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Effects of Altered Somatosensory Input on Lower Limb Mechanics via Different Shoes and Barefoot Walking in Individuals with Chronic Post-Stroke Hemiparesis

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Abstract

[Purpose/Hypothesis]

Stroke is a leading cause of disability that results in various neurological deficits. Stroke can cause impaired somatosensory input, which results in decreased balance and gait speed, ultimately increasing fall risks. Therapies to increase somatosensory input have shown promise for people with stroke as well as other neurological populations. However, few studies have systematically investigated varying somatosensory input via different footwear to improve walking in people post-stroke. The purpose of this study was to investigate the effects of altering somatosensory input via different types of footwear (i.e., barefoot, self-selected shoes, and memory foam shoes) on gait kinetics and ankle kinematics during gait in individuals with chronic post-stroke hemiparesis. We hypothesized that increased somatosensory input via barefoot walking would improve paretic propulsive force, reduce paretic braking force, and improve paretic ankle kinematics.

[Number of Subjects]

9 individuals post-stroke (62.9±11.2 years old; 5.9±4.4 years post-stroke) and 5 non-neurologically impaired (53.4±17.0 years old) individuals.

[Methods/Materials]

Reflective markers were placed over lower extremities landmarks, and surface electromyography sensors over ankle muscles. Participants then walked over a dual belt instrumented treadmill for 5 minutes, under self-selected walking speed, wearing self-selected shoes. Subsequently, trials were conducted barefoot and with memory foam shoes, in randomly assigned order.

Peak propulsive force, peak braking force, peak plantarflexion angle at push-off, and peak dorsiflexion angle during swing phase were assessed using a 3 (Limbs: paretic, non-paretic, and non-impaired) X 3 (Shoes: self-selected footwear, memory foam shoes, and barefoot) mixed factorial ANOVA. A priori significance was set at $p<0.05$.

[Results]

A statistically significant interaction was observed for Shoes x Limb for peak propulsive force ($p=0.04$). Additionally, simple main effects revealed that in non-impaired legs, greater propulsive forces were generated when wearing self-selected shoes compared to memory foam or barefoot. A statistically significant main effect of Shoes was observed for ankle angle at toe off ($p<0.01$), suggesting that regardless of limb, wearing self-selected shoes increases plantarflexion at toe off, whereas wearing memory foam shoes increases dorsiflexion at toe off. A statistically significant main effect of Shoes was observed for peak dorsiflexion during swing ($p<0.01$), indicating that regardless of limb, wearing memory foam shoes causes more dorsiflexion during swing than self-selected shoes.

[Conclusion]

We found that memory foam shoes can encourage paretic ankle dorsiflexion during swing phase of gait, which could be used to address foot-drop in post-stroke gait training. If the goal of gait training was to target propulsive force to increase walking speed, then memory foam shoes or barefoot is not recommended.

[Clinical Relevance]

Findings can help inform clinicians on appropriate footwear recommendations to ensure safety for community ambulation and may be incorporated into gait training paradigms in rehabilitation.

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Introduction

According to the Center for Disease Control and Prevention, over 795,000 people in the US have a stroke each year (Benjamin et al., 2017). Stroke, or cerebrovascular accident, occurs when there is a lack of blood flow to an area of the brain that results in loss of function to the corresponding areas of the body. Most stroke survivors regain walking function, but gait dysfunction including asymmetric gait pattern, diminished walking speed, step length, and decreased knee flexion and ankle dorsiflexion of the paretic limb results in inefficient gait and high fall risk (Von Schroeder et al., 1995; Szopa et al., 2017). More notably, paretic ankle kinematics include reduced or absent push off during terminal stance (Gaviria et al., 1996). These gait discrepancies may contribute to greater weight bearing asymmetry during ambulation and impaired balance in individuals post-stroke, putting them at a greater risk for fall (Punt et al., 2016). Additionally, these gait disturbances limit the individuals' ability to self-care and participate in their community (Lord, McPherson, McNaughton, Rochester, & Weatherall, 2004).

Somatosensory input, such as limb load, plays a significant role in the timing of gait cycle transitions from stance to swing (Pearson, 2004). Somatosensory input also plays a role in adapting motor patterns to suit the environment, as it provides feedback on the previous activity and needed signal corrections (Pearson, 2004). Previous studies have demonstrated that people have better postural control in standing when wearing textured insoles designed to increase somatosensory information from the plantar region (Hatton et al., 2009; Hatton et al., 2011; Palluel et al., 2008). By that logic, increasing somatosensory stimuli to the plantar aspect of the foot via barefoot walking may correct gait asymmetry as there is no barrier between the plantar aspect of the foot and walking surface. In studies of younger populations, barefoot walking has been associated with a decrease in vertical impact force and a more even force distribution along the foot. These force changes could decrease risk of falling (Chaiwanichsiri, Janchai, & Tantisiriwat, 2009).

It is possible that further reduction in plantar sensory input via footwear (e.g., memory foam shoes) may cause more severe gait dysfunction in individuals post-stroke. The existing literature shows that individuals with diabetic neuropathy who wear shock absorbing insoles, which distribute pressure between foot and insole, have reduced sensory input negatively impacting postural stability (Van Geffen et al., 2007). In Robbins et al. (1992), healthy men older than 60 years old wearing hard midsoles had fewer falls from a balance beam when compared to those in soft midsoles. In Menant et al. (2007), healthy individuals wearing hard soles had an improved choice stepping reaction time (CSRT), compared to those wearing softer soles. CSRT is a predictor of falls that measures speed, balance, neuropsychological function, and sensorimotor function as the participant steps on one of four randomly illuminated panels (Lord & Fitzpatrick, 2001). It should be noted that no researchers have examined the effects of barefoot walking as a strategy to increase somatosensory input among individuals post-stroke.

Additionally, research has shown that a stroke significantly affects ankle musculature. In Lamontagne et al. (2001), plantar flexors of the paretic limb were found to have increased passive stiffness, with the medial gastrocnemius demonstrating lower activation compared to controls walking at their self-selected speed. Additionally, the tibialis anterior on the paretic limb was found to have either decreased or increased activation, suggesting its inability to overcome passive plantar flexor stiffness, or overcompensating for plantar flexor stiffness, respectively (Lamontagne, A. Malouin, F., Richards, C.F., Dumas, F. 2001). Additionally, Li et al. (2018) explain that one of the most common clinical presentations among people post-stroke is a lower extremity extensor synergy; implying that the abnormality in the posterior shank muscles (gastrocnemius, tibialis posterior, soleus) override spasticity from the tibialis anterior. However, in Banks et al. (2017), no set pattern of co-contraction was found in post-stroke gait, implying it may not be a primary source of gait disturbance. Therefore, while sensory input may play a role in gait mechanics post-stroke, changes on an EMG exam may not be present.

Therefore, the purpose of this study was to investigate the effects of altered somatosensory stimuli (i.e. self-selected shoe, memory foam shoe, and barefoot conditions) on propulsion and braking forces, ankle kinematics, and lower limb musculature co-contraction in individuals post-stroke compared to healthy controls during gait. We hypothesized that barefoot walking would result in improved propulsion force, reduced braking force, and improved ankle kinematics compared to self-selected and memory foam shod conditions in individuals post-stroke and that shoe type will have no effect on co-contraction.

Methods

Participants

This study included 9 subjects with chronic stroke and 5 control subjects. All subjects were evaluated under three altered somatosensory conditions. Each subject was compared to an age-matched (within 10%) healthy control. All subjects were 18 years of age or older. Inclusion criteria were subjects with chronic stroke (more than six months since most recent stroke) who were able to ambulate without assistive device for six minutes. Exclusion criteria were bilateral stroke, recent stroke or lower extremity injury within the past six months, joint replacement to lower extremity, or other neurological pathology.

Instrumentation

We used a 12-camera motion analysis system (Vicon, Oxford Metrics Ltd., Oxford, UK) to capture kinematic data of the lower extremity at 200 Hz. Ground reaction forces were collected at a sampling rate of 2000 Hz using force plates instrumented in a dual-belt treadmill (Fully Instrumented Treadmill, Bertec Corp., Columbus, OH, USA).

Procedures

Upon arrival, subjects underwent Timed Up & Go (TUG), 10 Meter Walk Test, and Lower Extremity Fugl-Meyer Assessment. These tests were used to quantify the subjects' functional ability post-stroke, as well as observe any difference between overground and treadmill walking speed. Investigators used subjects walking speed from the 10 Meter Walk Test for the treadmill walking trials.

Prior to treadmill testing, reflective markers were placed by investigators at the L5/S1 junction, and bilaterally on the PSIS, ASIS, iliac crest apex, greater trochanter, medial and lateral femoral epicondyle, medial and lateral malleoli, lateral aspect of the fifth metatarsal head, medial aspect of the first metatarsal head, and great toe nail (Ho, French, Klein, & Lee, 2018). A cluster of markers were also placed bilaterally on the midpoint of the lateral thigh, proximal lateral shank, and calcaneus (Ho, French, Klein, & Lee, 2018). Additionally, EMG markers were placed bilaterally on the primary ankle movers: proximal tibialis anterior and medial gastrocnemius head, as these are the most active muscles during normal walking (Winter & Yack, 1987).

Subjects were fitted with a body support harness for safety, prior to walking tests on the treadmill. In each condition, static data was collected prior to the walking trial to facilitate 3D data modeling. Subsequently, all markers except the L5/S1 junction, iliac crests, and clusters were removed for walking tests.

Subjects then walked in self-selected shoes for a baseline measurement. Further trials were conducted in barefoot condition and soft-sole shod condition, with the order of the testing being randomly assigned. In each of the three conditions, subjects walked at self-selected speed for up to five minutes. Data collection occurred in three 30-second intervals after a one-minute warm up period for subjects to familiarize themselves to testing conditions.

Data Analysis

The kinematical, kinetic, and EMG data were calculated as a function of gait cycle. For each walking condition, a total of 15 strides (5 strides per walking trial) were analyzed. Stance phase of gait was identified by the researchers as the time that the foot was in contact with the ground and presented with a positive ground reaction force as recorded by the force plate. The swing phase of gait was identified by the researchers as the time that the foot had no contact with the ground and there was no ground reaction force being recorded by the force plate. Peak propulsion force and peak braking force during the stance phase were obtained for statistical analyses. We also calculated the propulsion impulse and braking impulse by taking the propulsive force-stance phase integral and braking force-stance phase integral, respectively.

To obtain kinematics, reflective markers were labeled and digitized using Vicon Nexus software. Visual 3D software (C-Motion, Rockville, MD) was used to quantify the lower extremity kinematics. Specifically, we obtained peak ankle dorsiflexion angle, ankle angle at heel strike, ankle angle at toe off, and peak plantarflexion angle during swing phase using a custom Matlab code (MathWorks Inc., Natick, MA, USA).

The tibialis anterior (TA) and gastrocnemius muscle (GA) co-contraction index was derived from the wireless EMG surface electrodes. Overlap of EMG activity between the medial gastrocnemius and tibialis anterior was used to determine the co-contraction index (GA/TA at peak dorsiflexion, TA/GA at peak toe off). Taking the root mean square of the EMG activation values for each muscle (medial gastrocnemius and tibialis anterior), the co-contraction calculation was made using a previously developed formula (Deffeyes et al., 2012). For this work, we used the co-contraction index (GA/TA) at peak dorsiflexion during swing phase and co-contraction index (TA/GA) at toe off for statistical analyses.

The data from both limbs (paretic and non-paretic limbs) for the individuals in the stroke group and data from the corresponding limb (called control limb hereafter) for the participants in the control group was compared statistically.

Statistical Analysis

The primary variables were 1) peak propulsion force during stance; 2) peak ankle dorsiflexion angle during swing phase; 3) co-contraction index (GA/TA) at peak dorsiflexion during swing phase; 4) co-contraction index (TA/GA) at toe off. We also explored secondary variables, including 1) peak braking force during stance; 2) braking impulse during stance; 3) propulsion impulse during stance phase; 4) ankle angle at heel strike; 5) ankle angle at toe off; 6) peak plantarflexion angle during swing phase. The peak propulsion force, peak braking force, peak plantarflexion angle at push-off, and peak dorsiflexion angle during swing phase were assessed using a 3 (limbs: paretic, non-paretic, and control) X 3 (conditions: self-selected footwear, memory foam shoes, and barefoot) mixed factorial ANOVA. A priori significance was set at $p<0.05$. Tests of post-hoc effects were performed with Bonferroni corrections.

Results

	Subject	Sex (M/F)	Age (years)	Weight (kg)	Height (m)	LE Fugl-Meyer Score (max=34)	Time Post Stroke (years)	Overground Walking Speed (m/s)	Treadmill Walking Speed Self Selected (m/s)	Treadmill Walking Speed Memory Foam Shoes (m/s)	Treadmill Walking Speed Barefoot (m/s)
Control	1	F	60.10	75.74	1.64	NA	NA	1.51	0.78	0.95	0.96
	2	M	59.47	87.07	1.77	NA	NA	1.57	0.75	0.85	0.75
	3	M	56.61	68.48	1.63	NA	NA	1.44	0.95	0.95	0.95
	4	F	23.72	54.42	1.57	NA	NA	1.47	0.87	0.88	0.88
	5	M	66.93	99.32	1.80	NA	NA	1.39	0.69	0.69	0.69
Post Stroke	1	F	64.82	82.54	1.68	29.00	5.15	1.02	1.02	0.67	0.67
	2	M	62.91	126.53	1.85	29.00	6.46	1.24	0.57	0.57	0.63
	3	M	79.85	79.37	1.80	29.00	3.37	1.55	0.39	0.39	0.39
	4	M	52.27	76.64	1.68	26.00	9.03	1.17	0.90	0.90	0.90
	5	M	77.40	63.49	1.80	33.00	0.65	1.33	0.75	0.75	0.75
	6	M	51.04	99.77	1.65	18.00	9.75	0.67	0.27	0.27	0.27
	7	M	62.70	73.92	1.70	24.00	4.79	0.32	0.15	0.15	0.15
	8	F	52.16	77.10	1.68	18.00	10.72	0.37	0.30	0.21	0.14
	9	F	21.28	97.51	1.73	28.00	3.17	1.37	0.84	0.87	0.87

Table 1. Participant demographics of control and post-stroke subjects

Primary variables

Peak Propulsion Force during Stance

We observed a statistically significant interaction between “shoe” and “limb” on peak propulsion force in stance (Greenhouse- Geisser adjusted F= 3.2, p=0.042). A Bonferroni adjusted post- hoc comparison showed that in the barefoot condition, the mean propulsion force was greater in the control limb (mean=-1.3, SD=0.2) than the paretic limb (mean=-0.642, SD=0.142), p=0.011. In the memory foam condition, the mean propulsion force was greater in the control limb (mean=-1.312, SD=0.180) than both the non- paretic (mean=-0.823, SD=0.134), p=0.041, and paretic limb (mean=0.663, SD=0.134), p=0.009 There was no statistically significant difference in peak propulsion force between the control limb, non-paretic limb, and paretic limb (F= 3.027, p=0.071). There was no statistically significant difference in peak propulsion force between the self- selected shoe, memory foam shoe, or barefoot condition (F=2.829, p=0.094).

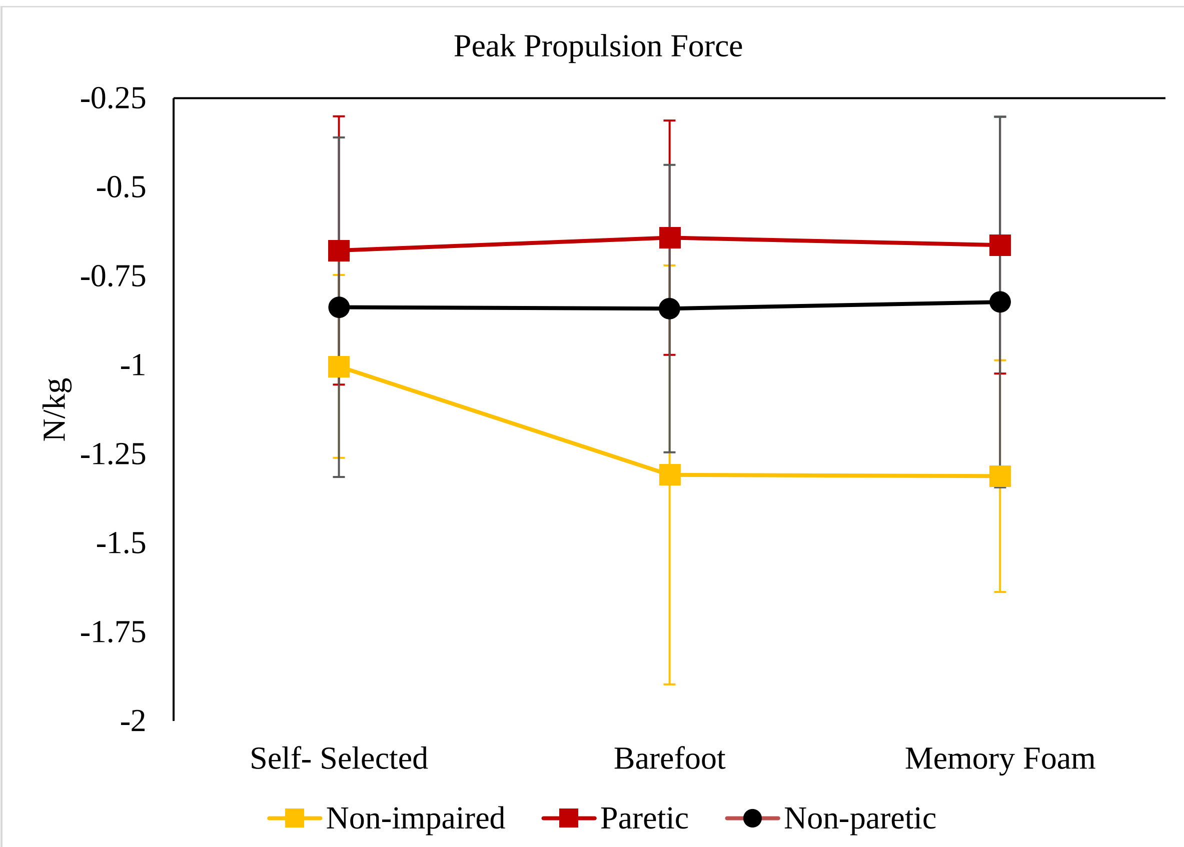

Figure 1. Comparisons of mean peak propulsion force during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limbs, non-paretic limbs, and control limbs. The error bars indicate standard deviations.

Peak Dorsiflexion during Swing

We observed a significant difference in peak dorsiflexion during swing between shoe conditions (F=5.458, p=0.008). Specifically, a post- hoc comparison showed a significant difference in peak dorsiflexion during swing between memory foam (mean=8.440, SD=0.1.412) and self-selected shoes (mean=5.368, SD=0.1.428), p=0.014. There was no significant difference between paretic, non-paretic, and control limbs (F=1.958, p=0.167). There was no significant interaction between "limb" and "shoe" (F=1.108, p=0.366).

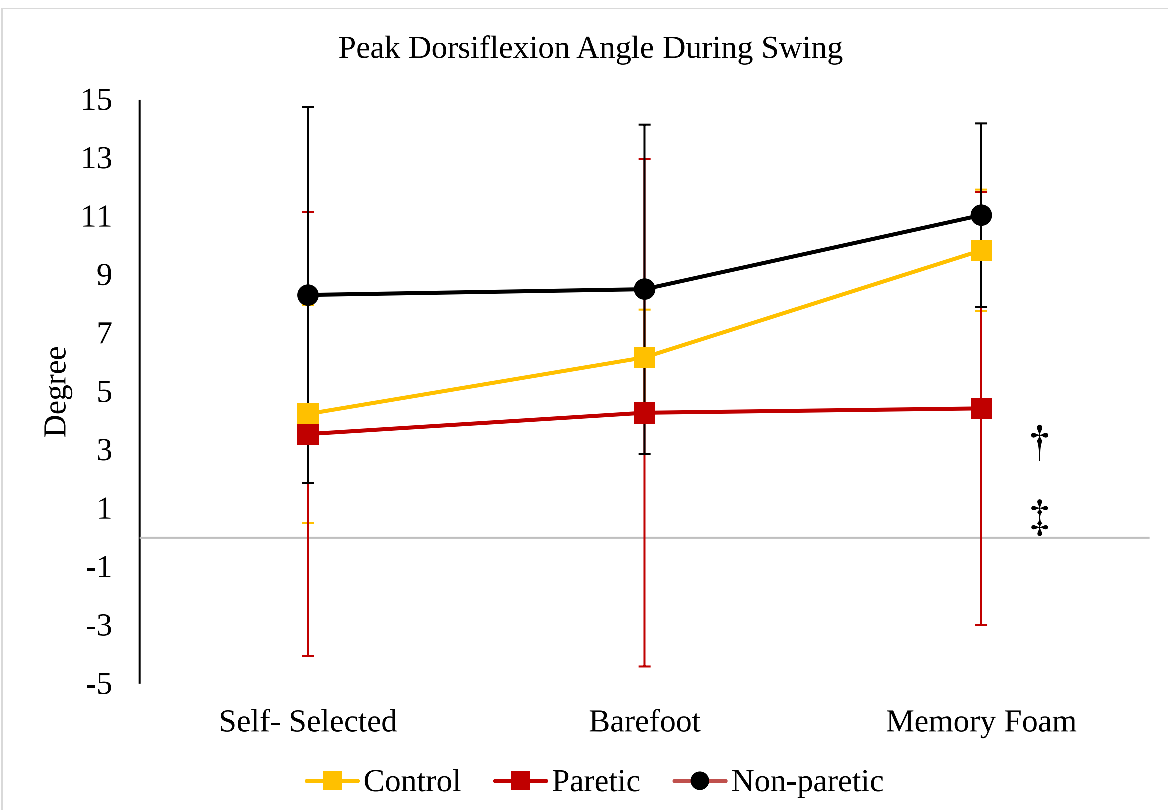

Figure 2. Comparisons of mean peak dorsiflexion angle during swing across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limbs, non-paretic limbs, and control limbs. The error bars indicate standard deviations. * indicates a significant difference between memory foam and self- selected shoes.

Co-contraction index at Peak Dorsiflexion during Swing Phase

Regarding co-contraction index at peak dorsiflexion during swing phase, there was a significant main effect (F = 7.240, p =0.004) for "limb." A Bonferroni corrected post-hoc comparison showed that the co-contraction index at peak dorsiflexion during swing phase for the control limb (mean=34.650, SD=4.636) was significantly higher than the paretic limb (mean=16.787, SD=3.456), p = 0.017, and non-paretic limb (mean=33.008, SD=3.456) was significantly higher than the paretic limb (mean=6.787, SD=3.456), p = 0.010. We observed no significant interaction among shoe types (Sphericity assumed F = 0.639, p =0.533) and no significant interaction between "limb" and "shoe" (F = 0.995, p =0.421).

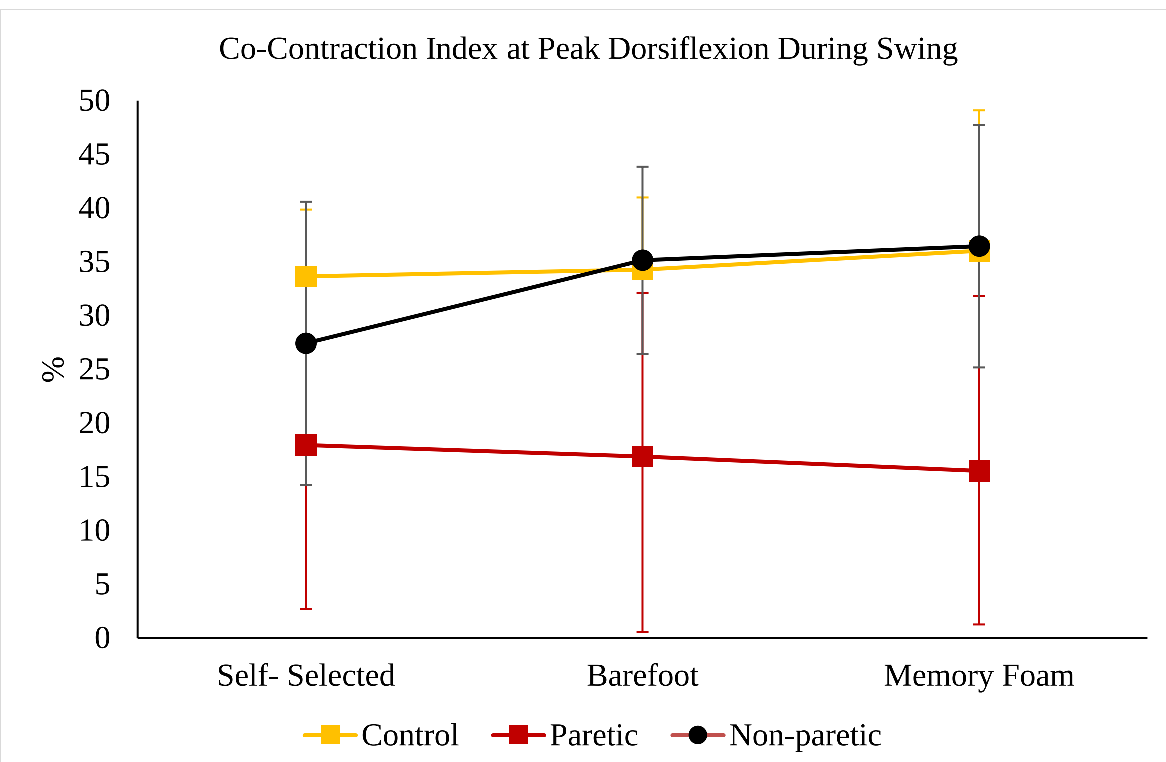

Figure 3. Comparisons of mean co-contraction index at peak dorsiflexion during swing across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limbs, non-paretic limbs, and control limbs. The error bars indicate standard deviations.

Co-contraction index at Toe Off

We observed no statistical difference in co- contraction index at toe off comparing the paretic, non-paretic, and control limbs (Sphericity assumed F = 2.872, p = 0.080), no significant interaction between “limb” and “shoe” (F = 1.133, p = 0.355), and while there was a significant main effect (F = 3.922, p = 0.028) for shoe condition, no significance difference between shoes conditions was identified in the post-hoc analysis.

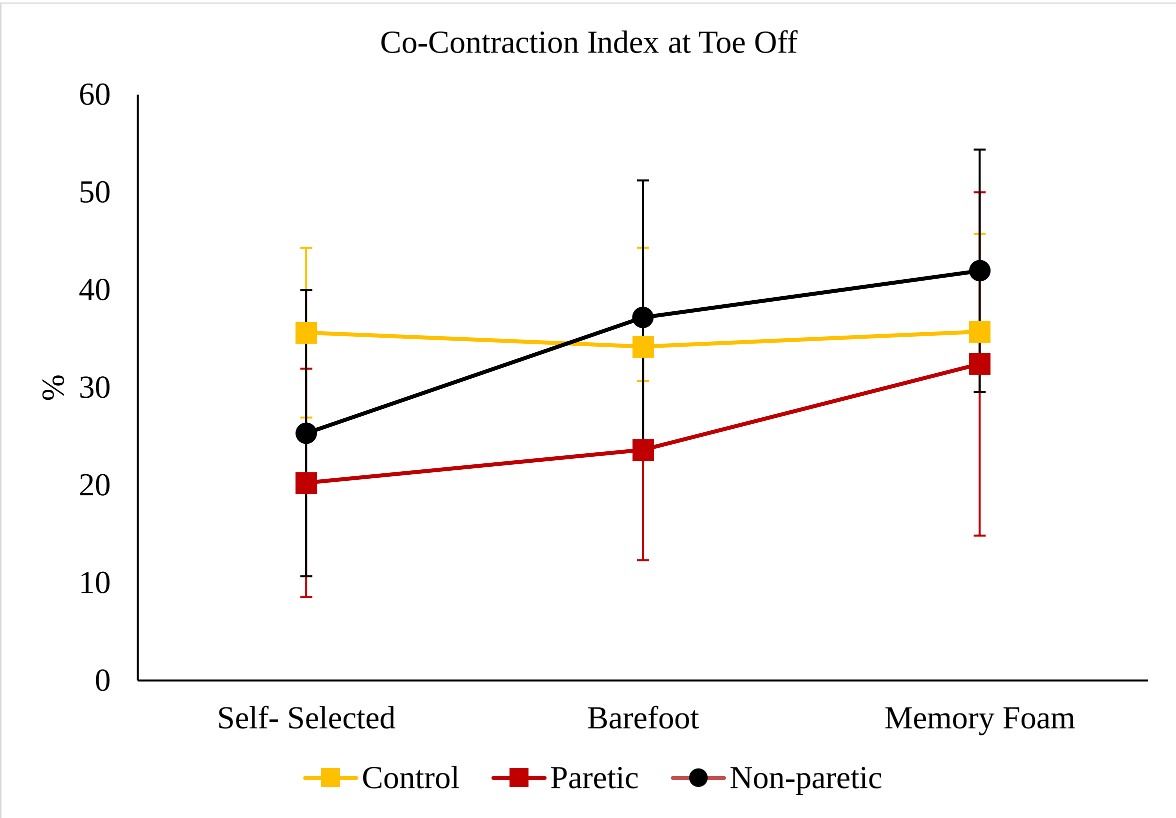

Figure 4. Comparisons of co-contraction index at toe off across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations.

Secondary variables

Braking Force during Stance

There was a statistically significant difference between “limb” in peak braking force during stance (F= 4.779, p=0.020). A post-hoc comparison showed that the mean peak braking force during stance in the control limb (mean=1.269, SD=0.159) was significantly higher than in the non-paretic (mean=0.732, SD=0.119), p= 0.041, and paretic limb (mean=0.695, SD=0.119), p= 0.027 . There was no significant difference in braking force during stance among the different shoe types (F=0.046, p= 0.897) and no interaction between “shoe” and “limb” (F= 1.117, p= 0.355).

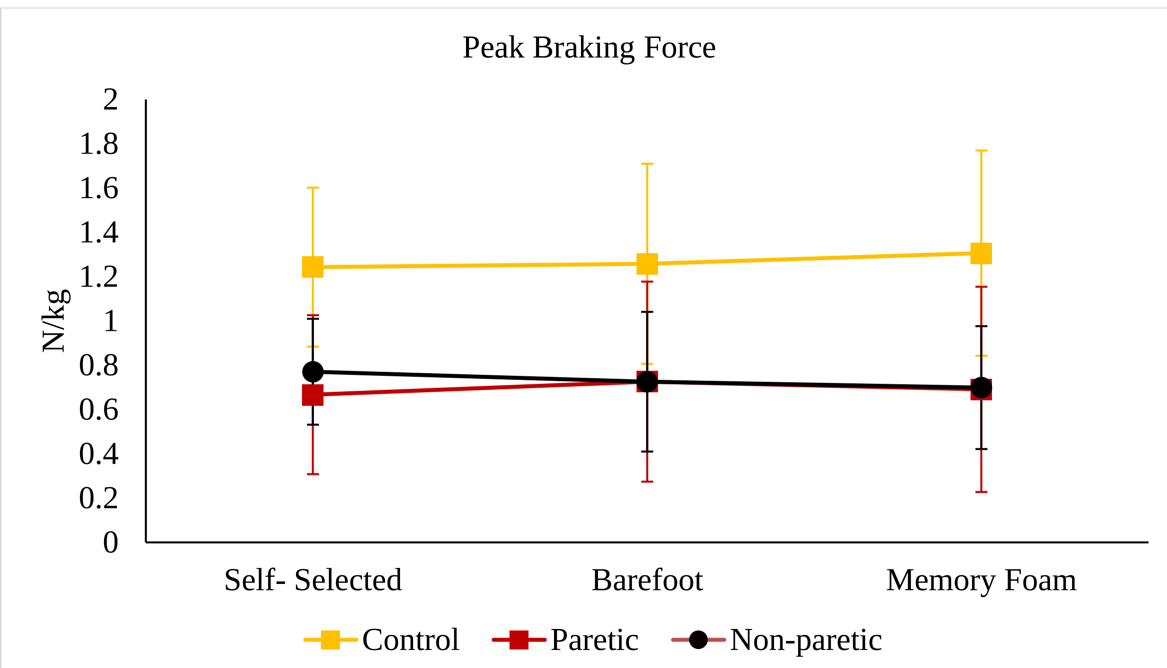

Figure 5. Comparisons of mean peak braking force during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations.

Braking Impulse during Stance

Regarding braking impulse during stance, there was no significant interaction between "shoe" and "limb" ($F=0.843$, $p=0.506$). We observed a statistically significant difference between "limb" ($F= 6.525$, $p= 0.007$). In a post-hoc comparison we observed that the mean braking impulse during stance from control limb (mean=21.838, SD=2.672) was significantly higher than non-paretic (mean=0.381, SD+1.992), $p= 0.008$, and paretic limbs (mean=11.641, SD=1.992), $p= 0.019$. There was no significant effect on braking impulse during stance among the different shoe types ($F= 2.808$, $p= 0.072$).

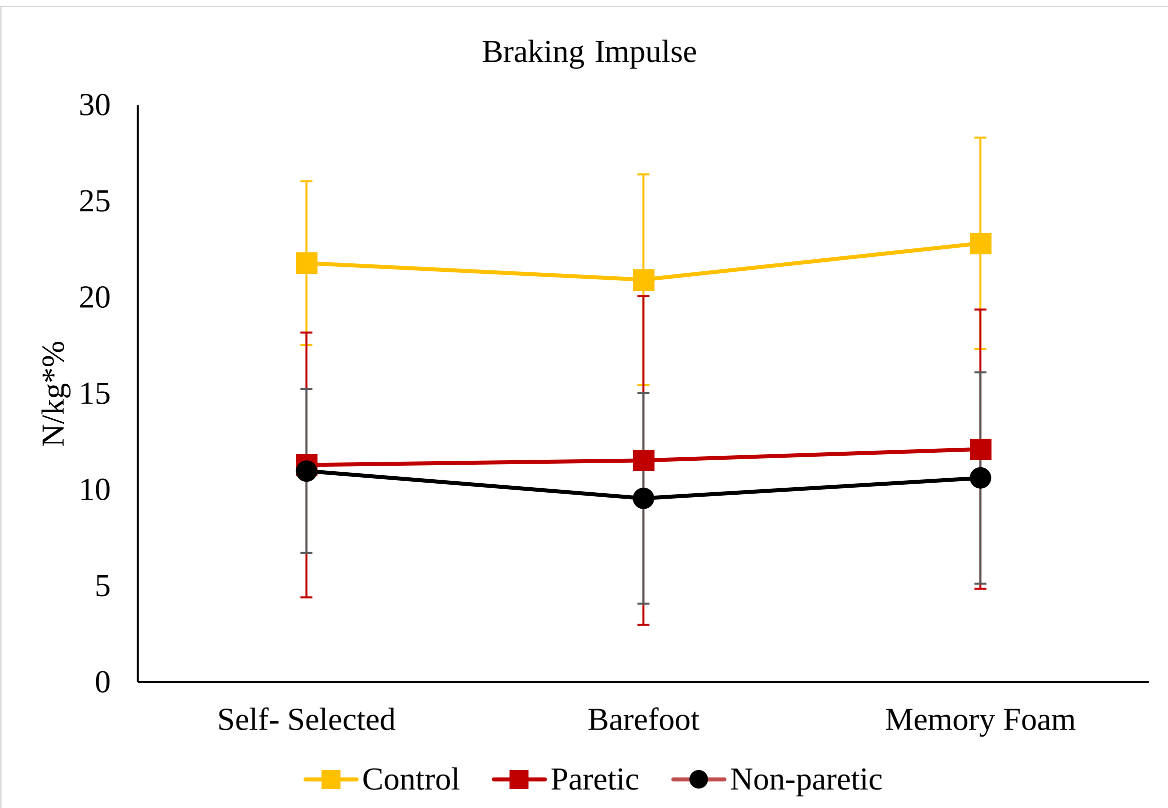

Figure 6. Comparisons of mean braking impulse during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations.

Propulsive Impulse during Stance

We observed a statistically significant difference between “limb” (F= 4.629, p= 0.022). A Bonferroni adjusted post-hoc comparison showed that the mean propulsive impulse during stance in the control limb (mean=-20.58, SD=2.71) was significantly higher than in the paretic limb (mean=-10.68, SD=2.02), p= 0.025. There was no significant difference in propulsion impulse during stance among “shoe” conditions (F= .182, p= .835) or from the interaction between “shoe” and “limb” (F=1.487, p= .224).

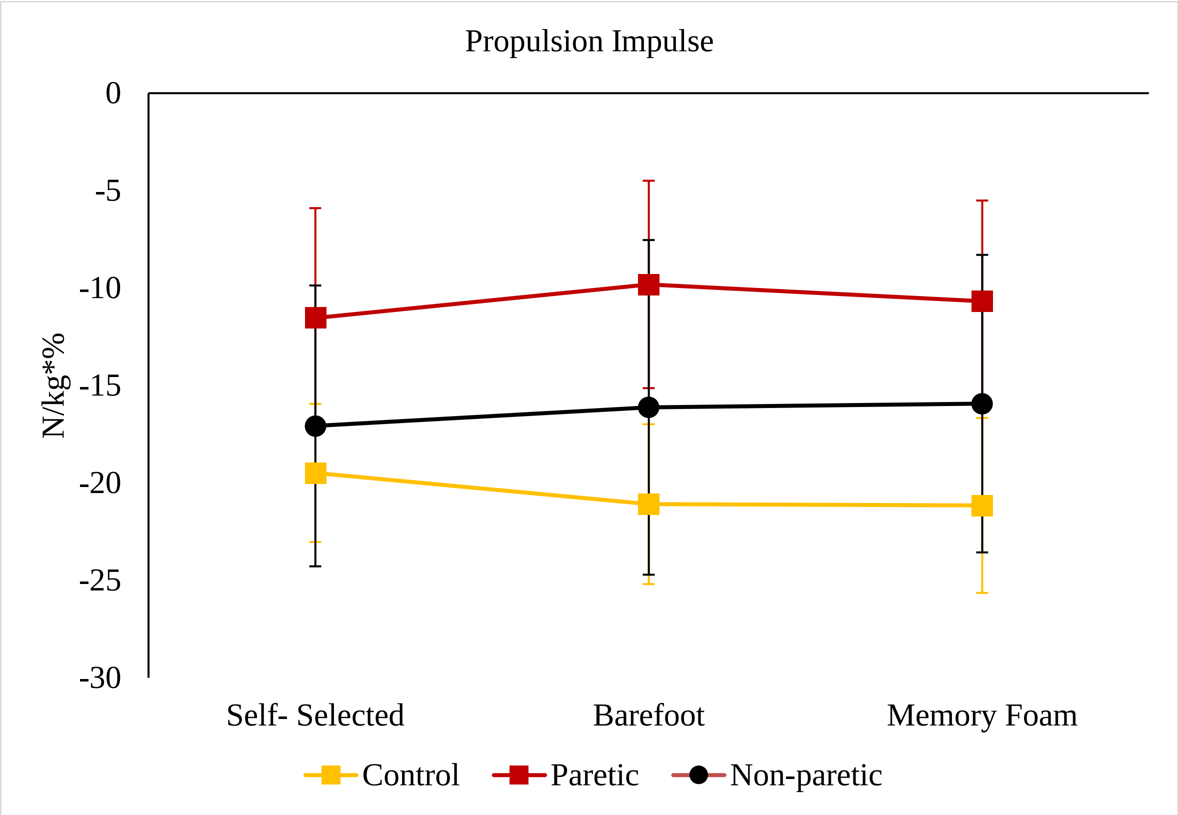

Figure 7. Comparisons of mean propulsion impulse during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations.

Ankle Angle at Heel Strike

We observed a significant difference in ankle angle at heel strike between "shoe" conditions (Greenhouse-Geisser adjusted F= 4.120, p= 0.037), however no significant difference was found in pairwise post-hoc comparisons. There was no significant difference among "limb" groups and no interaction between "shoe" and "limb."

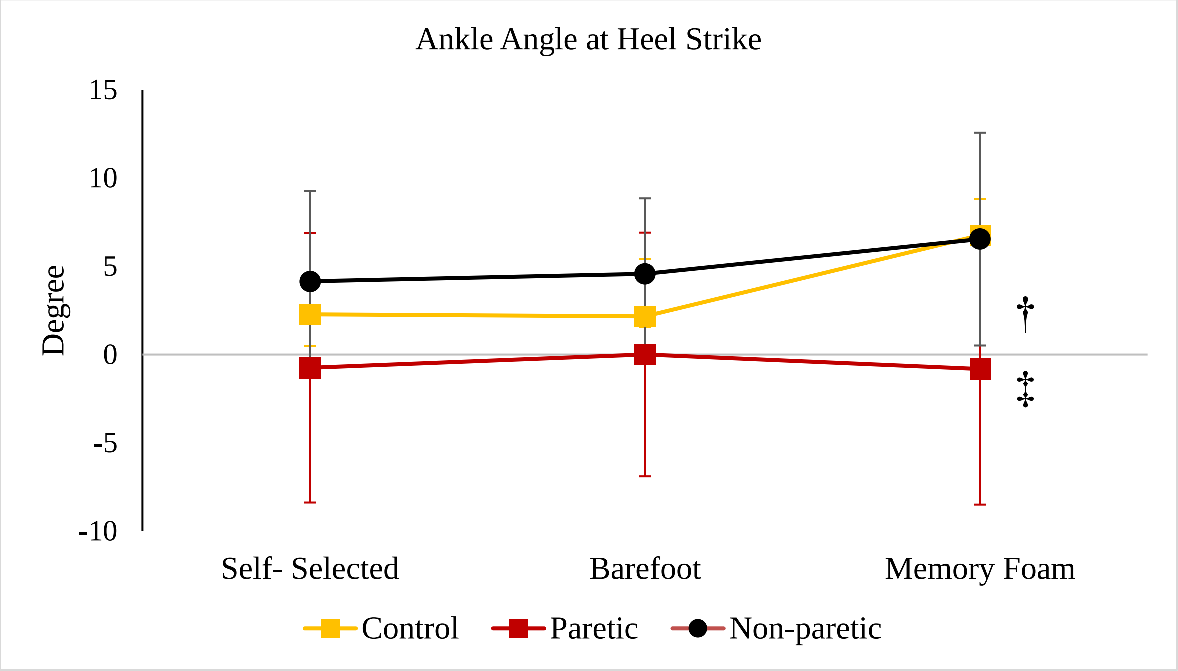

Figure 8. Comparisons of ankle angle at heel strike during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations. * indicates a significant difference between control and paretic limb. ** indicates a significant difference between control and non-paretic limb.

Ankle Angle at Toe Off

We observed no significant interaction between "shoe" and "limb" on ankle angle at toe off (F=2.003, p=0.135). There was also no significant difference among "limb" groups (F=1.444, p=0.260). However, there was a statistically significant difference in ankle angle at toe off comparing "shoe" conditions (Greenhouse-Geisser adjusted F= 6.347, p= 0.009). The mean ankle angle at toe off from self-selected shoes (mean=4.079, SD=1.515) was significantly different than memory foam shoes (mean=0.217, SD=1.501), p= 0.025, with negative values corresponding to degrees plantarflexion and positive to degrees dorsiflexion. No significant difference between self-selected shoes and barefoot was found.

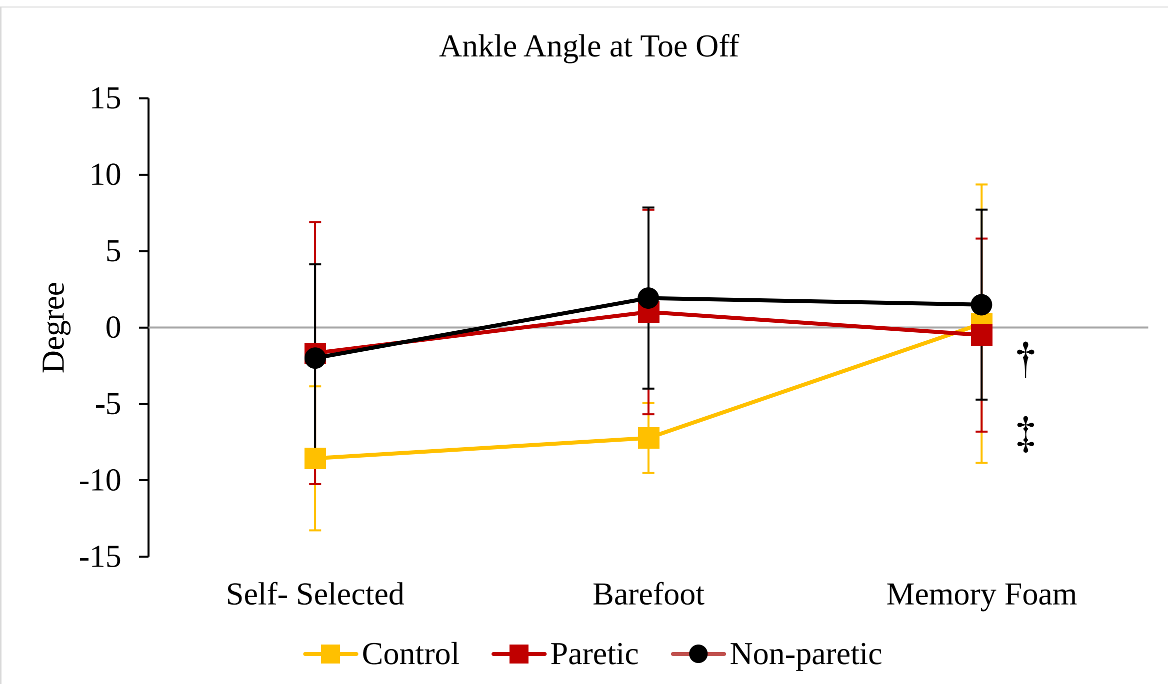

Figure 9. Comparisons of ankle angle at toe off during stance across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations. * indicates a significant difference between control and paretic limb. ** indicates a significant difference between control and non-paretic limb.

Peak Plantarflexion Angle during Swing

There was a statistically significant difference between "shoe" in peak plantarflexion angle during swing ($F= 5.518$, $p= 0.010$). The mean peak PF angle during swing from self-selected shoes (mean=-5.648, SD=1.636) was significantly higher than barefoot (mean=-3.277, SD=1.349), $p= 0.034$, and memory foam conditions (mean=-1.908, SD=1.653) $p= 0.044$. There was no significant difference among "limb" groups ($F= 1.551$, $p= 0.237$) and no interaction of "shoe" and "limb" ($F= 2.065$, $p= 0.104$).

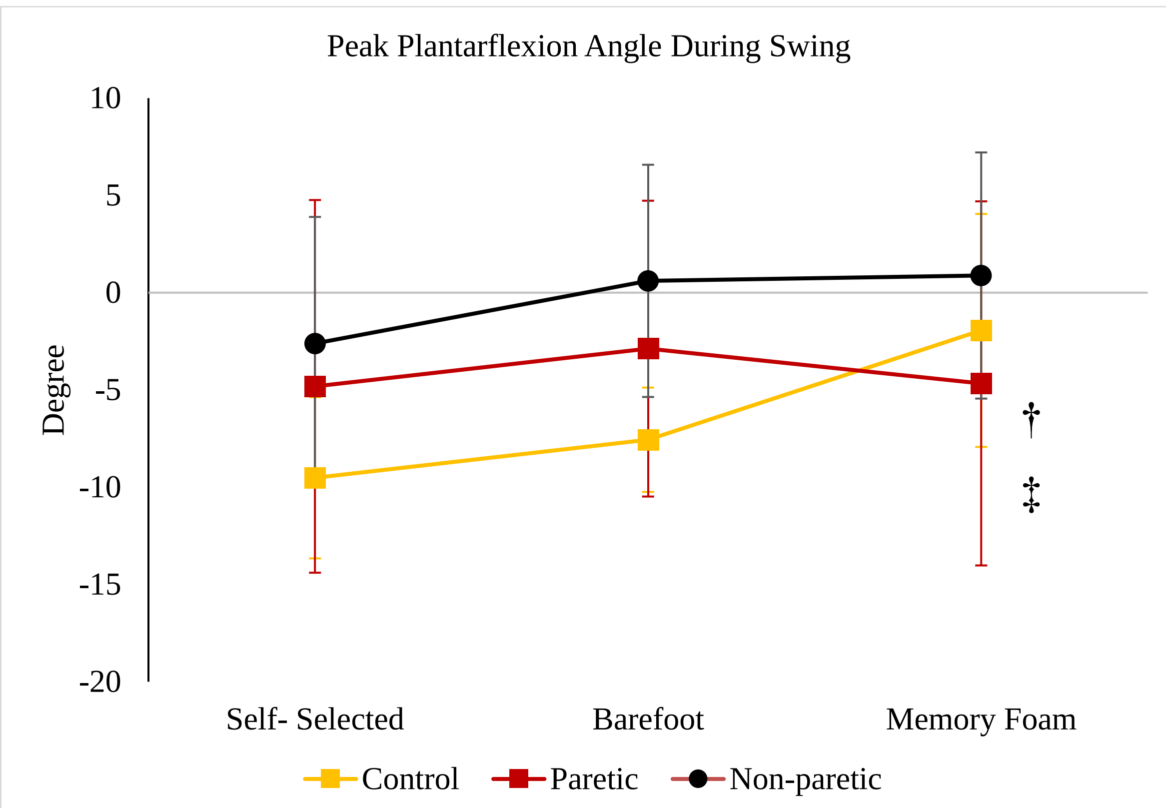

Figure 10. Comparisons of peak plantarflexion angle during swing across self-selected shoe, memory foam shoe, and barefoot conditions among paretic limb, non-paretic limb, and control limb. The error bars indicate standard deviations. * indicates a significant difference between self- selected and memory foam conditions. ** indicates a significant difference between self- selected and barefoot conditions.

Discussion

We examined the effects of altered somatosensory via footwear on propulsion force, braking force, ankle kinematics, and lower limb musculature co-contraction during gait in persons with and without chronic hemiparesis. Contrary to our hypothesis, we found that barefoot walking had little effect on propulsion force, braking force, and ankle kinematics compared to self-selected and memory foam shoe conditions in individuals post-stroke. However, in support of our hypothesis, shoe type had no significant effect on co-contraction.

Our findings on shoe conditions are consistent with results from Tsai et al. (2009), who reported no significant difference in propulsion force in hard sole vs. soft sole shoes in healthy populations. This may be due to the similar walking speeds used, as walking speed and propulsion force are highly correlated (Bowden et al., 2006). Since people may have less somatosensory input after a stroke, it is possible the change in footwear is not enough of a stimulus to result in increased force production compared to the controls. The controls had intact somatosensory systems; therefore, their propulsion forces could theoretically be affected by shoe condition, although this was not observed, as previously stated. There was also no significant difference between the control limb, paretic limb, and non-paretic limbs. Prior research has shown a significant correlation between stroke severity and propulsion force (Bowden et al., 2006). However, that study allowed participants to keep any assistive device they typically use. We required participants to be able to walk on a treadmill without an assistive device. It is likely that, since our subjects were capable of walking without a device, their propulsion forces were more comparable to the controls.

The peak braking force and braking impulse during stance were significantly higher in control limbs than in non-paretic and paretic limbs. Additionally, the peak propulsion impulse was significantly greater in the control limb than in the paretic limb. Peterson et al. showed that braking impulse and propulsion impulse are positively correlated with walking speed. In our study, controls had much faster walking speeds than the post- stroke subjects, resulting in the differences in propulsion and braking impulse.

We observed that participants had greater peak dorsiflexion during swing in memory foam shoes than self- selected shoes. Perry et al. (2007) indicated that more mechanical response was needed when the participants wore soft midsole shoes to maintain balance. They attributed this to the reduced plantar-surface mechanoreceptors when memory foam shoes were worn (Perry et al. 2001). As participants had decreased stability on soft sole shoes, the possible concern for foot clearance during swing phase may explain the increase in peak dorsiflexion. There were no significant differences between the limbs or the interaction of shoe and limb. Although we hypothesized that there would be a difference between paretic and non-paretic limbs, it is possible that allowing subjects to walk at self-selected speeds in different footwear conditions was insufficient to elicit a significant difference between limbs. Future research may want to use different walking speeds throughout the various conditions. While a significant difference for ankle angle at heel strike was seen between shoes, this was not observed in post-hoc analysis, and may warrant future research due to the limited sample size of this study.

We also observed significant differences between shoes in ankle angle at toe off, and peak plantarflexion angle. No difference was observed with effect from limbs or the interaction of shoe and limb. At toe off, greater plantarflexion was observed in self-selected shoes than memory foam shoes, while there was no significant difference when compared to barefoot condition. Current evidence supports a reduction in center of mass movement during gait when memory foam-like shoes are worn (Perry et al. 2007). This may elucidate the reduction in plantarflexion angle during toe off due to the decreased anterior-posterior movement of the center of mass. No significant difference was found between barefoot and the other footwear conditions in this study.

During swing, peak plantarflexion angle was increased in self-selected shoes compared to barefoot and memory foam shoes. Studies have shown that walking in athletic shoes, much like the self-selected shoes that our subjects wore, had increased stride length when compared to barefoot walking (Keenan et al. 2010). The increase greater peak plantarflexion angle may be to facilitate an increase in stride length. However, this does not explain the differences in memory foam shoes vs. self-selected shoes. Future studies may want to gather data on the differences in stride length comparing self-selected shoes vs. memory foam shoes.

We found significantly higher co-contraction during swing phase of the non-paretic and control compared to the paretic limbs. This appears to be congruent with other research reporting altered ankle co-contraction during the gait cycle for adults post-stroke. As described by Banks et al. (2017) and Kitatani et al. (2016), ankle co-contraction may contribute to altered gait mechanics, but with a heterogenous presentation in the stroke population. A study by Lamontagne et al. (2000) involving recent stroke patients (less than 6 months since injury) found increased co-activation of the non- paretic side compared to paretic side in both single limb stance and double limb stance. The increased co-activation on the non-paretic side is thought to be a behavioral adaptation allowing for improved balance in response to perturbation and walking challenge. Many of our subjects reported feeling unsteady on the treadmill while walking, and their successive trials resulted in decreased gait speed compared to overground walking. Co-activation was also found to be correlated with gait speed. As our subjects demonstrated decreased gait speed on the treadmill compared to overground walking, this reduction in gait speed may also explain the increased co-activation found on the control and non-paretic limbs to the paretic limb. Again, future research could involve subjects walking at various predetermined speeds on the treadmill.

With respect to co-contraction at toe off, we observed no significant difference in shoe, limb, or the interaction between the two. While this could be attributed to the varied presentation of co-contraction post-stroke, it may also be affected by the varied functional ability of the population we tested. While speed has been inversely correlated with co-contraction (Lamontagne et al. 2000), with decreased speed resulting in greater co-contraction, our subject's speed appeared similar in the three trials, which may help to explain the lack of significant findings. Additionally, a study by Souissi et al. (2018) suggested that changes in ankle co-contraction may be more noticeable during loading response of the gait cycle compared to toe off. The same study also noted increased co-contraction at the knee joint as a possible compensatory strategy for abnormal activation of the muscles around the ankle joint. We suggest that future studies may consider using multiple pre-determined walking speed trials as well as EMG sensors for muscles of the knee and ankle joints.

This study had several limitations. First, our study had a small number of subjects resulting from the loss of access to participants due to the COVID-19 pandemic that resulted in a state-wide lockdown and quarantine. Due to the high-risk nature of potential participants, data collection was halted and participants were also not able to be age matched appropriately. Further studies should be conducted using a larger sample size to better understand the effect of footwear on gait as there are large variabilities in the types and/or locations of stroke lesions, resulting in an even greater variability in functional deficits in people post-stroke.

Second, this study used a dual-belt treadmill and there is a difference in gait mechanics between treadmill and over ground walking. Treadmill walking induces an altered optical flow, non-variable ambulation speed and increased perceived instability; thus, these factors may have hindered the participants' ability to match speed on the treadmill with their overground walking speed (Lazzarini & Kataras, 2016). Future studies should take walking surfaces into consideration. It may be beneficial to examine how walking speed alone is affected by these factors. Third, while the participants were required to be independently ambulating with no assistive devices, some did utilize orthosis which were removed for data collection. Removing their orthosis could have affected their confidence while ambulating. Lastly, all participants were chronic stroke survivors, so our findings may not be applicable to acute stroke survivors during acute rehabilitation, and further studies should be conducted to determine appropriate footwear for the acute phase. Nevertheless, our initial findings are significant and indicate that further studies should be conducted with larger sample sizes.

Conclusion

Except for dorsiflexion angle, plantarflexion angle, and ankle angle at toe off, the type of shoe worn had limited effect on controls and post-stroke participants. However, controls did have greater propulsive force than paretic limbs in barefoot condition and both paretic and non-paretic limbs in memory foam shoes. This may mean that the difference in sensation between shoe conditions was not large enough to induce a great change in the post-stroke participants. Walking speed was also significantly different between the controls and post- stroke participants, however they were not significantly different across types of shoes worn. This may play a role in the lack of significant results when examining the shoes and the significant results between the controls and both paretic and non-paretic limbs.

Those with lasting somatosensory defects after a stroke are at a higher risk for falls. If a safe shoe option can be determined, rehabilitation specialists will be able to make recommendations that can decrease these risks and promote independence in this population.

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Curriculum Vitae

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Education

DPT	University of Nevada, Las Vegas Las Vegas, NV	2018 — 2021	Doctor of Physical Therapy
BS	University of Texas, Dallas Richardson, TX	2013 — 2016	Neuroscience

Licensure

- Pending National Physical Therapy Examination, May 2021

Certifications

- American Heart Association, BLS for Healthcare Providers — June 2020
- CITI Program: Human Research, Biomedical IRB Course, Basic — March 2019
- HIPPA Training — Jan 2019
- Bloodborne Pathogens Training — Jan 2019

Employment / Clinical Experience

- Select Physical Therapy — Henderson, NV
  Student Physical Therapist — Jan 2021 — April 2021
- Renown Regional Medical Center — Reno, NV
  Student Physical Therapist — Sept 2020 — Dec 2020
- Cleveland Clinic Lou Ruvo Center for Brain Health — Las Vegas, NV
  Student Physical Therapist — July 2020 — Sept 2020
- Tim Soder Physical Therapy — Henderson, NV
  Student Physical Therapist — July 2019 — Aug 2019

Research Activity

- Liang J, Ho K, **Arches J**, Keohane M, Lee W, Simon A. Effects of Altered Somatosensory Input on Lower Limb Mechanics vía Different Shoes and Barefoot Walking in Individuals with Chronic Post-Stroke Hemiparesis. *Submission Stage.*

Membership in Professional Organizations

- Member of the American Physical Therapy Association 2018 — Present

Service

- Moving Day Las Vegas Oct 20th, 2018 and Sept 28th, 2019
- Amputee Clinic Sept 14th, 2019
- Saving Strokes Oct 4th, 2019
- Balance and Memory Screen Sept 23rd, 2019
- Rock Steady Boxing Sept 22nd, 2018
- UMC – Rehabilitation Dept. March 2017— Aug 2017

Honors and Awards

- University of Texas, Dallas
  - Summa Cum Laude Dec 2016
  - Dean's List Dec 2016
  - AES Scholarship Aug 2013 — Dec 2016
- University of Nevada, Las Vegas
  - UNLVPT Student Opportunity Research Grant 2019

Continuing Education

- Online Continuing Education
  - "Beyond the Basics – Dystonia Evaluation and Treatment" August 2020
- Distinguished Lecture Series
  - "Well Aligned, Soft Landings: A Cure for Running Injuries?" Nov 16th, 2018
  - "Finishing the Job of Evidence Based Practice" Sept 12th, 2019
  - "The time for implementation is NOW" Sept 13th, 2019

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Education

DPT	University of Nevada, Las Vegas Las Vegas, NV	2018 – 2021 Doctor of Physical Therapy
BS	Saint Mary's College of California Moraga, CA	2012 – 2016 Allied Health Science

Licensure

- Nevada State Board of Physical Therapy – Pending Graduation, May 2021, and National Physical Therapy Examination, July 2021

Employment/Clinical Experience

Student Physical Therapist

Southern Hills Hospital — January 2021 – April 2021, Las Vegas, NV

Synergy Physical Therapy — September 2020 – December 2020, Henderson, NV

Boulder City Hospital – SNF — July 2020 – September 2020, Boulder City, NV

Banner Physical Therapy — July 2019 – August 2019, Kingman, AZ

Physical Therapy Aide/Technician

Human Performance Center — June 2016 – June 2017, Santa Barbara, CA

Rehab Volunteer

Cottage Rehabilitation Hospital — June 2016 – March 2017, Santa Barbara, CA

Membership in Professional Organizations

- Student Member of the American Physical Therapy Association (2019 – present)
- Student Member of the Nevada Physical Therapy Association (2019 – present)

Certifications

- American Heart Association, BLS for Healthcare Providers — June 2020
- CITI Program: Human Research, Biomedical IRB Course, Basic — March 2019
- HIPPA Training — January 2019
- Bloodborne Pathogens Training — January 2019

Honors and Awards

- 2018-2021 UNLVPT Scholarship

Service

- **Community**
    - High Rollers Adaptive Sports Foundation — 9/18/2019
    - Parkinson's Moving Day — 9/28/2021
    - UNLV Poverty Simulation — 10/4/2019

- **Professional**
    - UNLVPT Interview Day — 2/1/2019, 1/24/2020

Research

- **Create**
    - Liang J, Ho K, Arches J, **Keohane M**, Lee W, Simon A. Effects of Altered Somatosensory Input on Lower Limb Mechanics via Different Shoes and Barefoot Walking in Individuals with Chronic Post-Stroke Hemiparesis. *Submission Stage*

- **Consume/Share**
    - APTA
        - 2/2021: Combined Sections Meeting – Virtual
        - 3/9/2021: Nevada District Meeting virtual presentation "A How-to Guide for PTs on Implementation of the OTAGO Exercise Program: A Program to Reduce Falls"
    - UNLVPT Distinguished Lecture Series
        - 9/12/2019 – 9/13/2019: Anthony Delitto PT, PhD, FAPTA "Finishing the job of evidence-based practice" and "The time for implementation is NOW"
        - 11/15/2018 – 11/16/2018: Irene Davis, PhD, PT, FACSM, FAPTA, FASB "Footwear matters: Lets think differently about the foot" and "Well aligned, soft landings: A cure for running injuries?"
    - UNLVPT Brown Bag:

- 3/5/2020: Istvan Takacs, PT, DPT, “The Emerging Role of PTs in Bike Fitting”
- 10/2/2019: Greg Nordfelt, “Ride On: Adventrues in TBI”
- 9/4/19: Elizabeth McGehee, PT, DPT, OCS, “My journey to pelvic health”
- 11/8/2018: Charalambos Charalambous, PhD, “Can an acute exercise bout influence the sensorimotor locomotor memories?”
- 9/6/18: Baren Shah, PT, DPT and Rob Robb, PT, DPT “Why your DPT is worthless and what you can do to change it!”

o Student Special Interest Group
  - 6/6/2020: CA SSIG “LGBTQIA+ Health and Rehab”

o Clinical Education Inservice:
  - 8/6/2019“Muscle Flap Surgery following TKA”
  - 9/16/2020 “Isolation & Depression: Impact on patients and how physical activity can help”
  - 12/4/2020 “Skilled Physical Therapy for hemiplegia: PNF and other evidence-based treatment approaches”

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Education

DPT	University of Nevada, Las Vegas Las Vegas, NV	2018-2021	Doctor of Physical Therapy
BS	Brigham Young University Provo, UT	2016-2017	Exercise Science
	De Anza College Cupertino, CA	2014-2015	Biological Sciences

Licensure

- Pending National Physical Therapy Examination, July 2021

Certifications

- American Heart Association, BLS for Healthcare Providers June 2020
- CITI Program: Human Research, Biomedical IRB Course, Basic March 2019
- HIPPA Training January 2019
- Bloodborne Pathogens Training January 2019

Employment / Clinical Experience

- Select Physical Therapy, Henderson, NV

Student Physical Therapist, April 2021

- Mountain View Hospital, Las Vegas, NV

Student Physical Therapist, January 2021 — April 2021

- FYZICAL Therapy & Balance Center, Las Vegas, NV

Student Physical Therapist, September 2020 — December 2020

- Spring Valley Hospital, Las Vegas, NV

Student Physical Therapist, July 2020 — September 2020

- Ruby Mountain Physical Therapy, Elko, NV

Student Physical Therapist, July 2019 — August 2019

Research Activity

- Liang J, Ho K, Arches J, Keohane M, **Lee W**, Simon A. Effects of Altered Somatosensory Input on Lower Limb Mechanics vía Different Shoes and Barefoot Walking in Individuals with Chronic Post-Stroke Hemiparesis. *Submission Stage.*

Membership in Professional Organizations

- Member of the American Physical Therapy Association 2019 — Present
    - Member of APTA Nevada Chapter 2019 — Present

Service

- Parkinson's Foundation, Parkinson's Moving Day volunteer, Las Vegas (2020)

Continuing Education

- American Physical Therapy Association Combined Sections Meeting (Virtual), February, 2021
- American Physical Therapy Association Combined Sections Meeting, Denver, CO, February, 2020
- UNLVPT Distinguished Lecture Series. Dr. Irene Davis. Las Vegas NV, November, 2018
- "Pain Neuroscience in the Clinic" – Adriaan Louw, PT, PhD - Las Vegas, NV, April, 2019

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Education

DPT	University of Nevada, Las Vegas Las Vegas, NV	2018-2021	Doctor of Physical Therapy
BS	Brigham Young University Provo, UT	2009-2016	Therapeutic Recreation Spanish Minor

Licensure

- Pending National Physical Therapy Examination — May 2021

Certifications

- American Heart Association, BLS for Healthcare Providers — June 2020
- OTAGO Exercise Program: Fall Prevention Training — March 2020
- STEADI: Older Adult Fall Prevention Training — February 2020
- CITI Program: Human Research, Biomedical IRB Course, Basic — March 2019
- HIPPA Training — January 2019
- Bloodborne Pathogens Training — January 2019
- American Council on the Teaching of Foreign Languages — April 2016
  - Advanced Spanish

Employment / Clinical Experience

- University of Utah Neilsen Rehabilitation Hospital, Salt Lake City, UT
  Student Physical Therapist, January 2021 — April 2021

- VA Southern Nevada Healthcare System, Las Vegas, NV
  Student Physical Therapist, September 2020 — December 2020

- Renown Regional Medical Center, Reno, NV
  Student Physical Therapist, July 2020 — September 2020

- St. Mary's Regional Medical Center, Reno, NV
  Student Physical Therapist, July 2019 — August 2019

Research Activity

- Liang J, Ho K, Arches J, Keohane M, Lee W, **Simon A.** Effects of Altered Somatosensory Input on Lower Limb Mechanics vía Different Shoes and Barefoot Walking in Individuals with Chronic Post-Stroke Hemiparesis. *Submission Stage.*

Membership in Professional Organizations

- Member of the American Physical Therapy Association 2019 — Present
    - Member of APTA Nevada Chapter 2019 — Present

Service

- Henderson Senior Facility Fall Risk Screening Day Henderson 2020
- UNLVPT Interview Day 2019 — 2020
- Rock Climbing Rehab Special Interest Group 2019 — 2020
- Lou Ruvo Cleveland Clinic Fall Prevention Day 2019
- Red Rock Search and Rescue Field Team Member 2018 — Present
- OPAF First Step Clinic 2018

Honors and Awards

- UNLVPT Scholarship 2018 — 2021
- UNLV Access Grant 2019 — 2020
- BYU Dean's List 2015
- National Recreation and Parks Assocation Quiz Bowl Champion 2015
- BYU General Scholarship 2009 — 2016

Continuing Education

- APTA Learning Center, Las Vegas, NV 2020
    - "Health Coaching in Physical Therapy Practice"
    - "PACER Series: Cardiovascular and Pulmonary Anatomy and Physiology"
- APTA Combined Sections Meeting, Denver, CO 2020
- Symposium on Advanced Wound Care, Las Vegas, NV 2019
- UNLV Sports Medicine Didactics, Las Vegas, NV 2019 — 2020
    - "Approaching Hip Pain in the Athlete"
    - "Diagnostic Ultrasound: Terminology, Anatomy, and Image Optimization"
    - "Lateral Ankle Sprain Diagnosis and Treatment"
    - "Cervical Spine Injuries"
    - "Patellofemoral Syndrome, Hoffa's Disease, Chondromalacia Patellae, and Posterolateral Corner Injuries"
- UNLVPT Brown Bag Presentations, Las Vegas, NV 2019 — 2020
    - Istvan Takacs, PT, DPT "The Emerging Role of Physical Therapists in Bike Fitting"
    - Corey Sommerville, PT, MPT, NDT "Gait Outcomes for Stroke Rehabilitation"
    - Greg Nordfelt "Adventures in Traumatic Brain Injury"

- Leslie J. Waltke, PT, DPT “The Critical Benefits and Roles of Rehabilitation in Cancer Care”