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The effect of a novel gait retraining device on lower limb kinematics and muscle activation in healthy adults

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ABSTRACT

The Re-Link Trainer (RLT) is a modified walking frame with a linkage system designed to apply a non-individualized kinematic constraint to normalize gait trajectory of the left limb. The premise behind the RLT is that a user's lower limb is constrained into a physiologically normal gait pattern, ideally generating symmetry across gait cycle parameters and kinematics. This pilot study investigated adaptations in the natural gait pattern of healthy adults when using the RLT compared to normal overground walking. Bilateral lower limb kinematic and electromyography data were collected while participants walked overground at a self-selected speed, followed by walking in the RLT. A series of 2-way analyses of variance examined between-limb and between-condition differences. Peak hip extension and knee flexion were reduced bilaterally when walking in the RLT. Left peak hip extension occurred earlier in the gait cycle when using the RLT, but later for the right limb. Peak hip flexion was significantly increased and occurred earlier for the constrained limb, while peak plantarflexion was significantly reduced. Peak knee flexion and plantarflexion in the right limb occurred later when using the RLT. Significant bilateral reductions in peak electromyography amplitude were evident when walking in the RLT, along with a significant shift in when peak muscle activity was occurring. These findings suggest that the RLT does impose a significant constraint, but generates asymmetries in lower limb kinematics and muscle activity patterns. The large interindividual variation suggests users may utilize differing motor strategies to adapt their gait pattern to the imposed constraint.

1. Introduction

One of the primary goals for patients post-stroke is the restoration of walking ability (Mehrholz, 2013; Pollock et al., 2012). More often than not, those who go on to regain walking function will demonstrate slow walking speeds and asymmetries in a variety of gait parameters (Patterson et al., 2008). Up to 55% of patients will walk with significant spatiotemporal asymmetries (Patterson et al., 2008); particularly prolonged swing-time, reduced stance-time, and longer step-lengths for the paretic limb (Balaban and Tok, 2014; Patterson et al., 2008; Patterson et al., 2010). In addition to spatiotemporal asymmetries, kinematic asymmetries are also present in post-stroke gait most noticeably in the sagittal plane (Balaban and Tok, 2014; Olney et al., 1994). Gait symmetry is only one component of lower limb function during gait, and there are potentially other aspects contributing to gait impairments post-stroke. In addition to sensorimotor deficits, spasticity and weakness, gait impairments may also result from deficient neuromuscular control. It has been suggested that the timing of muscle activity is key to coordinated movement, normal gait patterns, and therefore safe ambulation (Daly et al., 2011). Slow or delayed activation of key muscles during walking poses a significant safety risk, and potentially increases the risk of falls during normal everyday tasks (Daly et al., 2011; Daly et al., 2007; Den Otter et al., 2007).

Conventional rehabilitation methods are not sufficiently retraining gait post-stroke, with half of all stroke patients not responding to existing therapeutic interventions to improve gait (Duncan et al., 2011; Mulroy et al., 2010). Robotic end-effector devices and exoskeletons are being developed to facilitate gait rehabilitation. It is thought that robots for gait rehabilitation can provide more repeatable and consistent therapy to patients compared to conventional rehabilitation methods, and therefore

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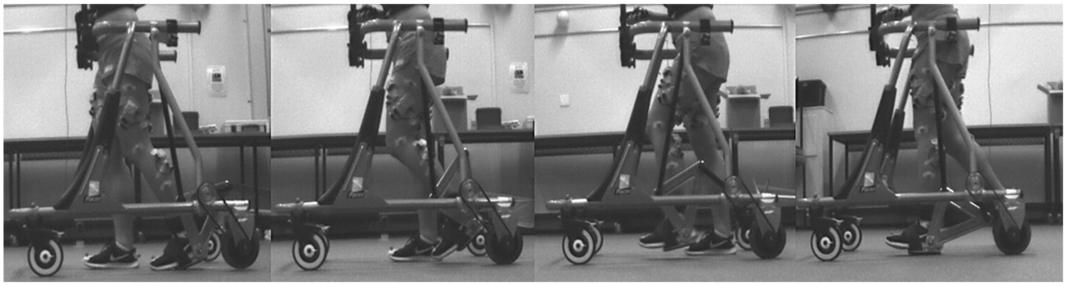

Fig. 1. Participant walking in the Re-Link Trainer (left toe-off to left heel strike). The left limb is the constrained limb in this study.

improve patient outcomes (Mehrholz, 2013). However, the currently available devices and exoskeletons for gait retraining (e.g. Lokomat, LOPES and ReWalk) are more commonly utilized in sub-acute to chronic post-stroke rehabilitation, and are associated with prolonged set-up times and high cost of access and use.

The Re-Link Trainer (RLT) is a potentially cost-effective device for retraining gait during the acute post-stroke stage. The RLT is a passive end-effector device for gait retraining, built on a commercially available walking frame (Pacer Gait Trainer, Rifton USA). The current device consists of a modified walking frame with a 4-bar linkage, and is designed to impose a kinematic constraint on the left limb by moving it through a normalized predefined gait path trajectory via a footplate. The gait path was modeled on step length data obtained from a healthy individual that was then scaled to 60% (Kora et al., 2016), to give a step length characteristic of stroke patients (Balaban & Tok, 2014; Patterson et al., 2008) (Fig. 1). The user's left foot is attached to the footplate via Velcro straps, keeping the ankle constrained in a neutral joint position while the hip and knee remain free. Therefore, the joint kinematics are a result of the ankle path and hip position, governed by the length of the limbs (Kora et al., 2016; Ward et al., 2017). The user pushes the RLT forward, as they would for a standard walking frame, and the footplate moves the users foot in the predefined gait path (Kora et al., 2016; Ward et al., 2017). In the current iteration of the RLT the gait path is not optimized for each user. A detailed description of the RLT design and optimization has been published in Kora et al., 2016 and Ward et al., 2017.

Changes to muscle activation patterning in the lower limb post-stroke can determine the quality, and functional limitations, of the gait pattern (Daly et al., 2011). Knowing that timing of muscle activation is important for an effective gait pattern post-stoke, it is important to ensure that the RLT creates appropriate lower limb muscle activation patterns in conjunction with the kinematic constraint. Therefore the aim of this pilot study was to examine the lower limb kinematics and muscle activation patterns of the constrained and unconstrained limbs when walking in the RLT, compared to normal overground walking. It was hypothesized that walking in the RLT will create significant alterations to the kinematics of the constrained lower limb in healthy individuals, and that lower limb muscle activity will be significantly lower in the constrained limb compared to the unconstrained limb.

2. Methods

2.1. Procedures

Nine healthy adults, with no history of lower limb injury within the previous 6-months took part in the study (5F/4M; mean ± SD: Height 1.70 ± 0.10 m; Weight 62.9 ± 7.03 kg; BMI 21.7 ± 2.48 kg.m^2; Age 25.5 ± 4.4 years). Participants all provided written informed consent, and the university ethics committee approved the study procedures. Participants wore their own athletic shoes for testing, and were outfitted with 16 retro-reflective markers (14 mm) bilaterally following the Plug-in-Gait lower body marker placement guidelines. Participants walked at a self-selected speed over a 7 m walkway a minimum of five times, followed by a minimum of five trials walking in the RLT. A period of familiarization with the RLT was provided for each participant in between overground walking trials, and RLT walking trials. The left limb was the constrained limb in the Re-Link Trainer for all participants in this study.

2.2. Gait analysis

Bilateral spatiotemporal and 3D kinematic data were collected at 100 Hz using a twelve camera Vicon motion capture system (Vicon Motion Systems Ltd). Initial contact and toe-off were manually identified through frame-by-frame inspection, and labeled in Nexus version 2.4 (Vicon Motion Systems Ltd) for each gait cycle and trial, for each participant. Video from two Bonita cameras (Vicon Motion Systems Ltd) was used for additional reference in identifying the gait events. Data were imported into MatLab for analysis offline using a custom algorithm. Walking speed, stride length and step length were determined for each participant. The following kinematic variables were extracted for each participant in each condition: peak hip flexion and extension, peak knee flexion (swing phase), and peak ankle plantarflexion and dorsiflexion. Peak joint angles were extracted for each trial, and averaged for each participant. The hip, knee and ankle sagittal plane kinematic waveforms for each limb were time normalized to 100% of the gait cycle (Boudarham et al., 2013). The shift in occurrence of peak angles was identified for the hip, knee, and ankle joints and expressed as a percentage of the gait cycle.

2.3. EMG analysis

To provide neuromuscular context to the gait assessment, bilateral EMG (Myon AG, Schwarzenberg, Switzerland) was collected simultaneously with the kinematic data in Nexus 2.4 at 1000 Hz using pre-gelled, bipolar Ag/AgCl electrodes from the following muscles: rectus femoris, vastus lateralis, vastus medialis, medial hamstrings, lateral hamstring (biceps femoris), and the lateral gastrocnemius. Skin sites were shaved where necessary and prepared using abrasive paste to lower the skin impedance. Electrodes were placed according to the recommendations of SENIAM (Hermens et al., 2000). The EMG signal was high- then low-pass filtered with a 4th order Butterworth filter at cut off frequencies of 400 Hz and 20 Hz respectively, then smoothed by calculating the root-mean-square (RMS) value for each 100 ms sliding window of data. The EMG trace of each muscle was then segmented according to the gait cycles – defined by initial contact to initial contact of the same side of the body. Noisy channels were identified manually to ensure channels with poor signal quality are eliminated before further analysis. Noisy channels were defined as those where muscle activity could not be visually distinguished from baseline noise.

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