



## **The Influence of Body Armor on Balance and Movement Quality**

ROGER O. KOLLOCK<sup>#1</sup>, DAVIS HALE<sup>#1</sup>, RACHELE VOGELPOHL<sup>#2</sup>, LOGAN KREMER<sup>\*2</sup>, JOSH HORNER<sup>\*2</sup>, CHRISTIAN COX<sup>\*2</sup>, and MATT ALLEN<sup>\*2</sup>

<sup>1</sup>Department of Kinesiology and Rehabilitative Sciences, The University of Tulsa, Tulsa, OK, USA; <sup>2</sup>Department of Kinesiology and Health, Northern Kentucky University, Highland Heights, KY, USA

\*Denotes undergraduate, #Denotes professional author

---

### ABSTRACT

*International Journal of Exercise Science 11(1): 648-656, 2018.* Body armor is essential to the protection of military personnel; however, body armor may impede the users balance and movement quality. A better understanding of the influence of body armor on balance and movement quality may help in the development of new guidelines for training standards and procedures to mitigate the risk of injury associated with wearing of body armor in warfighters. The purpose of this study was to identify the effects of body armor (combat boots, tactical vest and combat helmet) on balance and movement quality in male military cadets and personnel. Twelve male participants completed the Functional Movement Screen (FMS) and Star Excursion Balance Test (SEBT) under two separate conditions, body armor and non-body armor. Results indicated a significant difference in FMS composite score between the non-body armor and body armor conditions ( $p = .012$ ), with the non-body armor condition resulting in significantly higher FMS scores than the body armor condition. Additionally, the FMS item score for shoulder mobility was significantly higher ( $2.25 \pm 0.62$ ) in the non-body armor condition than the body armor condition ( $p = 0.03$ ). The SEBT composite and the three individual reach distances were not significantly different between conditions. Based on the current findings, body armor within a 4.8 kg - 5.3 kg range does appear to impact movement quality as evaluated using the FMS in male military personnel and cadets. More research is needed to determine a threshold of compensatory movement patterns relative to an increase in body armor weight.

**KEY WORDS: FMS, military, postural control, load carriage**

### INTRODUCTION

Musculoskeletal injuries (MSI) are a common occurrence in recruits (1, 12) and deployed military personnel (26). Studies (24, 27) tracking large cohorts of military personnel have revealed that 22 to 44% of deployed males will suffer a MSI during duty. Among male Army and Marine recruits, MSI rates range from 10-15 injuries per 100 individuals per month, with the majority of these injuries occurring in the lower extremity and back (12). MSI may impede physical or mental performance; limit the ability to perform their assigned duties (26), and result in future health consequences or decrease quality of life post military career.

Investigators have proposed that loads carried (i.e. load carriage) by military personnel may contribute to injury susceptibility (15, 19, 20). The loads carriage during physical activity can contribute to excessive fatigue (23, 30), diminished physical performance (10, 17, 30), impaired mobility, increasing the potential for MSI (2, 25). Army Soldier and Marines are often required to carry heavy loads during both training and combat. According to the information reported in the “Modern Warriors Combat Load”, the lightest average loads for infantryman is approximately 28 kg (62lbs) (6). Loads may include the modular lightweight load-carrying equipment system (MOLLE), combat helmet, weapon and body armor such as the improved outer tactical vest (IOTV); however, studies have shown that body armor alone can increase the wearer’s injury risk by as much as 3 to 5 times (2, 25). Although body armor serves a critical role in personnel safety, the weight of the armor can hamper stability (e.g. postural control) (16) and movement efficiency (e.g. marching or running) (10, 17), making it more challenging to balance and stop or initiate movements (28). The impairment in motor performance resulting from body armor may result in the development of compensatory strategies that could place greater stress on the individual units of the musculoskeletal system such as the spine and associated spinal muscles (25).

A greater understanding of the impact of body armor on balance and movement quality could not only help reduce MSI, but may also reduce the risk of developing other associated consequences such as number of works days lost per injury(26) and overall health costs (32). Minimizing MSI in this population limits both the immediate and future health consequences (e.g. potential for development of traumatic osteoarthritis) (3, 21) to the soldier and helps to ensure a better quality life.

Two tests commonly used to gather information on mobility and balance are the Functional Movement Screen (FMS) and Star Excursion Balance Test (SEBT). In theory, individuals who possess greater body control during dynamic movements are at a lower risk of injury (14). Normally practitioners have patients or athletes perform these tests under unloaded conditions; however, under conditions with additional loading, the tests could better approximate a warfighter’s balance, mobility and stability as it relates to their unique job setting (8). Performing each test with body armor may provide a more valid inference of performance in the field.

The knowledge gained through this study may be used as a guideline for future development of training standards and procedures to mitigate the risk of injury associated with wearing of body armor in warfighters. Thus, the purpose of this study was to identify the effects of body armor (combat boots, tactical vest and combat helmet) on balance and movement quality in male military cadets [e.g. Reserves Officers’ Training Corps (ROTC)] and personnel (e.g. active duty military or reservists). We hypothesize that wearing body armor will decrease FMS total and item scores. We further hypothesize that wearing body armor will decrease SEBT anterior, posterolateral posteromedial and composite reach distances.

## **METHODS**

### *Participants*

Twelve male military personnel and cadets in the United States Armed Forces were recruited for participation (age, 24.25±4.86 yrs.; height, 176.95±8.21 cm; mass, 82.11±11.15 kg). All study participants signed an approved IRB consent document.

### *Protocol*

This study is a cross-sectional repeated measures design conducted in a laboratory setting. Testing was completed in one session. The FMS and SEBT were completed by each participant under two test conditions (body armor and non-body armor), with the conditions separated by a 10-minute rest period. In the non-body armor condition, participants completed both the FMS and SEBT wearing shorts and a t-shirt. In the body armor condition (total added mass: 4.8 kg - 5.3 kg), participants also wore shorts and a t-shirt, and added an advanced combat helmet (mass: 0.6 kg - 0.7 kg) and an improved outer tactical vest (IOTV) (mass: 4.2 kg - 4.6 kg). For both test conditions, the participants wore standard issue combat boots, when performing the FMS and were barefoot while performing the SEBT. The with and without body armor test conditions were counter-balanced between participants. All participants completed the SEBT prior to FMS.

The main outcome measures were FMS total score, the 7 FMS item scores, and the SEBT anterior, posterolateral, posteromedial and composite reach distances. A physical activity readiness questionnaire (PAR-Q) and a 5-item lower limb injury questionnaire were used in order to exclude any individual that would be placed at increased health risk due to participation in exercise. Individuals were excluded if they had any of the following conditions: 1) answered yes to any of the questions on the PAR-Q, 1) history of an anterior cruciate ligament tear or 2) suffered a lower extremity injury within the last six months.

The FMS is a screening tool developed to assess movement pattern discrepancies and structural asymmetries. Scores from the FMS provide insight into movement patterns that could lead to possible injuries. The FMS has demonstrated appropriate reliability and validity (18, 29). The FMS™ consist of seven tests: 1) deep squat, 2) hurdle step, 3) inline lunge, 4) shoulder mobility, 5) active straight leg raises, 6) trunk stability test and 7) rotary stability test. Each of the seven tests were graded as either a 1, 2 or 3 as described by the FMS guidelines, with 3 being the best possible score (4). The scores of the seven tests were totaled to determine the FMS™ composite score, with a max score of 21. Administration of the FMS™ was conducted by a practitioner who was FMS™ Level 1 certified and conducted as per FMS guidelines (4).

The SEBT is a series of unilateral tests performed while standing on one leg and attempting to reach with the non-standing leg in three directions [anterior (ANT), posteromedial (PM), posterolateral (PL)]. Postural control is the primary component of the SEBT and the scores can provide insight into dynamic balance as potential risk for injury. The SEBT has been found to be valid and reliable (9). To perform the SEBT a grid was taped to the floor in the shape of a Y,

with one line located directly anterior, one line extending 2.36 rad (135°) from the right of the anterior line, and one extending 2.36 rad (135°) from the left of the anterior line. Participants were instructed to stand barefoot on their dominant in the middle of the grid (the intersection of the 3 lines) and reach out with their non-dominant leg as far as possible along each of the 3 lines. Three reaches in each direction were collected for the dominant limb. Leg dominance was determined by gently pushing the participant from behind and recording the foot used to step forward (11). The three scores recorded for each direction were averaged and normalized according to leg length (reach distance/leg length in cm) (9). Additionally, the scores from each direction were average to create the normalized composite score (9, 31). For the SEBT, only the dominant limb was assessed in the present study. Traditionally for the SEBT the reach for both the dominant and nondominant limbs are recorded. This is done to allow for bilateral comparison in order to determine the percent asymmetry between the dominant and nondominant limbs. However, since this study was exploratory in nature, evaluation of only the dominant limb allowed for a simple rudimentary measure of dynamic balance in which to build upon for future studies. An earlier study had found no significant difference in unilateral postural stability between the dominant and nondominant lower limbs in a sample of young healthy adults (11).

#### *Statistical Analysis*

The differences in FMS scores between conditions (body armor and non-body armor) were analyzed using SPSS Statistic 21(IBM, Somers, NY). Individual paired sample t-tests were performed to determine the difference between the body armor and non-body armor conditions for the following variables: FMS composite score, SEBT composite score, and the individual ANT, PL and PM scores from the SEBT. The difference between groups for the seven individual items of the FMS were compared a using Wilcoxon matched-paired signed rank tests for matched pairs the level of significance was set at  $p \leq .05$ . Post hoc analyses of power were conducted using G\*Power ver. 3.1.9.2 (Uiversität Kiel, Germany).

## **RESULTS**

The results of this study identified a significant difference in FMS composite score between the non-body armor and body armor conditions ( $t(11) = 3.026, p = .012$ ), with the non-body armor condition resulting in significantly higher scores than the body armor condition (Table 1). Additionally, the FMS item score for shoulder mobility was significantly higher ( $2.25 \pm 0.62$ ) in the non-body armor condition than the body armor condition ( $1.83 \pm 0.72$ ),  $z = -2.24, p = 0.03, r = -0.65$ ). None of the other FMS item scores were different between groups (Table 2). The SEBT composite and the three individual reach distances were also not significantly different between conditions (Table 1).

## **DISCUSSION**

The purpose of this study was to identify the effects of body armor on balance and movement quality in military personnel. The results of this study indicate that body armor may significantly influence FMS composite scores; however, shoulder mobility appears to be

influenced the most by body armor during screening. The Shoulder Mobility task required the participant to simultaneously reach one fist behind the neck and the other behind the back and the addition of the combat helmet and placement of the tactical may have caused restriction of normal shoulder range of motion in the body armor condition.

**Table 1.** FMS composite and SEBT individual reach directions and composite.

Test	No Body Armor		Body Armor		Mean Difference	±SD	p-value	95% CI		Estimated power†
	Mean	±SD	Mean	±SD				Lower	Upper	
Star Excursion Balance Test (SEBT)										
ANT	73.34	11.05	75.48	9.07	-2.17	7.96	0.37	-7.23	2.89	0.12
PL	99.31	17.77	103.01	18.07	-3.67	6.91	0.09	-8.06	0.72	0.12
PM	95.90	13.43	96.74	11.10	-0.80	7.74	0.73	-5.72	4.12	0.07
Composite	87.93	13.06	90.41	10.94	-2.21	6.00	0.23	-6.02	1.60	0.12
Functional Movement Screen (FMS)										
Composite*	16.25	1.77	15.17	2.29	1.08	1.24	0.01	0.30	1.87	0.33

ANT, anterior; PL, posterolateral; PM, posteromedial; \*statistically significant,  $p \leq 0.05$ ; SEBT values are represented as normalized reaches and composites; † estimated power determined post hoc (G\*Power, Universität Kiel, Germany)

**Table 2.** Wilcoxon matched-paired signed rank tests individual FMS tasks.

FMS	No body armor		Body armor		Z	p-value	Effect size r (size)	Estimated power†
	Mean	±SD	Mean	±SD				
Deep Squat	2.25	0.45	2.08	0.67	-1.41	0.16	-0.41	0.09
Hurdle Step	2.42	0.52	2.25	0.62	-1.41	0.16	-0.41	0.09
Inline Lunge	2.33	0.49	2.42	0.52	0.58	0.56	0.17	0.07
Shoulder Mobility*	2.25	0.62	1.83	0.72	-2.24	0.03	-0.65	0.76
Active Straight Leg Raise	2.17	0.72	2.08	0.90	-0.58	0.56	-0.17	0.05
Trunk Stability	2.83	0.39	2.67	0.65	-1.41	0.16	-0.41	0.13
Rotary Stability	2.00	0.00	1.83	0.39	-1.41	0.16	-0.41	0.26

\*statistically significant,  $p \leq 0.05$ ; Z=standardized test statistic; † estimated power determined post hoc (G\*Power, Universität Kiel, Germany)

Previous research by Glass et al. (8) also reported significant decreases in the FMS shoulder mobility task using a weight vest in recreationally active adults. However, in addition to decreases in shoulder mobility, they also found significant differences in the active straight leg raise and trunk stability and rotary stability tests, which were not observed in the current study. The differences in the trunk stability and rotary stability tasks in the research by Glass et al. (8) may be a result of the population measured in the study. The previous work used a sample of recreationally active adults, while the current study used trained ROTC and military personnel who had more experience downing loads during physical activity. The difference in participant populations as well as the ROTC and military personnel's prior experience with load carriage, the participants in the current study may have been able to maneuver with less disruption to the movement quality.

Another explanation for the conflicting results between the current study and the study by Glass et al. (8) could be the vests used in each study. The mass of IOTV is 4.2 kg – 4.6 kg (mass dependent upon size) and was designed with the intent of balancing protection and performance (22), while the weight vest (18.1 kg) used by Glass et al. (8) was designed with the intent of altering performance. The fit of the IOTV is close and covers a greater area of the torso than the weight vest used in the prior study. Additionally, the weight vest is more susceptible to shifting with motion, which could negatively influence movement quality, leading to the observation of lower scores for the rotatory stability test.

Based on the current findings it appears that shoulder mobility can be influenced by body armor, which can place cadets at a higher risk of developing MSI than without body armor specifically with an added load of 4.8 kg – 5.3 kg. In addition, limitations in shoulder mobility may result in decrease performance in job related duties requiring gross shoulder movements (e.g. grappling with enemy combatant, climbing over objects or rope climbing) (7). This study may justify the need for the development of body armor that allows for greater mobility, specifically at the shoulder, while maintaining a similar or better level of body protection.

In the current study, balance assessed by the SEBT was not influenced by body armor. The possible lack of difference in SEBT composite scores between conditions may be because the SEBT is not sensitive enough to detect changes in postural control. Another possibility for the lack of difference could have been that the load may have not been heavy enough to cause significant alterations to postural sway. Our findings are in agreement with a previous study by De Maio, Onate, Swain, Morrison and Ringleb (5) who reported no difference in SEBT composite scores in military personnel with and without body armor. However, when measuring postural control with a force plate, the authors found that anterior-posterior and mediolateral center of pressure were significantly altered because of body armor. Based on their findings the authors concluded the SEBT may lack the sensitivity in its ability to detect meaningful change in posture resulting from the addition body armor.

Several limitations should be noted with respect to this investigation. First, this was a small sample of military personnel, which may limit the generalizability of our findings. In addition, post hoc power analysis estimated that the study was underpowered (<.80) (13). Future studies should be conducted with larger samples to increase the power. Second, the study only included male participants. The influence of body armor on balance and movement quality may differ with respect to females versus males. Future studies should seek to examine influence of body armor on the movement quality in females. Third, the body armor load (47 N – 52 N) may not have induced enough mobility/balance changes due to its lighter weight. More research is needed to determine a threshold of compensatory movement patterns relative to an increase in body armor weight. Fourth, the investigators only assessed the dominant limb. Assessing both the dominant and nondominant may give additional insight into the influence of body armor on dynamic balance.

Body armor within a 4.8 kg - 5.3 kg range does appear to impact movement quality, specifically at the shoulder, as evaluated using the FMS in male military personnel and cadets. SEBT composite scores did not significantly differ with and without body armor. Results may be due to lack of sensitivity of the SEBT to detect changes in posture control resulting body armor.

## **ACKNOWLEDGEMENTS**

Northern Kentucky University's Office of Research, Grants and Contracts supported this project. The authors would like to acknowledge the Northern Kentucky University Veterans Resource Station. The results of the present study do not constitute endorsement by Northern Kentucky University.

## **REFERENCES**

1. Bell NS, Mangione TW, Hemenway D, Amoroso PJ, Jones BH. High injury rates among female army trainees: a function of gender? *Am J Prev Med* 18(3 Suppl): 141-6, 2000.
2. Burton AK, Tillotson KM, Symonds TL, Burke C, Mathewson T. Occupational risk factors for the first-onset and subsequent course of low back trouble. A study of serving police officers. *Spine* 21(22): 2612-20, 1996.
3. Cameron KL, Driban JB, Svoboda SJ. Osteoarthritis and the tactical athlete: a systematic review. *J Athl Train* 51(11): 952-61, 2016.
4. Cook G. *Movement: functional movement systems: screening, assessment, and corrective strategies*. Aptos, CA: On Target Publications; 2010, 406.
5. DeMaio M, Onate J, Swain D, Morrison S, Ringleb S. Physical performance decrements in military personnel wearing personal protective equipment (PPE). In: *Human Performance Enhancement for NATO Military Operations*. 2009. Available at: <http://www.dtic.mil/dtic/tr/fulltext/u2/a567881.pdf>
6. Dean C. The modern warrior's combat load. Dismounted operations in Afghanistan, April - May 2003. Ft. Leavenworth, KS: Army Center for Lessons Learned, 2004. Available at: <http://thedonovan.com/archives/modernwarriorload/ModernWarriorsCombatLoadReport.pdf>.
7. Dempsey PC, Handcock PJ, Rehrer NJ. Impact of police body armour and equipment on mobility. *Appl Ergon* 44(6): 957-61, 2013.
8. Glass SM, Ross SE. Modified functional movement screening as a predictor of tactical performance potential in recreationally active adults. *Int J Sports Phys Ther* 10(5):612-21, 2015.
9. Gribble PA, Kelly SE, Refshauge KM, Hiller CE. Interrater reliability of the Star Excursion Balance Test. *J Athl Train* 48(5): 621-6, 2013.
10. Heller MF, Challis JH, Sharkey NA. Changes in postural sway as a consequence of wearing a military backpack. *Gait Posture* 30(1): 115-7, 2009.
11. Hoffman M, Schrader J, Applegate T, Koceja D. Unilateral postural control of the functionally dominant and nondominant extremities of healthy subjects. *J Athl Train* 33(4): 319-22, 1998.

12. Kaufman KR, Brodine S, Shaffer R. Military training-related injuries: surveillance, research, and prevention. *Am J Prev Med* 18(3, Supplement 1): 54-63, 2000.
13. Kim J, Seo BS. How to calculate sample size and why. *Clin Orthop Surg* 5(3): 235-42, 2013.
14. Knapik JJ, Cosio-Lima LM, Reynolds KL, Shumway RS. Efficacy of functional movement screening for predicting injuries in coast guard cadets. *J Strength Cond Res* 29(5): 1157-62, 2015.
15. Knapik JJ, Reynolds KL, Harman E. Soldier load carriage: historical, physiological, biomechanical, and medical aspects. *Mil Med* 169(1): 45-56, 2004.
16. Ledin T, Fransson PA, Magnusson M. Effects of postural disturbances with fatigued triceps surae muscles or with 20% additional body weight. *Gait Posture* 19(2): 184-93, 2004.
17. Majumdar D, Srivastava KK, Purkayastha SS, Pichan G, Selvamurthy W. Physiological effects of wearing heavy body armour on male soldiers. *Int J Ind Ergon* 20(2): 155-61, 1997.
18. Onate JA, Dewey T, Kollock RO, Thomas KS, Van Lunen BL, DeMaio M, Ringleb SI. Real-time intersession and interrater reliability of the functional movement screen. *J Strength Cond Res* 26(2): 408-15, 2012.
19. Orr RM, Johnston V, Coyle J, Pope R. Reported load carriage injuries of the Australian army soldier. *J Occup Rehabil* 25(2): 316-22, 2015.
20. Orr RM, Pope R, Johnston V, Coyle J. Soldier occupational load carriage: a narrative review of associated injuries. *Int J Inj Contr Saf Promot* 21(4): 388-96, 2014.
21. Palmieri-Smith RM, Cameron KL, DiStefano LJ, Driban JB, Pietrosimone B, Thomas AC, Tourville TW, Consortium ATO. The role of athletic trainers in preventing and managing posttraumatic osteoarthritis in physically active populations: a consensus statement of the Athletic Trainers' Osteoarthritis Consortium. *J Athl Train* 52(6): 610-23, 2017.
22. Potter A, Karis AJ, Gonzalez JA. Biophysical characterization and predicted human thermal responses to U.S. army body armor protection levels (BAPL). US Army Research Institute of Environmental Medicine, Natick, MA, 01760, USA, Technical Report, T13-5, 2013, ADA#585406. Available at: <http://www.dtic.mil/dtic/tr/fulltext/u2/a585406.pdf>.
23. Ricciardi R, Deuster PA, Talbot LA. Metabolic demands of body armor on physical performance in simulated conditions. *Mil Med* 173(9): 817-24, 2008.
24. Roy TC, Knapik JJ, Ritland BM, Murphy N, Sharp MA. Risk factors for musculoskeletal injuries for soldiers deployed to Afghanistan. *Aviat Space Environ Med* 83(11): 1060-6, 2012.
25. Roy TC, Lopez HP, Piva SR. Loads worn by soldiers predict episodes of low back pain during deployment to Afghanistan. *Spine* 38(15): 1310-7, 2013.
26. Roy TC, Piva SR, Christiansen BC, Leshner JD, Doyle PM, Waring RM, Irrgang JJ, Moore CG, Brininger TL, Sharp MA. Description of musculoskeletal injuries occurring in female soldiers deployed to Afghanistan. *Mil Med* 180(3): 269-75, 2015.
27. Roy TC, Ritland BM, Sharp MA. A description of injuries in men and women while serving in Afghanistan. *Mil Med* 180(2): 126-31, 2015.



28. Strube EM, Sumner A, Kollock R, Games KE, Lackamp MA, Mizutani M, Sefton JM. The effect of military load carriage on postural sway, forward trunk lean, and pelvic girdle motion. *Int J Exerc Sci* 10(1): 25-36, 2017.
29. Teyhen DS, Shaffer SW, Lorenson CL, Halfpap JP, Donofry DF, Walker MJ, Dugan JL, Childs JD. The functional movement screen: a reliability study. *J Orthop Sports Phys Ther* 42(6): 530-40, 2012.
30. Thomas M, Pohl MB, Shapiro R, Keeler J, Abel MG. Effect of load carriage on tactical performance in special weapons and tactics operators. *J Strength Cond Res* 32(2): 554-64, 2018.
31. van Lieshout R, Reijneveld EAE, van den Berg SM, Haerkens GM, Koenders NH, de Leeuw AJ, van Oorsouw RG, Paap D, Scheffer E, Weterings S, Stukstette MJ. Reproducibility of the modified Star Excursion Balance Test composite and specific reach direction scores. *Int J Sports Phys Ther* 11(3): 356-65, 2016.
32. Walton SM, Conrad KM, Furner SE, Samo DG. Cause, type, and workers' compensation costs of injury to fire fighters. *Am J Ind Med* 43(4): 454-8, 2003.