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Impact of military type footwear and workload on heel contact dynamics during slip events

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A B S T R A C T

Introduction: Slips, trips and falls due to an induced loss balance have been identified as the leading cause of occupational injuries. This study aimed to analyze the impact of two military boots, standard boot (STD) and minimalist boot (MIN) on slip events, before (PRE) and after (POST) a military type load carrying task.
Methods: Sixteen male participants (age: 27 ± 3.9 years; height: 178 ± 6.2 cm, mass: 87 ± 12.4 kg) were tested for heel kinematics using motion capture, during unexpected (US) and expected slips (ES) both before and after the task. Slip parameters of heel slip distance (HSD) and mean heel slip velocity (MHSV) were analyzed with a 2 (STD × MIN) × 2 (PRE × POST) × 2 (US × ES) repeated measures ANOVA.
Results: Significantly greater HSD ($p = 0.002$) and MHSV ($p = 0.001$) were demonstrated in STD compared to MIN, regardless of the load carrying workload and the type of slip. No significant interactions between boots, workload and slip type were found. MIN exhibited a greater percent of non-hazardous slips compared to STD.
Conclusions: Greater HSD and MHSV seen in STD, suggests that MIN performed better under slippery conditions. The military type workload and the type of slip did not appear to influence slip parameters, with boot differences seen as the major influence on these slip outcomes. MIN boot's better performance could be attributed to the minimalist sole, tread and groove pattern, lighter mass and flexible shaft aiding in better maneuvering under slippery conditions.
Relevance to industry: Slip outcomes in two different military boots, before and after a military type load carrying workload are addressed. The lighter minimalist tactical boot outperformed the standard tactical boot, under slippery conditions. Findings from this study will help offer suggestions for footwear design in the military, especially for maneuvering slippery environment.

1. Introduction

The term “military personnel” is an extraordinarily large umbrella term for all United States service members regardless of the assigned duties. Many of the military occupations consist of environments that are further inclusive in extrinsic factors such as diverse terrains, lack of light, increased decibel range, unstable ground surfaces and intrinsic factors such as fatiguing workloads including load carriage. Proper postural control and responses to perturbations such as slips are essential in military settings in order to prevent falls and thus, injuries. The US Army Annual Injury Epidemiology Report in 2008 found 18.4% of all causes of injuries were attributed to falls/near falls (USAPHC, 2008). Slips, trips and

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falls (STFs) are a consequence of failure of normal locomotion and equilibrium recovery following an induced imbalance (Gauchard et al., 2001; Redfern et al., 2001; Hanson et al., 1999). Increased probability of falls have been related to decrements in balance control which could be brought about by extrinsic or environmental factors such as slippery surface or inappropriate footwear and by intrinsic or human factors such as muscular fatigue and the perception of slipperiness of the environment (Redfern et al., 2001; Gauchard et al., 2001). Postural instability can be hazardous due to an increased risk of falls, slips, trips and other accidents (Kincl et al., 2002) and in addition to acute fall related injuries, overexertion injuries have very high incidences for slip induced falls (Courtney et al., 2001). The combination of postural instability with overexertion makes the effort of recovering from an induced slip very demanding.

The biomechanical analysis of slips helps in evaluation of both the interaction of the footwear-floor interface and the description of motion of the body segments during the event of a slip (Li et al., 2004). During normal dry non-slippery gait, at heel strike, the heel has been shown to have an instantaneous forward velocity in most cases and rearward in some cases, followed by an achievement of minimum velocity, proceeding into mid-stance phase of the gait cycle (Perkins, 1978; Strandberg and Lanshammar 1981; Redfern et al., 2001; Cham and Redfern. 2002b). Heel contact dynamics have been used to identify the severity and the outcome of slips and slip induced falls. The most commonly reported slip parameters to analyze the heel contact dynamics include the heel slip distance and heel slip velocity (Cham and Redfern, 2002b; Moyer et al., 2006; Redfern et al., 2001; Chander et al., 2015a). Different terminologies exist for the classification of slips based on the severity of the slip outcome, by means of slip distances and velocities. Micro-slips are characterized by heel slip distance of 1 cm–3 cm and are not perceived by the individuals and easily compensated for by the automatic postural system. Macro-slips are characterized by the slip distances between 3 cm–10 cm, which will result in a loss of balance may or not result in fall, while slip distances greater than 10 cm are most likely to result a fall due to the failure of the automatic postural system (Perkins, 1978; Strandberg and Lanshammar, 1981; Redfern et al., 2001; Cham and Redfern, 2002a). Heel velocities less than 500 mm/s were seen as micro slips, with velocities between 500 mm/s – 1000 mm/s as midi-slips and heel velocities above 1000 mm/s as macro slips that lead to a slip induced fall (Redfern et al., 2001; Moyer et al., 2006).

The Occupational Safety and Health Administration (OSHA) and American National Standards Institute (ANSI) has developed recommendations to provide slip resistant walking surface in the workplace. OHSA's general requirements for walking and working surfaces recommend a coefficient of friction of at least 0.5, to provide a reasonable slip resistance to walking, although certain activities, such as carrying items, pushing or pulling objects, or walking up on down-inclined surfaces may require a higher coefficient of friction. Another vital extrinsic factor; the footwear which forms the interface between the foot and the ground have been studied extensively in occupational populations. Footwear characteristics such as the boot shaft height, mass, mid-sole hardness and thickness, elevated heels and type of material of the footwear influence balance and gait and ultimately the slip propensity in a slippery condition. Especially, the effect of the shoe sole tread patterns on slip propensity (Li et al., 2006; Li and Chen, 2005) and the effect of heel height on slip propensity have been studied previously (Blanchette et al., 2011). Design characteristics such tread groove depth, width and pattern help in prevention of slips and falls in liquid collected walking surfaces. The average coefficient of friction gain per mm of tread groove depth under slippery conditions ranged from 0.018 to 0.108 (Li et al., 2006), while wider tread groove and tread groove orientation that are perpendicular to the friction measurement have higher coefficient of friction. High heeled shoes have been shown to use a greater utilized coefficient of friction thereby increasing the friction demand during walking which is related to an increase in the resultant shear force and a decrease in the vertical force and thereby increasing the probability of a slip (Blanchette et al., 2011).

Individual intrinsic human factors such as physiological deficits of the postural control systems, can contribute to falls. Dysfunction in the visual, vestibular, somatosensory or the musculoskeletal system and any undue muscular fatigue due to excessive workload in the military environment can potentially lead to falls. A vital aspect of the military workload is the load that must be carried, which can vary in different military scenarios. Load carriage can induce a faster rate of muscular fatigue, which has been suggested to negatively affect the propriocetive system through either deficiency in the activation of the mechanoreceptors or a decrease in the muscular function (Vuillerme et al., 2002; Corbeil et al., 2003) and cause decrements in balance performance that potentially lead to falls. Biomechanical analysis of military load carriage has suggested decreased stability and greater incidences of injuries (Birrell et al., 2007). Subjective perception of the floor slipperiness is based on visual perception and proprioceptive recognition of maintenance of balance during slip events. Intrinsic factors like visual perception of the slip hazard, attentiveness and mental workload can influence the outcome of perceiving the slipperiness of surface (DiDomenico et al., 2007). Although small undetectable micro slips have been shown to occur regularly even during normal gait, the macro slips are usually perceivable to the individual (Hanson et al., 1999; Strandberg & Lanshammar, 1981). The perception and anticipation of a slip have been shown to reduce the possibility of a slip with biomechanical modifications to gait under slippery conditions (Chang et al., 2004; Cham and Redfern, 2002a). Thus the visual feedback from the visual system and the proprioceptive feedback from the somatosensory system are critical in determining the outcome of a slip.

Slips and slip induced fall prevention have been an important characteristic of ergonomics research and have focused on extrinsic and intrinsic factors leading to such events. While extensive literature exists on biomechanics of slips, there is still dearth of literature on the effect of different types of military footwear on slips with and without the knowledge or the perception of a slip, when exposed to a military type load carrying workload. Therefore, the purpose of the study was to analyze the impact of two military type boots on unexpected and expected slips, prior to and after experiencing a simulated military type load carrying workload. It was hypothesized that the heel contact dynamics assessed through slip parameters will be altered in slip events compared to dry normal gait and that differences in slip parameters would be evident between boot type, between slip type and due to the simulated military workload.

2. Methodology

2.1. Participants

A total of sixteen healthy male adults (age: 27 ± 3.9 years; height: 178 ± 6.2 cm, mass: 87 ± 12.4 kg) with no self-reported history of any musculoskeletal, neurological, cardiovascular or vestibular disorders were recruited for the study. Participant's physical fitness status was also above recreationally trained (>3–4 days/week with consistent aerobic and anaerobic training for at least the last 3 months). Sample size was determined by using G-Power statistical software with a desired power of 0.8, a desired effect size of 0.25 and at an alpha level of 0.05. All participants were recruited through flyers approved by the University's Institutional Review Board (IRB). All participants read and signed the informed consent and also filled out the physical activity readiness questionnaire (PAR-Q) to rule out any of the above mentioned health complications and cleared for participation in the study.

2.2. Instrumentation

Vicon Nexus (Oxford, UK) 3D motion capture system with 12 infra-red T-series cameras was used to collect and analyze kinematic gait data. A lower body plug-in gait model from the Helen–Hayes marker system was used for the participant configuration and the kinematic data was sampled at 100 Hz and collected using the Vicon Nexus software. A back-pack type fall arrest system with a movable trolley was used to prevent any undesired falls. Industrial vegetable based glycerol mixed with water in the ratio of 75% glycerol and 25% water was used as the slippery agent (Chander et al., 2015a). During the slip gait trials or slip events, glycerol was applied and evenly distributed on a force plate for contact of the leading left leg of the participants. The application of the slippery agent was always performed by the primary investigator using the same measured and calibrated container to minimize the errors due to inter and intra rater reliability.

2.3. Experimental procedures

The study followed a pre-test-post-test repeated measures design, with participants being tested for balance while wearing two industry standard military boots, prior to and after a simulated military type workload, performed while wearing the selected boot and a 16 kg military rucksack. Participants were tested on each boot condition using a repeated measures design on two days separated by a minimum of a 72 h, in a counter balanced design to remove order effects. The footwear used in the study were two army tactical boots that comply with the army AR670-1 regulations were used [boot #1: Belleville 310ST hot weather standard tactical boot (STD), a heavy boot with a stiff boot shaft and horizontal groove pattern (mass: 801.13 ± 40.4 gm; sole surface area: 288.6 ± 24.1 cm^2; stiff boot shaft height: 20 cm; heel-midfoot drop: 18 mm) and boot #2: Belleville TR101 minimil ultra-light minimalist tactical military boot (MIN), a lighter boot with thin mesh laced-up type boot shaft and a Vibram® tread groove pattern (mass: 500.13 ± 24.1 gm; sole surface area: 235.4 ± 8.2 cm^2; flexible boot shaft height: 20 cm; heel-midfoot drop: 2 mm) (Fig. 1)]. After obtaining informed consent, participants were also exposed to an initial familiarization session during which they were familiarized with the experimental protocol and anthropometry data was collected. Each testing session began with an initial warm up protocol of 10 min consisting of body weight squats, high-knees, jogs, gait swings and exaggerated lunges. Participants continued to wear the boots and put on the back-pack and were strapped to a harness and a fall arrest track and performed multiple gait trials until normal self-selected pace walking with appropriate foot positioning onto the force plate was achieved. Participants turned away from the walkway and listened to music on a noise cancellation head phones for about 1 min between each of these dry normal gait trials. Following these trials, one particular trial was chosen to be the unexpected slip (US) and the contaminant (75% glycerol & 25% water) was applied on the second force plate, without the knowledge of the participant. Upon completion of the US and cleaning of the floor and footwear, participants performed a similar protocol to complete an expected slip (ES) with instructions of “will be slippery” with the contaminant re-applied on the floor. Following this, participants were directed to a treadmill where they performed the simulated physiological workload consisting of walking on the treadmill wearing the boot and the 16 kg weighted rucksack. The walking protocol adapted from DeMaio et al. (2009) consisted of 3 min increment periods starting at 4.83 km/h (3 m/h) at 0% grade, and increasing to 5.632 km/h (3.5 m/h) and 6.44 km/h (4 m/h) at 0% grade until minute 9, following which the grade was increased by 5% every 3 min until minute 18. On completion of the load carrying protocol, participants then completed the same set of slip assessments consisting of another set of US and ES as a post-workload measure.

2.4. Data analysis

The slip parameters of interest included the heel slip distance (HSD) (mm) and the mean heel slip velocity (MHSV) (mm/s) during the first 120 ms following heel strike of the left/leading leg. The left heel marker was used to determine HSD and MHSV, while the ground reaction forces from the force plate was used to determine the heel strike, using Vicon Nexus software. The raw data was filtered using a zero lag Butterworth fourth order filter at 15 Hz and exported for further analyses. HSD is the horizontal distance traveled by the left heel marker after the foot strikes the floor and was calculated as the linear displacement of the left heel marker in the horizontal anterior-posterior direction from the moment of heel strike to 120 ms into the gait cycle. MHSV is the average of the horizontal velocity of the left heel marker after the foot strikes the

Fig. 1. Military boots: Belleville 310ST hot weather standard tactical boot (STD) and Belleville TR101 minimil ultra-light minimalist tactical military boot (MIN).

floor and until 120 ms into the gait cycle and was calculated from the instantaneous heel contact velocity in the one-dimensional horizontal anterior-posterior direction. Greater slip distances and higher slip velocities represent, larger slips that can potentially result in postural correction mechanisms to prevent a fall or result in an induced fall. The HSD and MHSV were plotted against each other to depict the relationship between them and to establish slip severity thresholds based on Moyer et al. (2006) and Chander et al. (2015a).

2.5. Statistical analysis

The dependent slip parameters were analyzed using a $2 \times 2 \times 2$ repeated measures ANOVA [2 boot (MIN & STD) × 2 time (Pre-workload & Post-Workload) × slip type (US & ES). If a significant interaction or main effect was found, it was followed up with univariate simple effects analysis and post-hoc pairwise comparisons with a Bonferroni correction. A bivariate correlation analysis was also performed between HSD and MHSV for each boot and each slip type both prior and after the workload. All statistical analyses were performed with and alpha level of $p = 0.05$ using the SPSS 21 statistical software package (IBM® SPSS® Statistics V20.0, Armonk, New York 10504-172).

3. Results

The $2 \times 2 \times 2$ repeated measures ANOVA for slip parameters, revealed significant boot main effect differences for both HSD and MHSV at $F(1, 15) = 13.385$, $p = 0.002$, $\eta^2 = 0.472$ (Fig. 2) and $F(1, 15) = 15.022$, $p = 0.001$, $\eta^2 = 0.500$ (Fig. 3) respectively. Pairwise comparisons revealed the STD boot to have significantly higher HSD and MHSV compared to the MIN boot. However, no significant interactions between boot, time and slip type or main effect for time or slip type were found. On average greater slip distances and slip velocities were found with STD for all slip trials and during both pre-workload and post-workload. Results from the correlational analysis revealed a very strong positive correlation (Pearson correlational coefficient of >0.90 between HSD and MSHV for both boots and both slip types during pre-workload and post-workload conditions. Additionally, based on the slip severity threshold, the unexpected and expected slips were classified as non-hazardous (NHZ) slips (<50 mm HSD and <500 mm/s MHSV), potentially hazardous (PHZ) slips (50–100 mm HSD and 500–1000 mm/s MHSV), hazardous (HZ) slips (>100 mm HSD and >1000 mm/s MHSV). (Fig. 4 and Fig. 5). A contingency table was created to determine the percent of slips that were classified as NHZ, PHZ and HZ slips (Table 1).

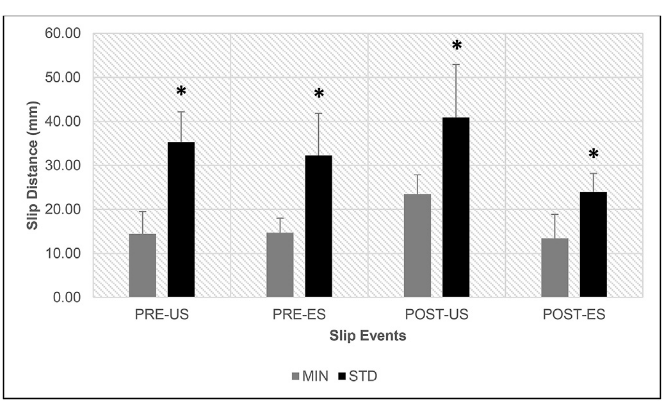


Fig. 2. Heel slip distance (HSD) for minimalist (MIN) and standard (STD) boots during unexpected (US) and expected (ES) slips, before (PRE) and after (POST) workload. * represent significant boot difference. Bars represent standard errors.

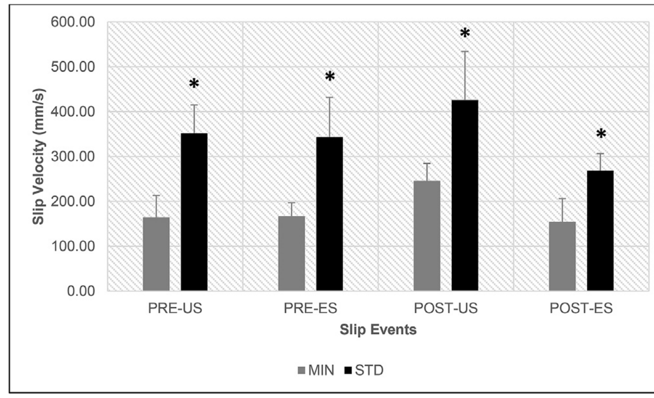


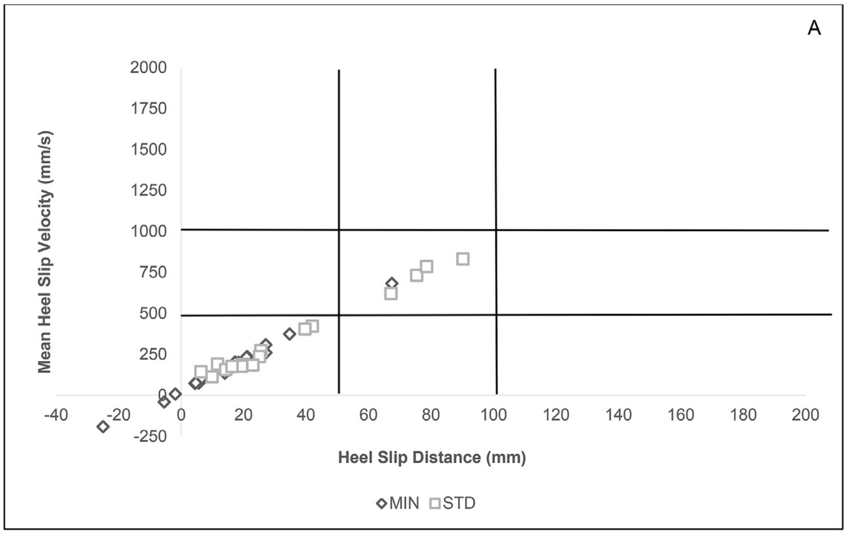
Fig. 3. Mean heel slip velocity (MHSV) for minimalist (MIN) and standard (STD) boots during unexpected (US) and expected (ES) slips, before (PRE) and after (POST) workload. * represent significant boot difference. Bars represent standard errors.

4. Discussion

The purpose of this research was to analyze the impact of two industry standard military boots on the biomechanics of slips, before and after a military type load carrying workload. On average, significantly greater slip distances and slip velocities were seen in the standard tactical boot. The results from the study suggest that the minimalist boot performed significantly better in comparison to the standard boot under both slip conditions, the results of which could be attributed to the differences in the design characteristics of these boots. The military type workload with a 16-kg rucksack did result in greater slip distances in the post-workload measure, which could be attributed to the physiological workload and exertion, however the results were not significant and did not appear to impact the heel contact dynamics significantly during slip events.

4.1. Extrinsic and intrinsic factors as predictors of slip outcomes

The findings from this study demonstrate significant differences in the slip parameters for both heel slip distance (HSD) and mean heel slip velocity (MHSV) between MIN and STD, suggesting the type of footwear worn during both slippery gait conditions were seen to impact the heel contact dynamics while walking on slippery surfaces. However, significant differences were limited to boot type main effect. Based on the magnitude of the slip, a greater or an increased HSD and MHSV have been shown to contribute or lead to a slip induced fall (Perkins, 1978; Strandberg and Lanshammar 1981; Redfern et al., 2001; Cham and Redfern, 2002a; Lockhart and Kim, 2006; McGorry et al., 2010; Moyer et al., 2006; Brady et al., 2000). Although none of the slips trials resulted in a fall, the STD demonstrated significantly greater slip parameters that can contribute to an increased incidence of slip induced falls compared to the MIN. Extrinsic factors such as the footwear's geometrical design characteristics have been shown to affect human balance, gait and slip outcomes (Chander et al., 2014, 2015a, 2015b; Perry et al., 2007; Menant et al., 2008; Chander et al., 2016a, 2016b, 2017) and especially the sole design parameters such as the depth, width and orientation of the tread groove have been demonstrated as important factors affecting the coefficient of friction between the footwear-floor interface (Li and Chen, 2005; Li et al., 2006; Chander et al., 2016b). Even though the surface area of



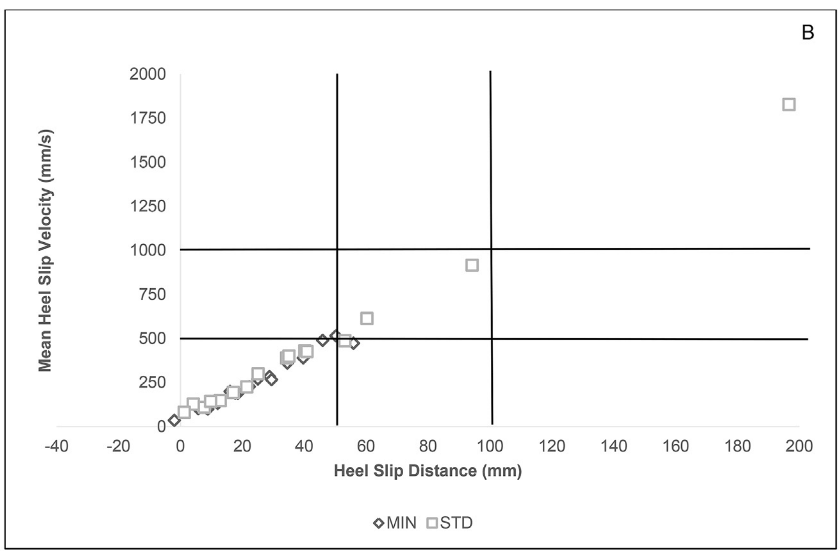


Fig. 4. Heel slip distance (HSD) and mean heel slip velocity (MHSV) relationship for unexpected slip events (US) before workload (PRE) (Fig. 4A) and after workload (POST) (Fig. 4B) in minimalist (MIN) and standard (STD) boots. Non-hazardous slips (<50 mm HSD and <500 mm/s), potentially hazardous slips (50–100 mm and 500–1000 mm/s), hazardous slips (>100 mm and >1000 mm/s).

the sole of STD was greater than MIN's sole ($288.6 \pm 24.1\ cm^2$ compared to $235.4 \pm 8.2\ cm^2$), the number of tread grooves were more in MIN compared to STD. Moreover, the MIN features a novel Vibram® tread pattern in comparison to a standard horizontal pattern on the STD (Fig. 1). These design features could be attributed to the significantly lower HSD and MHSV seen in MIN boots. The groove depth on both boots averaged at 3–4 mm, suggesting the pattern and the number of grooves played a more significant part in the findings compared to groove depth. Moreover, the MIN has a thin midsole, a lower mass (300 gm lighter than the STD), flexible boot shaft and a zero-heel drop. These design features in a footwear have shown to enhance postural stability of an individual by increasing proprioceptive feedback, delaying muscular fatigue and allowing for better range of motion at the ankle (Menant et al., 2008; Chander et al., 2014, 2015b; Garner et al., 2013; Bohm and Hosl, 2010; Cikajlo and Matjacic, 2007). These design features in the MIN could have also aided in its significantly superior performance compared to the STD during slip events.

The intrinsic human factors, which include muscular fatigue and knowledge or anticipation of slippery environment, also serve as a predictors of slip events. The perception of a slip hazard can be an interaction of various factors, such as prior knowledge of a slip prone environment, ability to use visual perception in the presence or absence of adequate lighting, arousal/alertness levels and mental workload while encountering a slip (Cohen and Cohen, 1994a, 1994b). Prior knowledge and anticipation of a slippery floor allows the individuals to reduce the potential slips by making adaptations to the biomechanics of gait (Cham and Redfern, 2002a; Lockhart et al., 2007; Chander et al., 2016b). However, in the current study no significant differences were seen between unexpected and expected slips, suggesting that these military boots were providing adequate slip resistance, even with the absence of the knowledge of a slippery flooring conditions. Participants continued to walk with no significant difference between the slip types. Postural control mechanisms are inhibited after fatigue, especially seen under strenuous muscular exertions (Chander et al., 2014, 2016a, 2017; Garner et al., 2013). The intrinsic musculoskeletal fatigue can inhibit response times and automatic postural

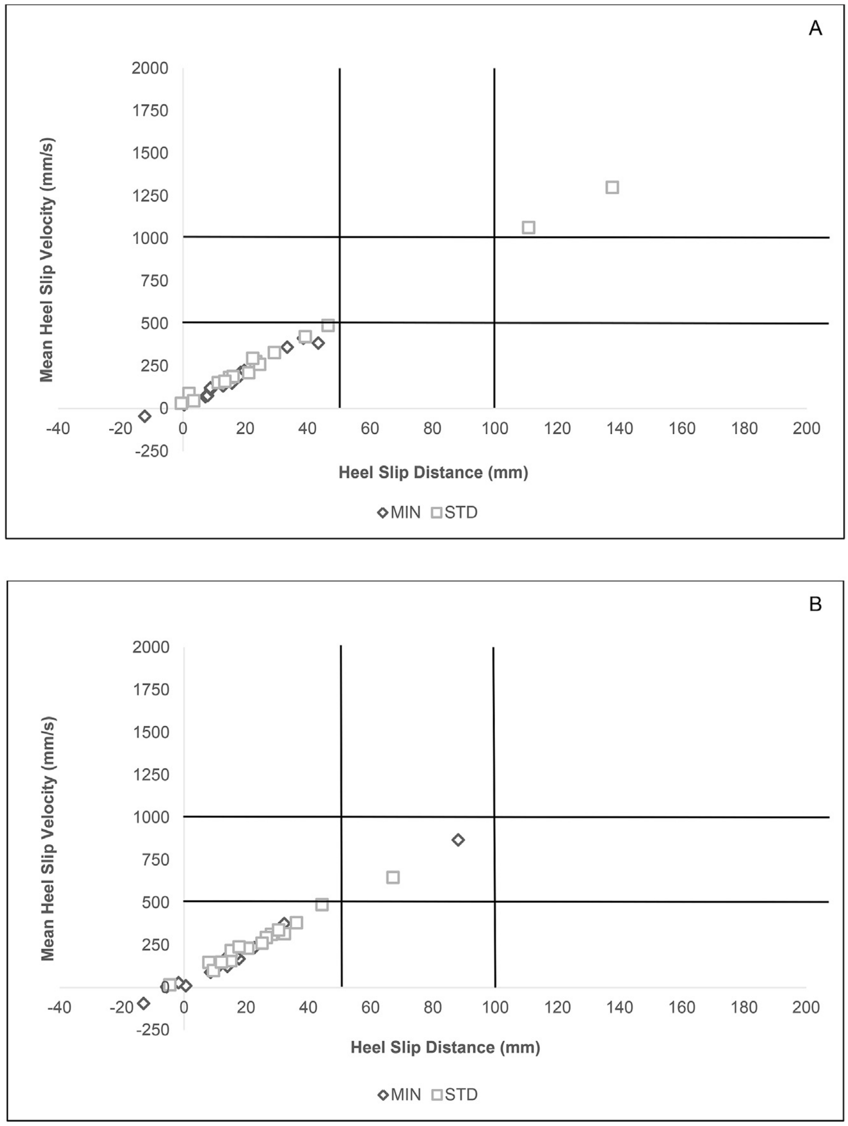


Fig. 5. Heel slip distance (HSD) and mean heel slip velocity (MHSV) relationship for expected slip events (ES) before workload (PRE) (Fig. 5A) and after workload (POST) (Fig. 5B) in minimalist (MIN) and standard (STD) boots. Non-hazardous slips (<50 mm HSD and <500 mm/s), potentially hazardous slips (50–100 mm and 500–1000 mm/s), hazardous slips (>100 mm and >1000 mm/s).

Table 1
Contingency table for slip severity based on slip thresholds for unexpected and expected slips during both pre-workload and post-workload for standard tactical boot (STD) and minimalist tactical boot (MIN). Slip thresholds: Non-hazardous (NHZ) slips: <50 mm HSD and <500 mm/s; potentially hazardous (PHZ) slips: 50–100 mm and 500–1000 mm/s; and hazardous (HZ) slips >100 mm and >1000 mm/s. Percent scores represent the percentage of slips that were NHZ, PHZ or HZ.

	Pre-Workload						Post-Workload					
	Unexpected Slips			Expected Slips			Unexpected Slips			Expected Slips		
	NHZ Slips	PHZ Slips	HZ Slips	NHZ Slips	PHZ Slips	HZ Slips	NHZ Slips	PHZ Slips	HZ Slips	NHZ Slips	PHZ Slips	HZ Slips
STD	12 (75%)	4 (25%)	0	14 (87.5%)	0	2 (12.5%)	12 (75%)	3 (18.5%)	1 (6.25%)	15 (93.75%)	1 (6.25%)	0
MIN	15 (93.75%)	1 (6.25%)	0	16 (100%)	0	0	14 (87.5%)	2 (12.5%)	0	15 (93.75%)	1 (6.25%)	0

control mechanisms when exposed to slip perturbations. Muscular exertion due to the physiological simulated military style workload with the 16 kg rucksack did not seem to have an effect on the slip parameters, with no significant difference in HSD and MHSV before (PRE) and after (POST) workload conditions. However, during the post-workload assessments, greater HSD and higher MHSV were exhibited in the unexpected slips, which could be attributed to muscular fatigue. Moreover, the lower HSD and slower MSHV exhibited in the expected slips could be attributed to the prior knowledge of the slippery environment, similar to what has been reported in previous literature (Cham and Redfern, 2002a; Lockhart et al., 2007; Chander et al., 2015a, 2016b) and potentially a possible learning effect of the type of slips that was exposed to each participant, as a pre-test measure. Since, these differences were not statistically significant, these conclusions should be used with caution and more research focusing on different types of workloads such as high intensity-short duration and low intensity-long duration workloads are warranted.

4.2. Slip distance and slip velocity relationship

Slip distance and velocity exhibit a linear relationship (Moyer et al., 2006; Chander et al., 2015a, 2016a) and the current results demonstrated a very strong positive correlation between HSD and MHSV. Based on these slip parameters, Moyer et al. (2006) classified the slip outcomes into (i) non-hazardous slips (<100 mm slip distance and <1000 mm/s slip velocity) which had shorter slipping distance and slower slipper velocity and were unlikely leading to falls and (ii) hazardous slips (>100 mm slip distance and >1000 mm/s slip velocity) which had greater slipping distances and faster slipping velocity and were more likely to lead to falls (Moyer et al., 2006; Chander et al., 2016a). Moreover, using the concepts of Moyer et al. (2006), newer threshold values of the slip distance and velocity relationship were proposed more recently by Chander et al. (2015a). The zone below 50 mm of slip distance and 500 mm/s of slip velocity could be considered as the safe zone or the non-hazardous zone, in which the slips are often perceived by the postural control system and there is not often a need to have corrective postural responses. The zone encompassed within 50 mm–100 mm slip distance and within 500 mm/s – 1000 mm/s could be considered as the potentially hazardous zone, in which the slip perturbations would require a corrective postural responses to prevent a slip induced fall, but not always lead to a fall. The zone beyond 100 mm of slip distance and 1000 mm/s slip velocity could be considered as the hazardous zone, which requires a greater corrective postural response and is very likely to lead to a slip induced fall. These were identified by comparing an industry standard "treadsafe" slip resistant footwear against more casual alternative footwear (Chander et al., 2015a). By using these thresholds for unexpected slips (Fig. 4) and expected slips (Fig. 5), both military boots predominantly stayed within the safe non-hazardous thresholds of 50 mm and 500 mm/s in both pre and post workload conditions. Unexpected slips exhibited a greater percent of PHZ and HZ compared to expected slips. Expected slips resulted in NHZ slips compared to unexpected slips. Differences between pre-workload and post-workload were marginal. However, in comparison between boot types, MIN exhibited a greater percent of NHZ slips compared to STD, especially in unexpected slips (Table 1). These percent scores are supported by the results from the repeated measures ANOVA that demonstrated a significantly lower HSD and MHSV slip parameters in MIN boot compared to STD boot. Thus, the MIN boot performed better under slip events and could be the recommended choice of footwear, compared to STD, for maneuvering slippery environments both with and without the knowledge of an impending slip.

5. Conclusion

Consideration of extrinsic factors such as footwear design and intrinsic factors such as muscular fatigue is critical for understanding risk of slips and slip induced falls in the military so that military personnel can perform operations in a safe manner. Footwear design should focus on characteristics that minimize slips and provide the ability to maneuver slippery environment with little to no attentional demands to the environment. Muscular fatigue in the current study did not significantly alter heel contact dynamics, however more extended duration workloads can impact the outcome of slips. It is also important to schedule work-rest intervals due to the detrimental nature of a heavy prolonged duration workload on the postural control system. This study emphasizes these extrinsic and intrinsic factors and the impact of such factors on the heel contact dynamics in slip events. Limitations to the study included a small sample size, presence of one potential outlier and a potential order effect during the slip events, during which the unexpected slip always preceded the expected slip, but every measure discussed earlier was taken to avoid any anticipation of an unexpected slip. Overall, the minimalist tactical boot with its advantageous design features exhibited lower slip distances and velocities compared to the standard tactical boot and aided in a greater percent of non-hazardous slips during both unexpected and expected slips. The findings from the study will help offer footwear design suggestions in the military to improve gait performance under known and unknown slippery environments and on muscular exertion levels in an attempt to help prevent footwear type and overexertion induced slips and slip related injuries.

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