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Review

Occupational Footwear Design Influences Biomechanics and Physiology of Human Postural Control and Fall Risk

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Abstract: While design modifications present on work boots improve safety, they may not always provide optimal human performance during work tasks. Understanding the impact of these different design features on biomechanical and physiological postural control and locomotion variables can aid in better design modifications that can provide a safe and efficient human performance. This brief review focuses on a series of studies conducted by the current research team, that have tested three different work boots (SB: high-top steel-toed work boots; TB: high-top tactical work boots; SR: low-top slip-resistant work boots). The series of studies included testing of these work boots or combinations of them under acute and chronic simulated occupational workloads, assessing biomechanical variable such as postural stability, gait, slips, and muscle activity, as well as physiological variables such as heart rate, energy expenditure, oxygen consumption, and pain perception. The impact of each of the work boots and their design feature on postural control and locomotion are summarized from these studies' previously published literature. Finally, work boot design suggestions for optimal human performance are provided for better work boot selection, modification, and design.

Keywords: occupational footwear; postural stability; slips and trips; balance; fall risk

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1. Introduction

The human foot serves as the point of contact between the body and the environmental terrain, making proper function crucial for efficient somatosensory and proprioceptive feedback for the central nervous system (CNS). With footwear serving as the connecting link, its interaction between the environment and the foot plays an important role in maintaining postural stability without sustaining a fall in static and dynamic conditions and having a safe and efficient gait pattern with minimal muscle activity and energy expenditure. While research is abundant regarding athletic footwear design intended to improve performance, there is limited research on occupational footwear design's effects on postural stability. Therefore, occupational footwear design safety features may not provide optimal physiological and biomechanical functions in the workplace. According to the Bureau of Labor Statistics (BLS), injuries due to slips, trips, and falls are one of the leading causes of time away from work, placing construction workers at the top of the list at 46.1%. Moreover, more than one in five workplace deaths occurred in construction environments, with over one-third due to slips and trips [1]. While a fatal fall causes catastrophic effects on the worker's family and the workplace, the effects of non-fatal falls could be detrimental as well. Depending on the severity, such falls could cause permanent disability, loss of earning potential, and poor quality of life to the employee, while decreasing productivity and increasing financial loss to the employer [2]. These fall-related injuries are due to inefficient postural control strategies in response to both intrinsic and extrinsic perturbations that cause a loss of balance [3]. Some intrinsic factors that impact postural stability include deficits in postural control feedback (visual, vestibular, proprioception), weakness, fatigue, cognitive awareness, etc. Furthermore, several extrinsic factors can disturb the environment to result in a fall, including lighting, the walking surface, temperature, carrying asymmetric loading, and a less studied factor, footwear.

Furthermore, current safety regulations on occupational footwear design, along with the commonly occurring inappropriate selection of footwear for a specific task, could result in detrimental effects on postural stability and balance. Occupational footwear that are designed to improve postural stability while also abiding by safety standards can help improve postural stability, promote efficient locomotion, and reduce the risk of falls in the workplace. Some specific design features that have been reported to affect postural control and locomotion include, but are not limited to, sole thickness, midsole hardness, sole/heel height, heel-to-toe drop, boot shaft height, sole grove pattern, presence of lacing, mass, and material. These design features and their impact on postural control and locomotion being assessed through biomechanical and physiological variables are critical in designing better occupational footwear. Occupational footwear is designed for safety as the primary focus and the addition of hazardous occupational environments can easily impact an individual's postural control and locomotion. As the maintenance of dynamic balance is considered more challenging than static [4], the resulting postural instabilities could be more pronounced during gait/locomotion. While static work tasks are not uncommon in occupational settings, the majority of the tasks in ergonomic settings are dynamic in nature. Hence, the workers are at high risk of falling, especially the occupational categories such as construction workers, firefighters, military personnel, and manual laborers. Therefore, the purpose of this article is to elaborate on the effects footwear design features on postural stability from both a biomechanical and physiological perspective. This article also offers design suggestions for occupational footwear design to improve human performance, minimize fall-related injuries, and improve overall safety. Previously, three commonly used occupational work boots/footwear (ST: high-top steel-toed work boots, TB: high-top tactical work boots, and LT: low slip-resistant work boots) (Figure 1 and Table 1) were identified and were tested for their impact on the biomechanics and physiology of human postural control and locomotion. The series of these studies, included testing of the aforementioned work boots or combinations of them, under acute and chronic simulated occupational workloads, assessing biomechanical variables such as postural stability, gait, slips, and muscle activity, as well as physiological variables such as heart rate, energy expenditure, oxygen consumption, and pain perception. A brief review of the findings from these studies and footwear design suggestions to aid optimal postural control and locomotor performance are also discussed.

Table 1. Occupational footwear design features.

Design Features	Occupational Footwear		
	SB	**TB**	**SR**
Mass (kg)	0.9	0.5	0.4
Boot shaft height (cm)	18.5	16.5	9.5
Rearfoot sole width (cm)	9.6	8.8	8.5
Forefoot sole width (cm)	12	11	10.5
Heel height (cm)	3	4.1	4.1
Midsole hardness (Shore HA)	82	74	74

Figure 1. (**A**) Steel-toed work boot (SB), (**B**) tactical work boot (TB), (**C**) low-top slip resistant work boot (SR).

2. Biomechanics and Physiology of Postural Control

Postural stability is defined as the ability to maintain a person's center of gravity within the base of support (BOS) and is achieved by coordinating movements across several joints with the help of the postural control feedback systems (visual, vestibular, and proprioception) [5]. Being bipedal makes human postural control and locomotion unique, with static postures assumed with both or one foot on the ground, while locomotion involves phases during which only one foot is in contact with the ground during walking and no foot in contact with the ground during running [5]. The fundamental prerequisite for a fall includes; an initial loss of balance induced by a perturbation such as a slip, trip, misstep or a collision and a failure of the balance recovery mechanisms to counteract the destabilization [6]. Increased probability of falls has been related to decrements in balance control and these falls are often a primary causative factor for injuries and disabilities in the athletic population, different occupational populations, and among the general population where postural stability is challenged with unfavorable and unfamiliar environments [7,8]. To understand how to prevent fall-related accidents in the workplace, it is critical to understand factors that impact fall risk, including intrinsic and extrinsic factors. Unlike the elderly population, factors related to falls in young and/or healthy individuals are not well known and may vary. However, similar to the elderly population, intrinsic factors seem to also play a role in falls in occupational settings, and extrinsic factors in the environment seem to reveal these physiological deficits [9]. Although a considerable number of studies have been conducted on athletic footwear and their effects on athletic performance, there is a lack of research regarding occupational footwear. With annually growing numbers of occupational falls, the attention of contemporary ergonomic researchers has been directed toward studying occupational footwear biomechanics/physiology. However, more research is warranted to understand the optimal design features of occupational footwear.

3. Influence of Footwear on Postural Control and Locomotion

The anatomical, physiological, and cognitive constraints, including the efficient transmission of afferent somatosensory information from the periphery to the CNS [4] and the efficient transformation of mechanical power output produced by the musculoskeletal system through the footwear is responsible for a good balance and gait performance [10]. Hence, the design features and mechanical characteristics of the footwear become important for human postural control and locomotion. In quiet standing, the BOS is formed by bilateral feet, whereas during gait, the BOS varies depending on the phase of the gait cycle, where it is made by bilateral feet in the double support and single foot during the single support phase. Since the foot is essentially the BOS for human balance, its stability is essential in the preservation of postural control, and due to the relatively small size of the

BOS, even the smallest alterations could have profound effects on postural control [11]. For example, inefficient insole and arch support have been shown to impact postural stability via plantar fasciitis [12], especially in the anteroposterior direction, ultimately impairing sensory receptors in the plantar fascia during static posture and the Windlass mechanism during locomotion [13,14]. Furthermore, because the BOS is limited to a relatively small area, individuals must rely on postural control strategies to maintain balance (ankle and hip). While footwear may not play a role in the postural strategy utilized for the maintenance of balance, an ankle strategy is predominantly used until there is conflicting sensory feedback [15]. However, localized fatigue of the sagittal plane movers of the lower extremities can impair postural control [16]. Additionally, previous research has reported that muscle weakness compromises gait kinetics which can predispose an individual to falls and fall-related injuries [17]. Therefore, footwear that can minimize lower extremity muscle activity may effectively prolong the onset of fatigue, ultimately slowing down the postural instability that occurs over time. It should be noted that work boots that are either all flexible or all stiff when referring to the shaft and soles have greater muscle activity and earlier onset and higher rates of fatigue. In addition, such footwear affects the plantar pressures generated under the medial and lateral midfoot, heel, medial and lateral metatarsals, hallux, and lesser toes, suggesting a mixed construction may be optimal [18,19]. Moreover, with a decrease in sensory feedback and localized fatigue being linked to a decrease in postural stability, this increases the risk of falls and fatal and non-fatal fall related injuries. In an occupational setting, slips, trips, and falls are one of the leading causes of time away from work, and they are the leading cause of fatalities and injuries in a construction environment [20]. Therefore, it is critical that an individual's work boots meet the demand placed on their lower extremities, otherwise, the risk of both acute and chronic injury is increased [21].

Based on previous research, footwear can significantly impact both static balance and gait mechanics depending on the environment in which they are worn, and proper footwear design and selection could be used to aid in postural stability in occupational settings. Fatal and non-fatal falls are highly prevalent among the occupational population, especially in the categories such as construction workers, firefighters, military personnel, and manual laborers. The inability to regain postural stability following intrinsic and extrinsic perturbations is known to cause such falls. With occupational workers being at the highest risk of injury from falls in an occupational setting, both from a height and at the same level, footwear designed to improve postural stability may reduce the number of both fatal and non-fatal fall accidents.

4. Occupational Footwear Safety

Protective footwear regulations are regulated by the Occupational Safety and Health Administration (OSHA) and are included by the Occupational Safety and Health Standards as Personal Protective Footwear (PPE) in the Code of Federal Regulations (CFR), specifically 29 CFR 1910.136. Protective footwear regulations vary among occupations depending on the task at hand and the environment to which an individual may be exposed. For construction workers, OSHA requires protective footwear to be worn at all times, regardless of a hazard present. The current safety standards for protective footwear in construction must comply with the standards of the American Society for Testing and Materials (ASTM) 2413-18, stating protective footwear must be worn at all times, toe caps must be built into the boot/shoe, must have a leather upper, puncture and electrical hazard resistance, conductive protection, and must pass the ASTM 2412-18a testing standard for impact and compression resistance with a rating of 75 [22]. However, one negative aspect of a concentrated focus on occupational safety is attention not being given to the importance of functionality and comfort [23]. Some design features have been associated with lower back, hip, ankle, and foot pain. With an individual's footwear being the interface between the foot and the environment, proper design is crucial to postural stability and significantly impacts gait, joint range of motion, posture and balance, physiological measures, muscle activity, and occupational tasks. Additionally, internal design features of specific occupational footwear, such as wool liners in firefighter boots, were demonstrated to have a significant impact on comfort, causing greater complaints of chafing and discomfort, which could alter normal gait mechanics [24].

Footwear selection concerning foot shape is also a commonly overlooked feature that impacts normal biomechanics and comfort and can result in foot problems such as blistering, chafing, black toes, bunions, pain, and tired feet. For example, in a recent survey that interviewed underground coal miners, more than half of the participants reported foot problems (55.3%) associated with their boots, and out of those listed, 62.3% associated their pain with their boots [25]. Although most coal miners indicate their work boot fit to be reasonable to good, their three-dimensional foot shape does not match the internal design features of their work boots, ultimately increasing discomfort and impacting normal biomechanics [26]. This further emphasizes the need for occupational footwear research, along with improvements in footwear design that will not only meet standard guidelines for safety regulations but also enhance postural stability and comfort. Moreover, seeing that falls are the leading cause of fatalities among construction workers, properly designed occupational footwear to enhance postural stability is critical in reducing fall risk and fall-related injuries.

5. Occupational Footwear Characteristics That Influence Biomechanics and Physiology of Postural Control

Because occupational footwear is primarily designed to protect from acute impact injuries, they are not necessarily designed for optimal biomechanical or physiological function. Footwear characteristics such as heel height, heel drop, insole, midsole, outer sole, and boot shaft height have been shown to impact postural stability. A higher heel height and increased heel drop place an individual's ankles in a plantarflexed and supinated position, ultimately limiting the range of motion at the ankle joints and altering normal proprioceptive feedback to the CNS to prevent an efficient ankle strategy for postural control [27]. Additionally, other possible mechanisms include an anterior shift in an individual's center of mass (COM), which modifies posture and plantar pressure distribution, and a higher heel may lead to lateral instability due to a smaller critical tipping angle compared to lower heel shoes [28]. According to the BLS, fatalities from falls from a roof account for 20% of construction deaths and 84% of roofing industry deaths in 2019 [29]. Additionally, insoles and midsoles have been shown to impact balance. Textured insoles are believed to improve postural stability via an increase in proprioceptive feedback, especially in the mediolateral direction [30]. Softer midsoles, providing a softer interface, offer less mechanical support to create reactive forces needed during perturbations [31]. Ankle postural control strategy is primarily used to maintain balance during quiet standing [15], while stepping and grasping strategies are utilized to counteract greater postural decrements [4]. Hence, softer midsoles may not be optimal for ergonomic settings as they may increase the requirements to maintain postural stability, such as acquiring a stepping or grasping strategy [31]. Moreover, thick midsoles reduce the somatosensory feedback to CNS, affecting postural control. Postural decrements are more pronounced when the thick midsoles are soft in nature, making it similar to standing on foam, providing an unstable standing surface [28]. Therefore, midsoles must be thin and hard to provide successful postural control.

Furthermore, boot shaft height and stiffness have been shown to significantly impact postural stability. A higher boot shaft that allows for an compression around the ankle and that is lower mass can aid in postural stability [8,32,33], which becomes critical for construction workers carrying asymmetric loads on uneven surfaces. Having a higher boot shaft/ankle support increases the proprioception around the ankle joint and aids in executing the ankle strategy. However, stiffer boot shafts can potentially restrict the ankle joint ROM, affecting the execution of ankle strategy [10,32]. Previous research has shown that carrying as little as 20% of an individual's body weight unilaterally significantly impacts gait mechanics [34]. Therefore, it is reasonable to assume that increasing proprioceptive feedback via a higher, yet flexible boot shaft may be critical for construction workers carrying asymmetric loads. Occupational footwear must be oil and slip resistant. Walking on slippery surfaces results in significant balance decrements and modified gait mechanics as opposed to stable surfaces [35]. Occupational footwear with a greater mass also decreases biomechanical efficiency as opposed to boots of a lighter mass, resulting in greater postural sway, especially when visual and proprioceptive feedback is are altered [36]. This becomes significant in occupational environments with low light and uneven surfaces with lack or altered visual and somatosensory/proprioceptive feedback.

6. Occupational Footwear Characteristics That Influence Biomechanics and Physiological Workload

Previous studies included the testing of these work boots or combinations of them under acute and chronic simulated occupational workloads, assessing both biomechanical and physiological workloads, such as postural stability, gait, slips, and muscle activity, as well as heart rate, rate of perceived exertion (RPE), energy expenditure, oxygen consumption, and pain perception [8,15,32,35,37–42]. In order to assess the chronic effect these boot types have on postural stability, previous literature reported participants completing a simulated workload wearing each boot for four hours on separate days [8,38,42]. Results showed significantly greater postural stability with TB and SB compared to SR, with all three footwear leading to decrements in postural stability over the course of the workload [8]. Similarly acute workloads have also been reported to cause decrements in postural stability and lower extremity muscular exertion and muscle activity due to the physiological workloads [32,42].

Regarding the physiological effects of footwear, the greater mass has been shown to increase energy expenditure, with every 100 g of increase in mass causing a 0.7–1.0% increase in energy expenditure [43]. Moreover, an increased rate of muscular fatigue and greater energy expenditure has been reported in firefighter boots, steel-toed work boots, and even military boots respectively [40,44,45], thus increasing the risk of falls due to decreased postural stability. Previous research has reported multiple findings revealing footwear with a lighter mass can significantly improve postural stability and energy expenditure over time [35,40–42]. Furthermore, when comparing SB and TB, Turner et al. [39] revealed no significant effect on heart rate, RPE, and pain perception. However, a significant difference in oxygen consumption and energy expenditure between footwear with SB was reported resulting in a 6.2% and 7.1% increase in horizontal and graded treadmill walking protocols, respectively [40].

A summary of the different biomechanics and physiology studies using the occupational footwear SB, TB and SR are presented in Table 2 followed by a summary of the findins with pictorial demonstrations of data collection of the different studies presented in Figure 2.

Table 2. Summary of occupational footwear research.

No.	Study	Occupational Footwear	Human Performance Assessment	Variables Assessed	Workload	Conclusion
1	Chander et al., *Footwear Science*, 2014 [8]	SB, TB, SR	Postural stability using sensory organization test.	Anterior–posterior and medial–lateral postural sway velocity and root mean square sway.	Walking for 4 h in self-selected pace and path.	SB and TB had better postural stability than SR. Workload caused a decrement in postural stability.
2	Chander et al., *Footwear Science*, 2015 [37]	SB, TB, SR and Barefoot	Postural stability during dynamic balance perturbations.	Postural reaction time, mean and peak muscle activity, and time to peak muscle activity.	No Workload.	Barefoot had better postural stability than SB, TB, SR, with no difference between occupational footwear. TB demonstrated efficient lower extremity muscle activity.

Table 2. *Cont.*

No.	Study	Occupational Footwear	Human Performance Assessment	Variables Assessed	Workload	Conclusion
3	Chander et al., *Safety*, 2017 [38]	SB, TB, SR	Postural stability using sensory organization test.	Equilibrium scores and composite scores.	Walking for 4 h in self-selected pace and path.	SB and TB had better postural stability than SR. Workload caused a decrement in postural stability.
4	Turner et al., *International Journal of Exercise Science*, 2018 [39]	SB, TB	Subjective and objective measures of muscular fatigue and pain.	Maximal voluntary contraction, pressure pain threshold, ratings of perceived exertion, time to exhaustion, and heart rate.	Acute high intensity treadmill with sequential increase in speed and graded inclination.	No differences between SB and TB. Workload caused a decrease in pressure pain threshold and lower extremity muscle activity.
5	Krings et al., *Footwear Science*, 2018 [40]	SB, TB	Physiological energy expenditure.	Oxygen consumption, heart rate, breathing rate, and ratings of perceived exertion.	Four 20-min walking sessions with increase in speed without and with graded inclination.	SB had increased absolute oxygen consumption than TB.
6	Chander et al., *Work*, 2019 [32]	SB, TB	Postural stability using modified clinical test of sensory integration of balance.	Anterior–posterior and medial–lateral postural sway displacements, 95% ellipsoid area and sway velocity.	Acute high intensity treadmill with sequential increase in speed and graded inclination.	SB had better postural stability than TB. Workload caused a decrement in postural stability.
7	Hill et al., *Safety and Health at Work*, 2019 [41]	SR, SR with anti-fatigue mat and anti-fatigue slip on	Postural stability and cognitive performance on anti-fatigue mat and slip-ons	Mean, peak, root mean square muscle activity, co-contraction index, time to exhaustion, ratings of perceived exertion and cognitive interference.	Four bouts of wall sits and split squat lunges.	No differences in footwear and surfaces. Workload caused an increase in muscle activity.
8	Chander et al., *Biomechanics*, 2021 [42]	SB, TB, SR	Postural stability using sensory organization test and muscular fatigue.	Maximal voluntary contraction, mean muscle activity and % maximal voluntary contraction.	Walking for 4 h in self-selected pace and path.	No differences in footwear. Workload caused a decrease in muscle activity.
9	Chander et al., *International Journal of Environmental Research and Public Health*, 2021 [15]	SB, TB, SR	Postural stability using sensory organization test.	Postural strategy scores.	Walking for 4 h in self-selected pace and path.	No differences in footwear. Availability of sensory feedback rather than workload, caused a change in postural strategy.
10	Kodithuwakku Arachchige et al., International *Journal of Environmental Research and Public Health*, 2021 [35]	SR in dry and slippery surface	Postural stability in stable and unstable surface	Anterior–posterior and medial–lateral postural sway displacements, 95% ellipsoid area and sway velocity.	Walking for 1 h in self-selected pace and path.	SR in dry surface had better postural stability compared to SR in slippery surface. Workload caused a decrement in postural stability.

Figure 2. Biomechanics and physiology tests performed with occupational footwear. Various biomechanical and physiological human factors assessment in occupational footwear. (**1**) Static balance and postural stability, (**2**) Overground gait trials, (**3**) Treadmill gait trials, (**4**) Electromyography (EMG) from lower extremity muscles (tibialis anterior), (**5**) Treadmill workload used for fatigue induction with EMG (gastrocnemius pictured), (**6**) Overground dry surface gait trials, (**7**,**8**) Overground slippery surface gait trials, (**9**) Energy expenditure during treadmill workload, (**10**) Pressure pain threshold (PPT).

Past research has focused on the interaction of these occupational footwear and different types of simulated occupational tasks and workloads on the biomechanics and physiology of postural control and fall risk [8,15,32,35,37,38,40–42]. Occupational environments such as construction, roofing, and mining have workloads and work durations that are of low intensity and long duration, rather than high intensity and short duration as in athletics. Hence, the initial studies used a 4-h long walking protocol in a self-selected pace and path in each occupational footwear (SB, TB, SR) with postural stability assessed in 30-min increments. Postural stability was reported to significantly decrease over time and that the above ankle elevated footwear (SB and TB) aided in better postural stability compared to the low-top footwear (SR) [8,38] even though occupational footwear type did not impact the postural strategy used but was only influenced by the sensory organization test condition [15]. Additionally, muscular exertion and muscle activity during postural stability tasks, while had significant decrements over the 4-h duration, was not significantly influenced by the occupational footwear type [42]. While these results suggest that wearing SB and TB aids postural stability which may be attributed to their elevated boot shaft height and thin and hard midsoles providing greater somatosensory feedback compared to a low-top, thick, and soft midsole occupational footwear. However, footwear type did not influence lower extremity muscle activity during these postural stability tasks as well as during maximal voluntary contractions and perceived fatigue and pain [39,41]. However, when assessing physiological parameters of energy expenditure in response to an acute workload, the lighter TB contributed a significantly lower oxygen consumption compared to the heavier SB [40] and TB further demonstrating efficient muscle activity during non-workload postural perturbations [37], even though both had elevated boot shaft and hard midsoles. The only contrasting finding in postural stability was with an acute workload, with which SB demonstrated greater postural stability compared to TB, where the greater sole surface area of base of support evidenced by a larger forefoot and rear foot width might have contributed to the observed findings, while the workload still caused a decrement in postural stability [32]. Subsequent research with SR tested for postural stability when exposed to a dry and slippery surface during a 1-h self-selected pace and path walking workload, reported greater postural stability decrements in slippery surface and with the workload, suggesting the negative impact of walking on slippery surface for long durations [35], which are common in occupational environments such as restaurants and processing plants. Thus, suggesting the need for an elevated boot shaft, a thin and hard midsole with lower mass, and slip resistant sloes as the preferred design features.

7. Occupational Footwear Design Suggestions

Based on past research with occupational footwear, design suggestions for optimal human performance (biomechanics and physiology) are discussed below. Table 3 provides a summary of positive and negative impacts of various occupational footwear design features and their influence on the biomechanics and physiology of postural control and fall risk. The design features that have positive impacts should be adopted while the design features that have negative impacts be avoided or at least find alternatives. However, beyond all these suggestions, occupational footwear must follow and meet minimum safety standards regulated by OSHA through ASTM and CFR that were previously discussed.

Table 3. Summary of design features impacting biomechanics and physiology of postural control and fall risk.

Footwear Design Feature	Effect on Biomechanics/Physiology of Postural Control and Fall Risk
Midsole thickness	Thin soles increase the proprioception and somatosensory feedback from feet, resulting in better postural control and reduced fall risk
Midsole hardness	Harder midsoles provide the sense of standing on a stable surface, aiding in better postural control and reduced fall risk
Insole	Textured insoles improve the proprioceptive feedback to the CNS, aiding in postural control and reducing fall risk
Ankle support/boot shaft height	Ankle support/higher shaft increases the proprioception around the ankle joint due to its mild constriction around the ankle; thus, causing optimal postural control while reducing fall risk
Ankle support/boot shaft flexibility	Flexible ankle supports/boot shafts facilitate the ankle strategy and allow the maximum ankle range of motion to counterbalance the postural decrements; therefore, resulting in better postural control and reduced fall risk
Heel height	Higher heel heights are associated with a constant state of plantar flexion, an anterior shift of the center of mass, altered force distribution, and altered gait patterns. Due to the absence of such effects, lower heel heights allow better postural control and reduced fall risk
Heel-to-toe drop	Lower heel-to-toe drop results in better postural control and reduced fall risk due to the absence of the same effects mentioned under heel height
Heel type	Due to lower heel-to-toe drop, the wedge heel type is preferred over pointed heels for white-collar workers. However, having a thicker heel anteriorly could make push-off propulsion harder during gait. Hence, lower heel types may facilitate better postural control, energy-efficient gait, and reduced fall risk
Sole thread and groove pattern	Having an appropriate tread and groove pattern on the bottom of the sole will increase the friction of the footwear, leading to successful postural control, energy-efficient gait, and reduced fall risk
Mass	As increased mass causes higher postural sway, energy expenditure, and undue muscle fatigue, lighter shoes are preferred for postural control, energy-efficient gait, and reduced fall risk
Material, footwear shape, lacing	Discomfort and improper fitting of shoes alter gait biomechanics. Thus, comfortable, and properly fitting shoes enhance postural control while minimizing the falls.

Occupational footwear with thinner and harder midsoles is suggested for better postural stability as the thin midsole promotes and increases the availability of somatosensory and proprioceptive feedback, which are critical afferent sensory information for postural control, especially if there is a lack of visual feedback in low lit and unstable occupational environments such as coal mines. Additionally, textured, and thin insoles promote better proprioceptive and somatosensory compared to smooth and thick insoles. Boot shaft height is an important predictor of ankle joint movement during postural stability and gait. Elevated above ankle boot shaft provides a compression effect around the ankle and increases proprioceptive feedback and promotes static postural stability, however, elevated above ankle boot shafts can also restrict ankle joint range of motion, thereby negatively impacting dynamic postural stability and gait. Hence, an elevated above ankle flexible boot shaft with mesh and lacing can provide an optimal solution for static and dynamic postural stability for various occupational tasks. A lower heel height and a lower heel-to-toe drop height that promotes a more neutral ankle joint position is suggested against a high heel height that forces the ankle joint into a plantar flexed position that can causes an anterior tipping of foot and minimizes the base of support, decreasing postural stability. The outer sole material and tread pattern, groove, and depth are critical in making sure an acceptable coefficient of friction of minimum 0.5 according to OSHA regulations, thereby preventing slip and trip induced accidents. Minimizing the mass of the occupational footwear should be one of the major concerns, as an increased mass of the footwear increases cardiorespiratory energy expenditure and increases the rate of localized muscular fatigue, both of which in occupational environments can increase the risk of accidents and injuries. Finally, preference of type of footwear material and lacing type, selection of correct size, checking for excessive wear and tear should all be considered for occupational footwear selection and adoption to promote optimal human performance and minimize risks of accidents and injuries.

Novel design and manufacturing process for footwear, by using customized individual foot scans and using 3D printing (bionic shoes) have already been proposed and tested against normal shoes for human performance. These bionic shoes have been reported to aid in greater lower extremity joint kinematics, minimize joint reaction forces, and improve muscle activity during athletic tasks [46–48]. Such, individualized and customized design of footwear may be adopted in the future for occupational footwear, provided they are meeting or exceed minimum requirements for OSHA standards.

8. Conclusions

As the medium between human feet and the contact surface, footwear acts as a decisive extrinsic factor of postural stability, gait, and subsequently fall risk. Based on the series of studies conducted to assess the impact of three occupational footwear (steel-toed work boot, tactical boot, and slip-resistant footwear) on human biomechanics and physiology of postural control, the tactical work boot appears to provide more positive design features that promote postural control. Occupational footwear designed to meet safety regulations, might always be appropriate for optimal Although occupational footwear research is still growing, certain design features such as lower mass, lower heel height and heel-to-toe drop, elevated and flexible boot shaft, a thin and hard midsole, and textured insoles have been shown to encourage better postural control and thereby minimize fall risk. Applying these design characteristics to occupational footwear, while simultaneously abiding by OSHA safety regulations, could promote better postural stability and prevent falls and fall-related injuries in ergonomic settings.

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