





Article

# Muscle Activity during Postural Stability Tasks: Role of Military Footwear and Load Carriage

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**Abstract:** Decrements to postural control manifest as an increase in muscle activity, indicating continuous attempts to maintain body equilibrium and postural stability. Extrinsic factors such as footwear, and intrinsic factors such as muscle fatigue, can affect postural stability. The purpose of this study was to analyze the impact of two types of military footwear and a military-type load-carrying task on lower extremity muscle activity during various postural stability tasks. Sixteen males' (age:  $26.63 \pm 3.93$  years; mass:  $87 \pm 12.4$  kg; height:  $178.04 \pm 6.2$  cm) muscle activity from knee flexors, extensors, ankle dorsiflexors, and plantar flexors were measured using electromyography in standard (STD) and minimalist (MIN) military footwear, before (PRE) and after (POST) a simulated workload during sensory organization and motor control tests on the Neurocom Equitest<sup>TM</sup>. Mean muscle activity was analyzed using  $2$  (footwear)  $\times$   $2$  (time) repeated measures ANOVA with an alpha level of 0.05. Results revealed a requirement of significantly greater muscle activity in POST and STD. MIN demonstrated lesser balance decrements POST workload, which could be attributed to its design characteristics. Results will help in suggesting footwear design characteristics to minimize muscular exertion while eliciting better postural control, and to prevent postural instability due to overexertion in military personnel.

**Keywords:** military footwear; postural stability; sensory organization test; motor control test

## 1. Introduction

Erect standing posture could be accomplished by a comparatively smaller degree of muscle activation. However, the regulation and maintenance of erect posture are more complex, which requires proper communication between the neuromuscular systems. Postural control is mainly acquired through the integration of sensory systems (visual, vestibular, and somatosensory systems), central control, and motor systems (neuromuscular system) [1,2]. When one or more of these systems

are compromised, maintaining postural control will be challenged, leading to falls. Decrements to the postural control manifest as an increase in postural sway and increased muscle activity, indicating continuous attempts to maintain postural stability. Moreover, the disruption to the postural control increases the demand for central control and peripheral muscles [3].

Among the diverse intrinsic factors that can affect postural stability, physiological workload causing muscular fatigue is highly distinguished [4]. It has been shown that muscular fatigue is associated with decrements in postural stability [5]. Different types of physiological workloads have been studied before, and military load carriage has been shown, especially, to decrease the postural stability, leading to increased incidence of falls and injuries [6]. Furthermore, extrinsic factors, for instance, footwear, play a significant role in postural stability. Many design characters of footwear such as mass, midsole thickness, midsole hardness, heel height, and shaft height have been investigated before. Among these design characteristics, increased mass [7], thick, soft midsoles [8], increased heel height [9], and shorter shaft [4] were found to cause postural instability, while altering lower extremity muscle activity.

Military personnel are highly prone to these occupational falls leading to occupational injuries, due to the nature of their occupation. They are required to carry out high levels of physically demanding tasks, such as carrying workload, lifting weights, and prolonged walking. Long work hours and sleep disturbances add to this. Military personnel are required to wear shoes that are recommended by the United States Army. These recommended shoes are expected to aid in locomotion and balance while protecting feet from injuries [10]; however, designing footwear which could achieve both functions can be challenging. Along with the high demanding physical workload, if they were to also wear footwear with unfavorable design characteristics, maintaining postural stability could not be at an optimal level. Strenuous physical workload causing muscular fatigue can act as an internal perturbation, and the inappropriate footwear can act as an external perturbation, to the postural control system. Hence, these factors might predispose inefficient muscular exertion, leading to increased postural sway, resulting in a fall. Previous research from the current authors have reported lower extremity muscular activation quantified by electromyography (EMG) with different types of occupational footwear, such as steel-toed boots, tactical work boots, and slip-resistant shoes, during postural stability tasks [11]. EMG responses identified significant differences, with tactical work boots demonstrating lower and efficient muscle activity, compared to other occupational footwear [11].

Currently, there are a few military footwear types with unique design characteristics that are approved by the United States Army. Although there are few studies conducted on those shoe types [12], their role in postural stability has not been widely studied, leaving a gap in the literature. With both footwear and imposed physiological workload playing a critical role in maintaining postural stability, the current authors assessed the impact of minimalist tactical and standard tactical military boots on postural stability, both before and after a load-carrying workload [13]. Postural stability was assessed using the sensory organization test (SOT) and motor control test (MCT) on the NeuroCom Equitest™. Postural stability was quantified by analyzing the postural sway velocity and root mean square sway in the anterior–posterior and medial–lateral directions during all six testing conditions of the SOT, and during backward and forward perturbations of the MCT. Results from this study indicate significantly greater center of pressure postural sway variables and postural response latencies in the standard tactical boot. The minimalist military boot was reported to be superior in postural stability performance compared to the standard military boot, especially in testing conditions that required greater somatosensory feedback from the feet [13]. These differences were attributed to the design characteristics of the minimalist tactical boot that aided postural stability performance. Such design characteristics of the minimalist tactical boot included a minimalist heel-to-toe drop, lower mass, a flexible mesh type laced-up boot shaft, and firm and thin mid and outer sole. These design characteristics were suggested to provide a more anatomically neutral foot position, a smaller tipping angle, lower energy expenditure, and increased somatosensory or proprioceptive feedback for maintain postural stability. While the postural sway results from this study have been reported [13], lower

extremity EMG muscle activation during these different postural stability tasks, with the two types of military footwear before and after a load-carrying workload, have not been previously analyzed. Therefore, the purpose of the current study was to analyze the impact of the two types of military footwear; a standard tactical military boot and a novel minimalist tactical military boot, when exposed to a load-carrying military-type workload on lower extremity muscular activity during SOT and MCT postural stability tasks. Based on previous research on type of footwear, their design and material characteristics, both without and with exposure to imposed physiological workloads, and their impact on postural stability, it was hypothesized that the minimalist military boot would demonstrate more efficient muscular activity during postural stability tasks, compared to the standard tactical boot, both before and after a load carriage workload.

## 2. Materials and Methods

### 2.1. Study Design

A total of sixteen healthy, recreationally active males (age:  $26.63 \pm 3.93$  years; mass:  $87 \pm 12.4$  kg; height:  $178.04 \pm 6.2$  cm), based on American College of Sports Medicine (ACSM) guidelines [14], completed the study. All participants gave their informed consent for inclusion before they participated in the study. The study was conducted in accordance with Mississippi State University's Institutional Review Board (IRB) under the approved protocol number (MSU IRB# 15-093). The study was conducted under a pre-test-post-test repeated measures design, where participants' muscle activity was measured during various postural stability tasks, before (PRE) and after (POST) a simulated military-type workload in two AR670-1 compliant military footwear types (Belleville TR101 MiniMil ultra-light minimalist tactical military boot (MIN) and Belleville 310ST hot weather standard tactical boot (STD)) (Figure 1) (Table 1). Footwear allocation was counterbalanced, and each participant was tested on two days in the two types of footwear, separated by a minimum of 72 h.



**Figure 1.** Two types of footwear used in the study. (a) Belleville TR101 MiniMil ultra-light minimalist tactical military boot (MIN); (b) Belleville 310ST hot weather standard tactical boot (STD).

**Table 1.** Design characteristics of the two types of military footwear used in the study.

Design Characteristic	MIN (Mean $\pm$ SD)	STD (Mean $\pm$ SD)
Mass	500.13 $\pm$ 24.1 g	801.13 $\pm$ 40.4 g
Sole surface area	235.40 $\pm$ 8.2 cm <sup>2</sup>	288.60 $\pm$ 24.1 cm <sup>2</sup>
Boot shaft height	20 cm (flexible)	20 cm (stiff)
Heel to toe drop	2 mm	18 mm

Comparison of footwear characteristics [mean  $\pm$  (standard deviation)] between MIN: Belleville TR101 MiniMil ultra-light minimalist tactical military boot; STD: Belleville 310ST hot weather standard tactical boot (STD).

## 2.2. Experimental Procedures

For the simulated workload, participants were advised to walk on a treadmill while carrying a 16 kg rucksack, until failure. Each participant started at 0% grade and 4.83 km/h. Until minute 9, the speed was gradually increased up to 6.44 km/h at 0% grade. Thereafter, the speed was held constant while the grade was increased every 3 min by 5%, up to 18 min [15]. All participants were instructed to provide maximal effort and stop only when they could no longer continue. This was also verified by the participant's rating of perceived exertion (RPE) scale [16], indicating a maximal effort at the end of their volitional cessation of the workload. Participants' PRE and POST mean muscle activity was measured using a Noraxon™ Telemyo™ T2400 G2 wireless EMG system (Scottsdale, AZ, USA) with a sampling frequency of 1500 Hz in the muscles vastus medialis (VM), medial hamstrings (MH), medial gastrocnemius (MG), and tibialis anterior (TA) [11,17–19], during the motor control test (MCT) and sensory organization test (SOT) on the NeuroCom Equitest™. In the SOT, participants were subjected to six different testing conditions, based on the sensory conflict hypothesis, by providing conflicting visual and somatosensory information. The six testing conditions included three trials of each for eyes open (EO), eyes closed (EC), EO sway referenced support (EOSRS), EO sway referenced vision (EOSRV), EO sway referenced vision and support (EOSRVS), and EC sway referenced support (ECSRS) conditions. The MCT involved a sequence of small, medium, and large backward and forward platform translations, providing postural perturbations. The sizes of the translations were scaled to the patient's height to produce sway differences of equal size at constant speed, to impart the body to an angular momentum of 2.8, 6.0, and 8.0 degrees per second for the small, medium, and large translations. The large translations produced a maximal response, while the small translations were just a threshold stimulus. The NeuroCom Equitest™ also has an in-built random time delay of 1.5 to 2.5 s in between MCT trials. The testing during the MCT followed NeuroCom's standardized testing procedures [20]. In the MCT, participants were subjected to backward and forward standing platform perturbations that ranged in magnitude, including small, medium, and large. The onsets of these perturbations were randomly provided, to prevent any anticipatory postural mechanisms. The backward large (BWL) and forward large (FWL) were used for the analysis, as the small translations represented a threshold stimulus, while the large translations required the participant to produce a maximal response. During both the SOT and MCT, participants were instructed to stand erect and be as still as possible, with head straight, staring straight onto the NeuroCom's visual surround. Apart from an initial familiarization session on the SOT and MCT during recruitment, participants were not provided with any information on the sequence of the assessments or the type of the testing condition. A full description of these tests is provided in Nashner et al. (1993) [20], and in the postural stability paper from the current study [13].

## 2.3. Data Analysis

EMG activity from all muscles was collected during the SOT and MCT, and time synced between the NeuroCom Equitest™ and the Noraxon™ Telemyo using a transistor–transistor logic (TTL) pulse. The start of an SOT or MCT trial triggered the start of EMG recording through the TTL pulse, and, subsequently, the automatic end of the SOT or MCT trial stopped the EMG recording. Hence, all trials for all participants lasted the same time duration. Raw EMG muscle activity throughout the SOT and MCT trials were filtered using a Butterworth bandpass filter at 20 Hz–250 Hz followed by full-wave rectification and used to calculate mean muscle activity (mV) during these trials. Mean muscle activity (mV) was calculated for all four muscles, for the entire duration of each of these trials. The current analysis used a calculation of amplitude mean value of EMG of a selected interval of time, bounded by the time synced start and stop cut-off time points with the NeuroCom balance tests, through the TTL pulse. The mean amplitude during this epoch window was used for analysis, as, according to Konrad (2005), is considered to best describe the gross innervation input of a selected muscle for a given task; here, balance tasks, and works best for comparison analysis [21]. Similar analysis using the mean amplitude of a specific time epoch during such balance tasks have been previously reported [5,17,18,22]. An average of three trials for each condition of the SOT was calculated, and BWL and FWL trials

analyzed individually for all four muscles. Mean muscle activity for each muscle, from each testing condition of the SOT and MCT, were individually analyzed using SPSS in a 2 × 2 (time (PRE-POST) × footwear (MIN-STD)) within-subjects repeated measures ANOVA at an alpha level of 0.05. If main effect significance or a significant interaction was observed, a post hoc pairwise comparison using a Bonferroni correction was performed.

### 3. Results

On average, significantly greater muscle activity was required to maintain postural stability in the POST workload condition and STD. Table 2 provides a summary of the significant results in both SOT and MCT. The summary is of significant findings of the repeated measures ANOVA with significant main effects and interactions, presented with F statistic, *p*-value, and partial eta squared values. Additionally, post hoc comparisons are made.

**Table 2.** Repeated measures ANOVA table for sensory organization test and motor control test.

Conditions	Muscle	Main Effect/Interaction	F	<i>p</i>	$\eta_p^2$	Post Hoc Pairwise Comparisons
<b>SOT</b>						
EO	MG	Time Main Effect	10.112	0.006	0.403	POST > PRE
EC	MG	Time Main Effect	7.354	0.016	0.329	POST > PRE
EOSRV	MG	Time Main Effect	5.376	0.035	0.264	POST > PRE
EOSRV	MH	Boot × Time Interaction	4.638	0.048	0.236	STD/POST > PRE
<b>MCT</b>						
BWL	VM	Time Main Effect	5.961	0.027	0.284	POST < PRE
BWL	MH	Boot × Time Interaction	5.619	0.032	0.273	STD/POST > PRE
	MG	Time Main Effect	6.117	0.026	0.290	POST > PRE
	MG	Boot × Time Interaction	5.918	0.028	0.283	STD/POST > PRE
FWL	MH	Time Main Effect	6.191	0.025	0.292	POST < PRE

Summary of statistically significant dependent variables. SOT: Sensory organization test; MCT: motor control test. Conditions in SOT: EO: eyes open; EC: eyes closed; and EOSRV: eyes open sway referenced vision. Perturbation types in MCT: BWL: Backward large; FWL: forward large. Muscles: VM: vastus medialis; MH: medial hamstrings; MG: medial gastrocnemius; and TA: tibialis anterior.

#### 3.1. Electromyographic Muscle Activity during SOT

The 2 × 2 repeated measures ANOVA for EMG muscle activity during SOT balance test revealed significant time main effect differences for MG muscle during EO ( $F(1, 15) = 10.112, p = 0.006, \eta_p^2 = 0.403$ ), EC ( $F(1, 15) = 7.354, p = 0.016, \eta_p^2 = 0.329$ ), and EOSRV ( $F(1, 15) = 5.376, p = 0.035, \eta_p^2 = 0.264$ ) conditions. Pairwise comparisons revealed significantly more muscle activity from the MG in the POST workload compared to PRE workload. Table 3 provides descriptive statistics for mean muscle activity of all significant findings as mean ± standard deviation during SOT (Table 3). No other statistically significant differences were observed for each SOT testing condition and each muscle.

**Table 3.** Descriptive statistics for mean muscle activity (mV) during sensory organization test.

SOT Conditions	Muscle	MIN		STD	
		PRE	POST	PRE	POST
EO	MG	6.36 ± 3.58	8.13 ± 5.10 *	7.87 ± 5.82	8.94 ± 5.99 *
EC	MG	7.37 ± 5.71	10.61 ± 7.41 *	9.26 ± 6.88	10.74 ± 7.62 *
EOSRV	MG	9.17 ± 6.04	10.30 ± 6.00 *	8.47 ± 6.49	11.96 ± 9.66 *
EOSRV	MH	4.50 ± 3.82	3.93 ± 4.10	3.09 ± 3.58	4.60 ± 4.82 #

Descriptive statistics for mean muscle activity (mV) of all significant findings as mean ± standard deviation. SOT: Sensory organization test. Conditions in SOT: EO: eyes open; EC: eyes closed; and EOSRV: eyes open sway referenced vision. VM: vastus medialis; MH: medial hamstrings; MG: medial gastrocnemius; and TA: tibialis anterior. PRE: before the simulated military workload; POST: after the simulated military workload. MIN: Minimalist tactical military boot; STD: standard tactical boot. \* Indicates significant time main effect, POST significantly different compared to PRE; # indicates significant boot difference due to boot × time interaction.

### 3.2. Electromyographic Muscle Activity during MCT

The  $2 \times 2$  repeated measures ANOVA for EMG muscle activity during MCT balance test revealed significant differences during BWL and FWL conditions (Table 2). Table 4 provides descriptive statistics for mean muscle activity of all significant findings as mean  $\pm$  standard deviation during MCT (Table 4). Significant time main effect differences were evident during BWL for VM ( $F(1, 15) = 5.961$ ,  $p = 0.027$ ,  $\eta_p^2 = 0.284$ ) and for MG ( $F(1, 15) = 6.117$ ,  $p = 0.026$ ,  $\eta_p^2 = 0.290$ ). Pairwise comparisons revealed significantly greater muscle activity in POST workload compared to PRE workload for MG, but not for VM. Moreover, during BWL, significant time  $\times$  boot interaction was also seen with MH ( $F(1, 15) = 5.619$ ,  $p = 0.032$ ,  $\eta_p^2 = 0.273$ ) and MG ( $F(1, 15) = 5.918$ ,  $p = 0.028$ ,  $\eta_p^2 = 0.283$ ), with pairwise comparisons for simple main effects revealing significantly greater muscle activity in both MG and MH in POST workload compared to PRE workload in the STD boot. Significant time main effect difference was seen during FWL for MH ( $F(1, 15) = 6.191$ ,  $p = 0.025$ ,  $\eta_p^2 = 0.292$ ), with pairwise comparisons revealing significantly greater muscle activity in PRE workload compared to POST workload. No other statistically significant differences were observed for each SOT testing condition and each muscle.

**Table 4.** Descriptive statistics for mean muscle activity (mV) during motor control test.

Perturbation	Muscle	MIN		STD	
		PRE	POST	PRE	POST
BWL	VM	3.92 $\pm$ 3.31	2.77 $\pm$ 2.51 *	3.51 $\pm$ 2.80	2.94 $\pm$ 3.34 *
	MH	9.77 $\pm$ 8.99	9.04 $\pm$ 8.44	8.00 $\pm$ 6.58	9.94 $\pm$ 8.14 #
	MG	16.00 $\pm$ 10.28	17.32 $\pm$ 11.47 *	15.69 $\pm$ 8.58	20.33 $\pm$ 12.09 * #
FWL	MH	8.19 $\pm$ 10.16	7.40 $\pm$ 10.02 *	7.30 $\pm$ 7.14	5.93 $\pm$ 4.83 *

Descriptive statistics for mean muscle activity (mV) of all significant findings as mean  $\pm$  standard deviation. MCT: motor control test. Perturbation types in MCT: BWL: Backward large; FWL: forward large. VM: vastus medialis; MH: medial hamstrings; MG: medial gastrocnemius; and TA: tibialis anterior. PRE: before the simulated military workload; POST: after the simulated military workload. MIN: Minimalist tactical military boot; STD: standard tactical boot. \* Indicates significant time main effect, POST significantly different compared to PRE; # indicates significant boot difference due to boot  $\times$  time interaction.

## 4. Discussion

The purpose of the current study was to analyze the impact of simulated military-type workload and two types of military footwear on muscular activity during postural stability tasks in young, healthy males. Overall, the results of the study identified an increased muscle activity after the simulated load-carrying task, and in the STD boot. However, these significant differences were predominantly seen in ankle plantar flexors and knee flexors, and were specific to the type of postural stability task performed. The significant differences identified between PRE and POST load carrying task, with a predominant increase in muscle activity in POST, could be attributed to the workload induced changes to the muscle activation; whereas the significant differences seen between STD and MIN could be attributed to the design characteristics in MIN that promoted postural stability performance compared to STD, especially after the workload and in testing conditions that rely heavily on somatosensory feedback from the feet to maintain upright postural stability.

### 4.1. Military Footwear Type as a Predictor of Muscular Exertion in Postural Stability

Due to its role as the interface between the foot and the standing surface, footwear is considered as a crucial extrinsic factor in postural control [4]. Among the many design characteristics of footwear, mass of the footwear is suggested as one of the main factors that can affect postural stability. Previous studies have shown increased energy expenditure [23] and increased muscle fatigue [7] with heavier footwear. Furthermore, the minimalist type of footwear, with less heel height and a lower heel-to-toe drop, is suggested to cause fewer balance decrements, due to less anterior shifting of the center of mass [24]. Additionally, such minimalist footwear has a less severe tripping angle [24]. These features favor better postural stability and requirement of lesser muscle activity to maintain postural control.

In the current study, a greater muscle activity in STD boot POST workload was observed, suggesting a greater requirement of muscle activation required to maintain postural stability. The differences in muscle activity between the two footwear could be attributed to the design characteristics. The STD boot is 300 g heavier than MIN and has an 18 mm heel-to-toe drop, compared to a 2 mm drop in MIN, which could be the design characteristics causing greater muscle activation when wearing STD. Moreover, the greater mass of a footwear increases the energy expenditure during load-carrying [25,26]. An increased mass at the distal end of a lever causes the muscle to produce more force, causing early fatiguing of the muscles. Many researchers have shown this association of footwear mass with muscular fatigue [26,27]. While Jones et al. (1984) suggest an increase of 0.7–1% of energy expenditure, Chiou et al. (2012) suggest a 5–11% increase in metabolic variables per every 100 g increase in the footwear mass, which is a reason for early muscular fatigue in footwear with heavier mass. The overall increase in muscle activity in STD boot POST workload in both SOT and MCT suggest that a greater amount of muscle activity is needed to maintain an adequate postural control while wearing STD.

While the MCT is an assessment of postural stability in response to forward and backward perturbations, and all sensory systems are readily available to relay the perturbation information to the postural control system, the SOT assesses postural stability with absent or conflicting sensory information. In EOSRV testing conditions, with conflicting visual input, the postural control system relies heavily on the somatosensory system for sensory feedback to maintain an upright stance. The MIN also had a thin hard midsole, as measured by the Shore A hardness scale [28,29], providing an optimal footwear design feature in addition to the low heel-to-toe drop and lower mass, for better and more efficient postural stability.

#### *4.2. Load Carriage Workload as a Predictor of Muscular Exertion in Postural Stability*

Intrinsic factors, such as muscle fatigue, can cause detrimental effects on postural control, which are inevitable during a workload causing balance decrements [4]. Impairment of kinesthetic properties disrupting the afferent feedback has been identified as a major reason for this postural instability [30]. Through increasing the threshold for muscle spindle firing, muscle fatigue could lead to the deterioration of proprioception of joints. This will impair the afferent feedback, causing conscious joint awareness [30], which ultimately results in the requirement of greater muscle activation in order to maintain postural stability. The higher muscle activity seen in POST workload during SOT and MCT suggests that a greater amount of muscle activity is needed to maintain postural stability following a fatiguing workload. Hence, the results of the current study support previous literature. In SOT, during EC condition, the participants' visual feedback was absent, and in EOSRV condition, their visual feedback was erroneous. In situations where there is absent or erroneous visual feedback, individuals will be more dependent on proprioception [31]. Therefore, the significant differences in EC and EOSRV conditions could be due to the impairment of proprioception and the inability to produce a sustainable output by the postural muscle following the workload [6,30].

There was an exception in MCT in BWL and FWL perturbations where there was a decreased muscle activity seen POST workload compared to PRE in more proximal muscles (VM and MH). However, in the distal muscles (MG), increased activity was seen during POST workload, indicating a decrement to the postural stability. As this was seen only with time as a main effect, there may be a learning effect for these perturbations from PRE to POST workload, where individuals might have selectively used an ankle strategy with greater muscle activation from the lower leg/ankle muscles of MG, compared to upper leg/knee muscles of VM and MH, especially in POST workload testing.

Finally, comparing the current observed results from EMG measures to the previously reported postural sway results aids in a greater understanding of the behavior of these military footwear and load carriage in postural stability tasks. Extrinsic factors such as military footwear, and intrinsic factors such as the military-type load-carrying physiological workload, impact balance and postural stability. The findings from the Chander et al. (2019) paper also report greater postural stability while wearing

the minimalist tactical boot, and decreased postural stability while wearing the standard tactical boot, as well as decreased postural stability during POST load carriage conditions [13]. In this study, postural stability was quantified using center of pressure postural sway variables and postural response latencies during SOT and MCT balance assessments. The current paper's findings also report that during SOT and MCT, the minimalist tactical boot performed better and more efficiently with lower EMG muscle activity compared to the standard tactical boot, especially after the load carriage workload. A follow-up study from the current research laboratory, conducted to analyze the impact of these two military footwear (MIN and STD) with the load-carriage workload on postural stability, used another healthy sample of the population and the modified clinical test of sensory interaction in balance (CTSIB-M) assessment [17,29]. It was found that the MIN was reported to have better postural stability compared to STD, and that postural stability was decreased after the load carrying workload [29]. Additionally, the MIN demonstrated lower muscle activity compared to STD, suggesting that minimalist footwear in the military aided postural stability and efficient muscle activation, even after a fatiguing load-carrying task. The current findings also support previous literature using the same types of military footwear and same load-carrying workload, but a different sample of healthy participants.

There were some limitations to the study. A total of sixteen participants were tested in the study. While similar previous research on footwear and postural stability [4,7,11,17,29] and the repeated measures within-subject design provide rationale for sample size, all the participants were healthy males, free of any disorder or injuries. This was done to narrow the observed results to the footwear and the workload, rather than due to any underlying conditions that could compromise postural stability. However, military individuals might be accustomed to the footwear and load carriage task and may have different adaptations to postural stability. The current findings can be more applicable to brand-new military recruits and how military footwear types and load carriage task might impact their postural stability. Additionally, only males were tested due to the footwear availability. The participants performed the load-carrying task until failure. However, there was no significant difference between the time taken until failure and the boot type, suggesting a similar exertion between both boot types along with the subjective RPE measure of maximal exertion. Finally, a significant difference among footwear types was seen only in one condition in SOT and two conditions in MCT, and hence the results should be interpreted with caution. Future studies should focus on military population on these footwear in different types of physical activities, such as running, sprinting, jumping, prolonged standing, garrison work, marching, etc., with measures of fatigue to understand their behavior and their impact on human performance.

## 5. Conclusions

The current study addresses the impact of minimalist and standard types of military footwear and a load carriage workload on postural stability. Findings revealed that a greater muscular exertion was required to maintain postural stability while wearing STD and after the simulated load-carrying task. A lower and more efficient muscle activation to maintain postural stability was observed while wearing MIN. The design characteristics in the MIN, such as a minimalist heel-to-toe drop, lower mass, thin and firm mid and outer soles, and mesh type laced-up boot shaft, were suggested to benefit postural stability performance. The current findings support the previously reported postural sway results from the study, and also support the follow-up studies with the same footwear and workload in other forms of postural stability tasks. In highly physically demanding occupations, such as military, special attention should be given to implementing measures to prevent physiological fatigue and enhancing postural stability performance, to prevent undue injuries. Footwear such as MIN could potentially accomplish such requirements, in promoting better postural stability and efficient muscular activation, thereby preventing falls and fall-related injuries in the military. Therefore, in designing military footwear, the favorable design characteristics of the minimalist boot could be incorporated into future footwear design. Furthermore, the current study shows that intrinsic factors, such as fatigue following a prolonged workload, can affect the postural control system, which should be considered



while constructing work–rest schedules in the military. Therefore, the findings from the study will help in suggesting footwear design characteristics, in order to minimize muscle fatigue while eliciting better postural control, as well as on work–rest schedules to prevent postural instability due to overexertion in military personnel.

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