©Journal of Sports Science and Medicine (2015) **14,** 515-521
http://www.jssm.org

Research article

Examination of the Effectiveness of Predictors for Musculoskeletal Injuries in Female Soldiers

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Abstract

The amount of training days lost to injury during military training has highlighted the need to identify a screening tool to predict injury. One hundred and fifty-eight female soldiers from the Combat Fitness Instructor Course (CFIC) of the Israel Defense Forces volunteered to participate in this study. All soldiers were free of orthopedic and neurologic conditions for at least one month before the study. All participants performed a battery of measurements during the first week of the course. Measures included anthropometric, functional movement screen (FMS), power performances (counter movement jump [CMJ], drop jump, single leg triple hop jump [SLTH], 10-m sprint) and a 2K run. Injury data was collected throughout the 3 month course. Median tests were used to compare between injured/non-injured soldiers. Chi-square and/or logistic regression analysis was used to examine the association between various predictors and injury. Percent body fat [%BF] was higher ($p = 0.04$), distance for SLTH was less for both left and right legs ($p = 0.029$, $p = 0.047$ respectively) and 2K run was slower ($p =0.044$) in injured compared to non-injured soldiers. No differences between groups were noted in total FMS score, however more zero scores in one or more movement pattern were found in the injured group (51.35 % vs. 30.5% $p=0.0293$). Only %BF, 2K run and SLTH distance were significant predictors of injury ($p = 0.05$, $p = 0.02$, $p =0.016$ respectively). The results of this study indicated that the FMS total score is not a predictor of injury in female soldiers in a CFIC. We found that %BF, SLTH, 2K run time, 10 meter sprint time and zero scores differentiated between injured and non-injured soldiers. In addition, %BF, 2K run and SLTH were each found to be separate predictors of injury. Further research is needed to determine threshold scores that predict injury.

Key words: military, combat fitness, functional movement screen, assessment.

Introduction

The amount of training days lost to injury during military training, and the subsequent financial implications related to days missed has highlighted the need to identify a screening tool to predict injury among military personnel (Jones et al., 2010; Knapik et al., 2001). For example, acute and overuse injuries were estimated to result in over 25 million days of limited duty in the US army in 2005 (Ruscio et al., 2010). Furthermore, injury-related musculoskeletal conditions were a leading cause of days of limited duty. Sports and physical training were the main cause, followed by falls (Ruscio et al., 2010). The purpose of assessments can vary, but often involve selection, goal setting, program evaluation, and monitoring training progress (Hoffman, 2006). In addition, assessments can also be used to predict an individual's risk for injury. Previously, the use of agonist and antagonist ratio's (i.e., quadriceps:hamstrings) or bilateral deficits have been suggested to be potential methods to determine injury risk (Hoffman et al., 1992; Knapik et al., 1991). Other studies have examined joint range of motion, muscle strength and muscle extensibility as potential predictors of injury (Heiderscheit et al., 2010; Myer et al., 2011). However, these assessments tend to focus on individual joints or muscle groups that are not consistent with functional movements seen during sport (Mottram and Comerford, 2008). Some investigators have suggested that assessment of muscle thickness and pennation angle may indicate risk of lower body injury (Hoffman et al., 2007; Mangine et al., 2014), however, the costs associated with these measures may also preclude the widespread use of these assessments. Further, these studies have been unable to provide any consistent support to be used as a screening tool. Often, this is the result of a small sample size as many investigators have examined using an elite group of competitive athletes (Mangine et al., 2014). Although injury prevention remains an important goal, at present little agreement exists regarding the assessment tool that can successfully predict injuries associated with physical training.

A relatively new approach has begun to focus on examining movement patterns as opposed to isolated muscle groups or joints. This concept is based on evidence suggesting that dysfunction or injury in one part of the body may contribute to weakness, tightness or pain in another region (Wainner et al., 2007). As a result, a tool to assess an individual's functional movement characteristics has been developed (Cook et al., 2006a; 2006b). The functional movement screen (FMS) is a series of seven fundamental movements that has been designed to provide a measure of an individual's ability to perform complex athletic movements, and be a tool that can be used to predict musculoskeletal injuries in athletes. Several studies have reported that the FMS can predict injury risk in competitive athletes (Butler et al., 2013; Chorba et al., 2010; Kiesel et al., 2007), while others have been unable to support this claim (Okada et al., 2011; Schneiders et al., 2011). Recently, several investigations have been performed on military personnel. O'Connor and colleagues (2011), indicated that low scores on the FMS ($\leq$ 14) were associated with increased injury risk, however

Received: 07 January 2015 / Accepted: 20 April 2015 / Published (online): 11 August 2015

the sensitivity of this parameter was low. In a subsequent study, Lisman and colleagues (2013), examined 874 soldiers during a 6–10 week Marine Corp Officer Candidate course. They reported an odds ratio of 2.0 between an FMS score ≤ 14 and injury risk, however when they combined the FMS scores with performance on the physical fitness test (run times) the odds ratio increased to 4.0. Thus the combination of FMS and performance measures appear to provide additive value to injury prediction. Lehr and colleagues (2013), suggested that by incorporating FMS and dynamic balance test scores with demographic information and injury history, one may be able to accurately categorize risk of lower extremity injury

The potential uses of the FMS in military personnel to predict injury has important implications for identifying soldiers that may be at risk for injury, and allow for training interventions to reduce injury occurrence. To date, research in military personnel has focused primarily on male soldiers. However, the opportunities for female soldiers to serve in positions that were primarily reserved for male soldiers are increasing rapidly. Whether the FMS and/or an additional performance measure can be used as a screening tool for female soldiers is unknown. Since there is agreement that injury risk is multifactorial and population specific the purpose of this study was to examine the effectiveness of the FMS, and measures of speed, power and endurance to predict serious injury risk in female soldiers during an advanced physically demanding military training course.

Methods

Participants

One hundred and fifty-eight female soldiers [median (range): 19.0 (18.1 – 20.2 y); 1.64 (1.46 – 1.81 m); 56 (43 – 82 kg); 20.8 (16.1 – 32.0 BMI); 22.9 (14.9 – 31.5 % body fat)] from the Combat Fitness Instructor Course (CFIC) of the Israel Defense Forces (IDF) volunteered to participate in the study. Following an explanation of all procedures, risks and benefits, each participant provided her written, informed consent to participate in the study. All soldiers were free from any orthopedic or neurologic conditions for at least one month prior to the study. The IDF Helsinki Committee approved the research protocol. Soldiers that were participating in this course were in the military for approximately two months, and had previously completed basic training. They were considered to be conditioned (evaluated by the endurance Yo-Yo test, and participants had to reach a level of 5/6 in the tryout), and were selected to participate in this three month advanced training course. During the course the soldiers were garrisoned on the base and had access to medical personnel (medics and base physician) on a daily basis.

Procedures

All participants performed a battery of measurements during the first week of the course. Injury data was collected by a military physician throughout the three month course. The CFIC is an intense three month course that prepares soldiers to become combat fitness instructors in various combat units. During the course the participants enhance their knowledge of combat fitness instruction, and maintain their level of conditioning. The typical daily CFIC schedule involved both classroom (51% of time) and field-based/applied (49%) training. The field-based/applied training included both endurance and resistance training. In addition, soldiers continued their military training as well. Soldiers spent an average of 4.7 hours per day fulfilling the physical activity requirement. The intensity of the training program gradually increased. Total volume per week, calculated by summation of running and marching distances was 48km in the end of the course. The remainder of the daily schedule involved typical military work expected from garrisoned soldiers (e.g., guard duty, kitchen duty, etc.).

Anthropometric measures

Anthropometric assessments included height, body mass, BMI, and body fat percentage. Body mass was measured to the nearest 0.1 kg. Body composition was assessed via skinfold analysis. Percent body fat (%BF) was estimated via a 4-site skinfold test, using methodology previously described (Jackson and Pollock 1978) and has been found to be reliable (Aandstad et al., 2014).

Functional Movement Screen (FMS)

The FMS is a screening procedure aimed to assess the quality of seven fundamental movement patterns (squat, hurdle step, lunge, shoulder mobility, active straight leg raise, push-up and rotary stability) to identify potential physical limitation and asymmetry of an individual (Cook et al., 2006a; 2006b). Each movement is scored on a 0-3 ordinal scale; with a score of 3 indicating that the participant is free from pain and compensation; a score of 2 indicates a movement free from pain with some degree of compensation; a score of 1 is indicative of the individual failing to perform the movement as instructed; while a score of 0 is indicative of pain during the movement, regardless of the quality of the performance. Five of the movements are performed separately for the right and left side of the body, but only the lower score of the 2 sides was used as the final movement score. FMS scores can range from 0 to 21 for each individual. All FMS evaluations were performed by seven licensed physical therapists familiar with the FMS assessment. Members of the research team who were certified in the FMS (5 of the 7), and routinely use it for physical-performance testing performed all FMS assessments. In order to increase reliability, each physical therapist was responsible for assessing all the participants for only one of the fundamental movement patterns. The other members were trained by a FMS certified physical therapist, and assessed the straight leg raise and shoulder mobility movement stations. Good to excellent interrater agreement have been reported even when using novice raters (Minick et al., 2010; Teyhen et al., 2012).

Performance measures

Power performance: A battery of four tests was chosen to measure lower body power performance. These tests included a 10-m sprint, vertical countermovement jump (CMJ), Drop jump (DJ) and a single leg three hop test

(SLTH). Participants performed two 10-m sprints separated by a 2-min recovery period. Times were recorded by photocells (Microgate, Bolzano, Italy). Timing began on the participants' initial movement from a static two-point starting position with both feet behind the start line. The fastest time recorded was used in the data analysis. All performance measurements were performed by the same investigator.

To quantify vertical jump power, participants performed two consecutive CMJ with 30 sec rest between each jump. During each jump, participants stood with their hands on their waist at all times and were instructed to maximize the height of each jump. In addition, lower body power was also assessed through a DJ. During the DJ participants were asked to perform two drop jumps from a height of 40 cm. Participants were instructed to jump for maximal height while minimizing ground contact time. Flight times were measured for all jumping protocols by Optojump (Microgate, Bolzano, Italy), as well as ground contact time for both the DJ and SLTH. Flight time was recorded and used to calculate height reached during the jump, jump height was also used to calculate power (Bosco et al. 1982). The highest power achieved during the performances was recorded.

During the SLTH participants were instructed to perform a series of three continuous jumps using both an arm swing and a countermovement. Participants were also instructed to maintain minimal contact time with the ground. The SLTH was performed using both dominant and non-dominant legs. The SLTH was used to examine bilateral imbalances between the left and right leg strength and power. Both the total distance for the three jumps and each single step length were recorded for analysis.

Aerobic fitness: To assess aerobic fitness, all participants performed a 2K run. Time to complete the 2 km was recorded.

Injury follow-up: Data on all injuries was collected throughout the three month CFIC. All injuries were recorded in a digital medical record system. For each injury the diagnosis was provided by the base medical physician. Injuries were classified by location and types. A serious injury was defined as any type of injury that resulted in an absence from at least two day of training. Participants may have experienced more than one serious injury, but were only counted once in the "injured group". For group analysis only soldiers with serious injury i.e. the "injured group" were included.

Statistical analysis

Median and range were used to describe all the variables, due to non-normality of almost all parameters. Non-parametric tests (Wilcoxon, or Median test if the distributional symmetry requirement of the Wilcoxon test was not satisfied) were used to compare injured and non-injured groups. Chi-square or Fisher Exact Test and/or logistic regression (likelihood ratio-based) and ROC (Receiver Operating Characteristic) analysis was used to examine the simple (univariate) association between serious injury and various predictors, primarily based on those found significant in the group comparisons. An alpha level of $p < 0.05$ was used to determine statistical significance. All data are reported as median (range).

Results

A total of 145 injuries (serious and not serious) in 97 participants were reported during the three month course. Distribution of all injuries can be observed in Table 1. Eighty percent of the injuries occurred in the lower extremity, with the shin, knee, ankle and foot having the highest injury occurrence. Most of the injuries were diagnosed as overuse injuries (84%). These injuries resulted in a total of 37 soldiers (with a total of 43 serious injuries) missing at least 2 days of training. Most of the serious injuries were in the shin, ankle and knee (see Table 1). Comparisons of differences in %BF between injured and non-injured soldiers indicated that those soldiers that were injured had a significantly higher (Wilcoxon $p = 0.047$) %BF 23.7 (20.5-29.2) than those soldiers that did not report any injury 22.5 (14.9-31.5). No significant differences in body mass were noted between soldiers reporting an injury 56.7 (43.4-70.0) kg compared to those that did not 55.0 (43.0 -82.0) kg. Similarly, no differences were noted in the BMI of soldiers injured (21.14 [18.06-25.78] $kg \cdot m^{-2}$) compared to soldiers that were not injured (20.70 [16.16-32.03.14] $kg \cdot m^{-2}$).

FMS score distribution

The distribution of participant's scores showed that shoulder mobility was the movement with the highest frequency of 3 as a score (82%), and push-ups and rotary stability were reported to have the lowest frequency of 3 as a score (15%, 14% respectively). The median FMS score among all participants was 16 (range 2 – 21, inter-quartile range 13-17.25), with no significant differences observed between injured (16 (range 7-20, inter-quartile range;

Table 1. Percentage distribution of injuries and injured individuals, by injury location.

Injury Location	Percentage of injuries		Percentage of injured individuals	
	Total injury (n=145)	Serious injuries (n=43)	Injured (n=97)	Seriously injured (n=37)
Shin	36	56	45	62
Knee	20	9	30	10
Ankle	16	16	22	18
Back	11	5	15	5
Foot	6	0	8	0
Shoulder	5	7	7	8
Forearm	3	5	6	5
Wrist	2	0	3	0
Hip	1	2	2	3

Table 2. Median (Range) power and speed performance between injured (serious injuries) and non-injured soldiers.

Power performance	Injured	Non-injured	P value
10 meter sprint time (sec)	2.30 (2.13 – 2.62)	2.27 (2.03 – 2.69)	.057[a]
SLTH Left leg, Total distance (cm)	418 (254 – 559)	446.5 (199 – 584)	.029[b]
SLTH Left leg, Contact time (sec)	.33 (.17 – .42)	.32 (.20 – .47)	ns
SLTH Right leg, Total Distance (cm)	434 (287 – 536)	460 (263 – 546)	.047[a]
SLTH Right leg, Contact time (sec)	.33 (.27 – .57)	.31(0.18 – .50)	ns
DJ contact time (sec)	.40 (.27 – .56)	40 (.24 – .59)	ns
DJ Time Flight (sec)	.44 (.35 - .58)	.45 (.31 - .57)	ns
DJ height (cm)	23.8 (14.8 - 41.7)	24.7 (12.0 - 40.1)	ns
DJ Power (W/Kg)	23.07 (16.9 - 36.65)	23.0 (14.9 - 34.0)	ns
CMJ Time Flight (sec)	.40 (.34 - .50)	.42 (.28 - .51)	ns
CMJ height (cm)	20.1 (13.9 - 30.8)	21.2 (9.6 - 32.8)	ns
CMJ Power (W/Kg)	11.3 (8.5 - 13.8)	11.5 (7.5 - 15.9)	ns

SLTH; Single Leg Triple Hop Test, DJ; Drop Jump, CMJ; Counter Movement Jump. [a]Wilcoxon test, [b]Median test, ns; not significant.

12.75-18.0)) and non-injured (16 (range 2–21, inter-quartile range; 13.25-17.0)).

When analyzing the data using the recommended cutoff of score ≤14, Fisher Exact Test revealed no significant difference between injured and non-injured (p= 0.70). In addition, the recommended FMS cutoff only correctly predicted 42% of those soldiers that reported an injury, and correctly predicted just 63% of those soldiers that did not report an injury, indicating poor overall sensitivity and specificity. In addition 51.35 % of the injured group vs. 30.5% of the non-injured, scored zero in one or more movement patterns (Fisher's Exact Test: p= 0.029) with sensitivity 51% and specificity 70%.

A logistic regression and ROC analysis was used to determine an optimal cutoff score for the FMS. The logistic regression model was not significant (p=0.77) and the odds ratio was calculated as 0.98 (95% CI: 0.87 – 1.1). ROC analysis yielded an area under the curve (AUC) of only 0.51. The optimal cutoff found in our study was a FMS score of 12, yet this only provided a sensitivity of about 24% and specificity of about 83%. Using the recommended cutoff score of 14 provided a sensitivity of 42% and a specificity of 63%.

Performance measures

Lower body power performance comparisons between soldiers that were injured compared to soldiers that did not report any injury can be observed in Table 2. Soldiers that missed training days because of injury tended to be slower in the 10 m sprint at the beginning of the CFIC than soldiers that did not report any injury (Wilcoxon p = 0.057). In addition, SLTH distance for the left and right legs were significantly shorter for the injured soldiers compared to the soldiers not reporting any injury (Table 2).

Soldiers that were injured were significantly (Wilcoxon p = 0.044) slower (658 (578 – 776) sec)) in the 2K run at the beginning of CFIC compared to soldiers that did not report any serious injury (640 (488-804) sec).

Tests for univariate predictors of injury were based primarily on the significant parameters reported in the section above. Of those, only body fat %, 2K run and SLTH of the left leg were found to be significant predictors, and are reported in Table 3.

In addition, A significant predictor (p < 0.0176) was observed when the lower performing leg was compared to higher performing leg SLTH percentage was calculated (lower performing leg/higher performing leg*100)) for distance. Odds ratio (95% CI) = 1.04 (1 – 1.09) (0.017-46.5) AUC = 0.60, optimized sensitivity = 61%, optimized specificity=72%. Optimum diagnostic cutoff was 94%.

Discussion

The aim of this study was to examine various physical performance assessments and determine their ability to predict risk for injury in female soldiers. The results of this study do not appear to support previous investigations suggesting that the total score of FMS is an effective tool in predicting injury in soldiers (Lisman et al., 2013; O'Connor et al., 2011). In contrast to this study, the previous studies examined the predictive ability of the FMS in male soldiers only. Although FMS scores have not been reported to be affected by gender (Schneiders et al., 2011), this study appears to be the first attempt to examine the efficacy of the FMS in female soldiers. Despite our findings that the FMS is a poor predictor of injury in female soldiers participating in an advanced military course, we did find that injured soldiers scored a zero in one or more of the FMS movement patterns more so than soldiers that remained uninjured during training. As suggested by Cook (2010), pain during movement needs to be considered as an early warning sign. Soldiers that were injured complained about more pain (zero score) during the initial assessment, suggesting that a score of zero

Table 3. Tests for univariate predictors of injury.

Variable	p value	Odds Ratio (95% CI)	ROC AUC	Sensitivity	Specificity	Optimum diagnostic cutoff
Fat %	.047	1.156 (1.002-1.343)	.62	.9	.4	21.6%
2K Run	.022	1.007 (1.001-1.014)	.61	.4	.86	11:33min
SLTH (Left)	.013	.994 (.988-.998)	.63	.6	.6	430cm

p values and Odds Ratio 95% CI based on Likelihood Ratio parameters from logistic regression analysis. Sensitivity, Specificity, and Optimum diagnostic cutoff based on subsequent ROC analysis and tuning of logistic regression model. SLTH=Single Leg Triple Hop Test; ROC = Receiver Operating Characteristic; AUC = area under the curve.

could serve as a warning sign for potential injury.

Another potential explanation for the difference in this study and others investigating the efficacy of the FMS on military personnel may be related to of the soldiers' military training phase. In the previous studies (Lisman et al., 2013; O'Connor et al., 2011), examining military personnel subjects were students participating in college Reserve Officers Training Corps (ROTC) programs and reported to an officer candidate training course that occurred during the summer months between semesters at school. Thus, any weakness in functional movement and subsequent injury would be first seen during the course period. In contrast, the female soldiers examined during this study were examined following their 3-week basic military training course it is possible that a soldier who was already injured in this period was disqualified prior to their enrollment in the CFIC course.

Examination of lower body performance measures did appear to have a greater specificity and sensitivity to predicting injury during the CFIC than the FMS. Both %BF and SLTH distance were separate predictors of injury during this study. The relationship of %BF to injury risk is supported by some investigators (Gomez et al. 1998), but not in others (Barber Foss et al., 2012). The predictive ability of the SLTH distance and injury rate was significant as determined by the logistic regression performed in this study. This appears to be the first study to provide evidence of the predictive nature of the SLTH. Single-leg hops represent an activity which places high demands on the ability of the leg's muscles to generate movement and power during the landing and take-off phases (Rudolph et al. 2000). Previous studies have indicated that the SLTH is reliable and is correlated to stability (Ageberg et al., 1998; Hamilton et al., 2008), however others have suggested that it is unable to predict dynamic malalignment of the lower limb suggesting it may not be a suitable predictor for injury (Schmitz et al., 2009). The latter study though examined young athletes between the ages of 9 – 18 years and may not have achieved the same level of sensitivity as we reported in this study due to the maturation level of their subjects. In a study examining female athletes, single leg one hop (SLH) distance helped identify those at risk for lower back and lower extremity injury. The authors found that a side to side asymmetry of greater than 10 % during the jump was associated with a 4 fold increase in foot or ankle injuries (Brumitt et al., 2013). In an agreement with Brumitt et al., 2013, in the current study, side to side SLTH distance differences were found to predict injuries.

The difference in 2K run times between injured and non-injured soldiers in this study supported the results of Lisman and colleagues (2013). Others have also shown the predictive quality of endurance ability. Poplin and colleagues, (Poplin et al., 2014) recently reported that firefighters in the lowest category of aerobic fitness were 2.2 times more likely to be injured on the job than those in the highest fitness category, while Wyss and colleagues (2012), indicated that in Swiss army recruits endurance performance was able to predict injury in several, but not all military occupational specialties. This evidence might suggest that the CFIC tryout criteria for aerobic performance need to be reevaluated in order to reduce injury occurrence.

The ability of the neuromuscular system to produce maximal power is critical for variety of movements that involve sprinting, change of direction, fall avoidance and jumping. The ability to accelerate, as required in a 10-m sprint is an important aspect to these athletic movements (Lehance et al., 2009). The trend towards significantly slower 10-m sprint times in soldiers that were injured compared to non-injured support previous results observed in rugby players (Gabbett and Domrow, 2005). Although poor performance in the 10-m sprint may indicate low anaerobic performance, it may also indicate poor running mechanics that may predispose the soldier to a lower body muscle injury (Small et al., 2009).

It is important to note the limitations of this study. Soldiers more prone to injury may not have enrolled in the CFIC course, and this may have affected the lack of a relationship between FMS scores and injury rate. Our relatively small number of female soldiers compared to studies investigated male participants could have also contributed to the differences reported in other studies (O'Connor et al., 20011; Small et al., 2009). Future studies examining female soldiers should, if possible, employ larger cohorts, which will also enable use of multivariate models (which would have been severely under-powered in our study) in order to simultaneously test combinations of the suggested predictors.

Conclusion

Our results suggest that functional tests can be used to predict injuries. This prospective study indicates that the FMS total score is not a predictor of injury risk in female soldiers in an advanced training as CFIC. However, a score of zero, which indicates pain during movement, could serve as a warning sign for potential future injuries during training. Body composition, SLTH 10 meter sprint and 2K run do appear to differentiate between injured and non-injured soldiers, and the SLTH, 2K run and body fat % are each separate predictors of injury for female soldiers in the CFIC. While these show promise as predictors of severe injury, further research is needed to determine optimal test cut-offs.

Acknowledgements

This study was supported from a research grant from Medical Research of Israeli Defense Forces. The authors would like to thank the physical therapists that assisted in this study. In addition, the authors appreciate the effort of the head of Combat Fitness department, the commander of Combat Fitness School, and participants and staff of the IDF's Combat Fitness Instructor Course.

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Key points

- A total of 145 injuries were reported during the three month Combat Fitness Instructor Course in a female soldiers, 37 of these injuries resulted in absence from at least two days of training.
- FMS total score is not a predictor of injury in female soldiers in a CFIC. However, a score of zero, which is indicative of pain during movement, could serve as a warning sign for potential injury.
- %BF, SLTH, 10 meter sprint, 2K run and number of zero scores in FMS appear to differentiate between injured and non-injured soldiers
- SLTH, 2K run and body fat % are each separate predictors of injury for female soldiers in the CFIC

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