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Assessment of the effects of body weight unloading on overground gait biomechanical parameters

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ABSTRACT

Background: Gait rehabilitation with body weight unloading is a common method of gait rehabilitation for clinical subjects with neurological and musculoskeletal impairments. However, the efficiency of this method was hard to assess given the confounding variables walking modality (treadmill vs. overground) and subjects' inability to maintain a comfortable speed when pulling a body weight unloading system by which they were suspended. By controlling the gait modality (overground) and devising a mechanical device that pulled the system at a constant speed, this study could examine the unique effects of body weight unloading on the biomechanical parameters of healthy subjects walking overground at comfortable speed.

Methods: Ten healthy subjects were instructed to walk overground under a control (no suspension vest) and three (0%, 15%, 30%) body weight unloading experimental conditions. Hip, knee and ankle spatiotemporal, kinematic, and kinetic measures were recorded for all conditions (six trials per condition).

Findings: ANOVA showed no changes in cadence, speed and stride length, a reduction in double limb support and increase in single limb support. Pairwise comparisons of gait parameters under 0%,15% and 30% body weight unloading conditions indicated significant reductions in lower joint kinematics and kinetics with increased body weight unloading. Additionally, despite changes in the peak values of kinematic and kinetic measures, the curvature patterns remained unchanged.

Interpretation: This study shows that overground gait with up to 30% body weight unloading reduces joint loads without modifying gait curvature patterns or the plantarflexion angle. Several clinical applications for gait reeducation conducted in situ with unloading are enumerated.

1. Introduction

Body weight unloading (BWU) conducted on treadmills has become a common method of gait rehabilitation for patients with neurological and musculoskeletal impairments (Barbeau et al., 2004; Hesse et al., 1994; Lee and Hidler, 2008; Mangione et al., 1996; Patiño et al., 2007; Threlkeld et al., 2003). The assumption behind this method is that the partial support of clinical subjects' body weight with a BWU suspension vest during treadmill walking will alleviate the load applied on the lower joints and the related pain experienced when patients start walking, thereby allowing them to generate the locomotor patterns (Sousa et al., 2009) and sensorimotor input essential for successful gait correction (Dietz, 2009). Gait rehabilitation on treadmills with a BWU suspension vest was, therefore, recommended early after injury or surgery to induce sensory stimulation (Threlkeld et al., 2003), and improve gait speed, balance and locomotion (Dickstein, 2008; Lamontagne and Fung, 2004; Perry and Davids, 1992; Perry et al., 1995; Schmid et al., 2007; Sousa et al., 2009; Van Hedel et al., 2006).

One of the main assumptions of gait research and rehabilitation on treadmills was that treadmill and overground gait patterns were similar enough so that gait corrections on treadmills could easily transfer to daily overground walking. However, research comparing treadmill and overground gait of healthy subjects refutes this assumption by showing that albeit small, the modifications of gait biomechanical parameters observed on a moving belt — the treadmill, were nevertheless significant (Murray et al., 1985; Riley et al., 2007; Strathy et al., 1983). In comparison to overground gait, healthy subjects' gait on treadmills became more conservative as exhibited by a significant reduction in speed and peak hip and knee flexion and extension which resulted in reduction in range of motion (Murray et al., 1985; Riley et al., 2007; Strathy et al., 1983). Similarly, significant modifications in healthy subjects lower joints' ground reaction forces (GRF) were observed during treadmill gait (Kram et al., 1998; Riley et al., 2007). In comparison to overground gait, healthy subjects' treadmill gait exhibited a significant decrease in ankle dorsiflexion and knee extension moments, and a significant increase in hip extension moments (Lee and Hidler, 2008; Riley et al., 2007).

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Research comparing overground vs. treadmill gait with BWU indicated significant deviations in gait motor patterns and kinematics during treadmill walking (Alton et al., 1998; Lee and Hidler, 2008; Threlkeld et al., 2003; Van Hedel et al., 2006). Healthy subject's foot on a treadmill was observed to be pulled posteriorly and to remain for a longer period of time on the moving belt which required proximal knee and hip kinematic adjustments to permit foot clearance (Threlkeld et al., 2003). The observed differences in gait patterns led to the conclusion that treadmill gait does not replicate overground gait. Consequently, the unique effects of BWU on gait parameters could not be assessed as long as research was conducted on treadmills (Carollo and Matthews, 2002; Harris and Smith, 1996; Hesse et al., 1997; Ivanenko et al., 2004, 2006; Lee and Hidler, 2008; Murray et al., 1985).

A limitation to be addressed prior to conducting overground gait research with BWU was related to healthy subjects' inability to maintain a comfortable overground walking speed when having to pull the BWU system to which they were attached. Consequently subjects' gait speed variability, which was easily controlled on treadmills with BWU, constituted a potentially confounding variable that had to be controlled prior to conducting this study. To meet this challenge a mechanical device was designed to pull the BWU system at a constant speed. No longer having to pull the BWU system, healthy subjects' gait speed variability overground was controlled thus allowing us to pursue the objectives of this study which were to examine the unique effects of BWU on gait spatiotemporal, kinematic and kinetic parameters under conditions that replicate daily walking.

We expected that partial reduction of healthy subjects' body weight, performed with a BWU system during overground walking, would reduce lower joint loads (kinetics), and result in modifications and changes of gait spatiotemporal and kinematic parameters to allow for gait curvature patterns to remain unchanged.

The hypotheses of this study were as follows: A reduction of 0%, 15% and 30% body weight load during overground walking will result in modifications and changes of healthy subjects' gait (1) spatiotemporal parameters, (2) kinematic parameters, and (3) kinetic parameters without modifying the gait kinematic and kinetic overall curvature patterns over the gait cycle.

2. Methods

2.1. Subjects

Ten male subjects were recruited for this study. The sample variability was controlled by including only healthy subjects with no previous history of lower extremity joint injuries or gait impairments. Additionally, all the subjects recruited were approximately the same age, height and weight: mean (SD) age in years was 23.8 (3), mean (SD) height was 1.72 (0.06) m and mean weight was 67.7 (5.7) kg. The study was approved by the Internal Review board, and informed consent was obtained from all subjects before data collection.

2.2. Instrumentation

The Biodex Unweighing System (Biodex Co., Shirley, NY, USA) (Fig. 1a) was used to manipulate subjects' body weight and accommodate for the vertical displacement of the center of gravity during overground gait under controlled BWU levels. This system includes a suspension vest with shoulder straps, a pelvic belt and a groin piece attached to the belt. Once suspended in the BWU device in an upright position, a pulley system lifted the subjects until the predetermined BWU level was reached, as a function of their body weight (in kg), and indicated on the screen of the Biodex system.

Previous gait research on treadmills with BWU has shown that a reduction of more than 30% BWU resulted in significant distortions of healthy subjects' biomechanical parameters. Subjects' gait speed and step length were greatly reduced (Lewek, 2011; Threlkeld et al., 2003; Van Hedel et al., 2006). Also observed were significant reductions in hip and knee kinematics (Finch et al., 1991; Threlkeld et al., 2003), in knee and ankle flexion moments, and in hip extension moments (Goldberg and Stanhope, 2013), and a significant increase in the ankle plantarflexion angle (Threlkeld et al., 2003; Van Hedel et al., 2006). Based on these findings, researchers concluded that a reduction of more than 30% body weight during treadmill walking resulted in a pronounced distortion in hip movement and impaired the ability of the ankle plantarflexors to produce propulsive forces. Learning from previous research (Lewek, 2011; Meinders et al., 1998; Sousa et al.,

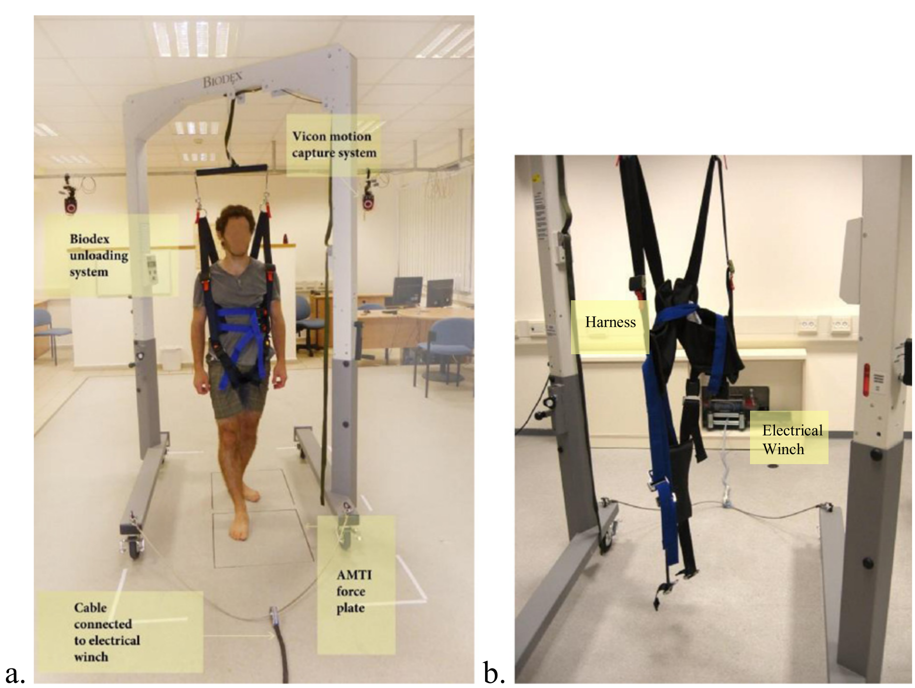

Fig. 1. a. The BWU Biodex system, b. The BWU system connected to the electrical winch.