	1.000	.380			.380
120	.00000	1.000	.381			.381
125	.00000	1.000	.381			.381
130	.00000	1.000	.382			.382
135	.00000	1.000	.382			.382
140	.00000	1.000	.383			.383
145	.00000	1.000	.383			.383
150	.00000	1.000	.384			.384
155	.00000	1.000	.384			.384
160	.00000	1.000	.385			.385
165	.00000	1.000	.385			.385

170	.00006	1.000	.386			.386
175	.00020	1.000	.386			.386
180	.00029	1.000	.387			.387
185	.00068	1.000	.387			.387
190	.00179	1.000	.388			.388
195	.00221	.970	.394	1.60	.08	.364
200	.00247	.939	.402	1.57	.15	.342
205	.00276	.939	.421	1.62	.14	.360
210	.00293	.939	.431	1.65	.14	.370
215	.00315	.939	.454	1.72	.13	.394
220	.00344	.909	.503	1.83	.18	.412
225	**.00367**	**.909**	.523	1.90	.17	.432
230	.00393	.818	.581	1.96	.31	.400
235	.00415	.818	.608	2.09	.30	.426
240	.00429	.727	.659	2.14	.41	.387
245	.00449	.727	.682	2.29	.40	.409
250	.00480	.697	.714	2.44	.42	.411
255	.00524	.697	.766	2.98	.40	.463
260	.00566	.424	.829	2.49	.69	.254
265	.00598	.424	.854	2.90	.67	.278
270	.00629	.424	.874	3.36	.66	.298
275	.00657	.394	.887	3.49	.68	.281
280	**.00695**	.242	**.920**	3.03	.82	.163
285	.00724	.182	.932	2.68	.88	.114
290	.00761	.152	.941	2.56	.90	.092
295	.00770	.152	.941	2.58	.90	.093
300	.00802	.152	.947	2.83	.90	.098
305	.00836	.152	.957	3.49	.89	.108
310	.00869	.152	.961	3.89	.88	.113
315	.00890	.152	.962	3.95	.88	.113
320	.00907	.152	.967	4.56	.88	.118
325	.00953	.152	.971	5.24	.87	.123
330	.00994	.152	.974	5.87	.87	.126
335	.01028	.152	.975	5.98	.87	.126
340	.01080	.152	.981	7.84	.87	.132
345	.01116	.152	.981	8.09	.86	.133
350	.01164	.152	.984	9.34	.86	.135
355	.01237	.091	.987	6.88	.92	.078
360	.01277	.091	.987	7.15	.92	.078
365	.01416	.091	.990	9.56	.92	.081
370	.01468	.091	.992	10.81	.92	.082
375	.01583	.091	.992	11.49	.92	.083
380	.01669	.091	.993	12.27	.92	.084
385	.01709	.091	.993	13.35	.92	.084

390	.01796	.061	.994	9.61	.95	.054
395	.01943	.061	.994	10.44	.94	.055
400	.02154	.061	.995	11.87	.94	.055
405	.02365	.030	.995	6.73	.97	.026
410	.02607	.030	.996	7.96	.97	.026
415	.02835	.030	.997	9.17	.97	.027
420	.03225	.030	.997	10.81	.97	.027
425	.03609	.030	.998	13.76	.97	.028
430	.04477	.030	.998	17.80	.97	.029
435	.05664	.030	.999	27.52	.97	.029
440	.07170	.030	.999	50.44	.97	.030
445	.09439	.030	1.000	302.67	.97	.030

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