Multiple Sclerosis and Related Disorders 16 (2017) 15–21

Contents lists available at ScienceDirect

Multiple Sclerosis and Related Disorders

journal homepage: www.elsevier.com/locate/msard

Effect of walking on sand on gait kinematics in individuals with multiple sclerosis

Maayken E.L. van den Berg[a,*], Christopher J. Barr[a], James V. McLoughlin[a], Maria Crotty[a,b]

[a] Rehabilitation, Aged & Extended Care, Faculty of Medicine, Nursing and Health Sciences, Flinders University, Adelaide, Australia
[b] Rehabilitation, Aged & Extended Care, Repatriation General Hospital, Adelaide, Australia

ARTICLE INFO

Keywords:
Multiple sclerosis
Gait pattern
Gait adaptation
Sand

ABSTRACT

Background: Walking in the real-world involves negotiating challenging or uneven surfaces, including sand. This can be challenging for people with Multiple Sclerosis (PWMS) due to motor deficits affecting the lower extremities. The study objective was to characterise kinematic gait adaptations made by PWMS when walking on sand and describe any immediate post-adaptation effects.

Methods: 17 PWMS (mean age 51.4 ± 5.5, Disease Steps 2.4 ± 1.0), and 14 age-and gender matched healthy adults (HA) took part in a case-control study. 3D gait analysis was conducted using an eight-camera Vicon motion capture system. Each participant completed walking trials over level ground (baseline), sand (gait adaptation response), and again level ground (post-adaptation). Spatiotemporal data and kinematic data for the hip knee and ankle were recorded.

Results: At baseline PWMS showed significantly less total lower limb flexion ($p < 0.05$) compared to HA. PWMS adapted to walking on sand by significantly increasing hip and knee flexion and ankle dorsiflexion ($p < 0.05$) during swing, resulting in an overall 23° greater total lower limb flexion ($p < 0.05$), reaching values within normal range. During the return to level ground walking values of temporal-spatial and kinematic parameters returned towards baseline values.

Conclusions: PWMS adapted to walking on sand by increasing lower limb flexion during swing, and returned to their gait pattern to near baseline levels, in a manner similar to but with values not equalling HA. Further work is required to determine whether this mode of walking has potential to act as a gait retraining strategy to increase flexion of the lower limb.

1. Introduction

In people with Multiple Sclerosis (PWMS), motor deficits commonly affect the lower extremities, and deterioration of walking performance has been reported as one of the most disabling symptoms as it is associated with quality of life (LaRocca, 2011; Zwibel and Smrtka, 2011). MS-related gait impairments have been reported, affecting numerous gait parameters (Comber et al., 2016) even when no clinical signs are present (Nogueira et al., 2013). It has been well documented that PWMS typically walk more slowly (Mevellec et al., 2003), with a decreased stride length (King et al., 1994; Mevellec et al., 2003) and a more prolonged double support phase. Additionally PWMS present with decreased ankle (Benedetti, et al., 1999a, 1999b), knee (Kelleher et al., 2010) and hip range of motion (King et al., 1994) as well as increased kinematic gait variability (Crenshaw et al., 2006). It is common for PWMS to display gait deviations related to deficiencies in overall flexion of the lower limb during swing, impairing foot clearance (Kelleher et al., 2010).

Walking in the real-world involves negotiating challenging surfaces or uneven grounds, which require constant adjustments of the body's movement patterns to maintain stability. A postural strategy to adapt the walking pattern to the surface under the foot (Menz et al., 2003) is required in order to maintain dynamic stability and thereby avoid falls and injuries (MacLellan and Patla, 2006). Therefore, challenges to adapt the basic gait pattern to meet the environmental demands are likely greater than in healthy adults (HA). Walking across different surfaces causes adaptations to gait parameters including a reduction in step length and velocity (Marigold and Patla, 2008) and increase in step width (Hak et al., 2013), most likely due to the increase in challenge of balance control (Marigold and Patla, 2008) when walking conditions require a high level of both stability and adaptability (Hak et al., 2013). It is known that older adults have a reduced ability to adapt their gait pattern, which may increase their falls risk (Caetano et al., 2016). While there is little research into the mechanics of walking across different or

* Correspondence to: Department of Rehabilitation, Aged and Extended Care, Faculty of Medicine, Nursing and Health Sciences, Flinders University, Adelaide, Australia.
E-mail address: maayken.vandenberg@flinders.edu.au (M.E.L. van den Berg).

http://dx.doi.org/10.1016/j.msard.2017.05.008
Received 1 February 2017; Received in revised form 19 May 2017; Accepted 21 May 2017

compliant surfaces in PWMS, it has been reported that PWMS avoid walking on uneven ground due to the increased attentional demands required (Nilsagård et al., 2009). Understanding how PWMS adapt to walking on varying surfaces may provide useful insights which could be used to improve locomotor patterns (Menz et al., 2003).

Sand is simultaneously uneven, unpredictable and movable and has a significant effect on the mechanics of locomotion, changing the pattern of movement. The forced use paradigm behind many therapy approaches (Eng and Tang, 2007; Ifejika-Jones and Barrett, 2011) suggests that if gait pattern shifts (e.g. increased knee and hip flexion) could be achieved by walking on sand then increased walking on sand may lead to improved patterns of usual walking. Before a therapeutic effect can be assessed, how PWMS adapt to walking on sand first needs to be established. Sand (beach) is generally an easily accessible, natural, no cost resource that many people across the globe could access. However, gait characteristics when walking over sand in PWMS, or HA, have not been described to date.

The aim of this study was to characterise kinematic gait adaptations made by PWMS in response to walking on an uneven dry-sand surface and to describe any immediate post-adaptation effects after walking on sand which occur when returning to walking on level ground. We hypothesised that individuals would adapt to walking on sand by increasing overall flexion of the lower limb during swing to facilitate foot clearance. We also hypothesised that there would be an immediate post-adaptation effect where improved flexion might persist after walking on sand.

2. Material and methods

2.1. Participants

In this descriptive exploratory case-control study we aimed to recruit a convenience sample of 16 PWMS. Similar to recruitment strategies in previous studies (Givon et al., 2009), a smaller group of 10 HA were recruited as controls, as heterogeneity in HA is expected to be smaller. PWMS who met the following criteria were eligible to participate in this study: a diagnosis of MS (self-reported); able to walk independently with or without the use of a walking stick (Disease Steps score 1–4, (Hohol et al., 1999)); able to understand instructions and give informed consent, and aged 18 years or over. Exclusion criteria included: currently participating in other clinical trials or exercise program; an exacerbation or relapse of MS within the past 3 months; use of a walker or bilateral support; diagnosis of other neural, cardiovascular, orthopaedic or muscular disease besides MS that would impact the ability to perform the walking tests safely.

PWMS were recruited from a database of participants from previous trials at the Repatriation General Hospital (RGH), Adelaide and from the MS Society of South Australia and Northern Territory. Staff members and their relatives acted as age-matched HA. All participants provided written consent prior to the commencement of the study.

The study protocol conforms to the ethical guidelines of the 1975 Declaration of Helsinki and was approved by the local health research ethics board of *Southern Adelaide Clinical Human Research Ethics Committee*.

2.2. Procedures

This study took place between December 2012 and February 2013 at the South Australian Movement Analysis Centre at the Repatriation General Hospital in Adelaide, Australia. Each participant attended one session that lasted approximately two hours.

Assessments included the Disease Steps (Hohol et al., 1999), a measure of functional disability in MS primarily based on ambulation, 12- Item MS Walking Scale (MSWS12) (Hobart et al., 2003), spatio-temporal gait parameters, and lower limb joint kinematics.

The Disease Steps scale consists of a single item that assesses MS patients' level of disability on a 7-point scale ranging from 0 to 6, with 6 representing the greatest disability (Hohol et al., 1995). It is validated against the Expanded Disability Status Scale (Hohol et al., 1999), a widely used physician-reported measure of disability. The MSWS12 is a self-report measure of the impact of MS on the individual's walking ability (Hobart et al., 2003). Individual items are scored on a 5 point Likert scale with higher scores indicating higher perceived impact.

3D gait analysis was conducted using an 8 camera Vicon MX3 system (Vicon, Oxford, UK), recording the trajectories of reflective markers using the Helen Hayes marker set and method (Kadaba et al., 1990; McLoughlin et al., 2012). Walking trials were completed on a level laboratory floor walkway and a dry-sand walkway. The sand walkway was 6.2 m long and 0.1 m deep. Spatiotemporal data and kinematic data for the hip knee and ankle was collected during forward walking at self-selected walking speed in comfortable footwear in the following order: 1) level ground (baseline), 2) sand (gait adaptation response), and 3) level ground (post-adaptation).

The first 10 level ground walk trials provided baseline data (condition I). Patients were simply asked to walk on the level floor walkway ten times, at their own comfortable walking speed. The participant was then asked to walk on the sand walkway for up to 2 min (condition II). The 2 min walk test is a strong predictor of the 6-min walk test, which can be used as a practical replacement in clinical assessment (Gijbels et al., 2011), whilst maintaining a level of exertion within the description of 'light activity' (McLoughlin et al., 2016a, 2016b) on the 0–10 scale of perceived exertion (Borg, 1982). Finally, once more 10 level ground walk trials were undertaken to examine the immediate post-adaptation response of gait on returning to level ground walking (condition III).

Participants could rest between condition I and II, but were encouraged not to do so between condition II and III, in order to maximize the post-adaption effect after sand walking.

Data were collected and processed using Vicon Nexus software (v1.4), and spatiotemporal parameters and joint kinematics (joint angles) were extracted via a customised software (MatLab v7). Sagittal plane hip, knee and ankle kinematics were of particular interest. The mean spatiotemporal and kinematic data for both limbs were calculated from the five walking trials with the best marker visibility for each participant in each of the 3 walking conditions. The sum of peak hip and knee flexion and ankle dorsiflexion during swing was used to describe total lower limb flexion. Phases of the gait cycle were identified by eyeballing the curves displaying the gait kinematics, setting a range, and within this range identifying the peak, as displayed in Table 1, The Vicon's software Butterworth filter was used for data processing. During the walking trials perceived fatigue and exertion were monitored using the Modified Borg Scale (Borg, 1982) and the Visual Analogue Scale for fatigue (Lee et al., 1991) at the end of each walking trial to ensure there was no fatiguing effect of walking on gait kinematics, and to encourage the participants to rest when required.

2.3. Statistical analysis

The data were analysed using IBM SPSS Statistics version 19 (SPSS, Inc, Chicago, IL, USA) by an independent researcher. Descriptive statistics were calculated for demographic and outcome measure data. The values of walking speed, cadence, and maximum hip, knee, and ankle flexion angles during swing extracted from the best quality five trials were averaged for each participant for each walking condition for the more affected limb in PWMS (Barr et al., 2016; McLoughlin et al., 2016a, 2016b). Independent samples *t*-tests were used to assess differences between PWMS and HA for all outcomes. To assess the effect of transitioning between walking surfaces, a mixed models repeated measures analysis of variance was used with surface (level 1, sand, level 2) as within surface factors and group allocation (PWMS, HA) as a between subject factor. To assess the changes in gait parameters when transitioning between different walking surfaces