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Comparative analysis of speed's impact on muscle demands during partial body weight support motor-assisted elliptical training

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ABSTRACT

Individuals with walking limitations often experience challenges engaging in functionally relevant exercise. An adapted elliptical trainer (motor to assist pedal movement, integrated body weight harness, ramps/stairs, and grab rails) has been developed to help individuals with physical disabilities and chronic conditions regain/retain walking capacity and fitness. However, limited published studies are available to guide therapeutic interventions. This repeated measures study examined the influence of motor-assisted elliptical training speed on lower extremity muscle demands at four body weight support (BWS) levels commonly used therapeutically for walking. Electromyography (EMG) and pedal trajectory data were recorded as ten individuals without known disability used the motor-assisted elliptical trainer at three speeds [20,40, 60 revolutions per minute (RPM)] during each BWS level (0%, 20%, 40%, 60%). Overall, the EMG activity (peak, mean, duration) in key stabilizer muscles (i.e., gluteus medius, gluteus maximus, vastus lateralis, medial gastrocnemius and soleus) recorded at 60 RPM exceeded those at 40 RPM, which were higher than values at 20 RPM in all but three situations (gluteus medius mean at 0% BWS, vastus lateralis mean at 20% BWS, soleus duration at 40% BWS); however, these differences did not always achieve statistical significance. Slower motor-assisted speeds can be used to accommodate weakness of gluteus medius, gluteus maximus, vastus lateralis, medial gastrocnemius and soleus. As strength improves, training at faster motor-assisted speeds may provide a means to progressively challenge key lower extremity stabilizers.

1. Introduction

Physical activity sustains functional independence [1–6] and prevents chronic conditions (e.g., diabetes, heart disease), [4,6–8], yet many individuals with walking limitations find functionally relevant exercise opportunities unattainable [9–11]. During rehabilitation, the need for one to three clinicians to help move the limbs and trunk of severely involved patients limits practical use of partial body weight support treadmill training (BWSTT). Robotic devices reduce labor demands compared to BWSTT, but the purchase price (some well over $300,000) prevents widespread use. Cardiovascular training devices commonly found in community settings and homes (e.g., treadmills and elliptical trainers) are designed primarily for nondisabled individuals, thus do not always accommodate the needs of individuals with profound weakness, balance deficits, or cardiovascular deconditioning. This is unfortunate given the notable cardiovascular deconditioning present in many individuals with physical disabilities [12–15].

A prototype motor-assisted elliptical training system (Fig. 1) was developed to address the need for affordable, accessible exercise technology to help individuals with physical disabilities and chronic conditions regain/retain walking capacity and fitness. Biomechanical testing was initially performed to identify an elliptical trainer that promoted joint motions and muscle demands that were similar to walking [16]. Then, the adjustable stride-length elliptical was modified to enable use by individuals with and without physical disabilities [17,18]. Stairs, ramps, support rails, pedal adaptations, and a bench were added. An auxiliary motor-drive system was integrated with the elliptical's flywheel to assist those with diminished strength/coordination to initiate and

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Fig. 1. Prototype motor-assisted elliptical trainer. An elliptical trainer was adapted to enable individuals with physical disabilities to improve walking and cardiovascular fitness. Stairs, ramps, support rails, pedal adaptations and a bench improved access to the device. An integrated sensor and motor system aided pedal movement and limb advancement. The system was integrated with a body weight support system.

sustain pedal movement at training speeds up to 65 revolutions per minute (RPM) [18,19]. Collectively, the modifications increased ease of access, safety and usability of the elliptical by individuals with disabilities and chronic conditions [17,18].

Subsequent use of the motor-assisted elliptical in rehabilitation and fitness settings highlighted the value of incorporating a partial body weight support (BWS) system [19–21]. The BWS enabled individuals with profound lower extremity weakness and motor control deficits to engage in upright locomotor and cardiovascular training on the motor-assisted elliptical. Clinically, we observed that patients were able to train for longer periods (i.e., increased mass repetition) when using the BWS [19–21].

Although individuals with physical disabilities are using the system, to date, no literature exists to elucidate the relationship between motor-assisted elliptical training speed and lower extremity muscle demands at different BWS levels. During treadmill walking, Hesse and colleagues [22] reported that faster walking speeds were associated with greater electromyography (EMG) activity of the rectus femoris, biceps femoris, vastus medialis, gastrocnemius and tibialis anterior in 24 ambulatory inpatients with hemiparesis. Given documented similarities in muscle demands during elliptical training and overground walking [16], it is possible that a similar relationship might exist during motor assisted elliptical training at different speeds.

The purpose of this study was to systematically compare how lower extremity muscle demands were influenced by training speed (20, 40, 60 RPM) when using the motor-assisted elliptical with different BWS levels (0%, 20%, 40%, 60%). Given that clinicians often pre-select a specific BWS level when working with a patient, we specifically elected to evaluate the impact of speed within BWS levels commonly used in the clinical setting. We hypothesized that faster motor-assisted speeds would result in greater peak and mean EMG activity of the primary stabilizer muscles, in particular gluteus medius, gluteus maximus, vastus lateralis, medial gastrocnemius and soleus, within each level of BWS. Understanding how muscle demands vary in response to differing speeds during motor-assisted elliptical training at different BWS levels should provide foundational knowledge to guide clinicians' selection of training parameters that maximize outcomes for individuals with differing therapeutic training goals (e.g., strengthening quadriceps vs. calf muscles).

2. Methods

2.1. Participants

Ten individuals (5 men and 5 women) free from musculoskeletal, neurological, and cardiovascular impairment that might affect their ability to walk or exercise participated. Their mean age was 26.8 years (SD = 3.8, range = 24–36), mean body mass was 80.4 kg (SD = 13.2, range = 52.7–98.6) and mean height was 174.2 cm (SD = 8.5, range = 157.5–182.9). Participants were recruited from staff at Madonna Rehabilitation Hospital (Lincoln, NE).

2.2. Instrumentation

2.2.1. Electromyographic activity

Pre-amplified surface EMG electrodes (DE-3.1, Delsys, Inc., Boston, MA) recorded muscle activity. The signals were transmitted via a 6.5 mm cable to a desktop unit (Bagnoli 16 EMG System, Delsys, Inc., Boston, MA), amplified with a gain of either 1000 or 10,000 prior to filtering at a bandwidth of 20–450 Hz and sampling at 1200 Hz using a 16-bit Analog to Digital conversion board. Visual3D Professional software (CA-Motion, Inc., Germantown, MD) was used for subsequent data processing.

2.2.2. Pedal trajectory analysis

The Qualisys Motion Capture System (Qualisys AB, Gothenburg, Sweden), including 12 Oqus Series-3 cameras recorded pedal trajectories (120 Hz) from reflective markers (12.5-mm diameter) placed on the motor-assisted elliptical pedals. The trajectories were processed with Visual3D Professional software.

2.2.3. Motor-assisted elliptical trainer

Participants performed all activities on the same motor-assisted elliptical trainer [18–21]. A SportsArt Fitness E870 adjustable stride length elliptical trainer (SportsArt Fitness, Woodinville, WA) was retrofitted with ergonomic and safety modifications previously described. Speed was preset and monitored using an integrated speed sensor. Motor assistance guided the foot pedals at the predetermined speeds of 20 RPM (slow), 40 RPM (medium), and 60 RPM (fast) [18].

2.2.4. Partial body weight support system

Each participant was fitted with an appropriately sized harness (Maine Antigravity Systems, Inc., Portland, ME). The harness was attached to an overhead BWS system (PnueWeight Unweighting System, Pnuemex, Sandpoint, ID) that was integrated into the base of the motor-assisted elliptical training platform.

2.3. Procedures

This repeated measures study was conducted from September to October 2010 in the Movement and Neurosciences Center,