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THE EFFECTS OF SHOE TYPE ON BIOMECHANICAL AND PHYSIOLOGICAL RESPONSES TO STEPPING AND INCLINED WALKING

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ABSTRACT

THE EFFECTS OF SHOE TYPE ON BIOMECHANICAL AND PHYSIOLOGICAL RESPONSES TO STEPPING AND INCLINED WALKING

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The purpose of this study was to examine the effect of hiking shoes and hiking boots on the biomechanical responses to a stepping task and physiological responses to an inclined walking task. Participants (n = 16) performed six two minute stepping trials at a stepping rate of 72 bpm; three trials in hiking boots and three trials in hiking shoes. Following the stepping task, participants (n = 19) walked at 3.0 mph and 10% grade for five minutes in hiking shoes and hiking boots. Lower limb joint angles and moments were calculated using Visual 3D. Physiological data was averaged over the last three minutes of the stepping task to determine mean variables during steady state exercise. Results showed that during the lowering phase of the stepping cycle, ankle ROM and ankle and knee moments were significantly greater in hiking shoes than hiking boots, indicating that no compensatory mechanisms of the knee and hip were implemented due to restricted ankle ROM. Additionally, VO_2 and V_E were significantly greater in the hiking shoe condition during the inclined walking task. While these variables are statistically significant, they may not be practically significant in an actual hiking scenario, as the magnitudes of differences observed in variables were minimal. Use of either shoe or boot may not result in an increased risk of injury, therefore leaving the choice of footwear up to the hiker’s personal preference.

KEYWORDS: hiking, footwear, boots.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS AND ABBREVIATIONS

Range of motion …………………………………………………………………..…… ROM

Ground reaction forces …………………………………………………………......… GRF

Body weight ……………………………………………………………………..…… BW

Oxygen uptake (absolute) ………………………………………………………………. VO_2

Oxygen uptake (relative) ……………………………………………………………. VO_2-kg

Ventilation …………………………………………………………………………….... V_E

Heart rate ………………………………………………………………………….….... HR

Energy expenditure ………………………………………………………………………. EE

Standard deviation ……………………………………………………………………….. SD

Maximal oxygen uptake ……………………………………………………….…. VO_{2max}

Excess post-exercise oxygen consumption ………………………………………………… EPOC

CHAPTER I: JOURNAL MANUSCRIPT

Introduction

Hiking is a popular recreational activity that provides multiple health benefits, such as improved cardiorespiratory fitness, reduced blood pressure, and lower risk of heart disease[1]. However, due to the physically demanding nature of the task, hiking may also increase the risk of injury among participants. Strains, sprains, and other soft tissue injuries to the knees, ankles, and feet account for about 75% of all hiking-related injuries[2].

In the outdoor industry, there is an ongoing debate regarding which type of shoe is better for performance and efficiency while on trail. Many hikers and outdoor enthusiasts rely on boots designed specifically for hiking, with a tall shaft that provides ankle support and therefore may reduce the risk of injury, specifically to the ankle and foot[3]. However, more and more hikers are choosing trail running shoes or other forms of tennis shoes as their footwear of choice due to their lightweight design and increased ankle range of motion[2,4–6]. While it is ultimately up to the hiker to decide which boot to wear, each design type has risks that may ultimately outweigh the benefits. Wearing boots with tall shafts may reduce the risk of ankle injury, but may also lead to increased forces at the knees and hips as a result of limited ankle range of motion[6]. Wearing lightweight shoes may allow for greater range of motion at the ankle, but may put the hiker at greater risk for ankle sprains and strains, as well as injuries to the knees and hips.

Previous literature has investigated the effects of footwear on several kinematic and kinetic variables, including functional gait[4–7], joint moments (knee and ankle)[8,9] and joint reaction forces[6,7,10–12]. Several studies have shown that wearing personal protection equipment (PPE) significantly decreases firefighters' lower body range of motion[6], as well as significantly reduces trailing toe clearance when stepping over an object[7], both of which may lead to higher incidences of tripping. Literature has also shown the impact of footwear on joint moments of the lower extremities. A study by Keenan et al. (2011) found that net joint moments of the knee and hip increased when wearing lightweight shoes compared to barefoot[8]. During downhill walking, something that is done extensively while hiking, joint reaction forces at the knee joint are increased compared to level walking and therefore may lead to an increased incidence of injury of the lower extremity[10–12].

Apart from recreational hikers, strains and sprains are also common among firefighters and military personnel. Due to the nature of PPE, firefighter and military boots tend to be heavy and bulky, containing up to 4.4 kg of added weight[6,7]. This added boot weight has been shown to increase physiological stress and increase oxygen uptake (VO_2) by 5-12%[13–21]. Neeves, Barlow, Richards, Provost-Craig, and Castagno (1989) found that in firefighters, wearing heavier boots resulted in greater VO_2, greater mechanical work production, and lower running speed compared to lightweight boots[6]. Previous research has also shown increases in ventilation (V_E), peak inspiratory flow rate (PIF), peak expiratory flow rate (PEF), and cortisol levels. Turner et al. (2010) found that increases in boot weight led to significant increases in V_E, PIF, and PEF[21]. Huang et al. (2009) found that salivary cortisol levels were elevated when boot weight was increased[13]. The evident change in physiological responses that comes with additional weight in the feet may influence hiking performance of the individual, as well as possibly lead to an increase in physiological stress on the body[13,21].

The change in various biomechanical and physiological variables (e.g., joint angles, joint moments, ground reaction forces, VO_2, V_E) as a result of footwear choice (i.e., hiking boots versus hiking shoes) has not been extensively investigated in the hiking community. However, as previously mentioned, these changes due to footwear have been widely researched in firefighters and military personnel and have been linked to increased injury risk, due to tripping, falling, and physiological stress. Investigation and analysis of these variables may provide insight and ultimately determine the better footwear choice to wear during recreational hiking activities to reduce risk of injury, increase efficiency of movement, and economy of effort while on trail. The results from this investigation may also be applicable to firefighters and military personnel to help educate on potential risks of injury related to footwear choice.

The purpose of this study was to examine the effect of hiking shoes and hiking boots on the biomechanical responses to a stepping task and physiological responses to an inclined walking task. It was hypothesized that ground reaction forces (GRF) and joint moments of the knee and hip would increase, while joint moments of the ankle would decrease, in the hiking boot condition compared to the hiking shoe condition during the stepping task. Additionally, it was hypothesized that ankle ROM would decrease and knee and hip ROM would increase in the hiking boot condition compared to the hiking shoe condition. It was also hypothesized that physiological variables (i.e., VO_2, V_E, and heart rate) would increase during the hiking boot condition compared to the hiking shoe condition during the inclined walking task.

Methods

The purpose of this study was to compare the effect of hiking shoes and hiking boots on the biomechanical and physiological responses to a stepping task and an inclined walking task. Permission to complete the study was obtained from the University's Institutional Review Board (Approval Number: HS18-960; Appendix A).

Participants

For this randomized, cross-over investigation, 10 males and 10 females (n = 20; mean ± SD: age = 25 ± 5 yr., height = 1.75 ± 0.08 m, mass = 77.6 ± 11.9 kg) volunteered. Inclusion criteria required the participant to be between the ages of 18-39, have an absence of lower extremity pain or injury in the 6 months prior to involvement of the study, and have previously participated in recreational outdoor hiking activities (i.e., day hiking, backpacking, thru-hiking) for at least one year.

Prior to beginning testing, participants met with the lead investigator to discuss the outline of the study, as well as sign a consent form (Appendix B). To verify that each participant met the inclusion criteria to participate, subjects took a brief survey that outlined their activity level, hiking experience, and current footwear preference for outdoor hiking activities (Appendix C), as well as the Physical Activity Readiness Questionnaire (Appendix D). Participants were asked to report their dominant leg by answering the question, "Which foot would you kick a soccer ball with?"

Experimental Set-up

Kinetic data were collected at a sampling frequency of 750 Hz using three AMTI force platforms (OR6-2000, Advanced Mechanical Technology, INC. [AMTI], Watertown, MA, USA) integrated into the stepping apparatus (Figure 1-2). Kinematic data was recorded with Cortex (v. 4.0, Motion Analysis Corporation, Santa Rosa, CA, USA) using a 10-camera Motion Analysis

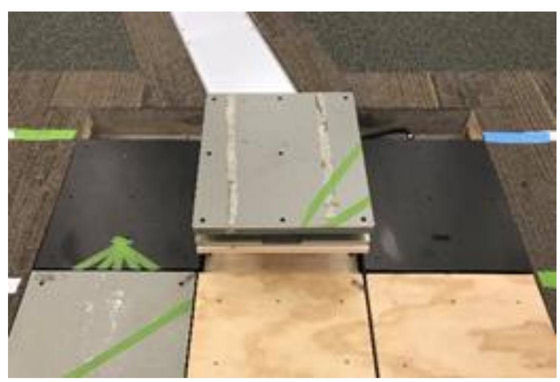

Figure 1. Force platform setup used for data collection, containing 3 AMTI force platforms, with one for platform built into a step.

Corporation (MAC) system consisting of a combination of RaptorE (3), RaptorH (4), and Kestrel (3) cameras, sampling at a rate of 250 Hz[22]. Cameras were positioned so that each marker was visible by at least 2 cameras throughout the stepping task. A rigid L-frame containing 4 markers of known locations was used to define a right-handed laboratory coordinate system. A 3-marker wand of known length was used for calibration of the system to scale individual camera views.

Figure 2. Schematic of lateral view of stepping apparatus, containing 3 AMTI force platforms. Height of the middle step was 18 cm. Area of the step was 0.23 m^2.

Physiological data was collected using a ParvoMedics True One Metabolic System (OUSW 4.3.4; Murray, UT, USA). Prior to each testing session, the metabolic measurement system was calibrated with a 3 L calibration syringe and medical gases of known concentrations (16.00% O_2, 4.00% CO_2, balanced N_2).

Experimental Procedures

On testing day, participant's mass and height were measured and recorded using a weight scale and stadiometer, respectively. Prior to beginning testing, participants selected the footwear (hiking boot: Adidas Outdoor Terrex AX2R Mid GTX; hiking shoe: Adidas Outdoor Terrex AX2R GTX; Herzogenaurach, Germany) they would wear for testing by trying on several sizes of each and choosing the best fit. Footwear weights were standardized within shoe sizes via high density lead golf tape. Participants were also issued a standard daypack (Osprey Daylite; Cortez, CO, USA), weighing 5 kg to mimic a day hiking pack (i.e., 1 L of water, snacks, first aid kit, etc.). Participants were then fitted and connected to the metabolic system and instructed to sit in a rest position for five minutes to collect baseline data. Following baseline, participants completed a standardized warm-up of walking on a TrackMaster treadmill (TMX428CP, Full Vision Inc., Newton, KS, USA) at a rate of 3.0 mph and 0% grade for 5 minutes.

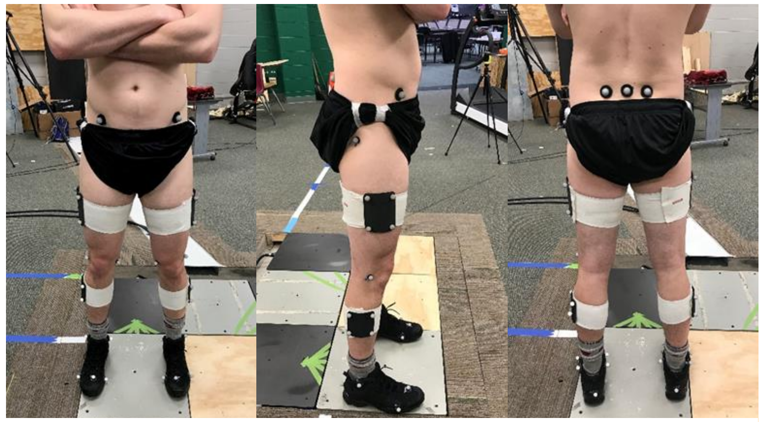

Figure 3. Modified Helen Hayes marker set, containing a combination of clusters and single markers, used to collect 3D kinematic data.

Following the warm-up, participants had 39 retroreflective markers placed on their pelvis and lower extremities following a modified version of the Helen Hayes marker set[23], consisting of a combination of clusters and single markers (Figure 3). Participants were instructed to stand in a neutral position, with their arms across their chest, so that one static trial could be used to align each participant with the laboratory coordinate system, as well as serve as a reference point for the data to be collected.

After marker placement, participants were instructed to step up and step down on a handmade wooden step (18 cm step height) containing three AMTI force platforms (Figures 1 and 2) at a rate of 72 steps per minute for a total of two minutes, equating to one trial. A metronome (Model XB-700, New Haven, CT, USA) was used to provide auditory cues for participants to maintain the step rate, with a step-up motion occurring on one beat and a step-down motion occurring on the following beat. Each participant completed three step-up/step-down trials, lasting two minutes each, in hiking shoes and hiking boots, for a total of six trials. Five minutes of rest were administered between each trial.

Following the stepping task, participants were once again fitted and connected to the metabolic cart and were instructed to walk at 3.0 mph and a 10% grade for five minutes while wearing the 5 kg daypack in either hiking shoes or hiking boots. Following each trial, subjects sat in a seated rest position for five minutes to collect physiological data to measure excess post-exercise oxygen consumption (EPOC). Subjects were given 10 minutes of rest between each trial, during which they changed footwear.

Data Analysis

The last 10 steps of the third trial in hiking shoes and hiking boots were used for biomechanical analysis. A reliability analysis was performed on ground contact time of the last 10 steps of each trial in hiking shoes and hiking boots using IBM© SPSS (v. 25, IBM, NY, USA). The analysis concluded that step contact time was consistent during all three trials in both hiking shoes (p = 0.383, ICC = 0.128) and hiking boots (p = 0.690, ICC = 0.401). Kinematic and kinetic data were filtered using a low pass, Butterworth filter with a cut-off frequency of 5.5 Hz[24]. Lower limb kinematic and kinetic variables were processed and calculated using a conventional gait model in Visual 3D (v. 4.0, C-Motion, Germantown, MD, USA), with standard gait events identified. The foot, shank, and thigh segments were modeled as cones and a CODA pelvis model was used. Joint centers of each segment were defined during analysis of participants' static trial. Foot, shank, thigh, and pelvis segments were determined using right-handed Cartesian local coordinate systems to define the position of each segment. Table 1 shows moving and reference segments used to determine joint range of motion (ROM) and joint flexion throughout the stepping task. ROM of each joint was calculated by subtracting the minimum angle from the maximum angle during the selected phase.

The lifting phase of each stepping cycle was defined from START to MID-STANCE (Figure 4). The lowering phase of each stepping cycle was defined from MID-STANCE to END (Figure 5). During the lifting phase of each step, peak ankle, knee, and hip moments and ankle, knee, and hip range of motion (ROM) of the lead and trail leg were measured (Figure 6). During the lowering phase of each step, ankle, knee, and hip moments and ankle, knee, and hip ROM of

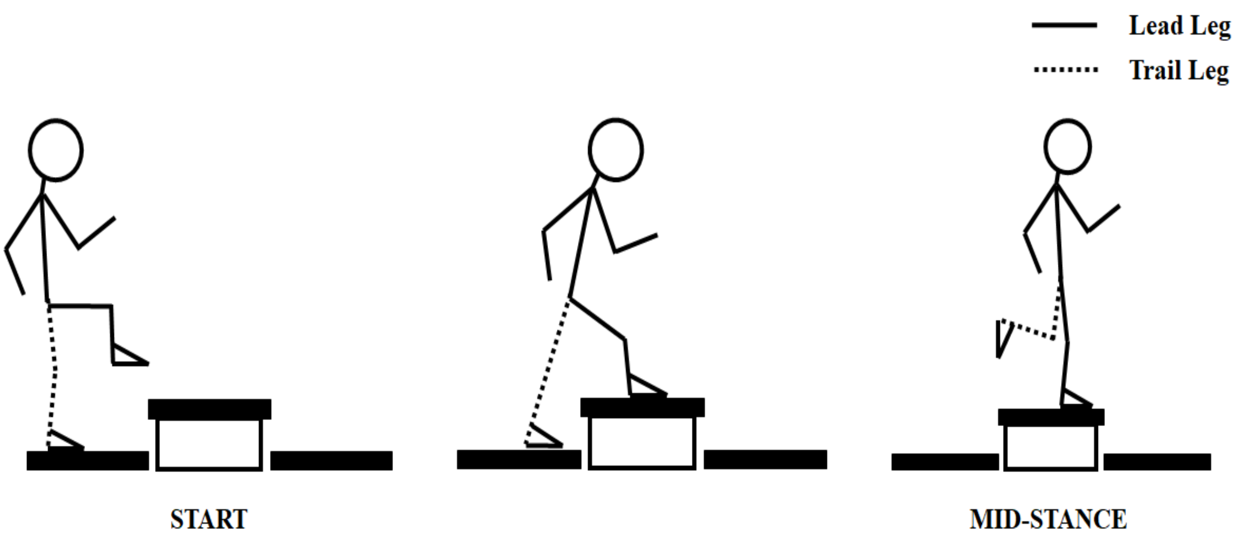

Figure 4. The lifting phase of each stepping cycle (START to MID-STANCE). Joint ROM of the lead leg and joint moments of the lead leg were measured during this phase.

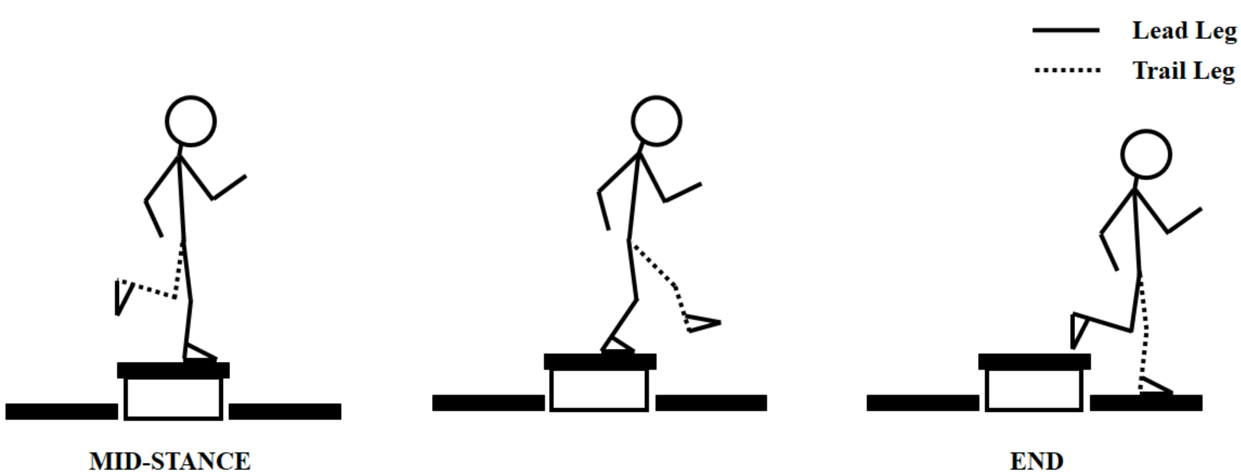

Figure 5. The lowering phase of each stepping cycle (MID-STANCE to END). Joint ROM of the lead and trail leg and joint moments of the lead and trail leg were measured during this phase. Joint flexion of the lead and trail leg were measured before END of the lowering phase, from toe-on of the trail leg to toe-off of the lead leg.

both the lead and trail leg were measured (Figure 4). Peak ground reaction forces (GRF) and joint flexion of the lead and trail leg were measured before END of lowering phase, after toe-on of the trail leg until toe-off of the lead leg (Figure 5). Toe clearance height of the lead leg and trail legs were measured and analyzed, in addition to joint flexion at lead toe clearance (Figure 6). Peak GRF were normalized to percentage of participant body weight (BW) plus weight of the day pack. All variables were analyzed separately using MATLAB (v. R2018a, MathWorks, Natick, MA, USA).

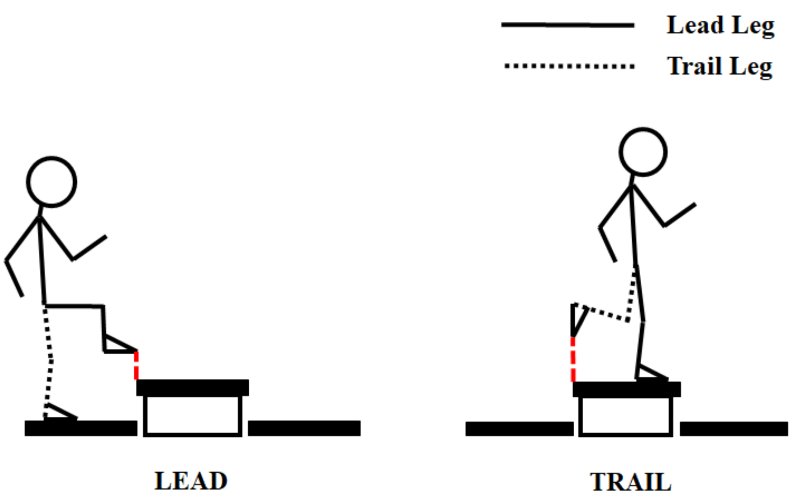

Figure 6. Phase of the stepping cycle in which lead toe clearance and trail toe clearance were measured. Additionally, joint flexion was measured at lead toe clearance.

Participants' oxygen uptake (VO_2 [L•min^{-1}], VO_2-kg [ml•kg^{-1}•min^{-1}]), ventilation (V_E [L•min^{-1}]), and heart rate (HR [beats•min^{-1}]) were averaged over the last 3 minutes of each inclined walking trial using Microsoft Excel (v. 2016, Redmond, WA, USA) to determine mean variables during steady state exercise. Baseline and exercise VO_2 (L-min) were exported in 20-second averages, with each average given a time value of 0.33 minutes. Baseline and exercise VO_2 were multiplied by the corresponding time value and summed to obtain gross VO_2 (L-min). Gross VO_2 [L], in conjunction with each average's corresponding kcal factor[25], were used to calculate net VO_2 [L] and net energy expenditure (EE, [kcal]) during exercise. Additionally, HR during the hiking shoe and hiking boot conditions were used to estimate percentage of maximal oxygen uptake (VO_{2max}) for each participant in both conditions, using the Karvonen formula[26].

Statistical Analysis

Descriptive statistics (mean, standard deviation [SD]) of all variables in participants' dominant and non-dominant leg were calculated using MATLAB. Paired t-tests were performed using IBM© SPSS (v. 25, IBM, NY, USA) to compare physiological variables (VO_2, V_E, HR, net VO_2, and EE), joint ROM, joint flexion, joint moments, and peak GRF across shoe types. Significance level was set at $p < 0.05$. Cohen's d effect sizes were used to determine magnitude of differences between conditions[27]. Hopkins' (2000) scale for effect size classification was used to interpret effect size: trivial = < 0.04, small = 0.041-0.249, medium = 0.25-0.549, large = 0.55-0.799, and very large = > 0.8[27].

Results

Descriptive Data

Table 2 displays descriptive statistics of participants, including anthropometrics and footwear sizes used in the current study. Table 3 indicates that 90% of participants have been involved in outdoor hiking activities for 7+ years. Table 4 shows footwear preferences when engaging in outdoor hiking activities, with 25% preferring a running/tennis shoe, 20% favoring a trail running shoe, 25% choosing a hiking shoe, and 30% choosing a hiking boot. Additionally, Table 5 indicates that 95% of participants typically go on day hikes, but also go on overnight and backpacking trips.

Kinematic Data

Tables 6-12 report kinematic variables measured during various phases of the stepping task in hiking shoes and hiking boots. Knee ROM of the lead leg during the lifting phase decreased significantly in hiking boots in the dominant leg compared to hiking shoes (p = 0.037, d = 0.19; Table 6). Ankle ROM of the lead leg during the lowering phase significantly decreased on the dominant leg (p = 0.020, d = 0.29) and non-dominant leg (p < 0.001, d = 0.35) in hiking boots compared to hiking shoes (Table 7). Additionally, the non-dominant lead leg had significantly less ankle plantarflexion at the end of the lowering phase when wearing boots (p = 0.010, d = 0.55; Table 9). No significant differences were found between footwear conditions in the lead leg for ankle or hip ROM during the lifting phase (Table 6) or knee and hip ROM during the lowering phase (Table 9).

No significant differences were observed for toe clearance height of the lead or trail leg, though toe clearance of the non-dominant lead leg tended to be lower in the hiking boot condition eliciting (absolute difference = 0.61 cm; p = 0.065, d = 0.41; Table 11). While no significant differences were found in joint flexion at toe clearance of the lead leg, ankle plantarflexion of the dominant leg tended to decrease in hiking boots (d = 0.30; Table 12).

Kinetic Data

Kinetic variables measured during various phases of the stepping task in hiking shoes and hiking boots are presented in Tables 13-16. There were no significant differences found between hiking shoes and hiking boots for peak GRF during landing of the trail leg (Table 13). Ankle plantarflexion and ankle dorsiflexion moments of the lead leg during the lifting phase were significantly greater in hiking boots compared to hiking shoes in both the dominant and non-dominant leg (Table 14). Additionally, knee flexion moments of the lead leg were significantly greater in the non-dominant leg during the lifting phase when wearing hiking boots (Table 14). No significant differences were found in hip extension moments in the dominant or non-dominant lead leg during the lifting phase (Table 14). During the lowering phase, ankle dorsiflexion and knee extension moments were significantly greater in the dominant leg when wearing hiking shoes (Table 15). No significant differences were found in hip flexion moment of the dominant leg or joint moments in the non-dominant lead leg during the lowering phase (Table 16).

Physiological Data

Tables 17 and 18 report physiological variables measured during baseline and the inclined walking task in hiking shoes and hiking boots. Significant differences were found in VO_2, VO_2-kg, and V_E between hiking shoes and hiking boots, with VO_2, VO_2-kg and V_E significantly greater in hiking shoe condition (Table 18). Additionally, net VO_2 and EE during exercise were significantly greater in the hiking shoe condition. No significant differences were found in HR between footwear conditions.

Discussion

The purpose of this study was to examine the effect of hiking shoes and hiking boots on the biomechanical responses to a stepping task and physiological responses to an inclined walking task. The hypotheses of increased GRF, increased physiological variables (VO_2, VO_2-kg, V_E, and HR), and increased knee and hip ROM in the hiking boot condition compared to the hiking shoe condition were not supported. Additionally, the hypotheses of increased knee and hip moments and decreased ankle moments in the hiking boot condition were rejected. The hypothesis of decreased ankle ROM during the hiking boot condition was accepted, but only during the lowering phase of the stepping cycle.

Kinematic Data

Ankle ROM of the lead leg during the lowering phase significantly decreased in hiking boots compared to hiking shoes in both the dominant and non-dominant leg (p = 0.020, < 0.001; d = 0.29, 0.35, respectively; Table 7). Additionally, ankle plantarflexion of the lead leg at the end of the lowering phase, at trail leg toe-on, was significantly lower in hiking boots compared to hiking shoes in the non-dominant leg (p = 0.010, d = 0.55; Table 9). The ankle ROM and ankle flexion observed in the current study during the hiking shoe and hiking boot conditions were similar to those found in the running shoe condition during a 10 m walking task by Park et al. (2015), with significant differences found in ankle ROM between the running shoe and rubber boot conditions[6]. Additionally, the researchers found significant increases in knee and hip ROM in the rubber boot condition compared to the running shoe condition and attributed these increases to firefighters swinging their leg upward to a greater extent to avoid hitting their toe on the ground or obstacle, which may result in tripping or stumbling. Park et al. (2015) attributed these significant increases in knee and hip ROM as an attempt to compensate for the reduced ankle ROM in order to continue gait[6]. This is contrary to the current study, where knee ROM of the lead leg during the lifting phase was significantly smaller in the hiking boot condition compared to the hiking shoe condition (Table 6). Additionally, no significant differences were found between footwear conditions for lead leg knee or hip ROM during the lowering phase or joint flexion of the lead leg at the end of the lowering phase at trail leg toe-on, leading the authors to believe that no compensatory mechanisms were implemented to account for the reduced ROM at the ankle in the current study. The current study also used a smaller boot shaft height when compared with previous research (mid-shaft versus tall-shaft)[6,7], meaning there was less restriction of the ankle, therefore compensations at the knee or hip during gait were likely not necessary[6].

A reduction in ankle ROM could potentially lead to an increased risk of stumbling due to the limited dorsiflexion (i.e., lead leg at toe clearance) necessary to step over obstacles[6], with the magnitude of the restriction dependent upon shaft height. In the current study, no differences were observed in ankle ROM during the lifting phase of the step. However, ankle plantarflexion of the lead leg at lead leg toe clearance tended to decrease in the boot condition in both the dominant and non-dominant legs (dominant: $p = 0.234$, d = 0.30; non-dominant: $p = 0.158$, d = 0.42; Table 12). The greater ankle plantarflexion observed in the hiking shoe condition may lead to increased incidents of tripping and stumbling, as the toe may be more likely to come into contact with the obstacle or step[6].

Lead and trail leg toe clearance heights observed in the current study were much greater than those observed in previous research, with previous research reporting toe clearance heights ranging from 1.5-3.8 cm during stair descent[28], compared to the 5.4 cm clearance height reported in the hiking boot condition in the current study (Table 11), though step heights were almost identical. Chiou et al. (2012) investigated the effects of various types of footwear on lead and trail toe clearance height and found no differences between lead toe clearance height during the low obstacle condition (15 cm)[7]. However, significant differences were found during the high obstacle condition (30 cm), with trailing toe clearance decreasing as boot weight[7]. Since Chiou et al. (2012) did not measure joint kinematics during the walking task, it could not be concluded that compensations at the knee and hip were implemented to maintain toe clearance height. Instead, the researchers attributed the lack of differences in toe clearance height during the low obstacle condition to participants swinging their feet outward to maintain toe clearance over obstacles[7]. During the high obstacle condition, decreases in toe clearance height may have been a result of insufficient knee and hip flexion, as participants wore full firefighting turnout gear, which restricted lower body ROM. Because of these reductions, additional compensations to clear the 30 cm obstacle may not have been possible due to the restrictions placed on lower body ROM. In the current study, compensations at the knee and hip were not required to lift the lead leg and achieve continuous gait during the stepping task (Table 12), however, these compensations may have been present if a taller step height had been used.

Kinetic Data

No significant differences were found in peak GRF in the current study (Table 13), which is consistent with previous research that has examined the effects of ankle bracing on GRF and during jump landing tasks. Theodorakos et al. (2016) investigated the effects of a braced ankle on knee and hip mechanics during landing on inclined surfaces and reported that no significant differences were observed in peak GRF between braced and unbraced conditions. Additionally, these authors found no significant differences in knee moments between braced and unbraced conditions, attributing the findings to the compensatory mechanism of the lower extremities at contact to account for lack of ankle ROM (i.e., increased knee ROM), as well as the characteristics of the ankle brace[29,30]. As previously mentioned, the shafts of the boots used in the current study were smaller than previous research, as well as shorter than the ankle braces used in both DiStefano et al. (2008) and Theodorakos et al. (2016). Therefore, knee and hip compensation were not required to achieve continuous stepping gait in the current study.

During the lowering phase of the current study, lead leg knee extension moments were significantly greater in the hiking shoe condition compared to the hiking boot condition in the dominant leg (p = 0.020, d = 0.48; Table 15), with similar meaningful differences in the non-dominant leg (p = 0.071, d = 0.37; Table 15). Additionally, as previously mentioned, ankle ROM of the lead leg during the lowering phase was significantly greater in hiking shoes than hiking boots in both the dominant and non-dominant leg. These findings may help explain why greater moments were observed in the knee in hiking shoes compared to hiking boots during the lowering phase, as the knee may be placed further in front of the foot throughout the phase. However, due to similar peak GRF reported between footwear, it can be suggested that the increased joint moments observed in the hiking shoe condition may be a compensatory mechanism to allow for better control throughout the lowering phase.

While significant differences between footwear in knee extensor moments during the lowering phase were observed, these differences may be negligible due to magnitude of the differences between footwear conditions (dominant: difference = 0.30 $N{\bullet}m{\bullet}kg^{-1}$ (6.3%); non-dominant: difference = 0.29 $N{\bullet}m{\bullet}kg^{-1}$ (6.2%)). These differences are smaller than those experienced by participants in a study by Powers, Ward, Chen, Chan, and Terk (2004), which found that during stair descent, knee extensor moments increased by 12.2% when the patella was braced. Interestingly, the 12% increase in knee extensor moments reported by Powers et al. (2004) were not associated with reductions in pain, as individuals reported a 56% decrease in pain during the braced knee condition[31]. Regardless of footwear choice, magnitude of knee moments observed in the lowering phase in both hiking shoes and hiking boots may be especially important for those with knee pain or knee osteoarthritis. Over time, greater moments exerted on the knees may lead to increased wear and tear and potentially lead to injury[32].

Physiological Data

In the current study, VO_2, VO_2-kg, and V_E were significantly lower in hiking boots compared to hiking shoes (Table 18). These findings are inconsistent with previous research, which has shown an increase in physiological demand due to the increased inertia of the loaded segments as a result of adding weight to the feet[7,18,21]. Chiou et al. (2012) investigated differences in VO_2 and V_E with increasing boot weight and noted that as boot weight increased, VO_2 and V_E increased significantly by 5% and 6% per 1 kg of added boot weight, respectively[7]. In the current study, VO_2 and V_E both increased significantly by approximately 3% in the hiking shoe condition. When translated to a hiking scenario, increases in VO_2 and V_E may result in a decreased ability to maintain pace and hike for prolonged periods. Due to footwear weights being standardized in the current study, it could be proposed that the mid-shaft height of the boot may explain the significant reductions in VO_2, VO_2-kg, and V_E in the hiking boot condition. The shaft of the boot may have caused participants to implement a more energy-efficient gait to complete the inclined walking task[6,7]. This is further supported by the similar HR observed between footwear conditions, which is consistent with past research that indicated that while significant differences were found in physiological variables (i.e., VO_2, V_E) between several boot types of varying weights, HR remained unchanged[7,21].

Stabilization of the knee joint is often a primary issue when walking on uneven ground. In a hiking shoe that allows for more ankle ROM, the ankle joint may be better able to adapt to the uneven terrain, therefore requiring less energy to stabilize the knee[33]. Cikajlo and Metjacic (2007) also speculated that increases in ankle joint movement and ankle power generation, as a result of boots with more flexible soles, may result in more energy-efficient gait, leading to lower oxygen consumption[34]. As previously mentioned, ankle joint ROM was significantly reduced in hiking boots compared to hiking shoes during the stepping task in the current study, however, no compensatory mechanisms (i.e., increased knee flexion) were observed. These results can be translated to the inclined walking task, where if lower body kinematics and kinetics were measured, a reduction in ankle ROM may have been observed in the hiking boot condition, but no compensation at the knee or hip found. This may result in a more supported ankle joint during inclined walking in the hiking boot condition, meaning the need to stabilize both the ankle and knee is lessened, requiring less energy during the task, therefore eliciting a lower VO_2, V_E, net VO_2, and EE during the task[7,33].

Though differences in VO_2 and V_E were statistically significant between footwear, due to the minimal differences between conditions (VO_2: 2.8%; VO_2-kg: 2.5%; V_E: 3%) and small effect sizes observed, these differences may not be practically significant in an actual hiking scenario. The increases in VO_2 and V_E in the hiking shoe condition may result in the hiker unable to maintain pace and hike for prolonged periods, leading the hiker to take more breaks to recover from the aerobic exercise[35]. However, a number of factors may affect a hiker's decision to take breaks, such as terrain, trail conditions, fatigue, and hydration. Additionally, these differences in VO_2, VO_2-kg, and V_E may have been a result of inter-unit variability of the metabolic measurement system, with up to 4% variability[36]. While all participants considered themselves avid hikers and had regularly participated in outdoor hiking activities, some hikers may have been more aerobically fit than others as a result of engaging in cardiorespiratory endurance exercises in addition to hiking, which may be evident by the large variability present in estimated percentage of VO_{2max} in the hiking shoe and hiking boot conditions (Table 18). This range of aerobic fitness of participants may explain the large inter-individual variability and small effect size reported for V_E.

<u>Limitations</u>

A limitation in the current study is that pre-obstacle distance was not measured during the stepping task. Doing so may have provided more insight into stepping strategies used by participants, such as how participants approach the step, which may influence the risk of contact with the step[7]. Another limitation of the current study is that lateral position of both the lead and trail legs were not measured. It is possible that participants swung their foot more outward in order to maintain sufficient toe clearance height during the step, which may explain the lack of differences observed in toe clearance height[7]. Additionally, participants' leg length to boot shaft height proportions were not measured and calculated. A larger proportion may have influenced ankle ROM, resulting in a decrease in ROM in the hiking boot condition compared to the hiking shoe condition[37]. Lastly, kinematics and kinetics were not measured during the inclined walking task. It is possible that step length may have decreased during the hiking boot condition, resulting in a more efficient gait pattern, which may help explain the significant differences in oxygen consumption and ventilation[7].

Conclusion

In conclusion, several significant differences were observed in biomechanical and physiological variables during the stepping task and inclined walking task, respectively. While differences in biomechanical and physiological variables between footwear are statistically significant, they may not be practically significant in an actual hiking scenario, as the magnitudes of differences observed in variables were minimal. When translated to a hiking scenario, it could be proposed that use of mid-shaft hiking boots may provide more ankle support during outdoor activities that involve stepping or inclined walking, without affecting the kinetic chain of the lower extremities. It can be concluded that the use of either shoe or boot may not result in an increased risk of injury, therefore leaving the choice of footwear up to the hiker's personal preference. Future research should continue investigating biomechanical and physiological responses across footwear, though a taller shaft should be implemented.

CHAPTER II: LITERATURE REVIEW

This chapter will introduce hiking, as well as discuss physiological and biomechanical responses in simulated activities similar to those seen on trail. Literature relevant to the subject area was gathered from various academic disciplines including sports science, biomechanics, and wilderness medicine. An extensive search of Northern Michigan University's library catalogue, specifically journal articles, was conducted. Key words such as footwear, hiking, gait, physiological responses, stepping, firefighter, and military personnel were used for electronic searches within Northern Michigan University's online catalogue and Google Scholar.

While there are numerous health benefits that result from hiking, there are some potential consequences that stem from footwear choice, including increases in physiological responses, such as energy expenditure and oxygen uptake. Changes in biomechanical variables, such as vertical ground reaction forces, joint moments, lower extremity range of motion (ROM), functional gait, may also be a result of footwear choice. These changes in physiological and biomechanical variables as a result of footwear and their implications on hiking will be discussed in this review.

Hiking Overview

Hiking is a common recreational activity for people of all ages that provides numerous health benefits, with over 50 million Americans participating in some sort of hiking activity in 2016[38]. Depending on experience, physical condition, and general preference, hiking can be a leisurely activity or a strenuous workout.

A day hike is a hike that is short enough to be completed within a single day, usually lasting 5 hours or less[39]. Most recreational hikers go on day hikes, with lengths varying based on a number of factors – experience, physical fitness, time allotted, etc. Those who go on day hikes tend to carry a light daypack with water, navigation tools, snacks, first aid supplies, and other miscellaneous items. Due to the short nature of day hikes and light load, many hikers will choose trail running shoes or tennis shoes as their footwear of choice.

According to the 2017 Outdoor Participation Report, compiled by the Outdoor Foundation, backpacking is defined as hiking and camping overnight more than 1/4 mile away from a person's vehicle or home[38]. Backpacking trips are longer than day hikes, as they typically last 1-2 days. Depending on experience and physical condition of the hiker, mileage covered each day can range from a few miles to upwards of 30+ miles. During a backpacking trip, hikers will carry the same essentials as for a day hike, as well as a tent (or other form of shelter), extra clothing, and multiple days' worth of food. Because of the increased load, many backpackers choose more rigid hiking boots to increase support in the lower extremities.

Regardless of the type of hiking that an individual is engaging in, whether it be day hiking or backpacking, there are many precautions that should be taken, including pack weight and footwear choice, to minimize risk of injury while on trail.

Epidemiology of Injury

With hiking and other outdoor activities, there is the obvious risk of injury, whether it be accidental, a force of nature, or an outcome of participating in an outdoor activity[40]. During a review of incidents occurring on expeditions with the National Outdoor Leadership School (NOLS), there were a total of 603 injuries reported between September 1998 and August 2002. About 50% of the reported injuries were considered athletic injuries, meaning they were a strain or sprain of the knee (35%) or the ankle (30%), with the majority of contributing factors being falls, slips, or overuse. It should also be noted that of the activities at the time of the injuries, 46% were while the individual was hiking with a weighted pack[40].

In a more recent review of injuries that have occurred within NOLS courses, Hamonko et al. (2011) gathered data on students participating in NOLS Rocky Mountain courses between March 2008 and October 2009[41]. Over the course of the study period, a total of 26 injuries were reported, with 22 sustained to the lower extremity. While the focus of this review was comparing pack weight and incidence of injury, the authors found that there was no direct correlation between increased pack weight and incidence of injury. Because of this, the authors propose that footwear may be a potential contributing factor influencing injury[41].

In addition to strains and sprains, paresthesia is another musculoskeletal injury that is common among hikers, especially those who partake in long-distance hiking or thru-hiking. Paresthesia is a neurological disorder that is characterized by painful burning, tingling numbness, and decreased touch and pain sensation[42,43]. Due to the nature of hiking and the equipment involved, hikers and backpackers are at risk for paresthesia, specifically in the feet. The feet may be at risk for various neuropathies, such as digitalgia paresthetica or tarsal tunnel syndrome. Digitalgia paresthetica is pain or numbness present in the toes and is usually a result of direct repetitive trauma to a nerve. In hikers, digitalgia paresthetica develops from direct, repetitive trauma to the ball of the foot, which is typically a result of poorly fitting hiking boots[42,43]. Tarsal tunnel syndrome is another common neurological disorder that is an entrapment neuropathy of the posterior tibial nerve and occurs due to intrinsic or extrinsic compression of the posterior tibial nerve, which may result in a burning pain, tingling, or numbness in the medial malleolus[43]. Tarsal tunnel syndrome has recently been associated with ski boots and hiking boots due to the significant external pressure that is present on the malleolus[44].

When a musculoskeletal injury occurs in hikers or backpackers, specifically paresthesia or a lower extremity sprain or strain, footwear choice should be explored to determine if it is a potential influential factor. A change in footwear may prevent tripping, slipping, or falling, as well as reduce direct pressure and trauma, potentially leading to a decrease risk of injury of the individual[42,43].

Physiological Responses

As previously mentioned, the effects of footwear choice on injury occurrence in recreational hikers and backpackers has extensively been investigated[40–43]. The effects of footwear on physiological variables during hiking, such as oxygen uptake, energy expenditure, ventilation, and blood lactate, has not yet been investigated in hikers or backpackers. However, changes in physiological variables as a result of footwear have long been researched in military personnel and firefighters[14–17,19–21], which can be applied to the hiking community, due to the similarities in footwear choices and required equipment.

Previous literature has compared oxygen uptake while wearing lightweight shoes (i.e., tennis shoes or trail running shoes) and heavier boots (i.e., rubber or leather boots). It was reported that there was an average increase of 5-12% in oxygen uptake per 1 kg of added footwear mass[14–17,19–21].

Due to the nature and purpose of the personal protective equipment (PPE) required for firefighters and military personnel, footwear choices are very similar to the type (i.e., tall shaft) and materials of boots preferred by many hikers. Because of this, much of the research that has been done on PPE, which can total 23-29% of a person's body mass[21], can be applied to the hiking community and those who wear tall shaft boots and backpacks, which can total up to 35% of a person's body weight[17,21,41].

The effects of boot weight on physiological factors, such as oxygen uptake, have been extensively investigated in military personnel, as well as in firefighters. Legg and Mahanty (1986) investigated the effect of increasing boot mass on the energy cost of level walking. The subjects walked under three conditions; with standard military boots and no load, with standard military boots and a backpack (35% of body weight), and with weighted boots (5% of body weight) and a backpack (35% of body weight). The authors found that increasing footwear weight significantly increased oxygen uptake, with a 7-10% increase in oxygen uptake for every 1 kg of added weight of footwear. This suggests that footwear weight is responsible for differences in physiological demand, which is believed to be a result of increased inertia of the lower extremities due to increased load[17,18].

Several previous studies have researched the effects of boot weight in firefighters. Turner et al. (2010) found that there was a significant increase in oxygen uptake per 1 kg of added boot weight during level walking for both men and women, with increases of 5-6% for men and 3-4.5% for women[21]. A study by Chiou et al. (2012) yielded similar results when comparing boot weight to physiological responses in firefighters. The authors found that per 1 kg increase of boot weight, there were significant increases in relative oxygen uptake, with an increase of 8.7% seen in men and an increase in 7.1% seen in women[7]. Collectively, the results of these previous studies conclude that increased boot weight leads to increased oxygen uptake and physiological burden[7,17,21].

The effects of boot weight on oxygen uptake during stair climbing have also been previously researched. Huang et al. (2009) investigated the physiological responses in firefighters when wearing rubber boots and leather boots and found that when wearing leather boots, participants' salivary cortisol (SCORT) values elicited a greater elevation compared to the rubber boots condition. This suggests that the type of boot worn during stair climbing activities may influence stress and fatigue[13]. Turner et al. (2010) also investigated the effects of boot weight on physiological parameters during stair ergometry and found that there was a 2-3% increase in oxygen uptake, as well as a 4-5% increase peak inspiratory (PIF) and expiratory flow (PEF) rates, per 1 kg of boot weight added. Similarly, Strydom et al. (1968) found that during a stair climbing activity (24 steps/min), oxygen uptake increased significantly with increased boot weight[20].

Based on previous literature, it is evident that adding mass (i.e., shoe, backpack) increases the physiological demand within the body and leads to increased oxygen uptake[14–17,19–21]. However, the extent of these increases depends on the type of activity (i.e., walking, stepping) and additional equipment (i.e., boots, PPE, backpack) incorporated during testing, as well as the intensity level of the task. During walking, oxygen uptake may increase anywhere from 5-12% per 1 kg of added weight, whereas only a 2-3% increase was seen during stepping. These differences may be a result of the basic function of the task, as individuals typically need to carry their foot a further horizontal and vertical distance during walking compared to stepping, where the horizontal distance traveled is much less[45]. From the research presented, numerous studies have investigated physiological responses to walking, however, stepping, specifically stepping with a backpack, is under investigated.

Kinetic Responses

In addition to physiological variables that change with footwear, there are also several kinetic variables that are affected, such as ground reaction forces and joint moments[9,11,12,46]. These changes in kinetic variables may lead to increased physiological stress, potentially leading to overexertion and falling[7].

During downhill walking, something that is done extensively while hiking, joint reaction forces at the knee joint are increased compared to level walking and therefore may lead to an increased incidence of injury of the lower extremity[10–12]. Paisis et al. (2013) found that in military personnel, there was an increase in vertical ground reaction forces, i.e., impact peak forces, push-off rate, maximum force, and loading rate, during downhill walking in heavy, tall shaft military boots compared to lightweight running shoes. The authors attributed this increase in vertical ground reaction forces to the notion that participants may have adopted different gait patterns to accommodate different footwear in order to reduce impact variables (i.e., peak impact force) and pain or discomfort experienced as a result of footwear[11].

Joint moments of the ankle, knee, and hip have also been observed during downhill walking. Kuster et al. (1995) revealed that during downhill walking, maximum joint moments of the ankle were significantly less than that of level walking. In addition, maximum joint moments of the knee and hip were significantly greater during downhill walking compared to level walking. These increases in joint moments result in increased eccentric muscle requirements to absorb shock during descent of inclines[47]. This may explain why hikers typically experience muscle soreness following a hike[9]. A similar study by Keenan et al. (2011) investigated joint moments of the hip, knee, and ankle when comparing walking barefoot to walking in industry recommended footwear, which would be classified as lightweight shoes[8]. The investigators found that there were increases in net joint moments of the knee and hip when wearing lightweight shoes versus walking barefoot. The authors attributed these increases to increases in stride length while wearing lightweight shoes, as well as significant differences in ground reaction forces in the frontal, sagittal, and transverse planes[8].

Many athletes who experience ankle sprains during sports choose an intervention method, such as taping or wearing a brace, to restrict ankle movement in the frontal plane and prevent future injuries[29]. With tall-shaft hiking boots providing similar rigidity and support to that of an ankle brace, it is possible for research regarding biomechanical effects of ankle braces to be applied to the hiking community. Theodorakos et al. (2016) investigated the effect of semi-rigid ankle braces on the knee and hip joints during landings on inclined surfaces. The researchers found that when landing on inclined surfaces with braced ankles, knee and hip loading were not increased compared to the unbraced condition. However, it remains unclear how the load was distributed to other structures, such as ligaments and menisci. Many participants in the study showed a decreased ROM at the knee joint during the braced condition, suggesting that loading at the knee may be absorbed differently, which may lead to an increased risk of injury[29].

Previous literature has shown that alterations in kinetic variables due to footwear choice, such as ground reaction forces, joint moments, and joint loading, may increase an individual's risk of injury[9,11,12,46]. The extent of these alterations is highly dependent on the task at hand (i.e., level walking, downhill walking) and footwear choice (i.e., barefoot, lightweight shoes, heavy boots). These changes in vertical ground reaction forces and joint loading may be due to the fact that heavy hiking boots are generally much more rigid and designed to be able to withstand environmental factors, such as rough terrain, rather than provide shock absorbance. Lightweight running shoes typically contain a shock-absorbing sole to prevent injury while walking and running[11]. Literature has investigated these variables during level and downhill walking, however, as previously mentioned, these variables have not been investigated during stepping with a backpack.

Kinematic Responses

Footwear selection, specifically when wearing heavy boots, has been shown to produce kinematic alterations, which may increase the risk of tripping[4–7]. Previous literature has shown that wearing boots with tall shafts reduces ROM, especially in the ankle and the ball of the foot. This was seen in the frontal, sagittal, and transverse planes in firefighters[6,7]. The limited ROM in the ankle while wearing boots implies that footwear may alter normal foot motion at the ankle joint, which may lead to altered gait and instability in firefighters due to limited dorsiflexion and plantar flexion, which is vital for successful obstacle clearance[6]. This reduced ROM, as well as the heaviness and bulkiness of the required PPE, may put firefighters at a higher risk of experiencing injuries to the foot, such as ankle sprains, as well as physical strains[4–6].

As previously mentioned, research has shown that wearing heavy boots leads to more incidents of tripping, specifically with the trailing foot during a gait cycle. Chiou et al. (2012) investigated the effects of boot weight on a firefighter's gait and found that for each 1 kg increase in boot weight, there was an estimated 2.9 cm and 4.4 cm decrease in trailing toe clearance for high and low obstacles, respectively[7]. The obstacles that firefighters face, such as debris, are similar to those seen by hikers. On trail, hikers come across rocks, tree roots, puddles, among other natural obstructions.

When stepping over an obstacle, after the leading limb has passed the obstacle, both the obstacle and trailing limb are outside the individual's field of view. This leads to the increased probability that the trailing limb may come into contact with the obstacle, such as a rock or root on trail, resulting in tripping[7,48]. Previous research has shown that placing the trailing foot closer to an obstacle reduces hip, knee, and ankle flexion in the trailing foot, leading to an increased risk of tripping. Chou and Draganich (1998) found that when wearing heavier boots, subjects tended to place their trailing foot closer to the obstacle. This placement increases the risk for contact between the obstacle and the trailing foot, therefore increasing the risk of tripping[49].

Wearing heavy boots has been linked to decreased ROM and decreased toe clearance when stepping over objects[4–7,49]. Decreases in these kinematic variables may increase an individual's risk of injury while on trail, specifically sprains and strains of the lower extremities. The reductions in toe clearance and ROM are likely due to the increased distal weight on the lower extremities. This increased weight may cause an individual to alter their gait in order to adapt, making it harder for the individual to pass through their full range of motion, leading to an increased risk for tripping and falling. Alterations in toe clearance and ROM have been extensively investigated while stepping over obstacles, but is under investigated when it comes to completing a stepping task, especially when comparing different footwear options.

Summary

Previous literature has shown that footwear choice alters kinematic (ROM, functional gait), kinetic (GRF, joint moments, joint loading), and physiological (oxygen uptake) variables. Changes in these specific variables has been shown to increase risk of injury, due to tripping, falling, and overexertion, among firefighters and military personnel. However, there is a lack of research on the effects of footwear choices on injury prevalence and physiological stress among the hiking community. The results from this investigation may help determine the better footwear choice for recreational activities to reduce the risk of injury and potentially increase efficiency during these activities.

CHAPTER III: CONCLUSIONS AND RECOMMENDATIONS

The current study investigated the effect of hiking shoes and hiking boots on the biomechanical responses to a stepping task and physiological responses to an inclined walking task. Several significant differences were observed in biomechanical and physiological variables during the stepping task and inclined walking task, respectively. Most notable are the decreases in ankle ROM during the lowering phase of the stepping cycle in the hiking boot condition, though no differences were found in knee or hip ROM, meaning compensatory mechanisms were not required to account for the reduced ROM of the ankle while still achieving a continuous stepping gait. Significant differences between footwear were also observed in knee extensor moments during the lowering phase, with the hiking shoe condition eliciting greater ankle and knee moments during the lowering phase. Lastly, VO_2, VO_2-kg, and V_E were significantly lower in the hiking boot condition compared to the hiking shoe condition. However, these differences may be negligible due to magnitude of the differences.

Since footwear weights were standardized in the current study, the mid-shaft height of the boot may have caused participants to implement a more energy-efficient gait pattern to complete the inclined walking task. In regards to physiological data, the increases observed in VO_2 and V_E in the hiking shoe condition may result in the hiker unable to maintain pace and hike for prolonged periods, leading the hiker to take more break. However, there are a number of additional factors that may affect a hiker's decision to take breaks, such as terrain, trail conditions, fatigue, and hydration.

While differences in biomechanical and physiological variables between footwear are statistically significant, they may not be practically significant in an actual hiking scenario, as the magnitudes of differences observed in variables were minimal. When translated to a hiking scenario, it could be proposed that use of mid-shaft hiking boots may provide more ankle support during outdoor activities that involve stepping or inclined walking, without affecting the kinetic chain of the lower extremities. It should be noted that differences in joint kinematics and kinetics in either hiking shoes or hiking boots may not be associated with immediate increased risk of injury, though over time, the magnitude of joint moments throughout the stepping task, specifically during the lowering phase, may lead to increased wear and tear and potentially injury.

It can be concluded that the use of either shoe or boot may not result in an increased risk of injury, therefore leaving the choice of footwear up to the hiker’s personal preference. Future research should continue investigating biomechanical and physiological responses across footwear, though a taller shaft should be implemented.

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TABLES

Table 1. Moving segments, reference segments, and value assignments used in Visual 3D to determine joint ROM and flexion at contact.

Angle	*Moving Segment*	*Reference Segment*	*Movement*	*Direction*
Ankle flexion	Virtual foot	Shank	Dorsiflexion	+
			Plantarflexion	-
Knee flexion	Shank	Thigh	Flexion	-
			Extension	+
Hip flexion	Thigh	Pelvis	Flexion	+
			Extension	-

Table 2. Descriptive statistics of participants displayed as mean ± standard deviation (n = 20).

	Mean ± SD
Age (yrs)	25.15 ± 5.36
Mass (kg)	77.62 ± 11.94
Height (m)	1.75 ± 0.08
Hiking shoe size (US)	9.10 ± 1.77
Hiking boot size (US)	9.05 ± 1.73

Table 3. Frequency data for the categorical question, "Approximately how many years have you engaged in outdoor hiking activities?"

	Percentage	*N*
< 1 year	0%	0
1-3 years	5.0%	1
4-6 years	5.0%	1
7+ years	90.0%	18
Total	100%	20

Table 4. Frequency data for the categorical question, "What type of footwear most closely represents your current preference for outdoor hiking activities?"

	Percentage	*N*
Running/tennis shoe	25.0%	5
Trail running shoe	20.0%	4
Hiking shoe	25.0%	5
Hiking boot	30.0%	6
Total	100%	20

Table 5. Frequency data for the categorical question, "What types of outdoor hiking do you typically engage in? Please check all that apply." Data are presented as a percentage of n = 20.

	Percentage	*N*
Day hikes (< 1 day)	95.0%	19
Overnight trips (1-2 days)	45.0%	9
Backpacking (3+ days)	30.0%	6
Thru-hiking (2+ months)	5.0%	1

Table 6. Joint ROM during the lifting phase of the lead leg in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM (deg)	6.89 ± 2.02	6.34 ± 2.86	0.319	0.23
Knee ROM (deg)	32.84 ± 5.22	31.81 ± 5.96	0.037*	0.19
Hip ROM (deg)	17.34 ± 4.64	17.22 ± 3.53	0.888	0.03
NON-DOMINANT				
Ankle ROM (deg)	6.21 ± 2.70	5.96 ± 2.32	0.501	0.09
Knee ROM (deg)	33.22 ± 7.28	33.24 ± 7.64	0.981	0.00
Hip ROM (deg)	16.61 ± 4.47	16.90 ± 2.99	0.765	0.08

* Statistically significant ($p < 0.05$)

Table 7. Joint ROM during the lowering phase of the lead leg in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM (deg)	28.29 ± 9.59	25.48 ± 10.15	0.020*	0.29†
Knee ROM (deg)	70.60 ± 9.88	71.25 ± 8.82	0.655	0.07
Hip ROM (deg)	23.68 ± 3.25	23.85 ± 3.45	0.738	0.05
NON-DOMINANT				
Ankle ROM (deg)	31.14 ± 8.54	28.24 ± 8.14	< 0.001*	0.35†
Knee ROM (deg)	71.21 ± 10.82	69.32 ± 14.22	0.323	0.15
Hip ROM (deg)	22.60 ± 4.41	22.75 ± 4.13	0.802	0.04

* Statistically significant ($p < 0.05$)

† Medium to large effect size

Table 8. Joint ROM during the lowering phase of the trail leg in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM (deg)	22.31 ± 6.59	21.39 ± 6.78	0.167	0.14
Knee ROM (deg)	32.49 ± 9.27	31.84 ± 7.45	0.568	0.08
Hip ROM (deg)	8.18 ± 3.84	8.23 ± 3.46	0.934	0.01
NON-DOMINANT				
Ankle ROM (deg)	22.36 ± 6.51	21.49 ± 6.38	0.201	0.14
Knee ROM (deg)	33.07 ± 7.37	32.90 ± 7.99	0.897	0.02
Hip ROM (deg)	15.29 ± 5.72	14.95 ± 4.72	0.764	0.07

Table 9. Joint flexion of the lead leg at trail leg contact at the end of the lowering phase in hiking shoes and hiking boots. Data are presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle plantarflexion (deg)	26.41 ± 7.82	24.95 ± 7.44	0.144	0.19
Knee flexion (deg)	76.05 ± 6.06	76.33 ± 5.63	0.789	0.05
Hip extension (deg)	15.21 ± 7.96	14.33 ± 10.20	0.465	0.10
NON-DOMINANT				
Ankle plantarflexion (deg)	26.94 ± 7.49	23.43 ± 5.38	0.010*	0.55†
Knee flexion (deg)	73.44 ± 7.91	74.40 ± 5.57	0.531	0.14
Hip extension (deg)	13.58 ± 9.19	13.18 ± 10.24	0.815	0.04

* Statistically significant ($p < 0.05$)

† Medium to large effect size

Table 10. Joint flexion of the trail leg at trail leg contact at the end of the lowering phase in hiking shoes and hiking boots. Data are presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle plantarflexion (deg)	6.06 ± 5.41	5.77 ± 3.98	0.780	0.06
Knee flexion (deg)	16.87 ± 7.72	16.70 ± 7.44	0.872	0.02
Hip extension (deg)	16.33 ± 9.45	15.18 ± 11.53	0.347	0.11
NON-DOMINANT				
Ankle plantarflexion (deg)	4.86 ± 8.53	2.96 ± 7.28	0.089	0.24
Knee flexion (deg)	12.44 ± 14.13	11.51 ± 13.46	0.583	0.07
Hip extension (deg)	13.33 ± 9.25	12.14 ± 11.20	0.420	0.12

Table 11. Toe clearance of the lead and trail leg in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Lead leg (cm)	5.62 ± 2.56	5.57 ± 2.26	0.851	0.02
Trail leg (cm)	4.97 ± 3.28	5.40 ± 3.62	0.356	0.12
NON-DOMINANT				
Lead leg (cm)	4.82 ± 1.57	4.21 ± 1.43	0.065	0.41†
Trail leg (cm)	4.09 ± 1.71	5.11 ± 2.89	0.270	0.44†

† Medium to large effect size

Table 12. Joint flexion of the lead leg at lead leg toe clearance in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle plantarflexion (deg)	18.71 ± 5.82	17.19 ± 4.53	0.234	0.30†
Knee flexion (deg)	83.10 ± 7.69	82.80 ± 7.88	0.839	0.04
Hip extension (deg)	58.01 ± 9.93	56.86 ± 11.32	0.484	0.11
NON-DOMINANT				
Ankle plantarflexion (deg)	19.34 ± 3.48	17.31 ± 6.16	0.158	0.42†
Knee flexion (deg)	82.72 ± 8.14	83.22 ± 8.68	0.791	0.06
Hip extension (deg)	56.63 ± 9.32	57.25 ± 11.49	0.681	0.06

† Medium to large effect size

Table 13. Peak GRF during landing of the trail leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
Peak GRF (% BW + pack weight)	136.83 ± 6.96	135.41 ± 9.75	0.474	0.17

Table 14. Joint moments of the lead leg during the lifting phase in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle plantarflexion ($N \cdot m \cdot kg^{-1}$)	0.56 ± 0.42	0.79 ± 0.56	0.012*	0.47†
Knee flexion ($N \cdot m \cdot kg^{-1}$)	0.54 ± 0.51	0.46 ± 0.31	0.430	0.19
Hip extension ($N \cdot m \cdot kg^{-1}$)	3.22 ± 1.81	3.15 ± 1.89	0.904	0.03
NON-DOMINANT				
Ankle plantarflexion ($N \cdot m \cdot kg^{-1}$)	0.65 ± 0.47	0.91 ± 0.51	0.005*	0.53†
Knee flexion ($N \cdot m \cdot kg^{-1}$)	0.42 ± 0.25	0.52 ± 0.30	0.025*	0.35†
Hip extension ($N \cdot m \cdot kg^{-1}$)	3.56 ± 3.18	2.99 ± 0.83	0.444	0.29†

* Statistically significant ($p < 0.05$)

† Medium to large effect size

Table 15. Joint moments of the lead leg during the lowering phase in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle dorsiflexion (N•m•kg^{-1})	1.38 ± 0.57	1.17 ± 0.58	0.015*	0.37†
Knee extension (N•m•kg^{-1})	4.64 ± 0.68	4.34 ± 0.62	0.020*	0.48†
Hip flexion (N•m•kg^{-1})	6.12 ± 2.36	5.28 ± 1.42	0.230	0.44†
NON-DOMINANT				
Ankle dorsiflexion (N•m•kg^{-1})	1.34 ± 0.55	1.12 ± 0.062	0.055	0.37†
Knee extension (N•m•kg^{-1})	4.69 ± 0.76	4.40 ± 0.84	0.071	0.37†
Hip flexion (N•m•kg^{-1})	5.58 ± 1.15	5.13 ± 1.10	0.131	0.40†

* Statistically significant ($p < 0.05$)

† Medium to large effect size

Table 16. Joint moments of the trail leg during the lowering phase in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle plantarflexion (N•m•kg^{-1})	1.10 ± 0.28	1.11 ± 0.30	0.919	0.02
Knee flexion (N•m•kg^{-1})	0.42 ± 0.36	0.30 ± 0.23	0.125	0.39†
NON-DOMINANT				
Ankle plantarflexion (N•m•kg^{-1})	1.20 ± 0.26	1.19 ± 0.28	0.911	0.02
Knee flexion (N•m•kg^{-1})	0.43 ± 0.40	0.36 ± 0.30	0.229	0.21

† Medium to large effect size

Table 17. Baseline physiological data presented as mean ± SD (n = 20).

	Mean ± *SD*
VO_2 (L•min^{-1})	0.32 ± 0.06
VO_2 (ml•kg^{-1}•min^{-1})	4.16 ± 0.69
V_E (L•min^{-1})	11.14 ± 2.43
RER	0.93 ± 0.13
HR (beats•min^{-1})	78.9 ± 8.6

Table 18. Physiological data during steady state inclined walking presented as mean ± SD (n = 19).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
VO_2 ($L\bullet min^{-1}$)	2.12 ± 0.38	2.06 ± 0.39	0.024*	0.14
VO_2 ($ml\bullet kg^{-1}\bullet min^{-1}$)	27.22 ± 2.39	26.54 ± 3.07	0.049*	0.25†
V_E ($L\bullet min^{-1}$)	49.35 ± 9.42	47.86 ± 9.71	0.032*	0.16
HR ($beats\bullet min^{-1}$)	144.7 ± 18.2	143.3 ± 15.9	0.210	0.08
Estimated % VO_{2max}	56.82 ± 14.08	55.56 ± 11.66	0.401	0.10
Net VO_2 – Exercise (L)	7.47 ± 1.54	7.23 ± 1.61	0.008*	0.15
Net kcal – Exercise (kcal)	36.08 ± 7.57	35.03 ± 8.20	0.023*	0.13
Mechanical efficiency (%)	16.01 ± 4.83	16.94 ± 6.13	0.104	0.17

* Statistically significant ($p < 0.05$)

† Medium to large effect size

APPENDICES

APPENDIX A

NORTHERN MICHIGAN UNIVERSITY

OFFICE OF GRADUATE EDUCATION AND RESEARCH
1401 Presque Isle Avenue
Marquette, MI 49855-5301
906-227-2300 | 906-227-2315
www.nmu.edu

Memorandum

TO:	Ashley VanSumeren School of Health and Human Performance
CC:	Sarah Clarke School of Health and Human Performance
DATE:	May 22, 2018
FROM:	Robert Winn, Ph.D. Interim Director of Research
SUBJECT:	**IRB Proposal** HS18-960 **IRB Approval Dates: 5/22/18 – 5/21/19** Proposed Project Dates: 5/22/18 – 5/21/19 "The Effects of Shoe Type on Various Kinetic, Kinematic, and Physiological Variables During Step-Up and Step-Down Motions"

The Institutional Review Board (IRB) has reviewed your proposal and has given it final approval. To maintain permission from the Federal government to use human subjects in research, certain reporting processes are required.

A. You must include the statement "Approved by IRB: Project # HS18-960" on all research materials you distribute, as well as on any correspondence concerning this project.

B. If a subject suffers an injury during research, or if there is an incident of non-compliance with IRB policies and procedures, you must take immediate action to assist the subject and notify the IRB chair (dereande@nmu.edu) and NMU's IRB administrator (rwinn@nmu.edu) within 48 hours. Additionally, you must complete an Unanticipated Problem or Adverse Event Form for Research Involving Human Subjects

C. Please remember that informed consent is a process beginning with a description of the project and insurance of participant understanding. Informed consent must continue throughout the project via a dialogue between the researcher and research participant.

D. If you find that modifications of methods or procedures are necessary, you must submit a Project Modification Form for Research Involving Human Subjects before collecting data.

E. If you complete your project within 12 months from the date of your approval notification, you must submit a Project Completion Form for Research Involving Human Subjects. If you do not complete your project within 12 months from the date of your approval notification, you must submit a Project Renewal Form for Research Involving Human Subjects. You may apply for a one-year project renewal up to four times.

   NOTE: Failure to submit a Project Completion Form or Project Renewal Form within 12 months from the date of your approval notification will result in a suspension of Human Subjects Research privileges <u>for all investigators listed on the application</u> until the form is submitted and approved.

All forms can be found at the NMU Grants and Research website:
http://www.nmu.edu/grantsandresearch/node/102

APPENDIX B

NORTHERN MICHIGAN UNIVERSITY
SCHOOL OF HEALTH & HUMAN PERFORMANCE

CONSENT TO ACT AS A HUMAN SUBJECT

Thank you for your interest in participating in this research study, "The Effects of Shoe Type on Biomechanical and Physiological Responses to Stepping and Inclined Walking". The purpose of the study is to determine the difference between hiking boots and trail running shoes on several physiological and biomechanical variables.

You are invited to be in this study because you regularly engage in outdoor activities and have past experience hiking. Additional research is needed about your hiking experience before participation in this research study. If you have not yet filled out a Hiking History Questionnaire, please request one from Ashley VanSumeren before continuing this form.

If you agree to participate, we would like you to attend a testing session at Northern Michigan University's Exercise Science laboratory, located in the Physical Education Instructional Facility (PEIF). This study requires one visit, lasting approximately 2-3 hours. The laboratory visit is outlined below:

1. **Introduction:** Participant is briefed on research study, completes Physical Activity Readiness Questionnaire (PAR-Q), general hiking experience survey
2. **Experimental Setup:**
    a. Body measures will be taken – height, weight, BMI, etc.
    b. Daypack will be fitted to participant, consisting of 5 kg
    c. Hiking boots and trail running shoes will be selected by participant based on best fit. Hiking boots and trail running shoes will be provided by the researcher.
    d. 3 electromyography (EMG) electrodes will be placed on the lower extremities (calf, shin, and thigh) to measure muscle activity during the stepping task
        i. EMG preparation will include light abrasion to the electrode site via alcohol wipe to remove oils and/or dead skin cells. A razor may also be used to remove hair from the electrode site.
    e. 39 reflective markers will be placed on the pelvis and lower extremities
3. **Data Collection:**
    a. 5 minute baseline collection at rest
    b. 5 minute treadmill warm-up at 3.0 mph, 0% grade
    c. 3 step-up trials wearing trail running shoes; each 2 minutes in duration
        i. 5 minutes of rest in between each trial
    d. 3 step-up trials wearing hiking boots; each 2 minutes in duration
        i. 5 minutes of rest in between each trial
    e. 5 minute treadmill walking at 3.3 mph, 10% grade wearing trail running shoes
        i. 15 minutes of rest
    f. 5 minute treadmill walking at 3.3 mph, 10% grade wearing hiking boots

We will keep the information you provide confidential; however, federal regulatory agencies and the Northern Michigan Institutional Review Board may inspect and copy records pertaining to this research. After collection of data, data will be tabulated and given to one of the principal investigators to assign an alphabetical letter to your data. This will be done to ensure the data analysis will serve to protect the confidentiality of the data collected. Any electronic files from this study will be stored on a password protected flash drive and in possession of the principal investigator for 7 years. Any hard copy files from this study will be stored in a locked filing cabinet in the principal investigator's office. Only members of the thesis committee who have been given written consent by you, the participant, will have access to any data from this study. If we write a report about this study we will do so in such a way that you cannot be identified.

The risks involved in this study include tripping, falling, stumbling, etc., as well as delayed onset muscle soreness (DOMS), as a result of completing a repeated stepping task. You may also experience irritation or light abrasions as a result of EMG preparation (alcohol wipe, razor). You may not benefit from this study personally. However, we hope that others may benefit in the future from what we learn as a result of this study.

You will not have any costs for being in this research study. You will not be paid for being in this research study. Taking part in this research study is completely voluntary. If you decide not to be in this study, or if you stop participating at any time, you won't' be penalized or lose any benefits for which you otherwise qualify.

If you have any further questions regarding your rights as a participant in a research project you may contact Dr. Robert Winn of the Human Subjects Research Review Committee of Northern Michigan University (906-227-2300) rwinn@nmu.edu. Any questions you have regarding the nature of this research project will be answered by the principal researcher who can be contacted as follows: Ashley VanSumeren (810-938-4999) asvansum@nmu.edu or Dr. Sarah Breen (906-227-1143) sabreen@nmu.edu.

I have read the above "Informed Consent Statement." The nature, risks, demands, and benefits of the project have been explained to me. I understand that I may ask questions and that I am free to withdraw from the project at any time without incurring ill will or negative consequences. I also understand that this informed consent document will be kept separate from the data collected in this project to maintain anonymity (confidentiality). Access to this document is restricted to the principle investigators.

_________________________________ ____________________
Signature of Subject Date

_________________________________ ____________________
Signature of Witness Date

Thank you very much for your consideration.

Sincerely,

Ashley VanSumeren
Graduate Student – Exercise Science
Northern Michigan University
School of Health & Human Performance

APPENDIX C

HIKING HISTORY QUESTIONNAIRE

Name: ______________________________________ **Email: _______________________**

Age (circle one): < 18 years 18-39 years > 40 years

What is your shoe size? If a half size, please round up to the nearest whole number (circle one):

9W/7M 10W/8M 11W/9M 12W/10M 11M 12M None of these sizes

Have you experienced any of the following to the lower limbs (hip, knee, ankle, foot) in the last 6 months (circle one)?

Injury Ligament reconstruction

Ligament tear or rupture Fracture

I have not experienced any of these

If you experienced any of the above injuries, please describe the injury and how it occurred.

Have you ever been injured while hiking? Please circle one.

Yes No

If you answered 'yes' to the above question, please list the date of the injury, the terrain on which the injury occurred, and a description of the injury.

Approximately how many times a month do you go hiking? Please circle one.

1-3 4-6 7+ I do not hike

Approximately how many years have you engaged in outdoor hiking activities? Please circle one.

1-3 years 4-6 years 7+ years I do not hike

What is your dominant leg? Please circle one.

Right Left I am unsure

What types of outdoor hiking do you typically engage in? Please circle all that apply.

Day hikes (< 1 day) Overnight trips (1-2 days)

Backpacking (3+ days) Thru-hiking (2+ months)

I do not hike

Which type of footwear below most closely represents your current preference for outdoor hiking activities? Please circle one.

Hiking Boot
Example: Vasque Breeze III GTX Hiking Boots

Hiking Shoe
Example: Salomon X Ultra 2 Low GTX Hiking Shoes

Trail Running Shoe
Example: Brooks Cascadia 12 Yellowstone National Park Trail-Running Shoes

Tennis Shoe
Example: Asics Court FF Tennis Shoes

APPENDIX D

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO		
☐	☐	1.	**Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	2.	**Do you feel pain in your chest when you do physical activity?**
☐	☐	3.	**In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	4.	**Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	5.	**Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	6.	**Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	7.	**Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ________________________ WITNESS ________________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

APPENDIX E

SUPPLEMENTAL DATA

Kinematics

Table A. Joint ROM during the lifting phase of the trail leg in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM (deg)	9.00 ± 3.64	7.97 ± 2.80	0.076	0.32†
Knee ROM (deg)	8.14 ± 6.78	7.71 ± 5.76	0.450	0.07
Hip ROM (deg)	8.15 ± 2.08	8.62 ± 2.11	0.348	0.23
NON-DOMINANT				
Ankle ROM (deg)	8.17 ± 3.92	7.73 ± 3.39	0.413	0.12
Knee ROM (deg)	7.75 ± 5.46	6.78 ± 4.93	0.097	0.18
Hip ROM (deg)	8.33 ± 2.73	8.30 ± 2.68	0.958	0.01

† Medium to large effect size

Table B. Joint ROM of the lead leg during the entire stepping cycle in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM	25.52 ± 7.45	23.49 ± 6.57	0.008*	0.29†
Knee ROM	58.94 ± 9.11	57.52 ± 6.40	0.382	0.18
Hip ROM	9.63 ± 2.69	9.58 ± 2.88	0.924	0.02
NON-DOMINANT				
Ankle ROM	25.22 ± 7.36	23.55 ± 6.74	0.021*	0.24
Knee ROM	57.64 ± 8.46	57.24 ± 6.46	0.815	0.05
Hip ROM	10.44 ± 4.12	9.38 ± 2.47	0.212	0.32†

* Statistically significant ($P < 0.05$)
† Medium to large effect size

Table C. Joint flexion at lead leg toe clearance of the trail leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle dorsiflexion (deg)	-9.55 ± 3.97	-9.08 ± 2.73	0.534	0.14
Knee extension (deg)	5.99 ± 5.61	5.72 ± 5.12	0.750	0.05
Hip flexion (deg)	-3.52 ± 9.55	-2.53 ± 11.94	0.426	0.09
NON-DOMINANT				
Ankle dorsiflexion (deg)	-10.13 ± 2.11	-9.68 ± 3.13	0.570	0.17
Knee extension (deg)	5.09 ± 5.02	5.95 ± 5.99	0.576	0.16
Hip flexion (deg)	-3.18 ± 9.45	-2.42 ± 12.14	0.643	0.07

Table D. Joint ROM of the trail leg during the entire stepping cycle in the dominant and non-dominant leg in hiking shoes and hiking boots presented as mean ± SD (n = 16).

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
DOMINANT				
Ankle ROM	41.19 ± 6.52	38.27 ± 6.95	< 0.001*	0.43†
Knee ROM	77.73 ± 7.88	78.07 ± 7.88	0.683	0.04
Hip ROM	48.12 ± 5.91	48.51 ± 4.98	0.548	0.07
NON-DOMINANT				
Ankle ROM	42.22 ± 6.39	39.85 ± 6.04	0.004*	0.38†
Knee ROM	78.17 ± 7.38	78.56 ± 8.24	0.748	0.05
Hip ROM	47.19 ± 5.64	47.63 ± 5.35	0.595	0.08

* Statistically significant ($P < 0.05$)

† Medium to large effect size

Physiology

Table E. Supplemental data of physiological variables measured during the inclined walking task presented as mean ± SD (n = 19)

	Hiking Shoes	*Hiking Boots*	*P-value*	*Cohen's d*
RER	0.88 ± 0.06	0.88 ± 0.08	0.479	0.01
Net VO_2 – Recovery ($L \cdot min^{-1}$)	1.10 ± 0.55	1.05 ± 0.56	0.094	0.09
Net kcal – Recovery (kcal)	5.83 ± 2.97	5.57 ± 3.15	0.130	0.08
Net total kcal (kcal)	41.91 ± 9.77	40.60 ± 10.80	0.032*	0.13
Mechanical efficiency (%)	16.01 ± 4.83	16.94 ± 6.13	0.104	0.17

* Statistically significant ($P < 0.05$)