

## Minimal Additional Weight of Combat Equipment Alters Air Assault Soldiers' Landing Biomechanics

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**ABSTRACT** The additional weight of combat and protective equipment carried by soldiers on the battlefield and insufficient adaptations to this weight may increase the risk of musculoskeletal injury. The objective of this study was to determine the effects of the additional weight of equipment on knee kinematics and vertical ground reaction forces (VGRF) during two-legged drop landings. We tested kinematics and VGRF of 70 air assault soldiers performing drop landings with and without wearing the equipment. Maximum knee flexion angles, maximum vertical ground reaction forces, and the time from initial contact to these maximum values all increased with the additional weight of equipment. Proper landing technique, additional weight (perhaps in the form of combat and protective equipment), and eccentric strengthening of the hips and knees should be integrated into soldiers' training to induce musculoskeletal and biomechanical adaptations to reduce the risk of musculoskeletal injury during two-legged drop landing maneuvers.

### INTRODUCTION

Musculoskeletal injury is a persistent and major health concern for individuals who are responsible for the medical care of military personnel. According to the Armed Forces Epidemiological Board (AFEB), injuries "impose a greater ongoing negative impact on the health and the readiness of U.S. armed forces than any other category of medical complaint during peacetime and combat."<sup>1</sup> More casualties have been caused among U.S. troops by noncombat injuries and disease than by combat.<sup>2</sup> Data presented to the AFEB's Injury Control Work Group by scientists from Navy and Army research organizations, and published military and civilian epidemiologic studies has revealed that the most common types of injuries seen in military populations are unintentional musculoskeletal overuse injuries.<sup>3</sup> A review of the medical treatment records in a group of 298 male infantry soldiers showed that musculoskeletal injuries were very common; musculoskeletal pain was the most common diagnosis followed by strains. Also, a higher cumulative incidence of soldiers with musculoskeletal injuries was associated with reduced physical fitness (2-mile run and sit-ups).<sup>4</sup> A study of data in an Army database of all hospital admissions (caused by an external injury) for active duty personnel showed that during a 6-year period, 11% (13,861) of the patients had injuries sustained during sports or physical training. Of these, musculoskeletal injuries were very common (fractures, 33%; sprains/strains, 29%; and dislocations, 15%). Sports and Army physical training inju-

ries accounted for a significant amount of lost duty time.<sup>5</sup> An analysis of the Navy Physical Evaluation Board data showed that the most common diagnostic categories of cases were musculoskeletal disorders (43%) and injuries and poisonings (15%).<sup>6</sup> Recently, a survey by Sanders et al.<sup>7</sup> among military personnel involved in Operations Iraqi Freedom and Enduring Freedom revealed that 34.7% of soldiers reported noncombat injuries.

Musculoskeletal conditions and injuries are the leading causes of hospitalization in the U.S. Army, accounting for 31% of all hospitalizations in 1992.<sup>8</sup> Orthopedic and musculoskeletal issues accounted for 53% of all U.S. Army injury cases that were reviewed by the disability evaluation process of the physical evaluation board in 1994.<sup>9</sup> Similarly, 58% of such cases in 2005 in the U.S. Navy were caused by musculoskeletal conditions and injuries.<sup>6</sup> The high rate of overuse injuries adversely affects military training, resulting in lost days and increased medical costs.<sup>10</sup> The annual cost of injury-related disability in the military had exceeded \$750 million in the mid-1990s,<sup>19</sup> and the annual expenditure of the U.S. Department of Defense to treat musculoskeletal injuries had been \$600–750 million before 2001.<sup>11</sup> Such injuries will have long-term consequences even after individuals have left active duty. For example, among the veterans returning from Iraq and Afghanistan who have sought Veterans Administration health care between 2002 and 2006, 42% were related to musculoskeletal issues such as joint and back disorders.<sup>12</sup>

The knee is one of the most common sites of musculoskeletal injury in the military, accounting for 10–34% of all injuries among different military groups from Army infantry to naval special warfare trainees.<sup>3</sup> The mechanism responsible for knee injuries in the military has not been clearly outlined, but they are hypothesized to be similar to the mechanism responsible for knee injuries in athletes. Most traumatic noncontact knee injuries occur during demanding athletic tasks that include sudden deceleration, landing, and pivoting

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maneuvers,<sup>13</sup> which are all prevalent in military training, tactical operations, and sports activities. Among these tasks, landing from a raised platform may be one of the most critical and the most common. Landing is involved widely in infantry soldiers' training and operations, such as jumping off the back of a vehicle, traversing a ditch, and landing after a climb over a wall or other obstacle.

These landings typically induce dangerously high ground reaction forces, which will be transferred through the knees. Biomechanical and epidemiological research has linked several dangerous kinematic and kinetic characteristics during landing to a greater risk of noncontact anterior cruciate ligament (ACL) and secondary injuries in athletes.<sup>14,15</sup> Our own research has demonstrated that groups at risk for knee injury perform landing and cutting maneuvers with dangerous landing positions, which includes greater ground reaction forces, altered electromyographic activity, and increased joint loading.<sup>16-19</sup> Because of similar injury mechanisms in the military, the same models employed to study biomechanics in athletes are appropriate for use in military populations.

Although soldiers perform very different tasks than typical athletes, soldiers must be able to perform and react similarly and can be considered tactical athletes. While athletes can sometimes modify equipment (lighter shoulder pads in football for instance), soldiers do not have the convenience of improving their agility in the field by using lighter equipment. Instead, soldiers must wear the required heavy and uniformed protective equipment and must also carry weapons, ammunitions, communication devices, and other equipment for combat. The weight a soldier carries while marching has increased throughout the past century.<sup>20</sup> Such additional weight can alter soldiers' normal body movement patterns, increase joint stress, and potentially increase their risk of suffering musculoskeletal injuries. For example, Army officials have reported that the 60–70 kilograms of weight (approximately 65% to 75% of the soldier's body weight [BW]) that U.S. soldiers routinely carry in the mountains of Afghanistan has increased the number of soldiers who have been categorized as "nondeployable" because of musculoskeletal injuries.<sup>21</sup> Previous research studies demonstrated that carrying a military rucksack (approximately 15%–30% of the soldier's BW) can initiate compensatory kinetic response at the knees,<sup>22</sup> elevate the forces applied on the upper and lower back,<sup>23</sup> and increase the thoracic and lumbar spine curvature.<sup>24</sup> The additional weight may also alter landing kinematics and ground reaction forces. Kulas et al.<sup>25</sup> studied the effect of a vest of 10% BW on recreationally active civilian participants performing two-legged drop landing from a 45-cm-height platform. They reported increased angular impulse and energy absorption but no significant change in maximum knee flexion angles, whereas ground reaction forces and knee valgus angles were not mentioned.<sup>25</sup>

The biomechanical response to additional weight has not been extensively studied in a military population. Therefore, the main purpose of this study was to investigate the effects

of additional weight on soldiers' kinematics and kinetics and their potential implication on lower extremity musculoskeletal injury using similar biomechanical models we have previously employed in athletes.<sup>16-19</sup> Although the effects of additional weight should be observed throughout the lower extremity, we chose the knee joint as the main focus of this study. We used standard military body armor, a helmet, and a rifle to represent the minimal additional weight a soldier would carry in a combat setting. As a part of our ongoing 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program, soldiers from the 101st Airborne Division (Air Assault) participated in this study. We hypothesized that wearing body armor, a helmet, and carrying a rifle would result in greater knee flexion and knee valgus angles at initial foot contact, greater maximum knee flexion angle, prolonged time from initial foot contact to maximum knee flexion, greater maximum vertical ground reaction forces (VGRF), and a prolonged time from initial foot contact to maximum VGRF, compared to not wearing the additional weight. This study is among a limited number of investigations examining the effect of additional weight on biomechanics of drop landing and is the only one recruiting participants strictly from a military population. We expect the results of this study will provide evidence-based insight to modify soldiers' training, accounting for the necessary loads carried during combat, to reduce the risk of injury.

### **Methods Participants**

Seventy 101st Airborne (Air Assault) soldiers volunteered to participate in this study (age,  $28.8 \pm 7.1$  yr; height,  $1.78 \pm 0.07$  m; weight,  $84.1 \pm 12.8$  kg). To be included, potential participants must have been 18- to 45-year-old males 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, and no history of neurologic or balance disorders. All participants were cleared for active duty without any recent prescribed duty restrictions. Participants provided informed consent before participation. The current study was approved by the university's institutional review board (0506094), Eisenhower Army Medical Center (DDEAMC 07-16), Army Clinical Investigation Regulatory Office, and Army Human Research Protection Office (HRPO A-14020). All tests were conducted at our Human Performance Research Laboratory, Fort Campbell, KY, a remote research facility operated by the Neuromuscular Research Laboratory, University of Pittsburgh.

### **Instrumentation**

Six high-speed cameras (Vicon, Centennial, CO) operating at 200 Hz were used to capture the participants' kinematic data. Vertical ground reaction forces were measured using two Kistler force plates (Kistler, Amherst, NY) at a frequency of 1,200 Hz. The soldiers used their own personalized intercep-

tor body armor (IBA) (Point Blank Body Armor, Pompano Beach, FL) and advanced combat helmets (Gentex, Simpson, PA) for the test. An assault rifle replica (M4 carbine model) was provided by the researchers. The total weight of the interceptor body armor, helmet, and rifle replica was  $15.0 \pm 3.7$  kg, or  $18.0 \pm 4.3\%$  compared to each participant's BW. The authors recognize the actual weight carried by the soldiers will vary considerably depending on their work demands and could not control for potential differences between soldiers. The weight of the IBA, helmet, and rifle, however, represented the minimal additional required weight to be carried by the soldiers as part of tactical operations excluding the combat uniform and boots not worn as part of this study.

**Procedures**

Sixteen reflective markers were placed bilaterally on the participants' anterior superior iliac spines (ASIS), posterior superior iliac spines (PSIS), lateral thigh, lateral femoral epicondyle, lateral shank, lateral malleoli, posterior calcanei, and second metatarsal head (dorsal surface), according to Vicon's Plug-in Gait model (Vicon). The lateral thigh markers (midfemur) were placed in line between participants' greater trochanter (as palpated) and the lateral femoral epicondyle marker, and the lateral shank markers were placed in line between the lateral femoral epicondyle marker and lateral malleolus markers.

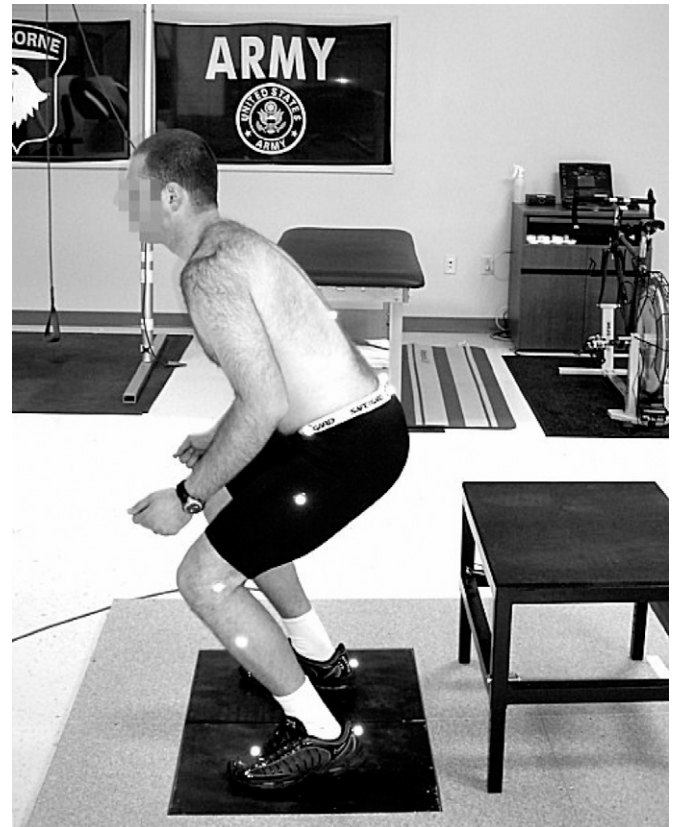
A static trial was captured for each participant in the anatomical position and served as the baseline for joint angle calculations. The participants were asked to perform two-legged drop landings from a platform of 50 cm high under two conditions: with and without wearing the IBA, helmet, and rifle; henceforth referred to as the IBA condition (Fig. 1) and non-IBA condition (Fig. 2), respectively. Participants were instructed to stand near the edge of the platform and drop off when the researchers gave the command. The participants were to land on both feet on the two force plates and remain standing for 2 seconds after regaining their balance. The task was described and demonstrated by the researcher. For each condition, the participants were given at least three practice trials. All trials for both conditions were performed on the same day with approximately 30–60 seconds in between trials within each condition and approximately 5 minutes between the two conditions. Trials during which the participants did not drop off the platform properly, failed to regain balance, touched the ground off the force plates, or did not land on the force plates were rejected.

**Data Reduction**

The 3D coordinates of the video-captured reflective markers were reconstructed and synchronized with the VGRF data using Vicon Nexus software (Vicon Motion Systems,



**FIGURE 1.** Two-legged drop landing task, IBA condition.



**FIGURE 2.** Two-legged drop landing task, non-IBA condition.



Centennial, CO). We used a general cross-validation Woltring filter to smooth the reconstructed 3D coordinates.<sup>26</sup> The Vicon Plug-in Gait model uses ASIS and PSIS markers to estimate the position of hip joint centers. However, to account for coverage of the ASIS markers by the IBA, we placed these markers on the IBA itself. Unfortunately, this invalidated the 3D joint angle calculations as they no longer reflected the anatomical landmarks on which they were intended. Therefore we decided to use 2D angles defined only by those markers on the legs, which were not affected by the ASIS markers.

The filtered *x*, *y*, and *z* coordinates and force plate data were processed with a custom Matlab (The MathWorks, Natick, MA) program to calculate joint angles and identify critical events. The knee flexion angle was defined as 180° minus the inner angle formed by lateral thigh, lateral knee, and lateral malleolus projected on the sagittal plane. The knee valgus angle was defined as 180° minus the inner angle formed by the three markers projected on the frontal plane. The joint angles during the dynamic tasks were corrected by the baseline angles from the static trial. Initial contact was defined as the point at which the vertical ground reaction forces exceeded 5% of the participant's body mass. Variables assessed in the current study included knee flexion and knee valgus at initial foot contact, maximum knee flexion, time to maximum knee flexion, maximum VGRF, and time to maximum VGRF. Three trials for each participant were averaged for statistical comparisons.

**Statistical Analysis**

Dependent *t*-tests were used to examine the differences of selected variables with (IBA) and without (non-IBA) wearing IBA. Each participant would serve as his own control. Statistical analyses were performed using SPSS software (SPSS, Chicago, IL). The  $\alpha$  level was set at <0.05.

**RESULTS**

The results are presented in Table I. The participants demonstrated no statistical difference between the IBA and non-IBA conditions for knee flexion or knee valgus angles at initial contact. Under the IBA condition, the participants had significantly greater maximum knee flexion and greater maximum

VGRF; the time from initial contact to these peak values were also significantly longer.

**DISCUSSION**

Equipment for personal protection and combat purposes places additional weight on the soldiers' bodies, which might alter their kinematics and kinetics and therefore increase the risk of musculoskeletal injuries. The purpose of this study was to investigate the biomechanical effects of additional weight on air assault soldiers performing landing tasks and the potential implication of the alterations on lower extremity musculoskeletal injuries, using the biomechanics model we previously developed.<sup>16-19</sup> This study focused specifically on the VGRF and knee kinematics during landing, which is a task that air assault soldiers frequently perform during combat activities, such as jumping out of a helicopter or a truck, and traversing uneven terrain or obstacles. On the basis of the 70 soldiers tested, we found greater maximum knee flexion, greater maximum VGRF, and prolonged time from initial contact to these two peak values with additional weight. We believe that specific strength training, proper landing skills, and properly increased exposure to weight carrying during physical training should be addressed to induce musculoskeletal adaptations that will likely reduce the risk of knee injuries in air assault soldiers.

The effects of additional weight carried by soldiers on knee kinematics and VGRF have several implications on training and injury prevention. First, the additional weight requires considerable lower extremity strength to land safely, especially at the knee, as the quadriceps must eccentrically contract to absorb and dissipate landing forces. Momentum is the product of the mass and the velocity of an object. Therefore, the kinetic influence of additional weight on soldiers' bodies and potentially landing kinematics is similar to landing without additional weight from a greater height or, equivalently, with additional weight at greater velocity. Maximum knee flexion angles,<sup>27</sup> as well as the range of knee flexion,<sup>27,28</sup> increases with drop landings from a raised platform height. A simulated parachute landing study demonstrated greater maximum knee flexion, greater range of knee flexion, and longer time to maximum knee flexion when participants dropped from a higher

**TABLE I.** Comparisons of Knee Joint Angles, Vertical Ground Reaction Forces, and Timings Between Non-IBA and IBA Conditions

	Right Leg			Left Leg		
	Condition		<i>p</i> value	Condition		<i>p</i> value
	Non-IBA	IBA		Non-IBA	IBA	
Knee Flexion Angle at Initial Contact (°)	10.5 ± 5.6	10.4 ± 5.5	0.905	12.5 ± 6.2	11.8 ± 6.5	0.107
Knee Valgus/Varus Angle at Initial Contact (°) (Positive = Valgus, Negative = Varus)	0.0 ± 10.1	-1.0 ± 11.8	0.466	-2.9 ± 13.8	-3.7 ± 14.8	0.566
Maximum Knee Flexion Angle (°)	76.2 ± 17.6	82.2 ± 14.4	<0.001	77.6 ± 18.8	84.4 ± 16.4	<0.001
Time to Maximum Knee Flexion Angle (ms)	239 ± 88	298 ± 73	<0.001	240 ± 102	292 ± 76	<0.001
Maximum Vertical Ground Reaction Force (Percent Body Weight)	371.2 ± 100.7	398.1 ± 94.3	0.002	330.5 ± 96.7	374.6 ± 88.2	<0.001
Time to Maximum Vertical Ground Reaction Force (ms)	37 ± 11	42 ± 9	<0.001	36 ± 12	40 ± 10	0.004

Statistical significance set at *p* < 0.05.

position.<sup>29</sup> During knee flexion, the knee extensors eccentrically contract to decelerate the body, and dissipate the impact, and absorb the energy transferred up from the ground.<sup>28,30</sup> As expected, our participants demonstrated increased maximum knee flexion and a longer time to reach maximum flexion with IBA; it naturally takes more knee angular displacement and time to stop the downward movement of the body with increased momentum. When such demand increases, a greater portion of the energy absorption shifts to the knee and hip extensors from the ankle muscles,<sup>28,30,31</sup> which have limited energy-dissipation capacity. The eccentric strength of knee extensors are considered a potential factor affecting maximum knee flexion during landing.<sup>16</sup> Although our participants demonstrated an appropriate adaptation of flexing the knees more, the additional weight added in the current study was only minimal and may not be reflective of actual carrying loads. As carry loads increase during tactical operations, the demand on muscular strength, especially eccentric strength at the knees and hips, would increase significantly to perform safe landings.

Second, proper landing techniques should be emphasized to address the increased VGRF and accompanied risk of injury. The vertical ground reaction force induces an external knee flexion torque. To counterbalance and control the knee flexion torque, there exists an internal knee extension torque (quadriceps activation), which simultaneously increases the ACL strain by producing an anterior shear force on the proximal tibia.<sup>32</sup> Our previous research has demonstrated that the greater the internal knee extension torque, the greater the proximal tibia anterior shear force.<sup>19</sup> Activation of the quadriceps, which increases anterior shear force by way of the patella tendon,<sup>32</sup> is also preactivated before initial contact.<sup>29,33-35</sup> Depending on the knee alignment at the instant of landing, the VGRF may increase the knee valgus torque, which can further increase ACL strain in the presence of anterior shear force at the knee.<sup>36,37</sup> Valgus alignment of the knee at landing has been considered a risk factor for noncontact ACL injury.<sup>15</sup> In addition to landing with greater knee valgus, those individuals at greater risk for injury experience greater proximal tibia anterior shear force during landing even when their vertical and posterior ground reaction forces are not significantly higher than those at less risk for noncontact ACL injury.<sup>18</sup> Although our participants did not show any sign of more dangerous knee alignment in the frontal plane with additional weight, the increased maximum VGRF they experienced has been linked to increased risk of noncontact ACL injuries.<sup>15</sup>

In the current study, an average of 18% of additional weight increased the maximum VGRF by 35% BW on each leg (based on data derived from Table I); with the additional weight of weapons, ammunition, and other combat equipment, the maximum VGRF during landing is expected to increase dramatically in tactical operations. In a previous study, the vertical ground reaction forces increased from 256% BW to 474% BW as the height of the dropping platform rose from 32 cm to 103 cm (equivalent to an increased velocity from 2.5 m/s to

4.5 m/s).<sup>28</sup> Our 50-cm platform, equivalent to a 3.1 m/s velocity, yielded a comparable 355% BW maximum VGRF under the non-IBA condition and 391% BW under the IBA condition. A high mobility multipurpose wheeled vehicle (HMMWV), widely used by the U.S. Army, has a deck height of approximately 84 cm, and the height of a window or a wall and the depth of a ditch can be close to a meter or more. Moreover, the maximum VGRF experienced during landing tasks performed in the field could be much greater than the standardized drop landing task performed indoors. A simulated parachute landing yielded 930% BW (9.3 times body weight) and 1,310% BW (13.1 times body weight) of maximum VGRF at vertical velocities of 3.3 and 4.5 m/s, respectively.<sup>29</sup> Such high VGRF was very close to the greatest value ever documented, in a single-leg double back somersault landing (1,440% BW).<sup>38</sup> The exact reason for such a large increase in maximum VGRF between tasks is difficult to determine; however, performing such a task is more dynamic, and has much higher uncertainty and unpredictability than a well-controlled standardized task. During tactical operations soldiers will quickly react to the environment and operation conditions and may not have time to prepare for the landing. In such context, soldiers may not be able to use their full capacity to reduce the impact. Thus, we would expect an even higher maximum VGRF that the air assault soldiers would encounter frequently in the battlefield.

One technique to reduce the VGRF is to increase the knee flexion angle at initial contact, and allow greater knee flexion throughout the landing.<sup>28,30</sup> Females, who are more vulnerable to noncontact knee injuries, demonstrate lower knee flexion angles at initial contact during two-legged landing,<sup>14,27</sup> although a limited amount of research has shown no gender differences<sup>39</sup> or increased knee flexion in females.<sup>34</sup> With less knee flexion, less energy can be absorbed, and more energy is transferred to the knees and hips from the ankles. We hypothesized that the knee flexion angles at initial contact would be greater under the IBA condition, assuming the additional weight would lead to a more cautious move. However, our participants demonstrated no statistical difference between conditions. We do not have sufficient information to conclude whether soldiers would land with a more extended knee when additional weight is carried on the basis of the current study and research design. Although the effect of additional weight was similar to increased dropping velocity in many ways, we also do not have a clear answer as to how a greater velocity would affect the knee flexion angle at initial contact. Huston et al.<sup>27</sup> found that knee flexion angle increased with increasing velocity during two-legged drop landings. In contrast, a more extended knee with greater velocity was observed in simulated parachute landing, which may explain the concurrent high maximum VGRF observed.<sup>29</sup> Although the task Huston et al.<sup>27</sup> used was more comparable to ours, the results from the simulated parachute landing may be more valuable to our research purposes. We cannot rule out the possibility that soldiers would land with more extended knees performing tactical operations in the field with additional weight.

In this study, we demonstrated the effect of additional weight on knee kinematics and VGRF of soldiers performing a two-legged drop landing task. These effects may increase the risk of lower extremity musculoskeletal injuries during a similar landing task; however, landing is not the only task that the additional weight could affect, and the knee is not the only joint subjected to increased risk of injury under the increased stress because of the additional weight. Military load carriage can also increase the ground reaction forces during walking,<sup>40</sup> alter pelvic and hip angles during standing,<sup>41</sup> and decrease balance and postural stability.<sup>42</sup> Craniovertebral angle and femur range of motion,<sup>43</sup> thoracic and lumbar spinal curvature,<sup>24</sup> forces suffered at the upper and lower back,<sup>23</sup> and trunk muscle activation patterns<sup>41</sup> can all be adversely affected by additional weight. Alterations in physiological performance, such as increased oxygen consumption, heart rate, ventilation, perceived exertion, and decreased knee muscle extension torque output were all evident in a simulated marching test with increased carried weight, suggesting the fatiguing effects of the heightened demands of additional load.<sup>22,44</sup> Our preliminary data from another study has also demonstrated similar effects with additional load (body armor and helmet = 18.6 kg). The addition of the body armor and helmet increased the peak VGRF during gait by 18.7% BW and the time to exhaustion during a VO<sub>2</sub> max test decreased by 50% and caloric expenditure increased by 20%. Considering the trend of increasing weight carried by soldiers throughout history,<sup>20</sup> the effects of this weight on soldiers' performance and safety in tactical operations is an ongoing concern for soldiers' effectiveness and safety.

Because additional weight considerably increases the mechanical and physiological demands and potentially contributes to musculoskeletal injuries, integrating additional weight into soldiers' regular physical training seems prudent. Soldiers build their strength through their daily Army physical training and sharpen their combat skills through regular tactical training. However, soldiers frequently wear only fitness clothing and running shoes during physical training. Additional weight may be worn during tactical training, yet a progressive program to induce adaptations has not been implemented. On the other hand, during their deployment, soldiers are equipped with additional weight sometimes significantly more than encountered in previous physical and tactical training. The inconsistent exposure to additional weight during training may not induce the musculoskeletal demands to allow soldiers to build and maintain sufficient strength and develop adequate kinematic adaptations to meet the combat mission tasks. Increased integration of additional weight into physical training that simulates the demand of their tactical operations is therefore encouraged, as it may reduce the risk of injuries and promote soldiers' combat readiness.

We acknowledge this study has several limitations. First, we had to use 2D projection angles instead of 3D joint angles because of marker placement issues. Knee flexion and knee valgus angles can affect each other when the values are large.

However, we only assessed knee valgus angle at initial contact, while knee flexion angles were small. And the knee valgus angle was low throughout the landing task and would have limited effect on the knee flexion angles. Second, the order of the two testing conditions was not randomized. A learning effect could have influenced the measurements during the IBA condition because it always followed the non-IBA condition. In an attempt to address this issue, we provided at least three practice trials for each condition and allowed more practice until participants felt comfortable and prepared. We believe participants could familiarize themselves with the landing tasks through practice, and therefore the order of the two testing conditions would not provide further alteration of performance. We also felt this order of testing was a safer protocol. Third, the current study did not include ankle kinematic calculations. Lephart et al.<sup>16</sup> suspected that ankle kinematics may affect the VGRF of landing tasks. Future studies investigating how the ankles would respond with increasing mechanical demands could provide additional insight of military injury prevention, particularly given the rate of ankle injury.

## CONCLUSION

Even the minimum additional weight soldiers carry such as the addition of body armor, helmet, and a rifle, causes altered kinematics and ground reaction forces. These alterations attributed to carrying additional weight may increase the risk of knee and other lower body injuries. Gradually integrating additional weight, such as body armor, into the soldiers' physical training is recommended to promote kinematic adaptations and safer performance during landing tasks.

## ACKNOWLEDGMENTS

This study is supported by the U.S. Army Medical Research and Materiel Command under Award No. W81XWH-06-2-0070, as a part of the 101st Airborne (Air Assault) Injury Prevention and Performance Optimization Program.

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