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Functional Movement Screen and Aerobic Fitness Predict Injuries in Military Training

PETER LISMAN[1], FRANCIS G. O'CONNOR[1], PATRICIA A. DEUSTER[1], and JOSEPH J. KNAPIK[2]

[1]Department of Military and Emergency Medicine, Uniformed Services University of the Health Sciences, Bethesda, MD; and [2]Uniformed Services University of the Health Sciences, Bethesda, MD

ABSTRACT

LISMAN, P., F. G. O'CONNOR, P. A. DEUSTER, and J. J. KNAPIK. Functional Movement Screen and Aerobic Fitness Predict Injuries in Military Training. *Med. Sci. Sports Exerc.*, Vol. 45, No. 4, pp. 636–643, 2013. **Purpose**: This study investigated associations between injuries and individual components of the Marine Corps physical fitness test (PFT), self-reported exercise and previous injury history, and Functional Movement Screen (FMS) scores. **Methods**: A cohort of 874 men enrolled in either 6 wk (n = 447) or 10 wk (n = 427) of Marine Corps officer candidate training was recruited. They completed an exercise history questionnaire, underwent an FMS during medical in-processing, and completed the standardized PFT (pull-ups, abdominal crunch, and 3-mile run) within 1 wk of training. Injury data were gathered throughout training from medical records and classified into overuse, traumatic, and any injury. **Results**: Three-mile run time (RT) was the only PFT component predictive of injury: candidates with RT ≥20.5 min were 1.7 times (95% confidence interval = 1.29–2.31, P < 0.001) more likely to experience an injury compared with those with RT <20.5 min. Prior injury, frequency of general exercise and sport participation, and length of running history were predictive of any, overuse, and traumatic injuries, respectively. Combining slow RT and low FMS scores (≤14) increased the predictive value across all injury classifications: candidates scoring poorly on both tests were 4.2 times more likely to experience an injury. The pull-up to exhaustion test was related to four of the seven FMS tests and the only PFT test positively related to total FMS score, although correlations were generally low (r ≤ 0.11). **Conclusion**: Slow RT was associated with increased injury risk, and combining poor RT and low FMS scores significantly increased the injury predictive value. Additional research is warranted to further clarify what combination of PFT and FMS tests are most suitable for predicting injuries. **Key Words:** INJURY PREVENTION, MILITARY PERSONNEL, PHYSICAL FITNESS, FUNCTIONAL MOVEMENT

Injuries occur frequently in active duty military populations and directly affect training, deployment, and overall retention of personnel. A 2010 study reported that injuries accounted for 1.95 million medical encounters in 2006 and almost 1 million nondeployed active service members were affected (18). Musculoskeletal injuries (MSK-I) are especially common and affect both deployed and nondeployed populations. Cohen et al. (4) reported that musculoskeletal and connective tissue disorders accounted for 24% of all medical evacuations of military personnel serving in Iraq or Afghanistan from January 2004 through December 2007. Previous reports also suggest high injury rates in military trainees with an overall MSK-I rate of 39.6% among 1296 male recruits undergoing 12 wk of boot camp training at Marine Corps Recruit Depot, San Diego, CA (1). The morbidity of MSK-I can significantly affect military manpower availability, consume medical resources, and compromise the operational readiness of the force. Given this major medical problem, several epidemiological studies have evaluated factors associated with physical training–related injuries and identified several strong predictors of future injury risk, including low levels of aerobic fitness or muscular endurance, a history of prior injury, and lower frequency of prior physical activity or exercise (17,21,24–28,37).

Physical fitness tests (PFT) are used by the military services to assess certain components of fitness, specifically cardiorespiratory fitness and muscular strength and endurance, and confirm service members have adequate levels of fitness for completing their assigned military duty. Although the types of exercises, distances, and standards vary for each military branch PFT, all service members must meet a minimum requirement on a semiannual or annual basis. Tests consist of an assessment of aerobic endurance, such as a maximal effort run (1.5 to 3 miles) or swim, and measures of muscular endurance, such as timed abdominal crunches (AC), sit-ups, and push-ups or pull-ups to exhaustion (PUE). Some studies have shown that low PFT scores on tests of aerobic or muscular endurance fitness are associated with higher injury risk (17,19,25–28). In addition to fitness

Address for correspondence: Peter Lisman, Ph.D., Department of Military and Emergency Medicine, Uniformed Services University, 4301 Jones Bridge Road, Bethesda, MD 20814; E-mail: peter.lisman@usuhs.edu.
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measures, researchers are currently trying to use various movement assessments to predict injury in athletic populations (13,14,22,33,36). These assessments are used to identify deficiencies in balance, core stability, flexibility, and mobility (6,11,32). The Functional Movement Screen (FMS), as described by Cook et al. (6,7), is a comprehensive series of movements that attempt to capture the quality of fundamental movement patterns and presumably identify an individual's functional limitations or asymmetries. Previous reports have demonstrated that low FMS scores are associated with MSK-I in both athletic (22) and military (33) populations. For example, Kiesel et al. (22) found that NFL players with FMS scores ≤14 had an 11-fold increased chance of injury in comparison with players with scores >14. Similarly, we recently reported that Marine officer candidates with an FMS score ≤14 were 1.7 to 1.9 times more likely to be injured than those with scores >14 (33). Interestingly, we also found a higher injury incidence rate among those with an FMS score ≥18. Moreover, analysis of receiver operating characteristic curves for FMS yielded similar results to total PFT scores for all injury classifications (33). Whereas research has shown that data obtained from both PFT and FMS assessments can be used independently to predict future injury occurrence, little is known about their potential additive effect or their association with one another.

The purpose of this present analysis was threefold. First, we examined the univariate association between injury risk and fitness, exercise and prior injury history, and FMS. Second, we investigated the multivariate association between injuries and these variables. Finally, we examined the association between FMS scores and PFT events.

METHODS

Study design and subjects. This was a prospective cohort study approved by the Institutional Review Boards at the National Naval Medical Center and the Uniformed Services University, Bethesda, MD. Without members of their chain of command present, all Marine officer candidates were thoroughly briefed about the project, including benefits and risks, and those choosing to volunteer provided written informed consent and signed Health Insurance Portability and Accountability Act authorization forms, permitting the use of protected health information for research. In addition, all study personnel wore civilian clothes to help minimize any coercion effect. Within 2 d after the briefing, all candidates underwent medical screening at the Officer Candidate School (OCS) medical facility. Those volunteering to participate in the study completed an exercise history questionnaire and underwent FMS as part of their medical screening. In addition, all candidates had to complete a PFT assessment within 1 wk of training commencement. Study participants were subsequently followed up for injuries that occurred during training.

The study participants (22.4 ± 2.7 yr) were enrolled in either 6 wk (n = 447) or 10 wk (n = 427) of Marine Corps officer candidate training during the summer of 2009. Candidates in the 6-wk short cycle (SC) are typically enrolled in collegiate Reserve Officer Training Corps programs, whereas those in the 10-wk long cycle (LC) are not and seek direct military commissions. Although both SC and LC programs have similar training activities, the SC is considered to be the more intense of the two programs because of its condensed time frame.

PFT. Within 1 wk of commencing training, candidates completed the standardized Marine Corps PFT (5). The test consisted of number of PUE and AC completed in 2 min and a run time (RT) for a 3-mile run, conducted in that order. For the pull-ups, a participant grasped the bar with either a pronated or supinated forearm/palm position and raised his body in a generally straight line until his chin was above the bar, followed by lowering his body to the starting point with arms fully extended. Participants performed repetitions until exhaustion, and the event was not timed. For the AC, the subjects were supine with their knees bent at a 90° angle and arms folded across the chest; a second person held the participant's ankles to keep his feet firmly on the ground. The subject then raised his upper body until either forearms or elbows simultaneously touched his thighs and then returned to the starting position. Participants completed as many repetitions as possible during the 2-min timed event. The 3.0-mile run was performed on a measured course, and the time to complete the event was recorded.

FMS. The FMS is a screening tool composed of seven specific tests to assess an individual's overall functional movement capacity. Tests are scored on a 0–3 ordinal scale and include the squat, hurdle step, forward lunge, shoulder mobility, active straight leg raise (ASLR), push-up, and rotary stability. A score of 3 indicates the subject was able to perform the movement correctly and without pain. A score of 2 indicates that the subject could complete the movement without pain but with some level of compensation. A score of 1 is given when the subject is unable to complete the movement as instructed. A score of 0 is recorded if the subject experiences pain with any portion of the movement. Overall FMS scores can range from 0 to 21. Detailed methods of FMS testing have been previously described (30).

Before participating in this research project, all study personnel were certified in the FMS by an instructor from Functional Movement Systems™. On the days of testing, the research team set up a total of nine stations; one designated for check-in, seven stations to conduct the FMS, and the last for check-out. Two evaluators operated each individual FMS station, allowing for multiple tests to be performed simultaneously. During check-in, volunteers were rebriefed, ensured an informed consent, and issued an FMS assessment sheet, which was completed by an evaluator at each of the seven evaluation stations. Participants would then proceed through the seven FMS stations, at which time, they were reeducated on successful performance of the station and then assessed. Although time limitations in the medical screening process prohibited ascertainment of test–retest reliability, previous investigators have reported high intersession and interrater reliabilities for total FMS scores (34,42).

Questionnaires. Participants were administered a questionnaire (see text, Supplemental Digital Content 1, http://links.lww.com/MSS/A248, questionnaire) to assess their history of previous injury and their specific exercise modality training frequencies, methods, and history before entering OCS training. The history of previous injury question asked, "Have you ever injured bone, muscle, tendon, ligaments, and/or cartilage in one or both of your lower limbs?" Response categories were "yes" or "no." The general sport and exercise (GES) participation question asked, "Over the last two months, what was the average number of times per week you exercised or played sports for at least 30 min at a time?" The specific exercise modality training frequency questions asked, "Over the last two months, how many times per week did you run or jog" and "In the 2 months before you entered Marine Corps training, how many times per week, on average, did you do weight training (WT) (such as free weights, universal, nautilus, etc.)?" For all three sport and exercise frequency questions, subjects could respond in one of the following nine categories: "never," "less than one time per week," "one time per week," "two times per week." "three times per week," "four times per week," "five times per week," "six times per week," or "seven times or more per week." To assess WT duration, subjects were asked, "When you performed WT, what was the average amount of time you trained during each session." Response categories included "none, did not do WT," "1–15 min," "16–30 min," "31–45 min," "46–60 min," "61–75 min," "76–90 min," and ">90 min." The running history question asked, "How long were you running or jogging before you entered Marine Corps training?" Response categories were "did not run or jog," "1 month or less," "2 months," "3 months," "4–6 months," "7–11 months," and "1 yr or more."

Injury data. Health care providers who were not part of the study saw subjects with medical problems and electronically recorded all information into the Armed Forces Health Longitudinal Technology Application. All medical encounters were subsequently inspected by physicians (part of the research team) and classified as an injury or an issue for other medical care. An injury was defined as an event that resulted in physical damage to the body during training that caused a subject to seek medical care one or more times during the study period. Injuries were classified by type into one of three categories. The first category (overuse injuries) included all visits presumably due to a long-term repetitive energy exchange that resulted in cumulative microtrauma. The second category was traumatic injuries and included visits due to acute or sudden energy exchanges resulting in abrupt overload and consequent tissue damage. The third category, "any injury," included all injury cases and was defined as a combination of overuse and traumatic injuries as described above. A subject could have experienced both traumatic and overuse injuries and be counted in both categories, but only once in "any injury."

Statistical analysis. A sample size estimate was performed using nQuery and based on previously published OCS injury data. We determined that 280 candidates would be sufficient to detect a 20% difference in injury rates with a Type I error rate of 5% and power of 80%.

Descriptive statistics were calculated for PFT results. To examine the relation between potential risk factors and injury, discrete and continuous variables were converted into categorical variables. PFT results were dichotomized using the median score as the cut-point for RT (≥20.5 vs <20.5), PUE (≥17 vs <17 repetitions), and AC (≥100 vs <100 repetitions). Running and GES frequencies were grouped as <5 or ≥5 times per week; WT frequency as ≤1, 2–4, or ≥5 times per week; WT duration as none, 1–30, 31–60, or ≥60 min; and running history as <1, 2–6, ≥7 months. Logistic regression analysis was used to examine the association between injury risk and PFT scores, prior injury, exercise history, and FMS. First, univariate logistic regression, with "injured/noninjured" as the dependent variable, was used to examine the association between various levels of each independent risk factor and any, overuse, and traumatic injury incidence. To control for the potential effect of training length (6 or 10 wk) on injury incidence, cycle length was included as an independent risk factor. Multivariate logistic regression by using a backward-stepwise method was then performed to investigate the independent effects of the risk factors for predicting injury and the interrelationships among factors. Risk factors were included in the multivariate models if they were found to be significant ($P < 0.05$) in the univariate analyses. Spearman's correlation coefficients were examined to measure the degree of association between individual PFT and FMS test results. Data analyses were performed using Statistical Package for the Social Sciences version 16.0 (SPSS, Inc., Chicago, IL).

RESULTS

Table 1 presents descriptive statistics for the Marine PFT (PUE, AC, RT).

PFT, FMS, and injury. Table 2 presents the associations between injuries and physical fitness, FMS scores, and cycle length. As shown, candidates with a slower RT or lower FMS score were at higher risk for any injury or traumatic injury. In addition, candidates with slower RT were at higher risk for an overuse injury. The association between injury risk and performance on PUE or AC tests was not significant. LC trainees were at higher injury risk for any, overuse, and traumatic injuries.

Exercise questionnaire variables and injury. Table 3 displays the risks of all types of injury and self-reported history of previous injury, specific exercise modality training

TABLE 1. Descriptive statistics for marine corps PFT measures.

Variable	N	Mean ± SD	Range
Pull-ups (no.)	857	16.7 ± 3.3	2–20
AC (no.)	858	98 ± 5.8	60–100
3-mile run (min)	858	20.5 ± 1.6	14.9–28.1

TABLE 2. Association between injuries risk and PFT measures, FMS score, and cycle length.

Variable	Variable Range	N	Any Injury OR (95% CI)	Any Injury P Value	Overuse Injury OR (95% CI)	Overuse Injury P Value	Traumatic Injury OR (95% CI)	Traumatic Injury P Value
Pull-ups (no.)	<17	354	1.04 (0.78–1.40)	0.777	1.00 (0.63–1.57)	0.990	1.01 (0.74–1.39)	0.940
	≥17	503	1.0	—	1.0	—	1.0	—
AC (no.)	<100	199	0.89 (0.63–1.25)	0.494	1.03 (0.61–1.74)	0.922	0.78 (0.53–1.15)	0.212
	≥100	659	1.0	—	1.0	—	1.0	—
RT (min)	<20.5	428	1.0	—	1.0	—	1.0	—
	≥20.5	430	1.72 (1.29–2.31)	<0.001	1.65 (1.04–2.61)	0.032	1.72 (1.25–2.36)	0.001
FMS	≤14	94	2.04 (1.32–3.15)	0.001	1.34 (0.70–2.56)	0.382	1.92 (1.21–3.02)	0.005
	>14	780	1.0	—	1.0	—	1.0	—
Cycle length (wk)	6	447	1.0	—	1.0	—	1.0	—
	10	427	1.46 (1.09–1.94)	0.010	1.63 (1.04–2.55)	0.032	1.42 (1.04–1.94)	0.029

frequencies, and exercise history. As shown, candidates who reported a prior history of lower limb injury were at higher risk for any injury. Candidates who reported a lower GES frequency were at higher risk of overuse injury, and those who reported fewer months of running before the course were at higher risk of traumatic injury. Injury risk was not associated with running frequency, WT frequency, or WT duration.

PFT scores, FMS scores, and injury. Table 4 presents the results of the multivariate analysis. As shown, FMS scores ≤14, slower RT, longer cycle length, and prior injury were independent predictors of any injury. For traumatic injury, FMS score ≤14, slower RT, and longer cycle length remained in the model. Only lower frequency of GES was found to be an independent predictor of overuse injury.

When the combination of low FMS scores (≤14) and slow RT (≥20.5 min) was entered into a logistic regression model when controlling for cycle length, the predictive value across all injury types increased. Candidates with both a low FMS score and slow RT were 4.19, 3.77, and 1.85 times more likely to experience any (95% confidence interval (CI) = 2.33–7.53, $P < 0.001$), traumatic (95% CI = 2.12–6.70, $P < 0.001$), or an overuse (95% CI = 0.84–4.10, $P = 0.129$) injury, respectively, in comparison with those whose scores were not low for both testing parameters.

PFT and FMS performance. Table 5 displays the Spearman's correlation coefficients between individual PFT performance scores and FMS test components. The PUE test was positively correlated with the squat, lunge, ASLR, and stability push up and was the only PFT test associated with total FMS score. The RT was significantly and negatively related to the lunge, whereas AC performance was positively related to both the squat and the lunge.

DISCUSSION

Identifying quantitative measures that can be used to predict injury risk can be useful in both military and athletic populations. Associations between injury risk and scores on a PFT, functional movement test, anatomical/biomechanical measure, or other self-report markers have been sought for many years. This study examined the predictive power of physical fitness, self-reported exercise modality training frequencies and history, previous history of lower limb injury, and FMS scores in an effort to improve injury prediction. Our results are consistent with some past findings demonstrating that slower RT, prior injury, lower frequency of exercise and sport participation, and shorter history of running were associated with higher injury risk (17,19,24–28,40). Importantly, we expanded on prior findings by showing that the odds of sustaining any injury were over fourfold times higher among those with FMS scores ≤14 and RT ≥20.5 min.

We examined relationships among PFT and FMS scores and subsequent injuries during military training. Overall, unlike RT scores, scores for pull-ups and AC were not related to subsequent injury incidence in these Marine officer candidates, although they have been shown to be associated with injuries

TABLE 3. Association between injury risk and history of previous injury, specific exercise modality training frequencies, and exercise history.

Variable	Variable Range	N	Any Injury OR (95% CI)	Any Injury P Value	Overuse Injury OR (95% CI)	Overuse Injury P Value	Traumatic Injury OR (95% CI)	Traumatic Injury P Value
GES frequency (wk^{-1})	<5	267	1.24 (0.92–1.69)	0.163	1.81 (1.16–2.83)	0.010	1.09 (0.78–1.53)	0.604
	≥5	607	1.0	—	1.0	—	1.0	—
Run frequency (wk^{-1})	<5	598	1.00 (0.74–1.37)	0.984	1.29 (0.78–2.12)	0.320	0.95 (0.67–1.33)	0.744
	≥5	267	1.0	—	1.0	—	1.0	—
Weight training frequency (wk^{-1})	<1	143	1.17 (0.74–1.87)	0.504	1.08 (0.51–2.27)	0.841	1.13 (0.69–1.87)	0.622
	2–4	544	1.04 (0.72–1.49)	0.832	1.19 (0.67–2.10)	0.551	0.92 (0.62–1.36)	0.667
	≥5	186	1.0	—	1.0	—	1.0	—
Weight training time (min)	None	49	0.66 (0.33–1.34)	0.253	0.62 (0.18–2.15)	0.454	0.76 (0.36–1.60)	0.468
	1–30	157	1.01 (0.66–1.55)	0.947	1.16 (0.60–2.23)	0.660	1.15 (0.73–1.80)	0.542
	31–60	413	0.87 (0.62–1.22)	0.424	1.17 (0.69–1.97)	0.556	0.78 (0.54–1.13)	0.186
	≥60	253	1.0	—	1.0	—	1.0	—
Run history (no. of months)	<1	46	1.53 (0.83–2.84)	0.178	0.61 (0.19–2.04)	0.426	2.07 (1.10–3.88)	0.023
	2–6	218	1.20 (0.86–1.67)	0.287	1.04 (0.63–1.72)	0.884	1.19 (0.83–1.71)	0.343
	≥7	599	1.0	—	1.0	—	1.0	—
Prior injury	None	506	1.0	—	1.0	—	1.0	—
	Yes	359	1.41 (1.05–1.88)	0.021	1.39 (0.89–2.17)	0.141	1.28 (0.93–1.76)	0.124

TABLE 4. Independent risk factors for injury (from multivariate logistic regression).

Injury	Variable	Variable Range	Adjusted OR (95% CI)	*P* Value
Any injury	Cycle length	6 wk	1.0	—
		10 wk	1.49 (1.11–2.01)	0.009
	FMS	≤14	2.10 (1.34–3.29)	0.001
		>14	1.0	—
	RT	≤20.5 min	1.0	—
		>20.5 min	1.74 (1.29–2.36)	<0.001
	Prior injury	None	1.0	—
		Yes	1.53 (1.13–2.07)	0.006
Overuse injury	Cycle length	6 wk	1.0	—
		10 wk	1.54 (.97–2.43)	0.065
	RT	≤20.5 min	1.0	—
		>20.5 min	1.53 (0.96–2.43)	0.073
	GES	<5 wk^{-1}	1.78 (1.12–2.82)	0.014
		>5 wk^{-1}	1.0	—
Traumatic injury	Cycle length	6 wk	1.0	—
		10 wk	1.47 (1.06–2.03	0.021
	FMS	≤14	1.80 (1.12–2.89)	0.015
		>14	1.0	—
	RT	≤20:53 min	1.0	—
		>20:53 min	1.64 (1.18–2.27)	0.003
	Run history	<1 mo	1.72 (0.90–3.28)	0.098
		2–6 mo	1.05 (0.73–1.53)	0.784
		≥7 mo	1.0	—

in Marine Corps basic training (28). Furthermore, the odds ratios (OR) for RT and FMS scores were independent risk factors in the multivariate analysis, which suggests they had independent predictive value. Our finding that participants with the lowest aerobic capacity, as measured by a 3-mile maximal effort RT, had an increased likelihood of injury is consistent with previous reports on Army (17,19,26,27), Marine (28), and Air Force (25) basic training populations as well as other military and nonmilitary populations (9,31,37,43). In fact, low aerobic fitness has consistently been related to increased risk for MSK-I injury. In the present study, the OR among all injury incidence classifications ranged between 1.65 and 1.72 and was comparable with those reported by others (26–28). Knapik et al. grouped 2-mile run performance into quartiles and reported that Army male trainees with the slowest RT were 1.5 (27) and 1.6 (26) times more likely to be injured than those in the fastest groups. The authors found similar results among a large cohort of Marine Corps basic trainees (28).

Given the high volume of running and other strenuous physical activities performed by Marine officer candidates during OCS, an association between aerobic fitness and injury incidence might be expected. Individuals with low levels of aerobic fitness would perceive formal physical and field training exercises as more difficult and may experience an increased level of fatigue relative to those with high aerobic fitness. Fatigue may compromise motor control and balance (16), alter landing mechanics during tasks involving jumping (2,39), and change specific gait kinematics and muscle activity patterns (35) during marching, running, and sprinting tasks, all of which may increase the likelihood of injury during training.

The current study's finding that lower levels of muscular endurance, as measured by low scores in the PUE and AC tests, were not associated with injury is not consistent with results reported by others (25,26,28). In three separate studies, Knapik et al. (25,26,28) reported that military trainees grouped into the lowest sit-up performance quartile were 1.5–1.6 times more likely to experience an injury than those in the highest scoring group. Specifically, Marine Corps basic trainees grouped into the lowest quartile (13–51 crunches) were 1.56 times more likely to have been injured than those in the highest quartile (74–159 crunches) (28). All of the Marine Corps officer candidates in the present study completed ≥60 crunches and thus 0% would have been grouped into the lowest performance group presented in the previous report. Given these results, the AC may have limited merit in predicting injury in individuals with higher levels of abdominal muscular endurance.

Previous findings regarding the association between upper body muscular endurance and injury risk also differ from those reported in the present study. Knapik et al. (25–27) found Army and Air Force trainees with low push-up scores were 1.4–1.8 times more likely to have experienced an injury than those with high scores. Likewise, the authors reported that Marine Corps basic trainees grouped into the quartile completing the fewest number of pull-ups (0–4) were 1.6 times more likely to have been injured than those in the highest performance group (12–26) (28). However, a significant difference was noted when comparing pull-up performance between Marine Corps basic trainees and Marine Corps officer candidates. Less than 1% (2/857) of Marine officer candidates performed ≤4 pull-ups, whereas 92% (791/857) completed ≥12 pull-ups. As with the AC, the PUE may have limited value in predicting injury in individuals with higher levels of upper body muscular endurance. Interestingly, studies investigating the association between push-up performance and injury incidence in Army soldiers (nontrainee population) found results similar to ours (24,37). Collectively, our physical fitness findings suggest that RT performance is the most influential PFT component for predicting injury occurrence and that PFT assessments of muscular endurance may have limited value in predicting injury risk in Marine Corps officer candidates, unless scores are very low. Our findings further highlight the need to emphasize aerobic conditioning for any pre-OCS conditioning and/or injury prevention training strategy.

Several responses on the questionnaire assessing candidates' history of previous injury and specific physical activity and exercise habits before OCS had some value in predicting injury. Previous studies have shown lower levels of physical activity and history of prior lower extremity injury

TABLE 5. Spearman correlation coefficients between FMS and PFT test components.

FMS Test	Pull-ups	Ab Crunches	RT
Squat	0.10**	0.07*	−0.04
Hurdle step	0.03	−0.04	−0.06
Lunge	0.11**	0.15***	−0.08*
Shoulder mobility	−0.02	−0.02	0.05
ASLR	0.07*	−0.01	−0.03
Push-up	0.09**	0.04	0.04
Rotary stability	0.05	−0.01	−0.01
Total FMS score	0.12**	0.06	−0.03

* Significant correlation at $P < 0.05$.
** Significant correlation at $P < 0.01$.
*** Significant correlation at $P < 0.001$.

to be associated with a higher risk of injury (17,19,25–28). In the present study, we further categorized physical activity and exercise habits into particular modalities of training, such as GES, running, and WT participation. Findings revealed that only GES frequency was associated with injury—individuals with a frequency <5 wk^{-1} had a 1.8 times higher incidence of experiencing an overuse injury than those with a frequency ≥5 wk^{-1}. This might be expected because higher levels of physical activity and exercise of the proper mode, frequency, and duration are associated with higher muscle (38) and connective tissue strength (8,23), lower body fat (41,44), and higher bone mineral density (29,41), all of which may result in a decreased risk of overuse injury during training. Although ≥5 wk^{-1} is a high frequency of activity, 31% reported exercising at this level, and activity below this level increased injury risk in this highly active Marine Corp group. The current study's finding that history of previous injury was associated with current risk of training injury is consistent with past findings (19,37). Past injury may result in reduced proprioception (3,20) and joint range of motion (15), muscle strength imbalances (12), and ligamentous laxity (10), all of which may increase the likelihood of injury during training.

The FMS, a qualitative assessment of fundamental movement patterns, is intended to identify an individual's functional limitations and asymmetries. Recent studies have provided some initial evidence of its efficacy for injury prediction in both athletic and military populations (22,33). Kiesel et al. (22) analyzed the relationship between FMS scores for 46 National Football League players and occurrence of serious injury and found that players presenting with scores ≤14 were 12 times more likely to experience a serious injury than those with scores >14. Likewise, we previously reported that Marine officer candidates with an FMS score ≤14 were 1.7 to 1.9 times more likely to be injured than those with scores >14 (33). In the current study, we examined the combined effects of specific PFT components and FMS on injury incidence in a military population. When RT was combined with the FMS, injury prediction was improved. When analyzed independently, the injury OR for those with poor RT or FMS scores were 1.7 and 2.0, respectively. When combined, those with low FMS and slow RT were about four times more likely to experience an injury compared with those who did not score poorly on both tests. Thus, an additive effect was clearly demonstrated when these two factors were combined. Interestingly, the combination had greater predictive value for traumatic than overuse injury. Because FMS is used to identify functional limitations and asymmetries, candidates scoring poorly may have relied on compensatory movement patterns during performance of strenuous physical activities. In addition, lower levels of aerobic conditioning may have resulted in fatigue-induced alterations in kinesthetic control, balance, and gait. Although we do not report mechanisms of injury, it is reasonable to expect that this detrimental combination of factors led to an increased susceptibility to those mechanisms causing acute traumatic injury. Although only 6% (52 of 855) of participants scored poorly on both the RT and FMS, this still represents a large number of OCS candidates at high risk for injury, given the large number of candidates entering OCS on a yearly basis. It is possible that appropriate training interventions may address both FMS-limiting factors and aerobic endurance to decrease risk of injury, although confirmation of this will have to await further research.

Several statistically significant, yet weak, correlations between individual PFT performance scores and FMS test components were noted. The strongest correlation was for the AC and in-line lunge, although the PUE was related to the greatest number of FMS tests and the only PFT test positively related to total FMS score. The lack of association between the FMS and PFT is not surprising, given they assess different physical fitness and performance components. In particular, the PFT assesses aerobic endurance and upper body and abdominal muscular endurance (5), whereas the FMS likely captures functional limitations related to deficiencies in proprioception, stability, and overall mobility (6,7). Furthermore, the range of PFT scores is wide, whereas FMS scores are limited to range from 0 to 3. Whether a more granular FMS score would rectify this relationship is currently unknown. The results of the multivariate analysis provide additional confirmation of the independence of these two measurements in predicting injury incidence risk.

A limitation of this study was that our sample of Marine Corps officer candidates represents a very homogenous population, one that is young and physically fit. Our population's fitness level, along with limitations imposed by the Marine Corps PFT scoring system, may have been influential in our findings that both PUE and AC test performance were independent of injury risk. The scoring system for the PFT assigns a maximum score of 100 for performing 100 AC in 2 min, completing 20 pull-ups before exhaustion, and running 3 miles in less than 18 min. Any performance above these levels does not improve one's overall score for the individual PFT. In addition, repetitions above 20 for the PUE and 100 for the AC were not recorded. Another limitation relates to the actual distribution of PFT scores: many candidates achieved the maximum number of repetitions on the AC and/or PUE tests, 77% and 31%, respectively. The large number of candidates achieving the highest attainable score would have negatively affected its ability to predict injury because of the limited scoring range. Of note, only 6.5% of candidates achieved a perfect score for RT. Given these results, additional work on military populations with more heterogeneous fitness levels is warranted.

In summary, slower RT (approximately 7 min per mile or slower) was associated with increased injury risk, but no other performance score had predictive value for injury. Importantly, combining poor RT and low FMS scores (≤14) increased the injury predictive value across all injury classifications. Additional research is needed to further clarify what combination of PFT and FMS tests would best predict future injuries and whether a particular set of criteria could be used for developing appropriate and effective pre-OCS injury prevention training programs. Given the homogenous population tested in this study, future research investigating the injury predictive value of specific PFT and FMS test components should seek to evaluate military cohorts entering basic training as well.

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