THESIS


THE EFFECTS OF FOOTWEAR CUSHIONING ON WALKING PERFORMANCE IN

FEMALES WITH MULTIPLE SCLEROSIS


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ABSTRACT


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Multiple sclerosis is a chronic and progressive neurodegenerative disease which incurs a multitude of walking impairments. Protective strategies targeted at maintaining postural stability during walking include increasing stance and double support time with reciprocal decreases in swing and single support time, however these adaptions inadvertently increase fall risk. The midsole construct of footwear has demonstrated the ability to mediate these deficits in running but has not been explored in a neurologic population with known fall risk. The purpose of this study was to investigate the effects of two different midsole conditions on the spatiotemporal parameters of gait in females with multiple sclerosis (MS). Gait testing was conducted while 18 females with MS performed two-minute walk tests in 1) a high-cushion and 2) a standard-cushion midsole shoe. Spatiotemporal gait parameters were assessed using wireless inertial sensors. Participants spent less time in double support and stance phase with concomitantly more time in single support and swing phase in the high-cushion midsole shoe as compared to the standard-cushion. The high-cushion shoe may decrease fall risk by improving gait parameters associated with increased risk of falls.

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# 1. INTRODUCTION

Walking, is a construct property of locomotion which involves the use of both legs alternatively providing support and propulsion, while ensuring one foot remains in contact with the ground at all times (Baker, 2007). Locomotive research has continually advanced over the past 2,000 years since it was first conceptually initiated by Aristotle between the years 384-322 BC. Over time, one feature has remained constant in bipedal locomotion; as long as humans have been walking they have also been falling (Baker, R 2007). Bipedal locomotion can take various forms, such as running, walking, or skipping, and gait is a term used to describe these different methods, with basic spatial and temporal parameters used to assess characteristics of pathological gait such as that observed in persons with multiple sclerosis (Kalron, Dvir, Frid, & Achiron, 2013).

Multiple sclerosis (MS) is a chronic and progressive neurodegenerative disease affecting 2.5 million people worldwide, it is a female dominate (3:1) disease and principally results in the breakdown of myelin sheaths surrounding axons in the nervous system (Dilokthornsakul et al., 2016)(Gooch CL et al 2017). In the US alone, there is an estimated 500,000 people affected by MS with approximately 75% of those individuals suffering from walking impairments (Hobart, Lamping, Fitzpatrick, Riazi, & Thompson, 2001; E. W. Peterson, Ben Ari, Asano, & Finlayson, 2013). In neurodegenerative disorders such as MS, this impaired gait results in an elevated fall risk, decreased quality of life, and increased morbidity. More than 50% of people with MS (PwMS) will suffer a fall-related injury within any 6-month period, providing evidence that falls are a significant quality of life concern(E. W. Peterson et al., 2013). To date, altered gait kinematics that contribute to the elevated fall risk in PwMS include decreased step length, gait

speed, cadence, minimum toe clearance, shorter stride length, and increased double support(Benedetti et al., 1999; Kasser, Jacobs, Foley, Cardinal, & Maddalozzo, 2011; Martin et al., 2006).

The human walking gait is an alternating sequence of single limb and double limb support involving periods of time with one foot on the ground followed by both feet. These phases are termed single limb support and double limb support respectively. A gait cycle, an occurrence of an ipsilateral event in the gait cycle, for instance from left heel strike to left heel strike, has two distinct phases; stance phase and swing phase. From heel strike to toe-off of one foot is considered the stance phase with the subsequent toe-off to foot strike of that same foot comprising the swing phase. A typical gait cycle for a healthy individual partitions the gait cycle into 60% stance phase and 40% swing phase for each leg (**Figure 1**). However, pathologic populations demonstrate alterations in this makeup. Specifically, PwMS exhibit a compensatory, cautious gait strategy characterized by prolonged double support phase (Benedetti et al., 1999; Kalron, Achiron, & Dvir, 2011; van Emmerik, Jones, Busa, Remelius, & Averill, 2014), a shorter single support phase (Kalron, 2015) and a truncated swing phase (Gianfrancesco et al., 2011; Givon, Zeilig, & Achiron, 2009; Jebb G Remelius et al., 2012). These compensatory gait adaptions aim to reduce postural instability, but they inadvertently have some contradictory detrimental effects that increase the likelihood of falls (van Emmerik et al., 2014). Despite prolonged foot contact increasing both somatosensory feedback and stability through creating a wider base of support (BoS), these alterations precipitate a loss of balance by hastening swing phase which encourages instability during the single limb support of the gait cycle (J. G. Remelius et al., 2012). The cautious gait strategy adopted by PwMS, prolonged double support phase, decreased single limb support phase, and shortened stance phase may cause an

unintentional increase in instability during opposite gait phases (J. G. Remelius et al., 2012). In addition, shorter stride length and reduced minimum toe clearance during the swing phase have been attributed to the increased fall risk observed in PwMS (Comber, Galvin, & Coote, 2017; P. N. Taylor, Wilkinson Hart, Khan, & Slade-Sharman, 2016). Minimum toe clearance during swing phase is a significant gait impairment in PwMS due to the increased prevalence of foot-
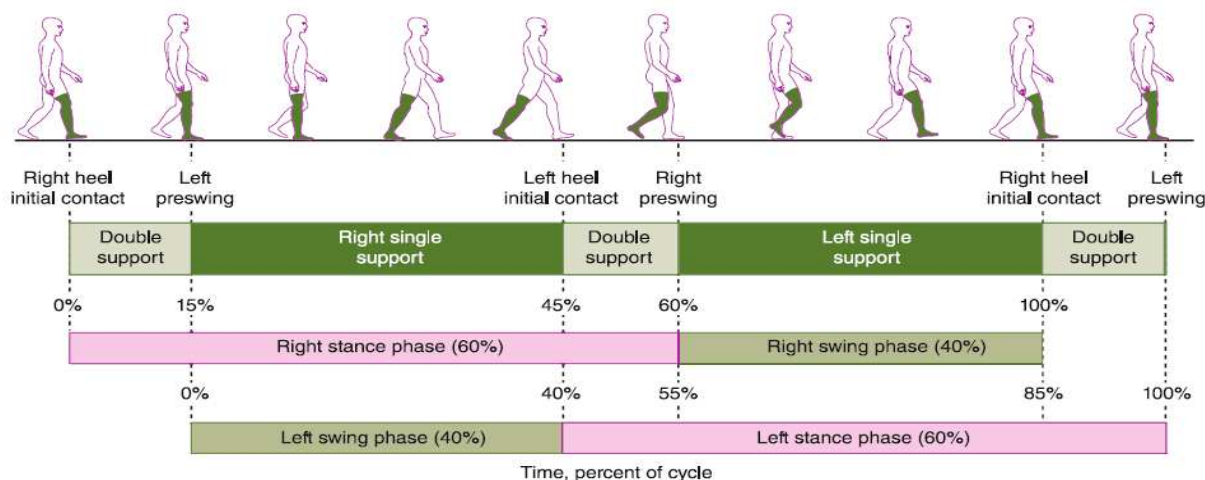


**Figure 1**: A typical gait cycle (GC) from right heel initial contact back to right heel contact. The GC consists of alternating sequences of double and single limb support. The GC is comprised of 60% stance phase with the remaining 40% swing phase. Alterations to this makeup in MS include longer duration of double limb support and increased percentage of the GC in stance phase. Adopted from Lord et al 2015.

drop. This well documented decrease in the amount of toe clearance demonstrated by PwMS is a significant contributor to the increased likelihood of tripping (e.g. an increased fall risk factor), a direct resultant of the toe clearance gait impairment (P. N. Taylor et al., 2016).

Although gait and mobility deficits are some of the most common complaints among PwMS, we currently lack sensitive and objective measures concerning how different shoe constructs can help mediate gait deficits in PwMS, in particular the shoe's midsole thickness. The midsole construct of the shoe incorporates shock absorptive materials such as ethyl vinyl acetate (EVA) or polyurethane and is the most important component of the shoe in terms of

cushioning and energy absorption, which can influence gait. The kinetic and kinematic effects of midsole thickness in running indicates that increased midsole thickness is associated with longer ground contact times (Chambon, Delattre, Gueguen, Berton, & Rao, 2014). Additionally, as the compliance of the midsole become softer, the vertical loading rates decrease (Clarke, Frederick, & Cooper, 1983). To date, spatiotemporal parameters of gait regarding various shoe types such as high heels, slippers, and other various footwear characteristics have been assessed in healthy older adults (Menz, Morris, & Lord, 2006; Roman de Mettelinge et al., 2015; Wunsch, Kroll, Stoggl, & Schwameder, 2017). The goals of these studies were to illuminate the effects of footwear characteristics on gait research and their correlation with fall risk. Wunsch et al additionally found that manipulating the properties of the midsole can increase stride length and improve economy in runners (Wunsch et al., 2017).

However, it remains unclear, how the midsole thickness in shoes influence kinematic gait parameters during over-ground walking in PwMS. Therefore, the aim of this study is to investigate how increased cushion (i.e. increased thickness) at the midsole affects kinematic gait parameters within PwMS. We hypothesize that increasing cushion at the midsole will improve gait kinematics via increasing both the length and elevation of the stride while walking at a self-selected pace during over-ground walking.

## 2. METHODS

### 2.1 Participants

Twenty females with a neurologist confirmed diagnosis of relapse-remitting MS were recruited to participate in this study. Eligible participants were required to have (1) the ability to walk for 10 minutes continuously without the use of an assistive device, (2) a self-reported expanded disability status scale (EDSS) of less than or equal to 4.5, (3) no neurological disorders other than MS or recent musculoskeletal injuries that would impact walking, (4) a shoe size between US Women's 6.5-9.0, and (5) not been taking medications known to impact walking. One participant was classified as an outlier and removed from the analysis, while an additional participant was unable to complete the protocol due to shoe size. Approval for this study was given by the local Institutional Review Board at Colorado State University and all participants provided written informed consent before participation.

### 2.2 Procedures

All assessments occurred within a single testing session and were experimentally designed as a cross-sectional study. All participants completed the following questionnaires; a self-report Expanded Disability Status Scale (EDSS), the Modified Fatigue Impact Scale (MFIS) and the 12- Item Multiple Sclerosis Walking Scale (MSWS-12). The EDSS is the most widely used clinical measure to assess the physical function and level of disability in MS and has demonstrated a very good correlation with physician scores (Bowen, Gibbons, Gianas, & Kraft, 2001). This scale is heavily-weighted on the mobility dimension with a score of 4.5 or greater indicating the reliance on a walking aid. The level of symptomatic fatigue was measured using the multidimensional 21-item MFIS, which has scores ranging from 0-84, with higher scores

indicating elevated levels of fatigue (Tellez et al., 2005). A representation of mobility

impairment induced by MS was assessed using the MSWS-12 which has an outcome ranging

from 0-100, with higher scores signaling increased walking impairment. These questionnaires

assessed the severity of disability incurred by MS patients and thus would enable a correlational

analysis of the dependent variables to the questionnaire outcomes. Demographic and

anthropometric measurements were taken prior to proceeding with gait analysis procedures.

Participants were asked to walk continuously for 2 minutes over-ground on a 52- meter

gym floor at their own self-selected pace. Research has shown the efficacy of the 2-minute walk

test as a valid alternative to the 6-minute walk test, allowing for sufficient descriptions of

walking capability in patients with neuromuscular diseases (Andersen, Knak, Witting, &

Vissing, 2016). Participants completed walks in two different footwear conditions: a (i) Standard

Midsole: New Balance 85v1 (Boston, MA) (216 grams, 10mm heel drop, injection-molded EVA

(IMEVA) foam midsole and a (ii) High Cushion: Hoka One One Clifton 3 (Goleta, CA) (204

grams, 5mm heel drop, Full Length Compression Molded ProFly EVA midsole (**Figure 2**).  All

footwear conditions were randomized, and a five-minute rest period was incorporated between

walking trials in order to prevent fatigue from becoming a potential cofounding factor. Further



**Figure 2.**  Measurements of the midsole were taken at the heel, midfoot, and forefoot. The New Balance 85v1 (**TOP**) serves as the standard cushioned midsole. Weight = 216 grams. IMEVA foam midsole. The Hoka One One Clifton 3 (**BOTTOM**) serves as the high cushioned midsole. Weight = 204 grams. ProFly EVA midsole.

precautionary measures to monitor fatigue were established through reported through self-reported Rated Perceived Exertion (RPE) scores after each walk using the BORG RPE scale. This scale has been identified as reliable tool and valid tool in evaluating and prescribing exertion in PwMS (Cleland, Ingraham, Pitluck, Woo, & Ng, 2016).

## 2.3    Mobility analysis

Gait data were collected using Opal wireless inertial sensors (128Hz), and Mobility Lab software (Version 2) (Opal Sensors, APDM Inc., Portland, OR) was used to automatically stream and export gait metrics (F. Horak, King, & Mancini, 2015). The Opals are triaxial inertial sensors consisting of an accelerometer, magnetometer, and gyroscope. For gait acquisition a six-sensor configuration with sensors placed on the feet, wrists, chest, and lumbar region of the lower back (**Figure 3**) was utilized and have been shown to be a reliable system for quantifying gait and understanding mobility disorders (Mancini et al., 2011). All gait measures were compared two
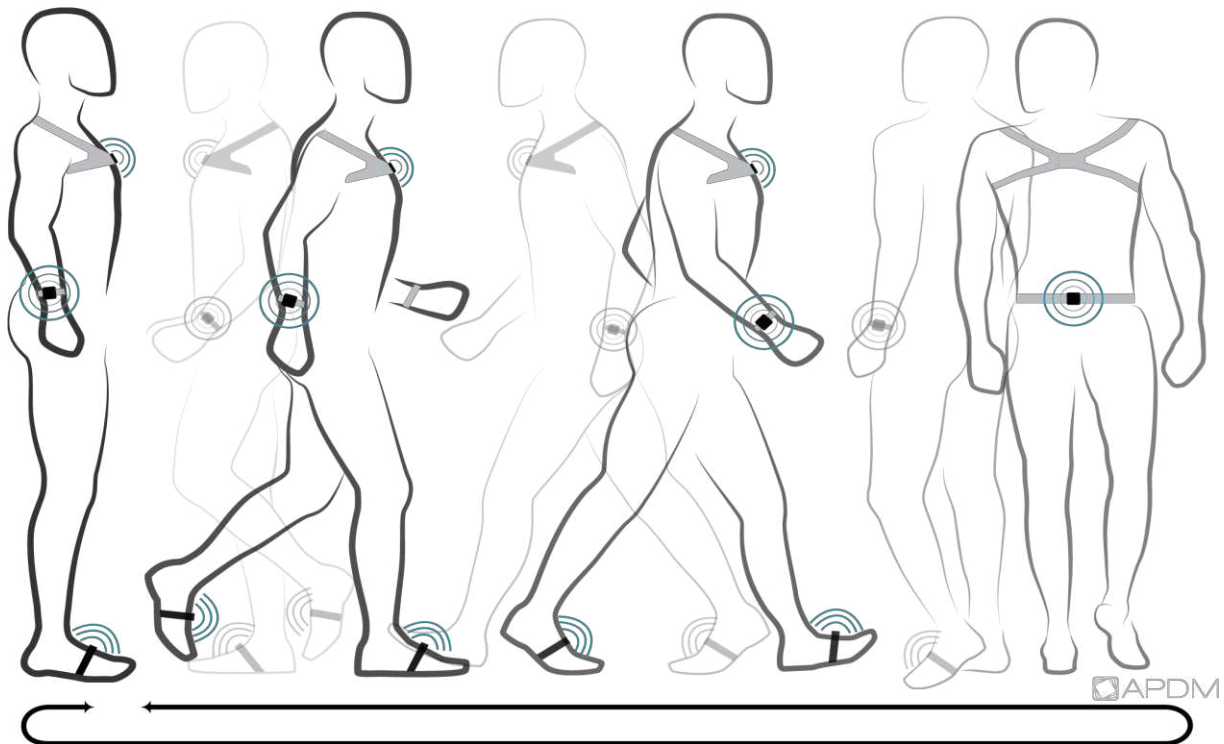


**Figure 3:** Opal sensor set-up during the two-minute walk test.  Sensors were placed on the sternum, on the lumbar, each wrist, and on each foot.

midsole conditions: standard cushioned midsole, and high cushioned midsole. The primary gait measure spatiotemporal parameters of gait consisting of: stride length (m), elevation at midswing (i.e. toe clearance) (cm), gait speed (m/s), stance (% gait cycle time (%GCT), swing (%GCT), double support (%GCT,), single limb support (%GCT). Gait measures were recorded for both limbs.

## 2.4    Statistical Analysis

This study was powered two ways to ensure adequate sample size. To find a difference between footwear conditions in two primary dependent outcomes: 1) stride length (Elboim-Gabyzon & Rotchild, 2017) and 2) minimal toe clearance during swing (Chien & Lu, 2017), 2-tailed tests (powered at 0.80 and an alpha of 0.05) was utilized. Assuming a similar effect size as observed using existing data, the toe clearance parameter was the least powerful analysis with a required sample size of 16. To ensure adequate power of the study while accounting for the minimum allowed adherence of 80%. Gait performance was assessed by output metrics of gait recorded by the wireless, inertial sensors. A paired sample t-test was used to identify differences in spatiotemporal measures of gait.

The normality of distribution for the spatiotemporal parameters of interest were assessed using a Shapiro-Wilks test and a Q-Q plot performed in R (R Foundation for Statistical Computing, Vienna, Austria). An outlier was identified and removed from the dataset. A further participant was unable to complete the protocol due to an inadequate shoe size. This left a total sample size of 18. The spatiotemporal gait parameters were normally distributed and did not violate homogeneity of variance after removal of the outlier. Differences in average gait parameters between the standard midsole and high cushion midsole were determined using paired sample *t*-test. The magnitudes of group differences were indexed by a 95% confidence

interval (95% CI All analyses were formed using JASP Version 0.8.4, (Amsterdam, The

Netherlands). All reported *P* values were two-tailed. The level of significance was set a *P* < 0.05.

The association between changes in gait parameters and EDSS scores and disease duration were

assessed using a Spearman's and Pearson's correlation respectively.

## 3.1    Characteristics

Eighteen PwMS (52 ± 10 years, 1.63 ± 0.05m, 63.96 ± 12.76kg) were classified with

relapse-remitting MS (RRMS) with an average disease duration of 15 years. Disease duration

was assessed from 16 participants as this information was not obtained from two participants.

Average self-report EDSS scores was 3.86 (± 0.85) indicative of the capacity to walk without

assistance. While two participants reported an EDSS score of 6, they were still able perform the

walking protocol appropriately.  Symptomatic fatigue was measured with the MFIS scale with an

average level of disability of less than 40 (± 13.82).  There was mild self-reported mobility

impairment as indicated by the MSWS-12 (35.53 ± 3.53).  The participants' characteristics and

assessment scores are summarized in Table 1.

**Table 1.** Demographic, Anthropometric, Clinical Characteristics of the Study Population

| Characteristics | |
|---|---|
| Age (years) | 52 (± 10) |
| Sex n, female (F)) | 18 F |
| Type of MS | RRMS |
| Disease Duration (years) | 15* |
| Height (m) | 1.63 (± 0.05) |
| Weight (kg) | 63.96 (± 12.76) |
| MFIS | 40 (± 13.82) |
| MSWS-12 | 35.53 (± 3.53) |
| srEDSS | 3.86 (0.85) |

*Note: Values are +/- SD*
*Abbreviations: srEDSS, self-report Expanded Disability Status Scale; MFIS, Multi Fatigue Impact Scale; MSWS-12, Multiple Sclerosis 12 Item Walking Scale.*
*\* Assessed from n=16.*

### 3.2 Gait

### 3.2.1 Spatiotemporal Gait Parameters

There were no differences in elevation at midswing (Left: P = 0.917; Right: P = 0.917) or stride length (Left: P = 0.425; Right: P = 0.917) for both left and right legs between the standard and high cushioned midsole condition Similarly, gait speed for both legs was not different across midsole conditions (Left: P = 0.519; Right: P = 1.000). However, participants demonstrated decreases in double support (Left: P = 0.004; Right: P = 0.004) and stance phases in the high cushioned midsole (Left: P = 0.005; Right: P = <0.001). Further, there was a reciprocal increase in the percentage of the gait cycle spent in single support (P = <0.001), although only on the left side, and swing phase (Left: P = 0.005; Right: P = <0.001) in the high cushioned condition. Gait variables across the two conditions are provided in **Table 2**. The average and percent changes for the significant gait parameters are provided in **Table 3** and **Figure 4**.

**Table 2.** Gait variables separated by condition for left and right limb. Values are mean (SD); p values refer to the main effect across conditions. Meters Per Second = m/s, Percent Gait Cycle = %GC

| Gait Variable | Left Mean (SD) | | P-Value | Right Mean (SD) | | P-Value |
|---|---|---|---|---|---|---|
| | Standard Cushion | High Cushion | | Standard Cushion | High Cushion | |
| Double Support (%GC) | 20.28 (3.16) | 19.61(3.10) | 0.004* | 20.28 (3.15) | 19.63(3.11) | 0.004* |
| Single Support (%GC) | 39.60 (1.88) | 39.97 (1.86) | <0.001* | 40.14 (1.72) | 40.41(1.55) | 0.070 |
| Elevation at Midswing (cm) | 1.37 (0.50) | 1.38 (0.51) | 0.917 | 1.46 (0.62) | 1.42 (0.63) | 0.651 |
| Gait Speed (m/s) | 1.16 (0.21) | 1.17 (0.21) | 0.519 | 1.15 (0.21) | 1.15 (0.22) | 1.000 |
| Stride Length (m) | 1.20 (0.15) | 1.20 (0.16) | 0.425 | 1.19 (0.15) | 1.19 (0.16) | 0.917 |
| Swing (%GC) | 40.13 (1.71) | 40.42 (1.54) | 0.050* | 39.58 (1.86) | 39.96(1.87) | <0.001* |
| Stance (%GC) | 59.87 (1.71) | 59.58 (1.54) | 0.050* | 60.42 (1.86) | 60.04(1.87) | <0.001* |

**Table 3.** Spatiotemporal Gait Parameters Difference in Spatiotemporal gait parameters from standard cushioned midsole to high cushioned midsole. Percent Gait Cycle = %GC.

| Dependent Variable | Difference from Standard Cushioned Midsole to High Cushioned Midsole |
|---|---|
| Double Support (%GC) | |
| Left | -0.66 |
| Right | -0.66 |
| Single Limb Support (%GC) | |
| Left | +0.37 |
| | |
| Swing (%GC) | |
| Left | +0.29 |
| Right | +0.37 |
| Stance (%GC) | |
| Left | -0.29 |
| Right | -0.37 |
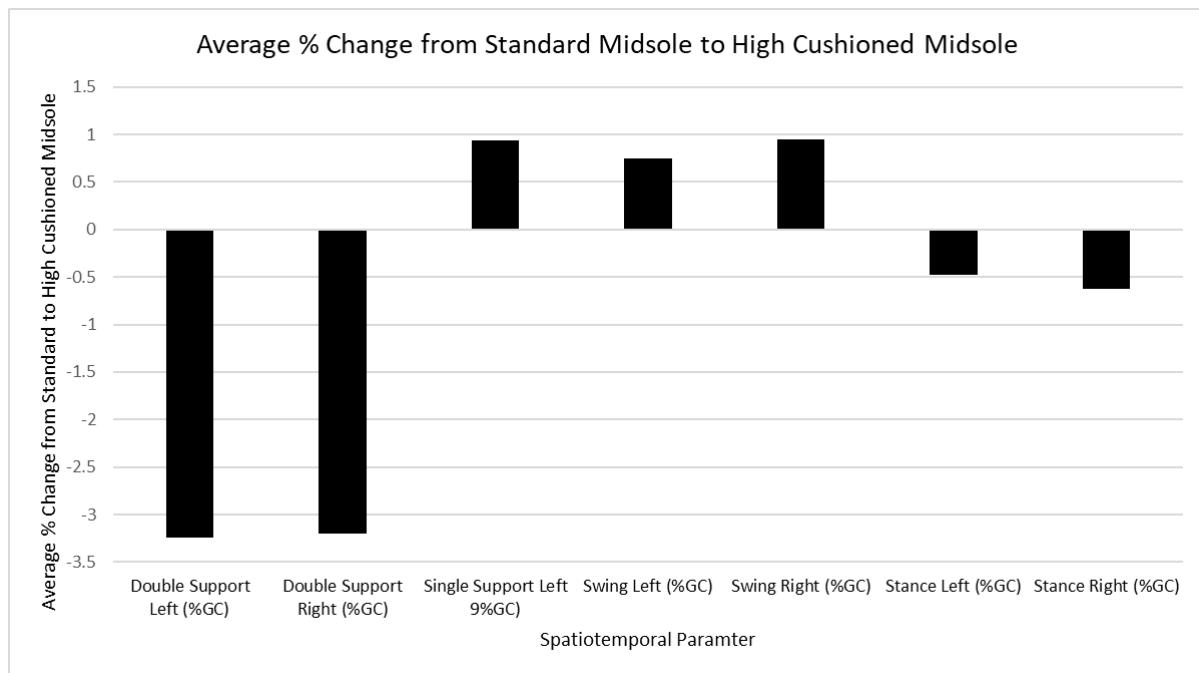


**Figure 4:** Representative bar chart showing the average percent change from the standard to high cushioned midsole condition across the spatiotemporal parameters that were significantly different between conditions. A negative percent change indicates a reduction to that magnitude

.

### 3.2.2   Correlations between Spatiotemporal Measures of Gait and Disease Characteristics

There was a trend towards greater percent change (i.e. greater reduction) in double

support time associated with less disease-based severity, as assessed by the self-report EDSS

(rho = 0.36**; Figure 5**). Moreover, participants who had been living with MS for a shorter

duration experienced greater reductions in double support time (r = 0.55; **Figure 6**) when

wearing the high-cushioned shoe in comparison to the standard cushion shoe.
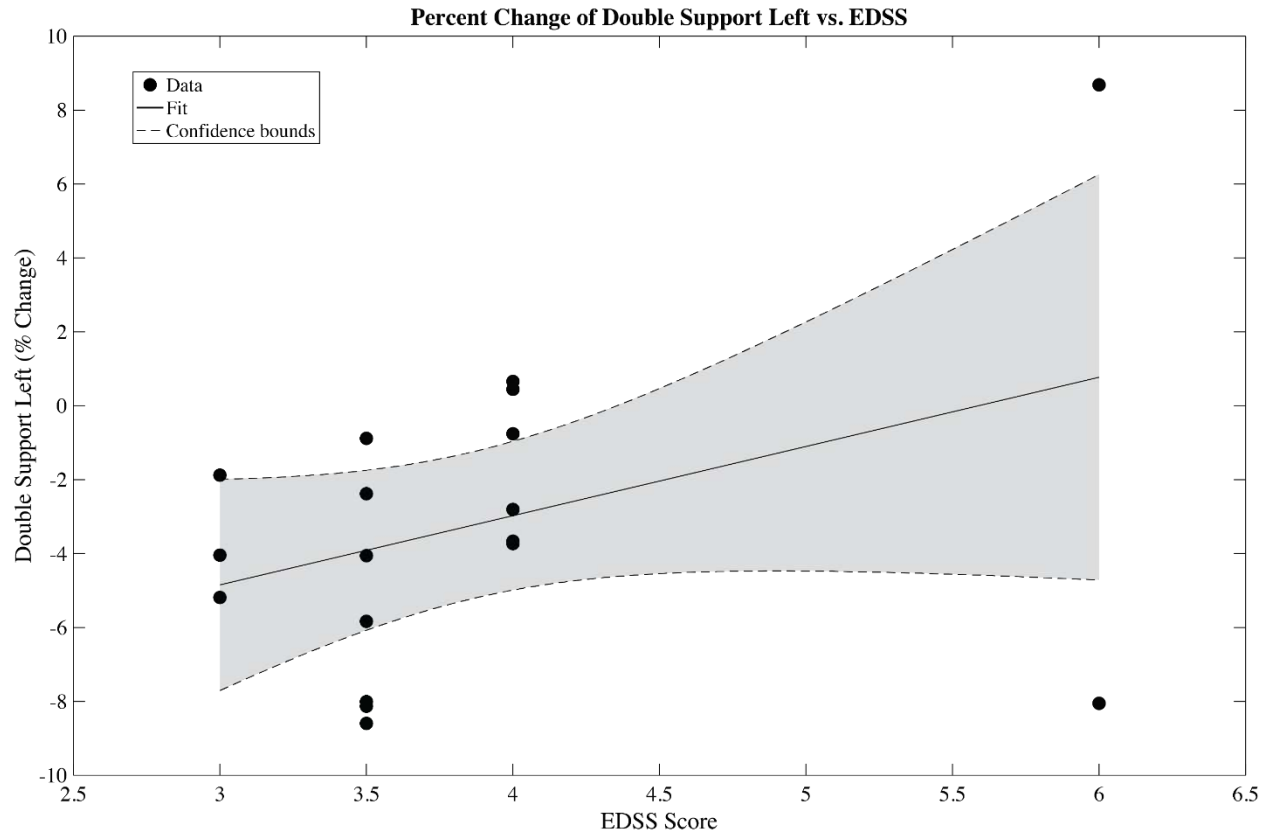


**Figure 5**: Spearman's correlation illustrating the association between EDSS score, a measure of disability, and the average percent change in double support left from the standard to high cushioned condition. (rho = 0.36; P-Value = 0.14)

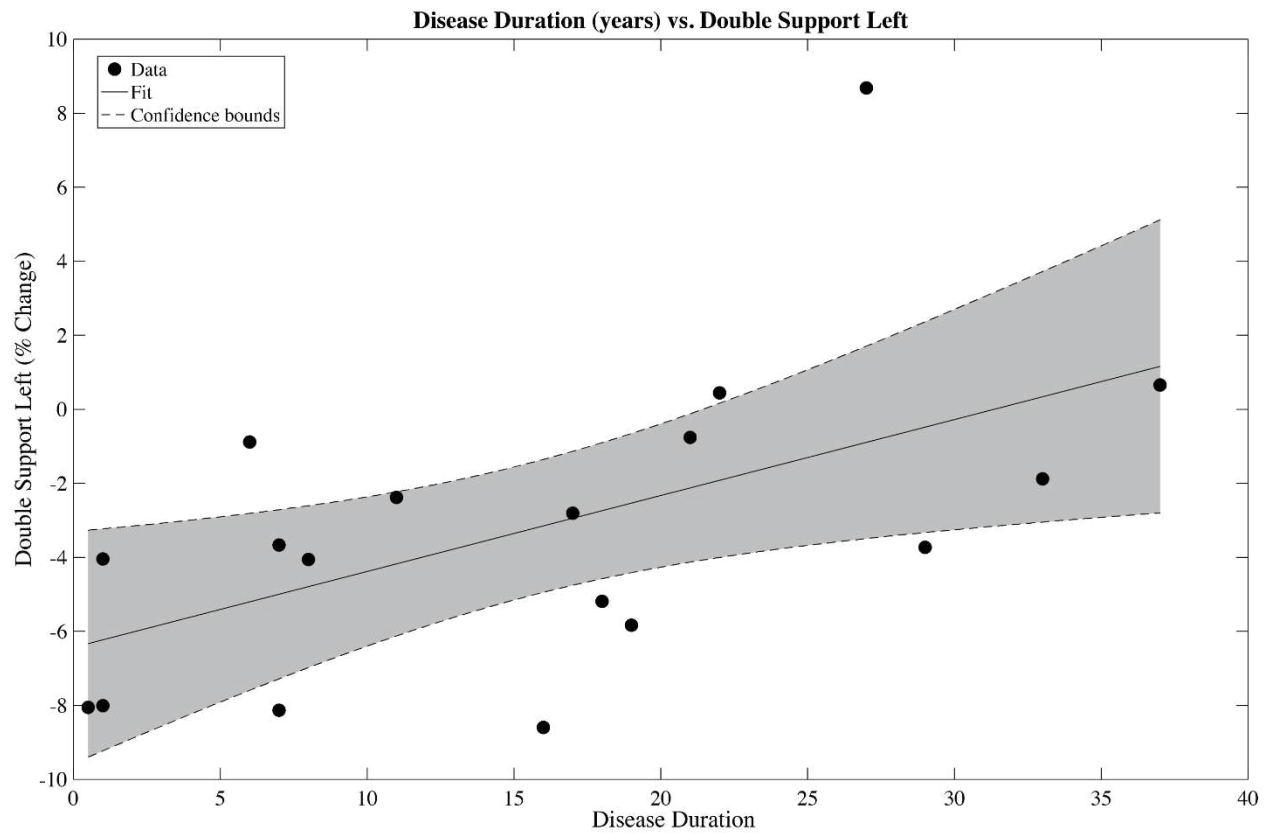**Figure 6:** Pearson's correlation illustrating the moderate association between years with MS and the average percent change in double support left from the standard to high cushioned condition (r = 0.54; P-Value = 0.02).

# 4. DISCUSSION

The primary goal of this study was to assess the relationship between varying levels of midsole cushion and spatiotemporal parameters of gait in females living with MS. As mobility deficits are highly prevalent in this clinical population and given the resultant increased risk for a fall, along with the lack of knowledge about how the application of different footwear can influence walking in PwMS, the outcomes of this study are highly relevant and can serve to increase the quality of life in PwMS. We used a standard and high cushioned midsole and conducted a spatiotemporal gait analysis to examine how they would influence known gait variables associated with increased fall risk. However, varying the midsole cushion had no effect on stride length or elevation at midswing. Therefore, we can reject our hypothesis which stated that increasing the cushion at the midsole would increase both the length and elevation of the stride. In contrast to the standard cushioned midsole, participants spent a decreased amount of time in double support and stance, with a reciprocal increase in single limb support and swing in the high cushioned shoe. This represents a shift from the well-known protective strategy adopted by PwMS which details a prolonged double support and swing time along with decrements in single support time and swing (Benedetti et al., 1999; Gianfrancesco et al., 2011; Givon et al., 2009). Finally, greater change was associated with a more recent diagnosis in addition to a milder disability. Taken together, the current results demonstrate that while absolute measures of spatiotemporal gait metrics did not change, the relative make-up of the gait cycle was improved when wearing the high cushioned midsole in comparison to a standard cushion shoe.

**4.1    Stride Length and Elevation at Midswing**

The negligible changes in both the length and elevation of the stride may have been influenced by another feature of the high cushioned shoe. The Hoka One One Clifton 3 contains a meta-rocker which is built within the midsole. The rocker is a contoured rigid platform that controls joint motion throughout a stride (Long et al., 2004) to reduce loading on the forefoot region and alleviate plantar pressure (Sobhani et al., 2014). The hypothesis of this study was anchored in an energy conservation mechanism based upon the energy absorptive properties of the midsole (Shorten, 1993) but the presence of a rocker may have diminished this effect. Our findings agree with previous research that has demonstrated no change in stride length whilst wearing a rocker sole (Myers et al., 2006; Taniguchi, Tateuchi, Takeoka, & Ichihashi, 2012).

Furthermore, Peterson et al discovered that the rocker soles resulted in reduced plantarflexion moments at the ankle at push off which may explain why no changes were seen in elevation of the stride from standard to high cushioned midsole (M. J. Peterson, Perry, & Montgomery, 1985).  Therefore, the rocker construct in the high cushioned shoe may have dissipated improvements in stride length and elevation between the varying cushion levels.

**4.2    Temporal Gait Changes**

Despite not seeing meaningful changes in spatial gait parameters there were significant differences in the composition of the gait cycle with less time spent in double support and stance with reciprocal increases in single support and swing during walking in the high cushioned midsole. The kinetic and kinematic changes observed throughout gait while wearing the high cushioned shoe may provide a possible explanation to these temporal adaptations. A method to examine the load on the body during locomotive tasks is by measuring the ground reaction forces (GRFs), which are dictated to us via Newton's third law which states, "for every action there is

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an equal and opposite reaction". Therefore, every time our foot hits the ground as we walk there

is a resultant force of equal magnitude in the opposite direction. In a normal gait cycle the

vertical GRFs forces project a double hump pattern, with the initial spike in the vertical GRF

representing weight acceptance and the second hump representing the propulsive force at push

off. The increased cushion at the midsole in the Hoka One One could reduce the magnitude of

these vertical GRFs, as described by Shorten et al trough the viscoelastic properties of the

midsole (Shorten, 1993) by reducing the negative power exerted due to the eccentric contraction

of the plantarflexors during mid to terminal stance, as well as decreasing the positive power,

which is the propulsive energy created immediately prior to toe-off as a result of the concentric

contraction of the plantarflexors. The high cushioned midsole provides a mechanism for the

conservation of energy from heel strike to toe-off resulting in more force being absorbed and

returned to the subsequent step, behaving similar to a spring. This positive energy turnover could

provide a mechanism for an increased time spent in the swing and single limb support phase of

the gait cycle. However, a more robust kinetic assessment is required to determine this as an

underlying mechanism for the results observed in our study.

Moreover, the observed alterations in the temporal parameters of the gait cycle are

important adaptations to decrease fall risk. It has been well established that PwMS adopt a

cautious, compensatory gait strategy in an attempt to maintain postural stability during walking,

which has been shown to be compromised in PwMS (Comber et al., 2017). The application of

this protective strategy is an attempt to reduce the risk for a fall, as a direct association exists

between instability during gait tasks and accidental falls in PwMS (Gianni, Prosperini,

Jonsdottir, & Cattaneo, 2014; Matsuda et al., 2011). One element of this compensatory gait

strategy involves prolonging the contact time of both feet with the ground which would increase

stability and further increase peripheral somatosensory feedback from the foot-surface interactions, which may be vital in PwMS as they have diminished afferent feedback (van Emmerik et al., 2014). However, since a gait cycle is comprised of alternating sequences of single and double limb support, altering the time spent in one of these phases will incur subsequent effects on the other. As a prolonged stance phase, and thus double support, is an adaptation favored by those with MS, independent of speed, it will result in less time spent in swing and single limb support (J. G. Remelius et al., 2012). Furthermore, to walk with a constant cadence and maintain a prolonged double support phase, PwMS must condense their swing time which can be achieved in two ways; firstly, through a reduced step length or, secondly, through an increased swing foot velocity. Significantly, the principal mechanism through which PwMS reduce swing time is the latter, which induces increased destabilization by increasing the velocity at which the swing foot crosses the anterior boundary of stability (J. G. Remelius et al., 2012), creating instability and reducing the available time to initiate a corrective postural response to a perturbation.

The alteration of swing timing exhibited in this MS gait strategy, because of prolonged double support, can further create instability through modifying when different segments of the body cross the anterior stability boundary. Stability is maintained when the body's center of mass (CoM) stays within the base support. A fall or corrective postural action occurs if the CoM moves outside of this region. Moreover, research has shown that PwMS tend to lead first with their head crossing this anterior boundary before their swing foot or trunk CoM (J. G. Remelius et al., 2012) and that they have significant impairments in stepping responses to external perturbations ((D. S. Peterson, Huisinga, Spain, & Horak, 2016). In healthy controls, it is paramount that the swing foot is positioned in front of the stance foot when the head and trunk

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CoM crosses the anterior physical stability boundary, as this ensures stability and provides time to make a postural or corrective adjustment should it be needed in response to a perturbation. However, as PwMS tend to position their head closer to that anterior stability border, as well as increasing the swing foot velocity, these individuals possess a diminished capacity to perform corrective behaviors, which has been identified as one of the key factors required to maintain postural stability (F. B. Horak, 2006). Thus, it would be advantageous for PwMS to demonstrate a gait cycle with more time spent in swing phase, and attempt to restore it to the well-established norm of 40% of the gait cycle. Strength and Tai Chi training have shown the potential to mediate these defects in swing timing (E. Taylor & Taylor-Piliae, 2017; White et al., 2004). The results of this study also indicate that wearing a high cushioned midsole could provide a potential additional avenue to augment the benefits of strength training through decreasing the time spent with both feet on the ground, therefore negating the possible risks associated with hastening the swing phase which include reducing the latency to make a corrective postural step.

A further explanation concerning the deviation from the compensatory gait strategy may be due to the perceived risk for a fall. 50% of adults with MS will experience a fall in a given three-month period with 62% reporting concerns about falling (Matsuda et al., 2011). This stems from a physical handicap but falls additionally instill a psychological morbidity which can increase the likelihood of a subsequent fall (Cameron, Asano, Bourdette, & Finlayson, 2013). In fact, certain spatiotemporal parameters of gait are demonstrated in PwMS who are more concerned with fall risk, including increased double support time and decreased single support time (Chamberlin, Fulwider, Sanders, & Medeiros, 2005; Kalron, Frid, & Gurevich, 2015). Therefore, it is plausible that the participants felt most comfortable and confident in a more highly cushioned shoe, in contrast to a standard midsole, and this was reflected in a less

conservative gait pattern demonstrated through increased single limb support and swing with reductions in time spent in double support.

## 4.3      Spatiotemporal Gait Correlations

There was a greater reduction in double support time with less disease-based severity as measured by the self-reported EDSS. Double support left was chosen as the gait parameter as this experienced the greatest change across the 18 participants between shoe conditions. Higher EDSS scores have been associated with greater impairments in mobility and prolonged double support time (Givon et al., 2009; Martin et al., 2006), and our present study supplements this by indicating that those with more disability (i.e.- higher EDSS scores) show less improvements. However, the correlation illustrated in the present study may not be truly reflective of disease severity as two participants self-reported an EDSS score of 6.0, which would indicate a more severe walking impairment despite performing the two-minute walk appropriately.

We demonstrated a moderate positive association between disease duration and improvements in a gait parameter in the high cushioned midsole. This is significant as mobility deficits and gait abnormalities are known to manifest even at the very early stages of the disease (Comber et al., 2017; Givon et al., 2009), so it may be prudent to intervene as soon as possible after diagnosis to elicit the most effective rehabilitation strategy.

## 4.4      Limitations/Future Exploration

This pilot study has demonstrated that PwMS altered their gait whilst walking in different midsole conditions in females with MS. In terms of future exploration, it would be important to expand this to males and to test the hypotheses put forward in this discussion to explain the temporal gait adaptations demonstrated in the high cushioned midsole. To examine if increased cushion lessens vertical GRFs and increases energy return, it would be prudent to conduct a

kinetic and kinematic gait analysis in PwMS in the same two midsole conditions. Furthermore, it would be interesting to assess the joint powers and torques at the ankle, knee, and hip which may augment the postulated conservation of energy mechanism. This would provide an insight into the forces that are causing the temporal adaptation demonstrated in this study. Further research is required on the composition of the midsole and which construct is responsible for the observed temporal changes in gait. Midsole hardness remains the most explored characteristic of the midsole (Onodera, Gavião Neto, Roveri, Oliveira, & Sacco, 2017) and affects the vertical loading rates (Clarke et al., 1983) while the midsole resilience, which is the amount of stored strain energy in the cushion when pressure is relieved, manipulates initial impact forces (Sun et al., 2008).

This pilot study was not without its limitations. The purpose of this study was to assess if females with MS walk differently in varying midsole conditions. The density, type, compliancy, nor the resiliency of the midsole were accurately measured. Instead, a gross approximation of midsole thickness was measured at the heel, midfoot, and barefoot. Therefore, we cannot conclusively state that the differences observed were exclusively because of the different levels of midsole cushion. Additionally, our participant recruitment was limited to women due to the cost in the acquisition of the New Balance and Hoka One One shoes. Since MS is three times more prevalent in female, we selected them as the sample population.

# 5. CONCLUSION

To date, mobility deficits and falls remain consistent concerns of PwMS while protective, compensatory walking strategies inadvertently elevate fall risk. Additionally, limited knowledge exists on the effects of midsole cushion at mediating these deficits. Our study demonstrated reductions in double support and stance time with reciprocal increases in single support and swing time while walking in the high cushioned shoe. The results of this study are highly relevant and applicable as the simple acquisition of a pair of shoes with a high cushioned midsole may have the potential to make an immediate improvement in functional gait and quality of life for PwMS through reducing fall risk.

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