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The Effects of Torso-Borne Loads on Functional Movement Patterns

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ABSTRACT

International Journal of Exercise Science 17(7): 975-984, 2024. Functional movement patterns are an important aspect of everyday life, and a growing area of interest for determining the risk of injury and performance ability. Police, military, and fire personnel often carry torso-borne loads that increase the demands on the body while performing occupational tasks. The purpose of this study was to compare movement screen results in both a loaded and unloaded condition to identify potential effects that torso-borne body armor load carriage may have on tactical performance. This provided objective data on the effects that external loads may have on functional movement patterns. Twenty-four physically active participants (11 males, 13 females) volunteered and completed the Fusionetics™ Movement Efficiency Test (FMET) in two conditions: loaded (wearing a 13.5 kg tactical vest) and unloaded, in a counterbalanced order. Participants were video recorded performing these movements and scored later. The overall scores, on a scale of 0 to 100, showed a large, statistically significant decline in functional movement pattern quality from the unloaded to the loaded condition (12.6±7.3 points, $p<.001$, $d=1.8$). In the subscales, statistically significant declines ($p<.001$) were seen in the 2-leg squat ($d=0.8$), push-ups ($d=1.1$), shoulder movements ($d=2.1$), and trunk movements ($d=0.9$). There was no significant effect of load on the cervical movements or 1-leg squat. Overall, torso-borne body armor loading decreased functional movement pattern quality, suggesting the potential benefit of performing loaded movement screens on tactical athletes.

KEY WORDS: Tactical athlete, injury risk, movement screening, load carriage

INTRODUCTION

Personal protective equipment is worn by tactical personnel (e.g. police, military, fire, and rescue personnel) to minimize risk to the wearer's health and safety. Such equipment may include torso-borne loads, such as body armor and stab-proof vests (3). Although these torso-borne loads provide critical protection during mission essential tasks, it may interfere with overall functional movement patterns due to the inherent restriction these loads impose on the torso and surrounding joints (20). However, little research has quantitatively assessed functional movement patterns under load.

These tactical personnel may perform occupational tasks that include climbing, lifting, and low crawling under load (13). However, these torso-borne loads have been shown to decrease range of motion (ROM) in both the upper and lower extremity (20). For example, a 16% decrease in ROM was observed for the shoulder forward cross body extension when wearing standard body armor with front, back, and side plates (20). This movement pattern is commonly required to operate controls in a vehicle or aircraft with subjective impairments noted during shooting in the prone supported and unsupported positions (20). Hip flexion ROM, measured via inclinometer, is impaired by 5% while wearing the same configuration, which may impede running to cover, lifting a leg over obstacles, and transitioning from prone to standing positions (20).

Functional movement patterns are often defined as movements that simulate the needs of real-life activities, with no unwanted compensatory movements (18). There is evidence to suggest that identifying and correcting for deficits in functional movement patterns may predict and minimize risk of injury during performance (10, 22). Therefore, functional movement testing has become increasingly popular as a means of identifying risk of injury and performance ability (3,4). Poor ROM or deficiencies in functional movement patterns y can have negative effects on tactical performance, and the effect of loading on assessment of functional movement patterns is not well understood.

One such test, the Functional Movement Screen (FMS), has gained popularity among sport and tactical athletes as a tool for quantitatively assessing seven fundamental movement patterns (5). Although the FMS is seen as a reliable means of screening functional movements for activities of daily living, some have questioned its translation to the physical demands of tasks performed in tactical populations (19). When similar movements to those in the FMS assessment are performed under load, scores are altered, reducing the overall construct validity of the FMS (1). Alternatives to the FMS, such as the Fusionetics Movement Efficiency test (FMET), have been shown to be reliable in the literature, but it is unclear whether the FMET is sensitive to changes in functional movement patterns under load (7). Its integration of discrete individual movement compensations in its scoring algorithms may make the FMET more sensitive to deviations in functional movement patterns that could make it a more valid and tactically useful assessment of overall movement quality (7).

Therefore, the purpose of this study is to assess differences in functional movement patterns during a movement screen test when unloaded and when wearing torso-borne loads. We hope to identify the potential effects of torso-borne load carriage on functional movement patterns and provide objective data on the effects of external loads.

METHODS

Participants

Twenty-four physically active adults (age: 25 ± 3 years, height: 170 ± 11 cm, weight: 74 ± 22 kg) were recruited for this study. Per American College of Sports Medicine guidelines, participants were defined as "physically active" if they participated in a minimum of 30-minutes of moderate intensity aerobic physical activity for five days per week or performed a minimum of 20-minutes of vigorous intensity aerobic activity for three days per week. We estimated that with a given alpha of 0.05 and statistical power 0.95 that a predicted meaningful pairwise effect size of d=0.8 would be statistically significant if 23 subjects completed the investigation. This was determined meaningful based on the limited experience that the sample had with torso-borne loads, given a sample only offers an approximate estimate of the magnitude of the effect in the population (17, 23). Sample estimations were determined a priori using G*Power 3.1.9.2. Participants were included if they were 18 years or older and if they met the minimum American College of Sports Medicine physical activity standards. Exclusion criteria included any musculoskeletal injuries over the past six months. This research was carried out fully in accordance with the ethical standards of the International Journal of Exercise Science (21). Each participant volunteered to participate in the study and was informed of the benefits and risks of the investigation prior to signing an institutionally approved informed consent document. The study was conducted in accordance with the Declaration of Helsinki and approved by the Institutional Review Board of the University of Nevada Las Vegas for studies involving humans.

Protocol
Prior to data collection, participants refrained from any strenuous physical activity for at least 24 hours and were instructed to wear fitted exercise attire. Upon arrival, height and weight were recorded for each participant, followed by a brief overview of the study procedures. Height and weight were recorded using a stadiometer and beam scale, respectively. Participants completed the movement screen in two conditions: the loaded condition was performed in a body armor carrier (Shellback Tactical, Cayce, SC) with Level IIIA full body and side plates (RMA Armament, Centerville, IA; figure 1), and dummy AR15 magazines (Blueguns, Melbourne, FL). The body armor carrier worn was chosen as it is most consistent with body armor worn by military and law enforcement. The total weight of the loaded condition was 13.5 kg. The unloaded condition consisted of the participant wearing standard athletic clothing. The order of the conditions was counterbalanced to avoid order bias.

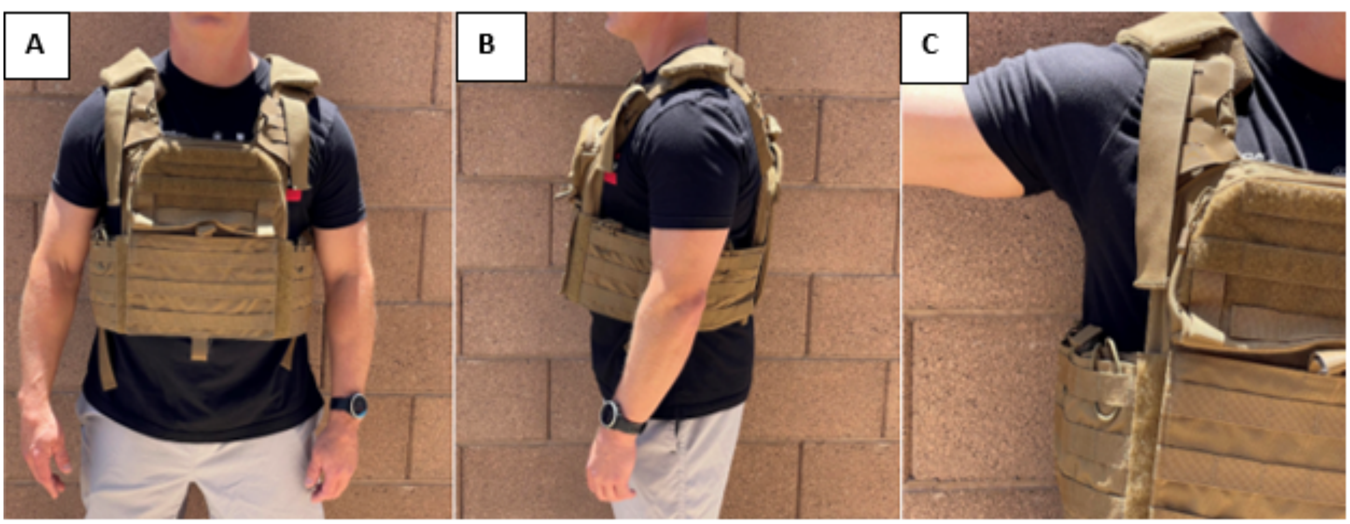

Figure 1. Placement of 13.5 kg Shellback Tactical body armor carrier in loaded condition (A) frontal view; (B) lateral view); (C) frontal view including fit of body armor at the shoulder.

We used the Fusionetics™ Movement Efficiency Test (FMET; Fusionetics™ Human Performance System, Milton, GA) to assess functional movement patterns. This assessment was found to have excellent intra-rater test-retest reliability overall, and each of the individual movement sections had fair-excellent intra-rater test-retest reliability (ICC=0.55-0.84) (7). The FMET is graded based on specific movement compensations commonly observed during the movements in each subtest. Movement compensations refer to any type of change in posture or additional movement that occurred along the kinetic chain to complete the movement. The FMET consists of seven sections: 2-leg squat, 2-leg squat with a heel lift, 1-leg squats, push-ups, shoulder movements, trunk/lumbar spine movements, and cervical spine movements. There are 60 compensations scored across all 7 sub-tests of the FMET, as previously described by Hanes et al. (16). The overall score is based on the cumulative observation of movement compensations, which is calculated and ranked from 0 (worst) to 100 (best) using a computer-based proprietary algorithm. The FMET was administered by a Fusionetics™ certified practitioner who administered the unloaded and loaded functional movement test for each participant.

Participants performed five repetitions each for the 2-leg squat, the 2-leg squat with heel lift, and the 1-leg squat as recommended by the Fusionetics™ guidelines. Three repetitions were performed for the push-up to standardize the ability to complete the push-ups twice in a single session. Many of the subjects would not be able to perform 10 pushups as required by the FMET while wearing body armor. The shoulder, trunk/lumbar, and cervical spine movements were performed one time on each side as a single repetition was sufficient for video recording. Participants were instructed to perform the movements in a way most comfortable and natural to them during both conditions. No cueing was provided to the participants outside of the published FMET verbal directions (12). Three cameras (Microsoft Surface Go; Model 1824) were set up around a partition wall to capture the performed movements: one facing the wall, one to the left, and one to the right of the wall to ensure front, back and side views of the movements were captured. Each movement pattern was video recorded from a front, side, and/or rear view. Participants were reminded that they would be asked to perform the discussed movement patterns while being video recorded.

Each subtest was scored in real time, where a "YES" was marked if a compensation was observed or if the participant was unable to perform the movement. A "NO" marking implied the movement was completed successfully without demonstrating any compensation. Following the real time scoring of each movement screen test, the tester reviewed each video and verified each score by marking either "yes" or "no" based on the presence of the compensations, which have been published previously (16). The scores of each subtest were then entered into the Fusionetics™ Human performance system, in which the FMET test score was calculated using the proprietary algorithm.

Statistical Analysis

Dependent t-tests were used to compare the loaded and unloaded FMET for the overall score and each of the seven sections of the test using SPSS Statistics (IBMBuild 1.0.0.124 6). Results are reported as the mean ± SD. An alpha level of 0.05 was used to determine statistical significance.

Cohen's *d* effect sizes of each dependent variable were calculated for the loaded and unloaded data set (9), and the Hopkin's scale was used for interpretation (23).

RESULTS

All 24 participants (11 males, 13 females) completed the FMET. Some participants could not perform certain movements in either condition, and are therefore not included in the subscale analysis. The overall mean scores showed a statistically significant decline in functional movement pattern quality when loaded (mean decrease 12.9±7.3; p<.001) with a large effect size (d=1.8; figure 2). For the subscales, large effects were also detected, with statistically lower scores (p<.001) seen in the 2-leg squat (d=0.8) push-ups (d=1.1), shoulder movements (d=2.1), and trunk movements (d=0.9) when performed in a loaded condition vs. the unloaded condition. A statistically lower score was seen with the 1-leg squat, and the effect size was moderate (d=0.7; p=.003). The 2-leg squat with heel lift and the cervical movements did not change with loading (d=0.1; p=.524 and d=-0.1; p=.534, respectively).

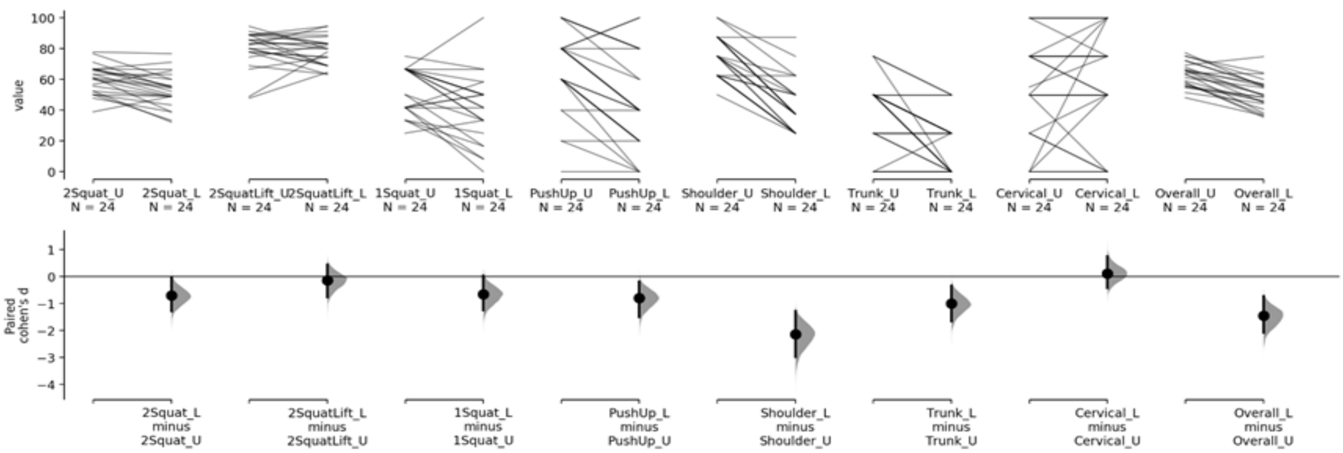

Figure 2. The paired Cohen's *d* for eight comparisons are shown in the above Cumming estimation plot. The raw data is plotted on the upper axes; each paired set of observations is connected by a line. On the lower axes, each paired mean difference is plotted as a bootstrap sampling distribution. Mean differences are depicted as dots; 95% confidence intervals are indicated by the ends of the vertical error bars. Statistically significant differences (p<0.05) are denoted by an asterisk.

DISCUSSION

The purpose of this study was to assess changes in functional movement patterns during a movement screen when wearing torso-borne loads. Overall, torso-borne loads negatively influenced functional movement patterns, as demonstrated by the large differences in the overall scores (d=1.8).

The largest difference was attributed to upper extremity movement patterns, most notably at the shoulder (d=2.1; Figure 2). The scores of two participants remained the same in both conditions, with the remaining 22 participants demonstrating lower scores in the loaded condition. Previous research has shown that reduced ROM in the shoulder is a potential cause for shoulder injury in male police officers (8). However, we believe this may have been due to reasons other than the weight of the vest; the fit may have contributed to the decline in movement quality at the shoulder (Figure 1C). Improperly fitted body armor has consistently been shown to decrease ROM in the upper extremity and increase the likelihood of overexertion and injury, particularly when body armor is oversized (3, 15). For example, there is a 17° decrease in shoulder forward extension ROM when wearing properly fitted body armor. However, when wearing larger fitted body armor, ROM decreases by an additional 5°, constituting an overall decrease of 22° at the shoulder (15). Body armor should be properly fitted to accurately assess its effects on functional movement patterns. Additionally, future studies should examine functional movement patterns while wearing the vest without the added plates to assess the effect of fit separate from load.

Reductions in upper extremity ROM have been shown to translate to reduced performance of occupationally relevant tasks, and these tasks can define survivability among tactical personnel. Our results revealed that a reduction in shoulder mobility limited the efficiency of performing other occupational movements, such as the push-up (d=1.1). When police officers wore stab resistant body armor plus ~8 kg of additional weight, there was a 13-43% decrease in performance of simulated occupationally relevant tasks that declined an additional 6-16% following a loaded 5-minute run (8). Tasks affected by the addition of load included an acceleration task, chin-ups, grappling, and a maneuverability task. Additionally, deficiencies in functional movement patterns at the trunk (d=0.9) were observed in the loaded condition. Limited trunk movements associated with torso-borne loads can be attributed to stiffness and bulk of the load and cause reductions in participant's time to exit a low car seat and completion of a ground mobility task (8). Those findings further suggest that the fit or design of certain tactical vests in addition to load may lead to decreased occupational performance. This decrease is also described during marksmanship tasks, in which speed of target engagement has been found to be 0.2 seconds slower when wearing a larger body armor configuration compared to a baseline, unloaded configuration, or a smaller body armor configuration (14). Given the relationship between occupationally relevant tasks and reduced upper extremity ROM, it is imperative to evaluate functional movement patterns relative to the fit and load of torso-borne body armor loads.

Interestingly, when the 2-leg squats were performed in our study, some participants' scores improved or stayed relatively the same under load (n=6). The majority of the sample, however, demonstrated compensations under the loaded condition that had not been present when unloaded. Given this discrepancy, this may be related to the relative strength of the participants. When firefighters wore an 18.6 kg weight vest during a squat assessment, there was substantial variation in compensatory responses across participants (11). Upon descent into the squat, the firefighters adopted an upright trunk posture in addition to decreased hip to ankle distance and increased trunk angle on squat ascent. However, although there were statistically significant load effects across the participants, these movement patterns were not performed by all participants (11). When the squat is assessed as a strictly lower body movement, variability of movement compensation exists, insinuating the influence of potential relative strength factors.

Unlike the FMET, the FMS consistently reported changes in functional movement pattern quality during the deep squat (4, 24). However, this test was performed as an overhead squat, challenging shoulder ROM while assessing overall squat performance. Additionally, comparisons between male and female participants were not conducted. Considering the likely differences in relative strength and ROM between sexes, this may be an area for future research.

The cervical spine movement test exhibited the least difference between the loaded and unloaded conditions in our study. Similar to the FMET cervical spine assessment, Mitchell (20) found only a 3% decline in ROM when assessing cervical rotation while wearing a plate carrier with front, back, and side plates. However, when measuring cervical ROM in an improved outer tactical vest (IOTV) with front, back, and side plates, ROM decreased 19% and 20% for both cervical rotation and ventral-dorsal cervical flexion, respectively (20). This further supports the notion that body armor fit can play a large role in influencing overall functional movement patterns. The IOTV is regularly issued to military personnel and is designed to provide both protection and performance, at the cost of covering a greater area of the torso compared to standard body armor. A functional movement assessment incorporating several conditions that compare fit and load in combination and in isolation should be evaluated in future studies. Further, helmets predominantly accompany body armor loads, which would also affect the cervical region.

It should be noted that the evaluator qualitatively observed changes in the performance of some of the FMET movements from the first condition to the second, regardless of the order. This may suggest a potential learning effect that should be examined quantitatively. Additionally, the participants recruited for this study were not tactical athletes, which may have influential effects on how participants moved under load. Tactical athletes are accustomed to the movement pattern and physical limitations imposed by load carriage, which may offer different results during a movement screen. Practice sessions may help stabilize scores on the FMET, which may further validate any similar observed movement compensations. When participants were given knowledge regarding proper FMS movement patterns following an initial movement screen, scores improved from 14.1±1.8 to 16.7±1.9, with significant improvements in the deep squat, hurdle step, in-line lunge, and shoulder mobility tests of the FMS (10). Also, given the fatiguing nature of tactical professions, performance outcomes of the FMET while fatigued may reveal a different set of altered movement patterns. The 1-leg squat, shoulder movement, and cervical movement subtest scores during an FMET decreased after a fatiguing protocol, with a mean difference of 6.6, 7.3, and 7.3 points, respectively (16). Evaluating this effect while wearing body armor could provide important insight into how tactical athletes alter their functional movement patterns in a neuromuscular fatigue state.

Understanding the effect of routinely required loads, and how they fit, on the functional movement patterns of tactical performance is essential for the proper implementation of training and mitigating injury risk by practitioners across all tactical professions. These movement screenings offer a noninvasive glimpse into the functional movement patterns of athletes, which may influence exercise programming intended to optimize performance and minimize the risk of injury. Tactical personnel often train using the Specific Adaptations to Imposed Demands principle to maximize the translation of their training into their occupational tasks. The convenient nature of the FMET could be easily integrated into a training program that provides consistent monitoring of movement quality while implementing this training principle. Additionally, it has been suggested that, although the FMET and FMS share similar intra-rater test-retest reliability, the ordinal 0-3 scoring scale of the FMS may reduce the sensitivity to change facilitated by the implementation of a corrective exercise intervention (7). Therefore, a 0-100 scoring scale used within the FMET could potentially introduce greater sensitivity to score changes induced by exercise interventions used by tactical personnel as they improve movement quality under load, although this hypothesis is yet to be tested (7). These data further support previous studies that suggest possible benefits to screening tactical populations in a loaded condition (2). It is important to understand how the effect of load carriage exacerbates movement deficiencies, especially in the context of body armor. Minimizing musculoskeletal injury risk while being able to efficiently perform threatening and non-threatening operational tasks is of utmost importance to tactical personnel.

Based on the data herein, torso-borne body armor loads negatively influence functional movement patterns and overall movement quality. Considering tactical athletes regularly perform their tasks under load, testing functional movement patterns in a loaded condition rather than in an unloaded condition may be useful for more accurate detection of compensatory movement patterns and for producing future training guidelines.

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