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Tomes, Colin; Lewis, Matt

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Effects of Personal Body Armor on Functional Movement Capability

COLIN D TOMES^{†1}, and MATTHEW D. LEWIS^{‡2}

¹Faculty of Health Sciences and Medicine, Bond University, Robina, QLD, AU; ²Department of Health, Nutrition and Exercise Science, Messiah College, Mechanicsburg, PA, USA

[†]Denotes graduate student author, [‡]Denotes professional author

ABSTRACT

International Journal of Exercise Science 12(6): 536-546, 2019. The Functional Movement Screen (FMS) is a tool used to assess fundamental movement patterns and has been utilized to determine movement readiness of tactical athletes. However, tactical athletes rarely perform tasks without load carriage, and limited research evaluating loaded tactical personnel via the FMS has been conducted. Therefore, the primary aim of this study was to determine if ballistic vest wear results in movement deficits as evaluated by the FMS. A convenience sample of college students ($n = 31$) completed test sessions in loaded and unloaded conditions. Subjects completed each FMS movement and indicated perceived effort on a Visual Analog Scale (VAS). The Sign test was used to determine difference between FMS composite and component scores collected under each condition. The level of significance was set at $p < 0.05$. A significant ($p < 0.001$) difference in FMS composite scores was identified between loading conditions. Significant FMS score changes between load conditions were identified in the dominant side in-line lunge ($p < 0.01$), non-dominant side in-line lunge ($p < 0.01$), dominant shoulder mobility ($p < 0.01$), non-dominant shoulder mobility ($p < 0.01$), and non-dominant rotary stability ($p = 0.01$). Our data indicate ballistic vest wear reduces overall functional movement capacity, as well as mobility related to certain individual FMS components in the population examined. Additionally, results suggest subjects may better tolerate additional load carriage when completing tasks on their dominant side. These results raise important questions regarding design, fit, and task completion for tactical athletes utilizing a ballistic vest.

KEY WORDS: Ergonomics, tactical personnel, movement screening, mobility, occupational fitness, load carriage

INTRODUCTION

The Functional Movement Screen (FMS) is an evaluation tool for quantitative, categorical assessment of fundamental movement patterns (2). Scoring is based on performance of seven movement patterns, each requiring unique combinations of balance, mobility, stability, and neuromuscular control, providing a global analysis of the dynamic body (2). In addition, the FMS helps to determine the subject's functional readiness to participate in dynamic movement patterns, an essential component of tactical athlete occupational performance (2). The FMS is also useful in the identification of neuromuscular deficits, movement asymmetries, and subsequent compensatory movement strategies (8). The current literature contains evidence linking composite scores below 14 (of a maximum score of 21) to a higher risk of non-contact

musculoskeletal injury (8). In order to reveal areas of deficiency within the kinetic chain, the FMS relies on a concept of proximal stability facilitating functional distal mobility in athletic activities (14). For this reason, the FMS has been utilized repeatedly in studies assessing both athletic and tactical populations with respect to their readiness for higher-level functional activity (8, 14).

However, tactical athletes will rarely perform occupational tasks without load carriage, and the weight of these loads can be significant. Loads less than 3.5 kg for the general duty law enforcement officer would be unusual (14), while loads commonly reach 22 kg in specialist police (15) and exceed 40 kg in certain circumstances, such as specific forcible entry loads (14). This upward trend in load carriage weight is due not only to the increasing complexity of modern tactical engagements but increased emphasis organizations are placing on improvements in survivability (14). Given that the additional load in the form of body armor has proven to be effective in reducing fatalities in military environments, use is becoming more widespread amongst Law Enforcement Operators (LEO) (14).

Current research within the military population has indicated load carriage as a causative factor in musculoskeletal injuries (10, 19, 20). Incidence of low back pain, lower limb stress fractures, neurological injuries including brachial plexus palsy, integumentary injuries including chaffing and blisters are all significantly elevated with loads exceeding 10% of the carrier's body mass or 13.61 kg (19). The effect is compounded if loads are worn for more than 4 hours (19). Mission capability and performance can also be adversely affected by load carriage due to reduced carrier mobility, increased time in accomplishment of functional tasks, elevated physiological exertion on duty, and biomechanical decompensation (23). While body armor provides protection to the wearer it also imparts risk and physiological cost (1, 18, 21).

While literature has extensively described the above concerns and the increasing use of body armor systems, the impact of body armor on functional performance capabilities as assessed by the FMS is still largely unknown (23). The FMS was selected for this study because it is affordable, can be used to assess large numbers of personnel in a time efficient manner, and can be easily implemented, with training, by individuals within a tactical unit (4, 14). The investigators hypothesized that a significant difference in FMS scores and perceived effort would be present between a loaded and unloaded condition in a population of healthy and physically active college students. Therefore, the purpose of this study was to determine if use of a ballistic vest resulted in functional movement deficits as evaluated by the FMS, and differences in perceived exertion as evaluated by a VAS, in the test population.

METHODS

Participants

A convenience sample ($n = 31$) of college students, 20 males and 11 females, volunteered for participation. Collected descriptive statistics for the subjects were: age (21.29 ± 1.94 yrs.), height (172.49 ± 10.52 cm), and mass (77.09 ± 13.80 kg). Exclusion criteria were as follows: musculoskeletal injury within previous six months or any chronic musculoskeletal or

neurological condition. Subject inclusion criteria were ages between 18 and 30 yrs., current regular participation in physical activity meeting American College of Sports Medicine (ACSM) guidelines for healthy adults (7), and willingness to participate in two test sessions under video surveillance. All data collection was performed within the athletic training facility at the host institution. Institutional Review Board approval was obtained prior to the start of the study.

Protocol

The present study utilized a crossover design. Prior to participation, informed consent was obtained from volunteer subjects. Next, subjects were instructed to select two FMS trial appointments at least 24 hours apart, during which one was performed in the loaded (LD) condition, and the other in the unloaded condition (UL). The order of testing (loaded or unloaded first) was randomized via coin flip. Subjects completed a paper-based visual analog scale (VAS) following each movement under both conditions.

Prior to the start of each screen, subjects were familiarized with the testing protocol using standard procedures published by the creators of the FMS (2, 3). The seven movement tasks of the FMS include the deep squat (DS), hurdle step (HS), in-line lunge (ILL), active straight leg raise (ASLR), shoulder mobility test (SMT), trunk stability push-up test (TSP), and rotary stability test (RST) (2, 3). For loaded trials, the ballistic vest (Condor, Irwindale, CA) was fitted to the subject by the primary investigator. Mass of the vest was 7.1 kg, consisting of one ceramic plate in the front, one in the rear, and simulated soft plate backers. Because modern ballistic protection systems are intended to accommodate a wide variety of personnel build types and sizes, only a single size of plate and vest was necessary for this trial. Proper fit was defined as coverage by the ballistic plate at the most inferior portion of the clavicles and secure enough to the thorax to limit vest movement during testing without interfering with normal breathing.

The FMS measures the motor control of fundamental movement patterns by categorizing the participant's performance on each movement (bilaterally where applicable) using a zero to three ordinal categorization (2, 3). A score of three (3) is awarded if the movement is performed as instructed, a score of two (2) is awarded if the movement is successfully completed, but with a compensatory strategy, and a score of one (1) is awarded if the individual is unable to complete the movement. A score of zero (0) is awarded if the participant experiences pain at any time during movement, regardless of overall performance (2, 3). For detailed instructions regarding the completion and scoring of each FMS component, please refer to previous publications (2, 3). At the conclusion of each exercise, subjects indicated their perceived effort on a VAS scale. The scale used was paper-based, consisting of an unlabeled 10 cm line adjacent to each exercise. Visual analog scales have previously been reported to be a reliable and valid measure of self-reported pain and fatigue (22). The left margin indicated low difficulty and the right indicated high difficulty.

Scores from the seven movement patterns comprising the FMS were summed and a composite score was obtained for each subject, using the lower of the two scores for bilateral movements in the event of an asymmetry, which was then also recorded. Five of the seven movements are scored unilaterally (2, 9). Additionally, analysis was performed on dominant and non-dominant

scores individually, providing the opportunity to capture differences between component scores in addition to the composite score.

The FMS has been reported to have intra-rater test-retest and inter-rater reliability of an ICC_{3,1} of 0.76 (95% CI: 0.63, 0.85) and an ICC_{2,1} of 0.74 (95% CI: 0.60, 0.83), respectively (6). Standard error of the measurement of the composite scores have fallen within 1 point, and MDC₉₅ values of 2.1 and 2.5 points on the 21-point scale for inter-rater and intra-rater reliability, have also been reported (13). The inter-rater agreement of component scores is known to range from moderate to excellent ($\kappa_w = 0.45-0.82$) (13).

Statistical Analysis

Data was collected and analyzed by both the primary investigator and co-author. FMS scoring was determined by the primary investigator, with discrepancies adjudicated by an experienced FMS practitioner. The Sign Test for ordinal and non-parametric data was selected for FMS component score analysis. The FMS scoring system is ordinal in nature and the Sign Test allows for identification of a simple difference between two sets of scores, in this case each FMS component in an unloaded or loaded condition. This test was performed in Minitab 17 (Minitab Inc., State College PA) on the absolute difference in scores between subjects for both the unloaded-loaded condition and dominant-non-dominant side. FMS composite scores were also analyzed via the Sign Test. VAS data was analyzed in SPSS for Mac (IBM, Armonk, NY) using a Wilcoxon Signed ranks test.

RESULTS

A *post hoc* power analysis conducted using G-Power version 3.1.9.2 for Windows (5) calculated a power 0.99. This was done based on the reported means and standard deviation for the FMS composite score between conditions, an alpha level of 0.05 and Cohen's d_z of 1.0. No scores of "0" were recorded during the course of data collection.

Significant load condition differences were identified for the In-Line Lunge (ILL) bilaterally ($p < 0.01$), Shoulder Mobility Test (SMT) bilaterally ($p < 0.001$) and the non-dominant rotary stability test (RST) ($p = 0.01$). For FMS scores within the same loading condition, dominant (DM) to non-dominant (ND) differences were not significant. Results of the statistical analysis for FMS data are reported in Figure 1.

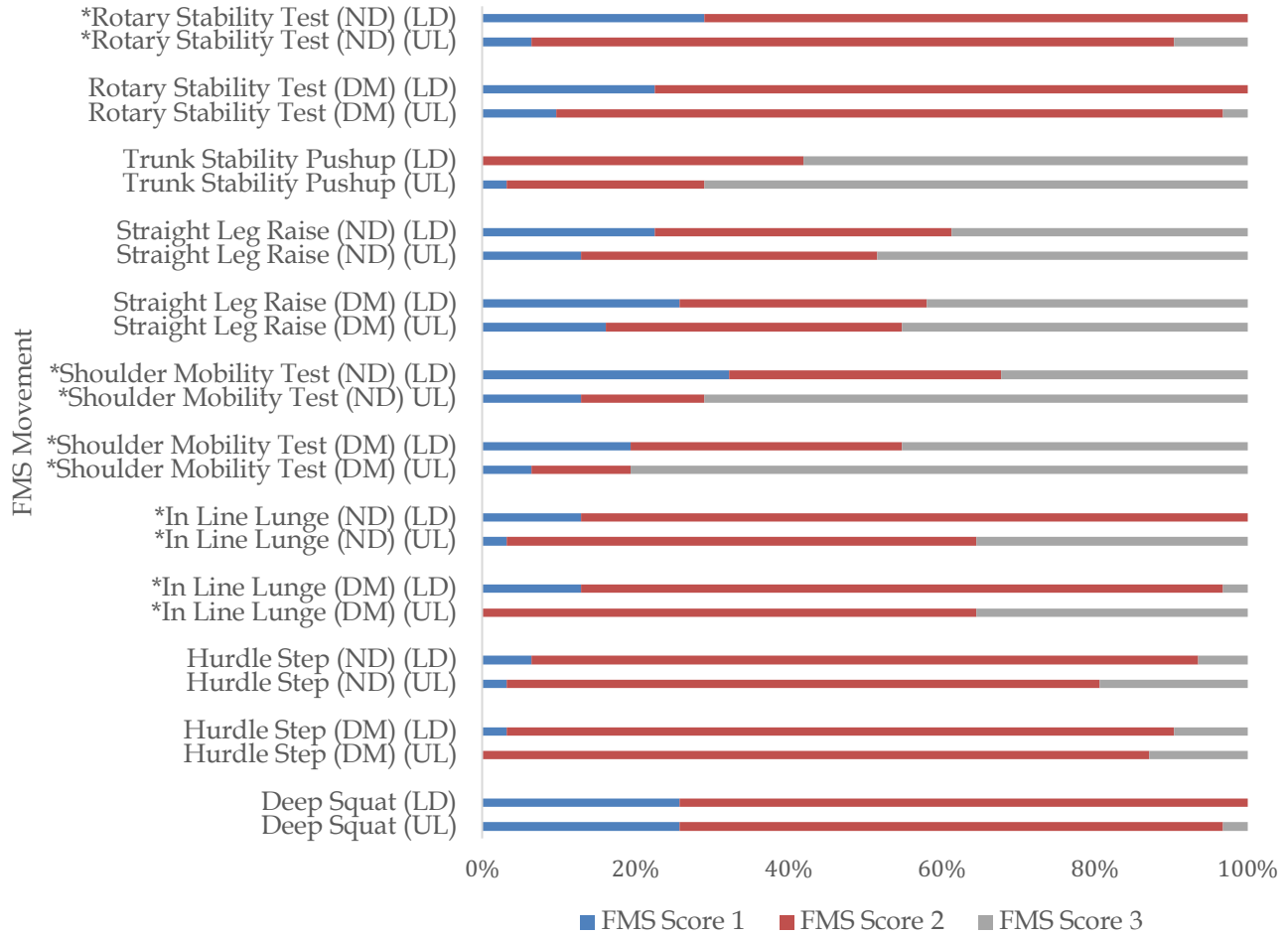


Figure 1. Comparison of FMS scores between load conditions. (DM) – Dominant Side, (ND) – Non-dominant Side, (LD) – Loaded, (UL) – unloaded, * indicates significant difference between loading conditions ($p < 0.05$)

A Shapiro-Wilk test was performed on VAS data, revealing they were not normally distributed. As a result, the Wilcoxon signed ranks test was performed on the pairs of VAS data per movement to determine significance and Cohen’s d analysis was then performed on those pairs of data that reached significance to determine effect size. An alpha level of .05 was selected *a priori*. The Deep Squat ($p = 0.031$, Cohen’s $d = 0.31$ (small-medium)) and Shoulder Mobility Tests (Dominant side, $p = 0.002$, Cohen’s $d = 0.41$ (small-medium), Nondominant side $p = 0.001$, Cohen’s $d = 0.54$ (medium)) bilaterally reached significance. The full results can be found in Table 1.

Table 1. Statistical analysis of VAS data.

Movement	Unloaded Score (Mean \pm SD)	Loaded Score (Mean \pm SD)	<i>p</i> -value
Deep Squat	2.64 \pm 2.27	3.3 \pm 2.04	0.031*
Hurdle Step (DM)	1.41 \pm 1.21	1.71 \pm 1.45	0.38
Hurdle Step (ND)	1.57 \pm 1.40	2.04 \pm 1.90	0.124
In Line Lunge (DM)	1.88 \pm 1.54	2.27 \pm 1.64	0.241
In Line Lunge (ND)	1.92 \pm 1.71	2.18 \pm 1.49	0.334
SMT (DM)	1.71 \pm 2.30	2.63 \pm 2.17	0.002*
SMT (ND)	2.08 \pm 2.48	3.38 \pm 2.34	0.001*
SLR (DM)	1.52 \pm 1.60	1.69 \pm 1.51	0.211
SLR (ND)	1.45 \pm 1.61	1.82 \pm 1.68	0.057
TSP	2.49 \pm 2.00	3.4 \pm 2.56	0.053
RST (DM)	4.8 \pm 3.06	5.01 \pm 2.85	0.614
RST (ND)	4.39 \pm 2.87	4.83 \pm 2.87	0.333

(DM) – Dominant Side, (ND) – Non-dominant Side, *indicates $p < 0.05$

Additionally, composite FMS scores differed significantly between loading conditions as analyzed using Student's *t*. The mean loaded FMS score was 14 ± 2 and the mean unloaded composite FMS score was 16 ± 2 ($p < 0.01$, Table 2). Cohen's *d* analysis was performed on the composite score, yielding an effect size of 1.07 (large). For all testing, the level of significance was set at the $\alpha < 0.05$ level. Finally, changes in the number of movement asymmetries for each FMS movement are reported by loading condition in Table 2.

Table 2. Analysis of movement asymmetries.

Movement	Number of Asymmetries (UL)	Number of Asymmetries (LD)	Percent Change
HS	5	6	+3
ILL	5	3	-6.42
SMT	6	9	+9.68
SLR	6	6	-
RST	5	11	+19.35

(UL) – Unloaded condition, (LD) – loaded condition

DISCUSSION

Significant functional movement deficits and increased perception of effort were present in the loaded condition. Specifically, functional capability of the upper extremity was significantly affected in all categories considered (VAS, FMS DM/ND, FMS UL/LD), indicating that a ballistic vest presents significant impairment to carrier activities involving the shoulder girdle. The large (1.07) effect size calculated for the difference between the FMS composite scores of the two loading conditions indicates a real-world change in overall FMS performance when the ballistic vest was utilized in the test population.

Figure 2 demonstrates the impairment presented by the vest in shoulder range of motion. Previous research investigating this phenomenon using a 12-camera motion lab reported trunk rotation changes based on presence of vest while completing certain tasks (i.e. ammo box lift

and place) (12). The agreement of these findings suggests that the FMS may be sensitive enough as a field test to obtain reliable and valid results as compared to a more sophisticated investigative method.



Figure 2. Loaded condition shoulder mobility test. The vest impairs advancement of both extremities, limiting functional range of motion and resulting in a score of 1.



Figure 3. Loaded condition in-line lunge. Note that the vest may affect proper positioning of vertical down and mass applied to torso above the center of gravity may affect balance. This attempt would score a 1.



Figure 4. Loaded condition rotary stability test. Mass applied to the subject by the vest may lead to unwanted trunk rotation as base of support is reduced during this activity.

Changes in wearer perception during completion of FMS movements, especially the SMT (Figure 2) and DS, are more likely due to ergonomic restriction of the shoulder girdle than the resistance imparted by the mass of the vest, especially given that both movements require substantial shoulder range of motion. Previous research evaluating a fatiguing, and non-overhead squat movement with a ballistic vest using 3D motion analysis also observed increased movement difficulty (17) suggesting that total body/LE/trunk functional movement may be limited by utilization of a ballistic vest in combination with wearer perceptions. Additionally, the change in subject assessment of movement difficulty may have been partially due to the added mass of the ballistic vest. The reported small-medium effect sizes indicate a meaningful difference between load conditions beyond statistical significance.

Ultimately, due to the requisite shape of common ballistic vests in providing adequate coverage, these results indicate tactical athletes may experience difficulty when attempting to access equipment carried on the back while operating in the field, or while completing overhead tasks. Therefore, training should address shoulder mobility, and particular care should be given to the shoulder joint by the multidisciplinary care team.

A composite score below 14 has been reported to increase injury risk, even in elite athletes (8). More than a quarter, 27.27% ($n = 6$), of subjects scoring above 14 in the unloaded trial scored below 14 in the loaded condition. This evidence suggests that body armor, independent of other load carriage, may contribute to injury risk in tactical athletes due to increased perceived exertion by the wearer and functional movement restrictions as identified by the FMS.

When loaded, the RST (Figure 4) FMS score decreased on the non-dominant side, and although dominant side scores decreased, the change did not reach significance. This result indicates that a larger sample size is necessary to detect dominant side changes between load conditions in the RST, or that functional movements relying on trunk stability are asymmetrically impaired when an individual is wearing a ballistic vest.

This study was not without its limitations. Our participants were recruited from the university gym, and involvement was based on willingness to participate, which could introduce a

volunteer bias. Additionally, the Hawthorne effect may have played a role in overall performance, as participants were aware of the video recording taking place throughout each screen. Finally, our data are based on fit, but not tactically trained personnel. Because none of our participants were familiar with ballistic protection, it is quite possible that the novelty of the vest played a role in the observed FMS score differences, although if this were the case, it would be expected that VAS scores would have differed more between load conditions. Previous research has also identified that standardized load carriage mass causes a disparate ratio in load carried to body mass, disadvantaging wearers with lower body mass (11, 16), which may explain the magnitude of some of our results. Because previous research has found an association with movement asymmetry as identified by the FMS and risk of injury, even in elite athletes (8), this specific phenomenon should be investigated further in a tactically trained participant sample. Finally, it is worth noting that the large effect size between the two loading conditions for the FMS composite score may be reduced in a population of tactically trained subjects due to their familiarity and experience with completing functional movement and operational tasks while wearing a ballistic vest.

Based on the results of the present study, additional research in the area of ballistic vest usage in tactical personnel is warranted. Specifically, the identified functional movement impairments suggest potential for considering tactical vest redesign in terms of mass and bulk. Due to the subjective increase in effort with some FMS tasks, further research specific to load carriage in tactical athlete fitness training programs may be indicated.

The results of the present study, as well as those of previous research, indicate that usage of a tactical vest with ballistic protection impairs functional movement and exacerbates movement asymmetries, both of which have been postulated to increase on-duty injury risk. Safety of tactical personnel is of the highest priority, however, protection from external threats cannot be the only consideration; the ability to evade threats, complete operational tasks efficiently and mitigate non-threat related injury must also be considered to optimize performance and effectiveness of tactical personnel equipped with ballistic protection.

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