

The Addition of Body Armor Diminishes Dynamic Postural Stability in Military Soldiers

Timothy C. Sell, PhD*; Jonathan J. Pederson, BS*; John P. Abt, PhD*;
Takashi Nagai, PhD†; Jennifer Deluzio, MS‡; COL Michael D. Wirt, MC USA‡;
LTC Larry J. McCord, MC USA§; Scott M. Lephart, PhD*

ABSTRACT Poor postural stability has been identified as a risk factor for lower extremity musculoskeletal injury. The additional weight of body armor carried by Soldiers alters static postural stability and may predispose Soldiers to lower extremity musculoskeletal injuries. However, static postural stability tasks poorly replicate the dynamic military environment, which places considerable stress on the postural control system during tactical training and combat. Therefore, the purpose of this study was to examine the effects of body armor on dynamic postural stability during single-leg jump landings. Thirty-six 101st Airborne Division (Air Assault) Soldiers performed single-leg jump landings in the anterior direction with and without wearing body armor. The dynamic postural stability index and the individual stability indices (medial-lateral stability index, anterior-posterior stability index, and vertical stability index) were calculated for each condition. Paired sample *t*-tests were performed to determine differences between conditions. Significant differences existed for the medial-lateral stability index, anterior-posterior stability index, vertical stability index, and dynamic postural stability index ($p < 0.05$). The addition of body armor resulted in diminished dynamic postural stability, which may result in increased lower extremity injuries. Training programs should address the altered dynamic postural stability while wearing body armor in attempts to promote adaptations that will result in safer performance during dynamic tasks.

INTRODUCTION

Postural stability has been defined by Riemann et al¹ as the process of coordinating corrective movement strategies and movements at the selected joints to remain in postural equilibrium. Dynamic postural stability is the ability to maintain the base of support when the base of support is moving or when an external perturbation is applied to the body.² Postural stability has been identified as a risk factor for ankle³⁻⁹ and knee^{10,11} injuries in athletic populations and is likely a risk factor for injury in the military. Soldiers are often required to carry heavy loads while deployed and on tactical operations for long distances and over-rugged terrains.^{12,13} The loads Soldiers carry are determined by the mission requirements and for protective purposes with the minimum load consisting of body armor, which accounts for approximately 43% of a Soldier's fighting load; the average rifleman's fighting load is approximately 29 kg.¹⁴ The effects of load carriage on physiological function¹⁴⁻¹⁶ and gait^{17,18} have been established. However, the effect of load carriage on postural stability^{19,20} is largely unknown and has only incorporated static testing conditions. Static testing conditions fail to replicate the dynamic military

environment,²¹ which places significant demands on postural control encountered during tactical training and missions.

Ankle and knee injuries²²⁻²⁴ are a common occurrence in military personnel and are associated with high medical costs,²⁵ lost time from duty,²³ and impact military readiness.²³ Ankle and knee injuries account for 10.9%²² to 15.1%²⁴ and 10.2%²² to 12.0%,²⁴ respectively, of all musculoskeletal injuries in military personnel. Additionally, the lower extremity is the most common anatomical location of hospitalized injuries in the military.²⁶ Furthermore, ankle and knee injuries were among the most common anatomical locations for nonbattle air evacuations during Operations Iraqi Freedom and Enduring Freedom.²⁷ Despite the frequent occurrence of ankle and knee injuries in the military, the risk factors for these injuries are largely unknown in this population.

Decreased postural stability has been prospectively identified as a risk factor for ankle^{4,7-9} and leg¹¹ injuries. Altered postural stability has also been observed following knee,^{10,11} and low back^{28,29} injuries. The effects of load carriage on postural stability^{19,20} in Soldiers are limited and have only assessed static testing conditions, which fail to imitate military activities. Schiffman et al²⁰ assessed the effects of three different loads (6, 16, and 40 kg) on static postural stability and observed linear increases in center of pressure excursions with increases in load. Moreover, May et al¹⁹ demonstrated decreased balance scores while carrying a load equal to 30% of body weight during the modified sensory organizational test. Although the effect of load carriage appears to be detrimental to static postural stability, its effect on dynamic postural stability is largely unknown and warrants investigation.

A direct connection between load carriage and risk of injury has not been established, but recent epidemiological

*Neuromuscular Research Laboratory, Department of Sports Medicine and Nutrition, University of Pittsburgh, 3830 South Water Street, Pittsburgh, PA 15203.

†Human Performance Research Laboratory, University of Pittsburgh, Building 7540 Headquarters Loop, Fort Campbell, KY 42223.

‡Blanchfield Army Community Hospital, 650 Joel Drive, Fort Campbell, KY 42223.

§Fort Campbell Army Post, Division Surgeon's Office, 6906 A Shau Valley Road, Fort Campbell, KY 42223.

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evidence indicates that the Soldier does perceive it to be a risk factor for injury.³⁰ Additionally, recent epidemiological evidence demonstrates an increase in ankle and knee injuries in Afghanistan compared to Iraq.²⁷ This study supports the personal observations of the Division Surgeons of the Army 101st Airborne Division (Air Assault) while in both theaters. The reported and observed increase is likely attributable to the challenging terrain that is difficult to traverse under normal conditions and even more demanding while carrying the load necessary for tactical missions. It is suggested that load carriage over long durations may result in injury, especially to the ankle and knee.³¹ The most common self-reported region being uncomfortable during loaded field marching were the foot and ankle.³² Additionally, it was documented that 24% of infantry Soldiers who participated in loaded road marching suffered an overuse injury.³³ The addition of carrying an unaccustomed load while deployed is suggested to increase ankle and knee injuries, which may be because of the detrimental effects load carriage has on postural stability.

Altered or diminished postural stability has been demonstrated to be a risk factor for lower leg³⁻¹¹ injuries. Military personnel carry and wear additional weight for tactical and protective purposes. This additional weight likely has impact on dynamic postural stability. The degree of this altered postural stability is unknown. The overall purpose of this study was to examine the effects of personal body armor on dynamic postural stability as measured by the dynamic postural stability index (DPSI). We hypothesized that the addition of body armor would significantly decrease the Soldier's dynamic postural stability as indicated by an increase in the DPSI. If our hypothesis is correct, the results will demonstrate that the minimal amount of weight Soldiers carry is detrimental to postural stability and should be addressed in physical training programs.

METHODS

Participants

Thirty-six subjects (male = 32, female = 4) were recruited from the Army 101st Airborne Division (Air Assault) to participate in this study (Table I). To participate, subjects must have been 18 to 45 years old from the 101st, with no history of concussion or mild head injury in the previous year, no upper extremity, lower extremity, or back musculoskeletal pathology in the past 3 months that could affect the

ability to perform the required tests, no history of neurologic or balance disorders, and not taking any medications that could disrupt balance or proprioception. Additionally, all subjects were cleared for active duty without any recent prescribed duty restrictions. Approval for this study was obtained from the University of Pittsburgh's Institutional Review Board, Eisenhower Army Medical Center, Clinical Investigation Regulatory Office, and the Human Research Protection Office as part of an ongoing research project focusing on injury prevention and performance optimization in the 101st Airborne Division (Air Assault). All testing was conducted at our Human Performance Research Laboratory, Fort Campbell, Kentucky, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

Instrumentation

A force plate (Kistler 9286A, Amherst, New York) was used to collect the ground reaction force data (1200 Hz) during the single-leg jump landing task to assess dynamic postural stability. Force plate data were passed through an amplifier and analog to digital board (DT3010, Digital Translation, Marlboro, Massachusetts) and stored on a personal computer.

Load Carriage Condition

The load carriage condition was comprised of standard U.S. Army clothing (boots, socks, T-shirt, and shorts) and equipment (body armor). Each subject wore their own personal body armor, the average weight of the body armor and the body armor as percentage of body weight can be found in Table I. The body armor was chosen as it is the minimum load Soldiers carry while on missions and during tactical training.

Procedures

Subjects reported to a research laboratory for a single test session. Dynamic postural stability was assessed using a single-leg jump landing in the anterior direction, which has demonstrated good intersession reliability (ICC 3, k), 0.86.²¹ The single-leg jump landing task was only conducted on the dominant limb. Limb dominance was defined as the limb the subject would use to kick a ball maximally. The jump distance was normalized to the subject's body height and the jump height was standardized at 30 cm (Fig. 1).²¹

Subjects were positioned 40% of their body height away from the edge of a force plate and a 30 cm hurdle was placed at the midpoint between the starting position and the force plate. Subjects were instructed to jump in the anterior direction using a two-footed jump over the hurdle and to land on the force plate with only the dominant leg, stabilize as quickly as possible, place their hands on their hips once stabilized, and remain still for 10 s while looking forward. Upper extremity movement was unrestricted during the jump; however, once subjects were stabilized they were asked to quickly place their hands on their hips. Subjects were allowed three practice trials for each condition to become familiar with the single-leg jump

TABLE I. Subject Demographics and Body Armor Weight (Mean ± SD)

| Characteristic | Mean | ± | SD |
|---------------------------------------|--------|---|-------|
| Age (Year) | 29 | ± | 6.6 |
| Height (cm) | 174.49 | ± | 8.84 |
| Weight (kg) | 82.38 | ± | 13.93 |
| Body Armor (kg) | 12.47 | ± | 2.56 |
| Body Armor Percent of Body Weight (%) | 15.55 | ± | 4.18 |



FIGURE 1. Anterior single-leg jump landing.

landing task. Following the practice trials, subjects completed the test trials. A 1-minute rest period was provided between trials to prevent fatigue.

Trials were discarded and repeated if subjects failed to jump over or came in contact with the hurdle, fell upon landing or if the nondominant leg came in contact with the dominant leg or the ground around the force plate. All subjects were able to complete the task. All of the subjects performed the task without body armor first. A total of three successful trials were collected for each condition (no-load and load) and used for data analysis.

Data Reduction

A custom MATLAB (v7.0.4, Natick, Massachusetts) script file was used to process the ground reaction force data for calculating the DPSI. Ground reaction force data were passed through a zero-lag fourth order low pass Butterworth filter with a frequency cutoff of 20 Hz. The dependent variable was the DPSI depicted in Table II. The DPSI is a composite of the anterior–posterior, medial–lateral, and vertical ground reaction forces and also provides stability indices for the anterior–posterior (APSI), medial–lateral (MLSI), and vertical (VSI) directions. The DPSI was calculated using the first 3 s of the ground reaction forces immediately following initial contact identified as the instant the vertical ground reaction force exceeded 5% body weight. This method of calculating DPSI has demonstrated good test–retest reliability (ICC 3, 1), 0.96.³⁴

Higher stability indices and DPSI scores represent worse dynamic postural stability. Each subject had a total of three trials, which were averaged and used for final analysis.

Statistical Analysis

Paired sample *t*-tests were performed for the dependent variables to determine if there was a significant difference between no-load carriage and load carriage conditions. All statistical analyses were performed using SPSS (v13.0, SPSS,

TABLE II. Calculation for MLSI, APSI, VSI, and DPSI

| Variable | Equation |
|----------|--|
| MLSI | $\left(\sqrt{\frac{\sum(0 - GRFx)^2}{\text{number of data points}}} \right) \div BW$ |
| APSI | $\left(\sqrt{\frac{\sum(0 - GRFy)^2}{\text{number of data points}}} \right) \div BW$ |
| VSI | $\left(\sqrt{\frac{\sum(BW - GRFz)^2}{\text{number of data points}}} \right) \div BW$ |
| DPSI | $\left(\sqrt{\frac{\sum(0 - GRFx)^2 + \sum(0 - GRFy)^2 + \sum(BW - GRFz)^2}{\text{number of data points}}} \right) \div BW$ |

BW, Body weight.

TABLE III. Dynamic Postural Stability During No-Load and Load Conditions

| Variable | Condition | | | | | | Effect Size | Observed Power | <i>p</i> -Value |
|----------|---------------|--------|-------|---------------|--------|-------|-------------|----------------|-----------------|
| | No-Load | | | Load | | | | | |
| | Mean (SD) | 95% CI | | Mean (SD) | 95% CI | | | | |
| MLSI | 0.025 (0.006) | 0.023 | 0.027 | 0.028 (0.006) | 0.026 | 0.030 | 0.500 | 0.882 | 0.005 |
| APSI | 0.119 (0.011) | 0.116 | 0.123 | 0.132 (0.012) | 0.128 | 0.136 | 1.127 | 0.999 | <0.001 |
| VSI | 0.299 (0.042) | 0.285 | 0.313 | 0.319 (0.047) | 0.303 | 0.335 | 2.013 | 1.000 | <0.001 |
| DPSI | 0.324 (0.041) | 0.310 | 0.338 | 0.347 (0.045) | 0.332 | 0.363 | 0.533 | 0.875 | <0.001 |

Statistical significance set at $p < 0.05$.

Chicago, Illinois). An α level of 0.05 was set a priori to determine significance for all statistical analyses.

RESULTS

The means and standard deviations (SD) for the demographic and body armor variables are presented in Table I. The means, SD, results of the paired sample *t*-tests, effect sizes, and power for all dynamic postural stability variables are presented in Table III. Overall, the subjects performed the dynamic postural stability test significantly different between the load and no-load conditions. Specifically, under the load condition, the subjects had significantly worse scores for the MLSI ($p = 0.005$, effect size = 0.500, power = 0.882), APSI ($p < 0.001$, effect size = 1.127, power = 0.999), VSI ($p < 0.001$, effect size = 2.013, power = 1.0), and DPSI ($p < 0.001$, effect size = 0.533, power = 0.875).

DISCUSSION

Decreased postural stability has been identified as a risk factor for ankle³⁻⁹ and knee^{10,11} injuries in athletic populations. The equipment Soldiers carry for personal protection and tactical purposes places considerable weight on the Soldiers' bodies, with the minimal load consisting of body armor. Load carriage negatively affects physiological function,¹⁴⁻¹⁶ gait,^{17,18} and static postural stability^{19,20}; however, its effect on dynamic postural stability has yet to be explored. The purpose of this study was to investigate the influence of body armor on dynamic postural stability. The results of this study indicate that the addition of body armor diminishes dynamic postural stability. Specifically, increases were noted in the MLSI, APSI, VSI, and DPSI confirming our hypothesis. The decrease in dynamic postural stability while wearing body armor may increase the risk of sustaining a lower extremity musculoskeletal injury and negatively impacting military readiness and mission success. Careful consideration should be given to developing training programs that incorporate balance training and the addition of body armor to induce adaptations that will likely mitigate the negative effects of body armor on dynamic postural stability.

The addition of body armor reduced dynamic postural stability. Ground reaction forces have consistently been shown to increase with the addition of a load,^{17,18,35} which was evidenced by higher MLSI, APSI, and VSI scores in the current study. Similarly, peak vertical ground reaction forces significantly

increased during two-legged drop landings with the addition of body armor, helmet, and rifle.³⁶ Additionally, carrying a load results in an increase in body sway^{20,35} resulting in less stability, which may explain the increase in ground reaction forces observed in this study. Furthermore, it has been established that carrying a load results in a forward lean³⁷ thereby, placing a subject closer to their limits of stability, which may result in an increase in ground reaction forces.

Poor postural stability has been prospectively identified as a risk factor for ankle^{4,7-9} and leg¹¹ injuries. In this study, the addition of body armor resulted in Soldiers landing with greater ground reaction forces in the APSI, MLSI, VSI. Landing with greater peak vertical ground reaction forces has been identified as a risk factor for anterior cruciate ligament injury.³⁸ A 10% increase was observed with the addition of body armor for the MLSI and APSI scores, whereas a 7% increase was observed for the VSI and DPSI scores. Increases in the MLSI may have important considerations for lateral ankle sprains as they occur in the frontal plane³⁹ and individuals with chronic ankle instability have increased MLSI scores compared to healthy controls.⁴⁰ The relationship between load carriage and injury rates has yet to be established; however, preliminary survey data indicate that the majority of the Soldiers who were injured under loaded conditions believe that carrying a load contributed to their injury.³⁰ The potential cause for an increase in musculoskeletal injuries may be as a result of diminished dynamic postural stability while carrying a load. The load utilized in this study was the minimum load a Soldier would carry. As loads approach those of tactical operations, decrements in dynamic postural stability are likely to increase.

A variety of postural stability training programs have been developed. These programs have demonstrated the ability to improve postural stability and reduce musculoskeletal injuries.⁴¹ Currently, postural stability training is not incorporated into daily Army physical training; however, it is included in newer military training programs.⁴² The Eagle Tactical Athlete Program has been implemented at the 101st Airborne Division (Air Assault). This program is an 8-week periodized training regimen that incorporates postural stability and physical training while wearing body armor that improved Soldier's postural stability. Additionally, proper landing technique may be important to reduce the effects of body armor on dynamic postural stability. Proper landing technique programs have been successfully developed to reduce anterior cruciate ligament injury in

female athletes.⁴³ Our previous research has demonstrated that hip flexion angle at initial contact are important predictors of DPSI during single-leg jump landings.⁴⁴ Specifically, a greater hip flexion angle resulted in lower DPSI scores indicating better dynamic postural stability. Additionally, greater knee flexion at initial contact and greater knee flexion throughout the landing results in a greater dissipation of ground reaction forces.⁴⁵ Furthermore, earlier onset of muscle activation improves reaction to the landing surface and reduces the time to transition from a dynamic to a static state resulting in a successful jump landing.⁴⁶

In this study, the average weight of the body armor was 12.5 kg, which was approximately 15.5% of subjects' body mass. This load was selected as it is the minimum amount of equipment Soldiers wear for protective purposes. It has been established that load carriage considerably alters physiological function,^{14–16} gait,^{17,18} static postural stability,^{19,20} knee kinematics during drop landings,³⁶ and potentially contributes to musculoskeletal injuries.³⁰ Carrying additional weight has been part of Army physical training, but has traditionally been limited to field marches. However, during deployment, Soldiers may be required to carry loads in excess of 100 pounds.¹⁴ Physical training programs that incorporate postural stability training and additional weight may mitigate the negative effects additional weight has on dynamic postural stability. Careful consideration should be given to the incorporation of additional weight into training programs as an increase in musculoskeletal injury rates has been reported.^{32,47}

We acknowledge that this study has several limitations. First, the weight of the body armor varied between subjects as each subject wore their own personal body armor. The weight of body armor can vary between individual Soldiers based on their needs and preferences. Incorporating a standardized body armor weight could have potentially negatively affected Soldier performance during the dynamic postural stability tasks as Soldiers may not have been accustomed to the body armor weight. The influence of different body armor weights would likely have the greatest effect on the VSI, which is most susceptible to variations in weight. Second, the order of the two testing conditions was not randomized. It is possible that a learning effect could have influenced the dynamic postural stability measures during the load condition because it followed the no-load condition. In an attempt to mitigate this effect, a minimum of three practice trials were provided for each condition. More practice trials were allowed, as needed, until subjects felt comfortable with the test procedures. Since subjects were provided time to become familiarized with the single-leg jump landing task during both conditions, it is unlikely that the order of the two testing conditions would provide further alteration of performance. It is possible that subjects adopted a different landing strategy during the load condition compared to the no-load condition; since kinematic and electromyography data were not collected during this study, we cannot comment if landing strategy changed. Last, it is possible that subjects became fatigued during the

course of this study and could have influenced the results. Subjects were provided with a 1-minute rest period between trials and between conditions, which should have prevented fatigue. Additionally, since subjects wore their own personal body armor, they should be accustomed to the load.

Future research should explore the influence of carrying additional weight on injury rates in the military during deployment and nondeployment. Additionally, future research should examine the effects of carrying additional weight during other dynamic postural stability tasks that replicate the military environment as well as incorporating various loads that are reflective of the loads Soldiers carry during combat and tactical missions. Furthermore, a prospective study is needed to demonstrate that dynamic postural stability is a risk factor for lower extremity injuries in the military.

CONCLUSION

The addition of a minimum load such as body armor results in diminished dynamic postural stability as evidenced by increases in MLSI, APSI, VSI, and DPSI. Altered dynamic postural stability may result in an increase in lower extremity musculoskeletal injuries. Because of the deleterious effects body armor has on dynamic postural stability, future research is warranted to develop physical training programs to promote adaptations that will result in safer performance during load-bearing dynamic tasks while not increasing musculoskeletal injury rates.

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