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How does wearable robotic exoskeleton affect overground walking performance measured with the 10-m and six-minute walk tests after a basic locomotor training in healthy individuals?

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ABSTRACT

It is still unknown to what extent overground walking with a WRE is equivalent to natural overground walking without a WRE. Hence, the interpretability of the 10-m (10MWT) and six-minute (6MWT) walk tests during overground walking with a WRE against reference values collected during natural overground walking without a WRE is challenging. This study aimed to 1) compare walking performance across three different overground walking conditions: natural walking without a WRE, walking with a WRE providing minimal assistance (*active walking*), and walking with a WRE proving complete assistance (*passive walking*) and 2) assess the association and the agreement between the 10MWT and the 6MWT during passive and active walking with a WRE. Seventeen healthy individuals who underwent basic locomotor training with a WRE performed the 10MWT (preferred and maximal speeds) and the 6MWT under the three conditions. For the 10MWT, the speed progressively and significantly decreased from natural walking without a WRE (preferred: 1.40 ± 0.18 m/s; maximal: 2.16 ± 0.19 m/s), to active walking with a WRE (preferred: 0.48 ± 0.10 m/s; maximal: 0.61 ± 0.14 m/s), and to passive walking with a WRE (preferred: 0.38 ± 0.09 m/s; maximal: 0.42 ± 0.10 m/s). For the 6MWT, total distances decreased from walking without a WRE (609 ± 53.9 m), to active walking with a WRE (196.6 ± 42.6 m), and to passive walking with a WRE (144.3 ± 33.3 m). The 10MWT and 6MWT provide distinct information and can't be used interchangeably to document speed only during active walking with the WRE. Speed and distance drastically decrease during active and, even more so, passive walking with the WRE in comparison to walking without a WRE. Selection of walking tests should depend on the level of assistance provided by the WRE.

1. Introduction

Wearable robotic exoskeletons (WRE) are increasingly used as an overground gait training intervention among individuals who have sensorimotor impairments and no or very limited walking ability [1–8]. In this population, performance during overground walking with a WRE is frequently quantified using standardized performance-based walking speed or distance tests. Among those, the 10-m walk test (10MWT) and the six-minute walking test (6MWT) are the most frequently used due to their ease of administration and their well-established psychometric properties [9]. Moreover, the 10MWT and 6MWT are often used as primary outcome measures to characterize the effects of overground gait training programs with a WRE among long-term wheelchair users with no walking ability. A recent meta-analysis revealed that the weighted mean gait speed attained by a heterogeneous group of individuals with a spinal cord injury (SCI) during overground walking with different models of WRE was 0.26 ± 0.15 m/s (*N* = 84; 15 studies included; speed: complete SCI = 0.25 ± 0.14 m/s and incomplete SCI = 0.32 ± 0.25) after having completed various training protocols encompassing a wide range of training sessions [2]. It is difficult to interpret these results since it is still unknown to what extent overground walking with a WRE is equivalent to natural overground

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walking without a WRE and no exoskeleton-specific benchmarking or normative data is available for the 10MWT or the 6MWT. Moreover, although manufacturers claim that overground walking with their WRE system may allow one to reach walking speeds comparable to able-bodied individuals walking at a natural self-selected comfortable speed or the walking speed threshold needed for community ambulation, no strong clinical evidence supports these claims to date.

Hence, it is timely to study the effects of a WRE on walking performance. To do so, the primary aim of the present study is to compare natural walking speeds (i.e., preferred and maximal speeds) and distances in able-bodied individuals who underwent basic locomotor training across three different overground walking conditions: 1) natural walking without a WRE, 2) walking with a WRE providing minimal assistance (*active walking*), and 3) walking with a WRE providing complete assistance (*passive walking*). Additionally, the secondary aim of the present study is to assess the strength of the relationship and the level of absolute agreement between the speeds measured during the 10MWT and the 6MWT when participants walked at self-selected preferred and maximal speeds in the active and passive walking modes with the WRE. For the primary aim, it was hypothesized that walking speeds and distances will be 1) similar between natural walking without a WRE and active walking with a WRE and 2) significantly reduced between passive walking with a WRE in comparison to the two other conditions (no WRE and active walking with the WRE). For the secondary aim, it was hypothesized that the 10MWT and the 6MWT will capture distinct aspects of walking performance as evidenced by the clinically important different walking speeds reached between these tests (i.e., non-redundancy: the two tests can't be used interchangeably) [10]. Study results will strengthen the current level of evidence regarding expected locomotor performance during overground walking with a WRE after a basic training among individuals who have sensorimotor impairments and evaluate the usefulness of using both the 10MWT and the 6MWT or only the 10MWT in clinical practice and research protocols.

2. Methods

2.1. Research design

A single-group multiple comparison design.

2.2. Setting

A pathokinesiology laboratory located within a physical medicine and rehabilitation center.

2.3. Participants

A non-probabilistic consecutive sample of 17 able-bodied adults, who have full range of motion and normal muscle strength at the hips, knees and ankles, and ambulate without mobility assistive devices, volunteered to participate to the study (sex = 8 females/9 males; age = 33.4 ± 10.1 years; height = 1.74 ± 0.1 m; mass = 68.8 ± 12.1 kg). For participants to be fitted within the WRE, they needed to conform to the following measurements: height between 1.52–1.93 m; weight less than 100 kg; pelvis width between 30–46 cm; thigh and lower leg lengths between 51–61.4 cm and 48–63.4 cm, respectively; and a length discrepancy of no more than 1.3 and 1.9 cm was at the thigh and lower leg segments, respectively. Potential participants with a history of musculoskeletal or neurological impairment(s) affecting their upper extremity, trunk, or lower extremity, a history of cardiovascular or pulmonary disease, or any other self-reported or observed conditions that could restrict their capability to stand and walk about 45 min with the WRE or otherwise confound the results of this study were excluded. All participants gave their written consent to participate in the study after being informed of the objectives and nature of their participation.

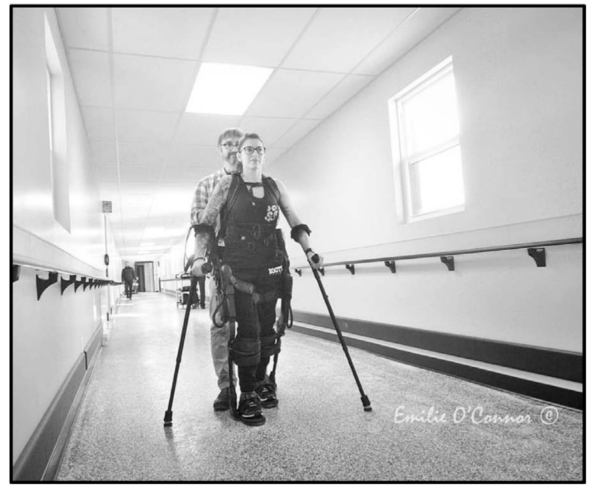

Fig. 1. Overview of a participant walking with the wearable robotic exoskeleton with contact-guard assistance of a certified physical therapist during a training session.

The Research Ethics Committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal approved the present study (CRIR-1225-0317).

2.4. Locomotor training with the robotic exoskeleton

Participants completed four 60-min training sessions, spread over a two-week period, under the direct supervision of a certified physical therapist (Table 2). During these sessions, participants were properly fitted with the EKSO™ (version 1.1) WRE (Ekso Bionics, Richmond, CA, USA) before performing sit⇔stand transitions, quasi-static and dynamic (i.e., postural oscillations) standing balance activities, and walking at first with an extra-wide walker at a self-selected safe and comfortable speed with visual, verbal and tactile feedback from the certified physical therapist (Fig. 1). As participants became familiar with the WRE and consolidated these basic skills, they were taught to safely ambulate with the exoskeleton at self-selected preferred and maximal speeds using forearm crutches under the direct supervision or with contact-guard assistance of a certified physical therapist. Participants also trained to walk with the exoskeleton set both in a "*ProStep*" mode (a passive walking where the participant is asked to avoid all voluntary muscular contraction of the lower extremities) and in a "*ProStep+*" mode (an active walking where the participant is asked to fully participate with voluntary muscle contractions of the lower extremities) to mimic individuals with different severity of sensorimotor impairments, such as complete or incomplete spinal cord injury, who are expected to train with the exoskeleton. The WRE generated at least 90% of the torque at the hip and knee joints in the "*ProStep*" mode whereas participants had to generate at least 80% of the effort needed to walk in the "*Prostep+*" mode. On average, participants stood 47.4 ± 3.3 min, walked 29.4 ± 3.7 min, and took 1375 ± 329 steps per training session. Participants were required to complete all four training sessions before being tested.

2.5. Performance-based walking tests

Locomotor performance without and with the WRE were assessed using two performance-based walking tests: the 10MWT [11], which measures the time required to walk over a 10-m distance, and the 6MWT [12], which measures the total walking distance travelled within a six-minute period (one trial). For the 10MWT, participants started two meters before the starting line and stopped walking two meters after the finish line. An electronic chronometer was started when the toes first passed the starting line and was stopped when the toes first passed the finish line. The 10MWT was performed at preferred (mean of three