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Modifiable risk factors predict injuries in firefighters during training academies

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Abstract. **OBJECTIVE:** To examine whether measures of physiologic function and fundamental movement are predictive of injury in firefighters during a training academy.
PARTICIPANTS: 108 firefighter trainees enrolled in the training academy.
METHODS: Baseline measures of physical performance and fundamental movement patterns were obtained in firefighters entering a training academy to determine predictors of injury. The physical performance measures were standardized tests of individual maximum performance on a set of four different total body tests and one firefighter specific performance test, the tower test. Measurements of fundamental movement patterns consisted of the seven tests of the Functional Movement Screen (FMS) along with the composite score.Performance on each of the individual tests was examinedto determine if any of the variables were predictive of injury.
RESULTS: ROC curve analysis established that a FMS cut score of $\leqslant$ 14 was able to discriminate between those at a greater risk for injury. In addition, the deep squat and push up component of the FMS were statistically significant predictors of injury status along with the sit and reach test.
CONCLUSIONS: Injury in firefighters during academy can be predicted by baseline measures of musculoskeletal movement and physiology.

Keywords: Occupational injury, injury screening, physical fitness

1. Introduction

Firefighters are recognized as having a high level of job related injuries due to the highly physical and dangerous nature of their profession [1,2]. It is reported that while a number of these injuries are due to the danger of the profession, a large number of injuries are associated with over exerting the musculoskeletal system which can lead to disability [1,3]. While a number of studies have examined current levels of physical fitness in firefighters, along with ways to improve fitness, few studies have examined how these measures are related to injury risk [4–9]. Studies in other populations that have examined isolated musculoskeletal measures have reported inconsistency in injury prediction [10–13]. As a result of these findings, measurement tools have been developed that examine large body relative movement patterns [14–16]. These more global measurement tools may be able to provide greater consistently in identifying individuals at risk for musculoskeletal injury.

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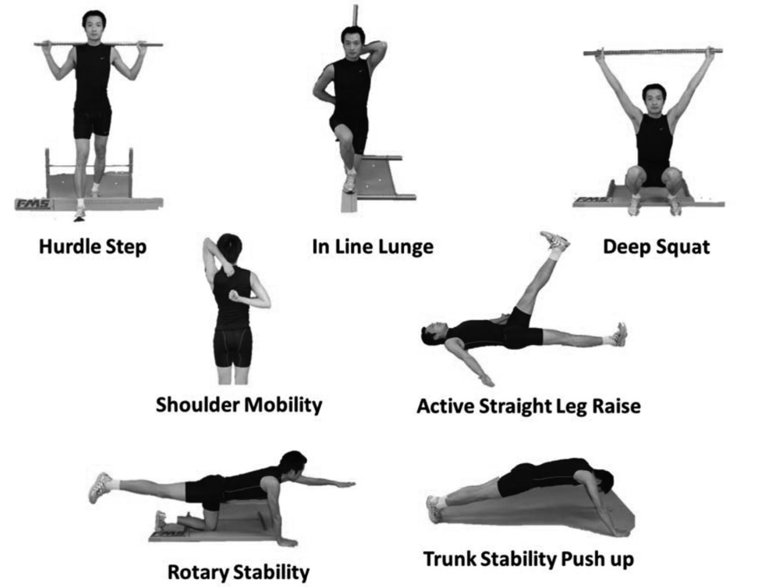

Fig. 1. Examples of the ending position to score a 2 on each of the tests of the Functional Movement Screen. (Colours are visible in the online version of the article; http://dx.doi.org/10.3233/WOR-121545)

One test that examines total body movement patterns is the functional movement screen [17]. The Functional Movement Screen (FMS) consists of 7 tests based on neurodevelopmental milestones and the screen is able to be reliably completed with a standardized kit in any environment with trained raters (Fig. 1) [18]. The 7 tests of the FMS are the deep squat, hurdle step, in line lunge, shoulder mobility, active straight leg raise, trunk stability push up and rotary stability. As a result, the FMS can have implications for the musculoskeletal screening of individuals in a field setting. The composite score of the FMS (sum of the 7 tests) has been successful in prospectively identifying professional football players and soldiers who are at an elevated risk for injury ($\leqslant$ 14 composite FMS score), as well as identifying firefighters who had sustained during the previous year (3 points lower on the FMS composite score) [19–21]. Multiple studies have supported that the composite score of the FMS is able to be modified with an appropriate physical training program [22–24]. Interestingly, one factor that was associated with not being able to improve an individual's composite score above the injury cut point was a low initial score on the deep squat [24]. Currently, there are no published reports of the diagnostic ability of the FMS in predicting injuries in firefighters.

The focus on the role of firefighters has placed a large amount of research on improving physical fitness in firefighters [4–9]. However, isolated limitations in strength and fitness have yet to be associated with injury risk in firefighters. Previous research studies have successfully utilized the FMS to identify individuals with an elevated risk of sustaining an injury that limited normal participation in professions with high physical demand [19,20]. Thus, the purposed of this study was to examine if the FMS is a successful predictor of injury in firefighter trainees. We also wanted to examine if any of the baseline tests on the FMS were associated with injury over the course of the Academy training. In addition, we also wanted to examine whether standard measures of performance in firefighters had a significant relationship with injury status. It was expected that the firefighters with lower performance on the FMS tests and who exhibited a low composite score would be at a greater risk of being injured. If this finding holds true, these data could be used to develop injury prevention strategies for firefighter applicants to optimize firefighter health and minimize health care costs for the fire departments.

2. Methods

2.1. Participants

Participants in the study were firefighters enrolled in four successive firefighter academies for the Orange County Fire Authority. All subjects enrolled in the study were currently free from any injury that would restrict active firefighter participation. In order to be enrolled in the academy all firefighters had to clear a physician administered physical. A total of 108 firefighters were enrolled and tracked for injuries over the course of the academy. All subject data was placed into an electronic medical record. The data that were collected for the purposes of this study were then de-identified prior to being sent to the research team for analysis.

In an attempt to identify meaningful measures for injury prediction, baseline measures of physical performance and fundamental movement, FMS,were obtained. The physical performance measures were standardized tests of individual maximum performance on a set of four different total body testsand one firefighter specific performance test, the tower test. Measurements of fundamentalmovementpatterns consisted of the seven subtests of the FMS along with the composite score.

2.2. Physical performance tests

Measures of general physiologic function included the sit and reach, push up, pull up, 1.5 mile run, as well as a firefighter specific "tower test". These tests were traditionally implemented at the baseline screening of all firefighter trainees who were entering the academy.

2.2.1. Sit and reach test

The sit and reach test was conducted in a standard manner with a sit and reach box (Acuflex I, Novel Products, Inc, Rockton, IL, USA). The box incorporated a reach indicator at a standardized height that provided a measurement of how far each individual was able to reach forward in a long sitting position with their knees straight. Subjects were required to maintain controlled flexion in a long sitting position as they reached forward with overlaying left and right hands. The subjects were instructed to slowly exhale as they flexed forward and were instructed to only move the measurement device with their middle fingers. Each subject was provided three trials separated by thirty seconds. Any trial where the subjects bounced, flexed the knees, or used momentum to move the device was not counted. The maximum value achieved (cm) was utilized for the analysis.

2.2.2. Pushup test

Pushups were assessed by examining the number of pushups that each subject could complete in 2 minutes. Subjects were forced to conduct the push up along with the beat of a metronome set at 40 beats per minute. To be recorded as a full push up each subjects chin had to make contact with a 5 inch prop placed under the subjects chin at the end of the down phase and then had to achieve full elbow extension at the end of the up phase. The test was stopped if the subject a) reached 80 pushups, b) performed three consecutive incorrect pushups or c) did not maintain continuous motion with the metronome. The maximum number of pushups completed during the test was utilized for the analysis.

2.2.3. Pull up test

Pull ups were examined by having the trainee perform a series of standard pull ups while hanging from a pull-up bar. Subjects were able to complete the pull ups until failure. All subjects started from a down position and were asked to pull their body up until their chin was above the bottom of the bar. Subjects were required to keep their body and legs still during the test and subjects were required to extend their arms fully at the end of each repetition.

2.3. 1.5 mile run

The 1.5 mile run was conducted as the time each subject took to cover the distance on a standard course. Subjects were instructed to cover the distance as quickly as possible but were asked to slow their pace if they experienced any pain, severe shortness of breath or other abnormal signs. The time to complete the 1.5 mile run was analyzed for the scope of this study.

2.3.1. Tower test

The tower test is a firefighter specific test that is completed in a standardized manner that induces physiologic stress during tasks that are common to firefighters. The tower test begins with a five-story climb that is followed by a two story descent. After the two story descent, each subject then performed 20 slam balls (combination of Squat and Downward medicine ball throw) followed by an additional one story descent where the subject then lowered a 25-pound bundle with a 50-foot rope section. The subject then performed a 150-foot run, 20 wall balls (combination of Squat and Upward medicine ball throw), 15 pull ups, a 200 foot run and a 400-foot hose pull. The time to complete the test was recorded to assess the firefighter specific fitness levels of the firefighters.

2.3.2. Fundamental movement pattern test

Fundamental movement patterns were examined by utilizing the FMS. The FMS testing kit (Fig. 1, Functional Movement Systems, Chatham, VA) is a portable way to reliably and objectively assess seven different total body movement patterns [15–18]. The movement patterns that are assessed in the FMS are the deep squat, hurdle step, in line lunge, push up, rotary stability, active straight leg raise and shoulder mobility. All movement patterns are carried out and scored in a consistent pattern. Scoring of the 21 point FMS consists of a score on each of the seven tests ranging from 0–3. For the tests where a bilateral component exists, the lowest score bilaterally is utilized for the calculation of the composite score as well as for the score on the test. A score of 3 on any of the tests suggests that the movement was completed fully and free from compensation. A score of 2 on the tests suggests that the movement was completely performed but compensation had to occur in order for the movement to be completed. A score of 1 indicates that the subject was unable to complete the movement pattern even in the presence of compensation. Scores ranging from 1–3 indicate pain free movement patterns. If the subject was painful during the movement pattern a score of 0 was recorded. In addition to the subtests there were also three clearing tests to assess pain. The clearing tests were the impingement sign, prone press up, and kneeling flexion. If any of the clearing tests were positive a score of 0 was recorded for shoulder mobility, push up or rotary stability, respectively.For the prediction model each individualtest score on the FMS was utilized. The composite score on the FMS, sum of each of the test scores, was utilized to identify a cut point that targets individuals at an elevated injury risk.

2.4. Injury surveillance

Over the course of the 16 week academy all firefighters were tracked for injuries. An injury was defined by any episode that caused the recruit to miss 3 consecutive days of training in the academy due to musculoskeletal pain (excluding burns). Injuries were tracked by the strength and conditioning staff of the Orange County Fire Authority. Presence of any injury over the course of the academy was scored dichotomously as positive or negative.

2.5. Statistical analysis

Statistical analysis was conducted to determine which of the performance test and fundamental movement variables were predictive of injury over the course of the academy. In addition, a cut point was established

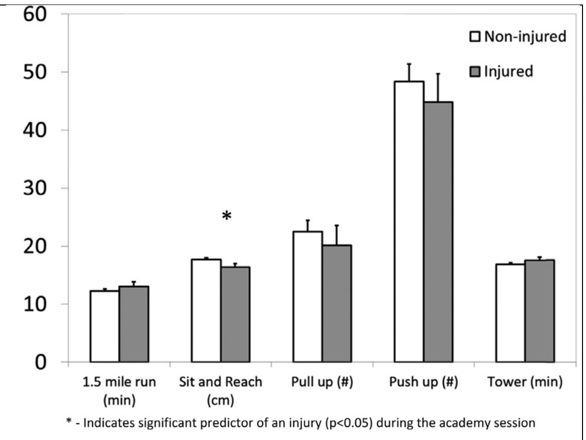

Fig. 2. Differences (Mean ± SEM) in the injured and non-injured firefighter recruits for the physical performance tests.

using the composite FMS to assist in identifying firefighters at an elevated risk of injury similar to what has been performed in other populations. Injury prediction models were run for the physiological variables and musculoskeletal movement variables separately using forward and backward logistic regression. Variables were kept in the model for the forward regression if the p value of each variable was $\leqslant 0.05$ while a p value of $\leqslant 0.10$ was utilized to include variables in the backwards regression model. In order to determine the cut point for the composite FMS score, a receiver operator characteristic (ROC) curve was developed and the point was chosen that maximized the correct prediction of injury classification based on the FMS score.Standard diagnostic measures were calculated based on the established cut point of the composite FMS score. Statistical analysis for the regression model an analysis of differences was carried out utilizing SPSS software (version 17, Chicago, IL) while the ROC curve and the standard diagnostic calculations were calculated using Stata (version 10, College Station, TX).

3. Results

Both physiologic and fundamental movement variables collected at baseline were significant predictors of injury over the course of the academy. The only physiologic variable that was predictive of injury was the sit and reach test (Fig. 2, OR: 1.24 ([95% CI: 1.06–1.42], $\beta = 0.218$, $r = 0.218$). Two of the musculoskeletal movement variables were predictive of injury. Both the deep squat (OR: 1.21 [95% CI: 1.01–1.42], $\beta = 0.190$) and push up (OR: 1.30 [95% CI: 1.07–1.53],

Table 1
Specificity and sensitivity for composite FMS score across different cut points

Cut off	Sensitivity	Specificity	Correctly classified	LR +	LR −
= 12	97.5	17.2	75.9	1.18	0.15
= 13	92.4	34.5	76.9	1.41	0.22
= 14	83.5	62.1	77.8	2.20	0.26
= 15	63.3	75.9	66.7	2.62	0.48
= 16	39.2	82.8	60.9	2.27	0.73
= 17	25.3	89.7	42.6	2.44	0.83

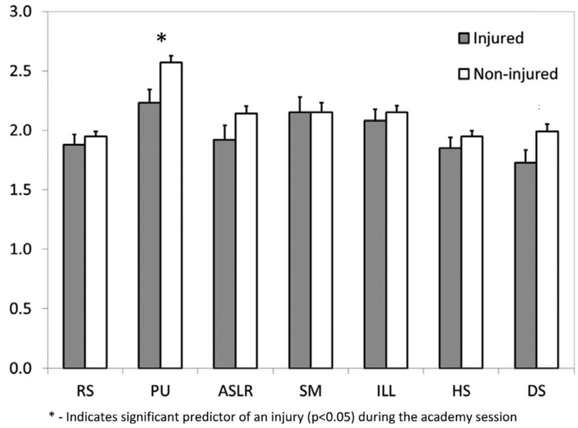

Fig. 3. Differences (Mean ± SEM) in the injured and non-injured firefighter recruits on the Functional Movement Screen tests (RS = rotary stability, PU = trunk stability push up, ASL = active straight leg raise, SM = shoulder mobility, ILL = In line lunge, HS = hurdle step, DS = deep squat).

$\beta = 0.266$) were variables that were statistically significant in predicting injury classification (Fig. 3, $r = 0.330$).

A cut point of $\leqslant 14$ out of 21 was identified to dichotomize those at a greater risk for developing an injury (Table 1). Standard diagnostic testing calculations resulted in this value exhibiting a Sensitivity of 0.83, Specificity of 0.62, Positive Predictive value of 85.7%, and Negative Predictive value of 58.1% with 77.8% of the population correctly classified at this value. At this cutpoint, the diagnostic odds ratio revealed a value of 8.31 (95% CI: 3.2–21.6) and corresponding likelihood ratios (+ LR = 2.20 and − LR = 0.26).

4. Discussion

Firefighters have a significant incidence of occupation related injury in comparison with other professions [1,2]. A large amount of research has focused on the physical fitness of physical fitness; however, little research has focused on how the movement profile of a firefighter is relatedto injury risk [4–9,21]. Previous studies have assessed total body movement patterns and have related the quality of those movement patterns to injury risk; however this has not been performed in firefighters [19,20]. The results of this study suggest that musculoskeletal movement patterns, along with the sit and reach test, are predictive of injury in firefighters going through a training academy. In addition, firefighters who scored $\leqslant 14$ on the FMS composite had a greater likelihood of sustaining an injury.

Previous research on modifiable movement basedinjury risk factors for firefighters is limited. The results of this study suggest that performance on the sit and reach, along with deep squat and push up on the FMS, are related to injury risk.Interestingly, all of these factors have been documented as modifiable in previous research studies. It was surprising to observe that the sit and reach was a significant predictor of injury; however the active straight leg raise of the FMS was not. It may be that the combined flexion of the hip and spine, which includes the obstacle of trunk girth, during the sit and reach performed in long sitting may provide a different construct of testing in comparison with the active straight leg raise which is tested in supine and primarily screens for hip mobility, hip and core stability. It is worthy to note that the last FMS variable that was removed from the equation in the logistic regression was the active straight leg raise.

Performance on the sit and reach test has been associated with injury in non-firefighterpopulations [25]. Specifically, the sit and reach test has previously been reported to be related to injury in distance runners [25]. However, this study was not prospective in nature. Regardless, it appears that flexibility as determined by the sit and reach may be an important factor to normalize prior to participating in a high demanding physical activity such as firefighting. Previous research in firefighters has observed that a 6 week fitness program is able to improve hamstring flexibility [5]. To date no research has examined the effect of improving hamstring flexibility on musculoskeletal injuries in firefighters. It may be appropriate for firefighters to be screened on the sit and reach test prior to entering the academy in order to reduce their risk for injury. In addition, for firefighters trainees who scored poorly on the sit and reach test it would likely be important for these individuals to continue with a maintenance program during the academy to maintain the improvementson the sit and reach test.

Another movement pattern that was related to an elevated injury risk in the firefighter was the deep squat. Rhea et al. [26] observed that endurance performance on the squat was moderately correlated with job performance in firefighters. Based on this one study, it appears that the deep squat is a potentially meaningful component of the firefighting profession.Previous research on the FMS has suggested that the deep squat is an integral part of correcting total body movement patterns [24]. This may be due to the fact that the deep squat, as scored by the FMS, involves upper extremity as well as the traditionally thought of lower extremity mobility and stability [15,18]. As a result of being a total body movement it may provide an indicator of overall movement system health. In addition, it has been previously reported that increased levels on the deep squat of the FMS require increased joint motion and joint torques in the lower extremity [27–29]. In summary, the deep squat of the FMS requires efficiency of the upper extremity, core and lower extremity and as a result this may be why it was successful in identifying individuals at an elevated risk for injury. Similar to the sit and reach, it appears that it may be appropriate for all firefighter trainees to meet a certain criteria on a bilateral deep squat prior to entering the firefighter academy to minimize injury risk.

The other component of the FMS that was predictive of injury in the firefighter trainees was the pushup. The push up, as scored by the FMS, combines core and lower extremity stability with glenohumeral strength [16]. Previous research has suggested a strong association between upper extremity strength and firefighting ability [26,30]. As a result this research would provide validity for the constructs measured during the FMS-pushup as potentially being meaningful predictive measure in firefighters. However, the push up is not solely a function of core stability it also requires a fundamental level of upper extremity strength and mobility as well [16]. The large quantity of firefighter specific tasks that are associated with upper extremity strength may explain the reason that this test was associated with injury in this cohort [5]. Unfortunately, we did not obtain the specific type of injury that was associated with the baseline scores. The addition of this measure would allow for us to more strongly associate the relationship with scores on the FMS tests and specific injuries.

Limitations of the current study include specificity of the physical fitness tests along with the generic injury surveillance. The physical fitness tests utilized for this study were current standards for the fire academy utilized for the study. The tests included global physical fitness tests of upper extremity, lower extremity, core, and total body function as well as a firefighter specific task. Future studies may include additional tests in the screening model due to the limited information received from these tests in regard to injury prediction. Injury surveillance during this study was performed using a generic musculoskeletal injury definition. The definition was successful in identifying those who were functionally removed from the academy due to a musculoskeletal injury, however, did not provide the researchers with information related to the development of specific injuries. Future research is encouraged to incorporate specific information on injury mechanism and location. These data may facilitate to determine which specific screening tests are related to a given set of injuries. While these authors acknowledge these limitations, it is not believed that these limitations detract from the overall results of the current study, but rather add to the development of future research studies.

In summary, it appears as if there are modifiable performance testing and fundamental movement testing variables that are related to injury risk in firefighter trainees. This would suggest that it may be beneficial for recruits to reach a baseline level of functional fitness prior to entering the academy to minimize injury risk as well as healthcare costs. Future studies should assess whether the implementation of protocols that require trainees to meet fundamental movement parameters prior to participating in the academy can reduce injury rates in firefighters. Similar studies should also occur in professional firefighters to examine the effect of movement pattern retraining on injury risk and health care costs.

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