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Overground versus self-paced treadmill walking in a virtual environment in children with cerebral palsy

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ABSTRACT

Treadmill walking offers several advantages for clinical gait analysis and gait training, but may affect gait parameters. We compared walking on a self-paced treadmill in a virtual environment (TM+) with overground walking in a conventional gait lab (CGL), and with natural walking (NW) outside a lab environment on a GaitRite measurement mat, for 11 typically developing (TD) children and 9 children with cerebral palsy (CP). Spatiotemporal parameters and subjective scores on similarity to normal walking were compared between all three conditions, while kinematic parameters and Gait and Motion Analysis Profile Scores (GPS and MAP) were compared between CGL and TM+. Subjects walked slower and with shorter strides in both lab conditions compared to NW. Stride width was 3–4 cm wider in TM+ than in CGL and NW. Mean kinematic curves showed a few differences between CGL and TM+: on the treadmill children with CP walked with on average 2° more pelvic tilt, 7° more knee flexion at initial contact, and more deviating knee and ankle kinematics as indicated by the MAP scores. These differences may in part be due to increased fatigue in TM+ as a result of longer continuous walking time. Our results indicate that differences between self-paced treadmill walking in a VR and walking in a conventional gait lab are generally small, but need to be taken into account when performing gait analysis on a treadmill.

1. Introduction

Instrumented treadmills are increasingly used in clinical gait analysis and gait (re)training, since they have several advantages over conventional overground gait labs. Treadmill walking allows for continuous gait and the measurement of many consecutive steps within a small measurement area. Recent developments have led to high quality instrumented treadmills, which can be placed in a virtual reality environment to allow for a natural, moving visual scene (optical flow). Real-time analysis software enables direct feedback and interaction with the subject, for instance to continuously adjust the belt speed to the subject's instantaneous walking speed, so called self-paced walking, allowing for natural variations in walking speed [1,2]. These features may enable gait analysis on a treadmill in children with cerebral palsy (CP), allowing them to walk at their own speed and in a realistic environment.

Previous studies have shown, however, that differences exist between overground and treadmill walking. On a treadmill, subjects tend to walk slower [3] and with shorter steps and higher (relative) cadence than overground [3–5]. Differences in kinematics, kinetics, and EMG have also been found [6–10], although these were generally smaller than measurement errors [7]. Patient populations such as those with stroke or prostheses generally demonstrate comparable effects of treadmill walking compared to healthy adults [11–13], although in stroke treadmill walking was also found to be more symmetrical than overground walking [12]. The differences between treadmill and overground walking may be due to the fixed, imposed treadmill speed [1], lack of optical flow [14], differences in belt surface [15], or small intra-stride variations in belt speed [7,16]. These differences possibly limit the transfer of gait analysis and training outcomes on a treadmill to overground walking.

The combination of a realistic virtual environment providing an optical flow and self-paced walking may make treadmill walking more similar to overground, but this has never been investigated. Furthermore, most studies comparing normal treadmill and overground walking evaluated adult populations, and it is not known whether the effects are any different in children with and without pathology, nor whether (potential) differences are

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clinically relevant. Different effects of treadmill walking for children are likely, especially for those with CP, since they have more stride-to-stride variability in their walking speed and gait pattern [17], a lower dynamic stability [18], and as a result they may have more difficulty adjusting to the altered environment.

The aim of this study was to compare self-paced treadmill walking in a realistic virtual environment to walking in a conventional overground gait lab, and to natural walking outside of a lab environment, both in children with CP and typically developing (TD) children. The study was set up in order to see whether treadmill walking could replace overground walking for clinical gait analysis.

2. Methods

2.1. Subjects

Twenty children participated in this cross-sectional study: 11 TD children (7 male, 4 female; age 10.6 ± 2.2 years, range 8–15; height 1.52 ± 0.15 m; weight 38.2 ± 10.5 kg) and 9 children with spastic CP (age 11.6 ± 2.1 years, range 8–14; height 1.49 ± 0.13 m; weight 40.9 ± 10.3 kg). There were no statistical differences between groups in terms of age, height, or weight. The inclusion criteria were that children with CP had to be able to walk independently without walking aids for at least 5 min on end and 30 min total within 2 h, were classified as level I or II on the gross motor function classification scale (GMFCS) [19]; had received no multilevel surgery, selective dorsal rhizotomy or baclofen treatment within the last year; nor botulinum toxin A treatment within the previous 16 weeks. CP patients fulfilling these criteria were randomly selected from the department's database, and all subjects who agreed to take part were able to fulfill the entire protocol and could be included. Two CP patients were unilaterally affected and 7 bilaterally, 4 of whom with one clearly more affected side. Two subjects had received SDR in the past and one a triceps myotenotomy. All parents and children aged 12 years and older provided written informed consent prior to participation. The protocol was approved by the local ethics committee of the VU University Medical Center in Amsterdam.

2.2. Study design and materials

All subjects walked in three conditions: overground in a conventional gait lab (CGL); on a self-paced treadmill placed in a realistic virtual environment (TM+); and in an indoor courtyard to allow for natural walking (NW). The order of conditions was randomized, with NW always first or last for practical reasons. For comfort reasons, subjects wore their own low, flat-soled shoes, including insoles (1 subject) or orthoses (3 subjects) if used daily. In all conditions, subjects were instructed to walk at their own preferred, comfortable walking speed.

CGL (Fig. 1A) consisted of a 10 m walkway with two embedded force plates. At least 5 successful trials were collected for both the left and the right leg, as defined by a full hit of one of the force plates.

TM+ (Fig. 1B) consisted of a dual-belt instrumented treadmill (R-Mill, Forcelink, The Netherlands) in a speed-matched virtual environment projected on a 180° semi-cylindrical screen, displaying an endless, straight forest road and scenery (Gait Real-time Analysis Interactive Lab (GRAIL) system, Motek Medical BV, Amsterdam, The Netherlands). The speed of the belt was real-time adjusted to match the subject's time-varying walking speed, by means of a self-paced (SP) speed algorithm [1]. Subjects were instructed to walk in the mediolateral middle of the treadmill, but not explicitly to place one foot on each separate belt. Subjects had between 6 and 10 min of habituation time to adjust to the treadmill, the virtual environment, and the SP speed algorithm.

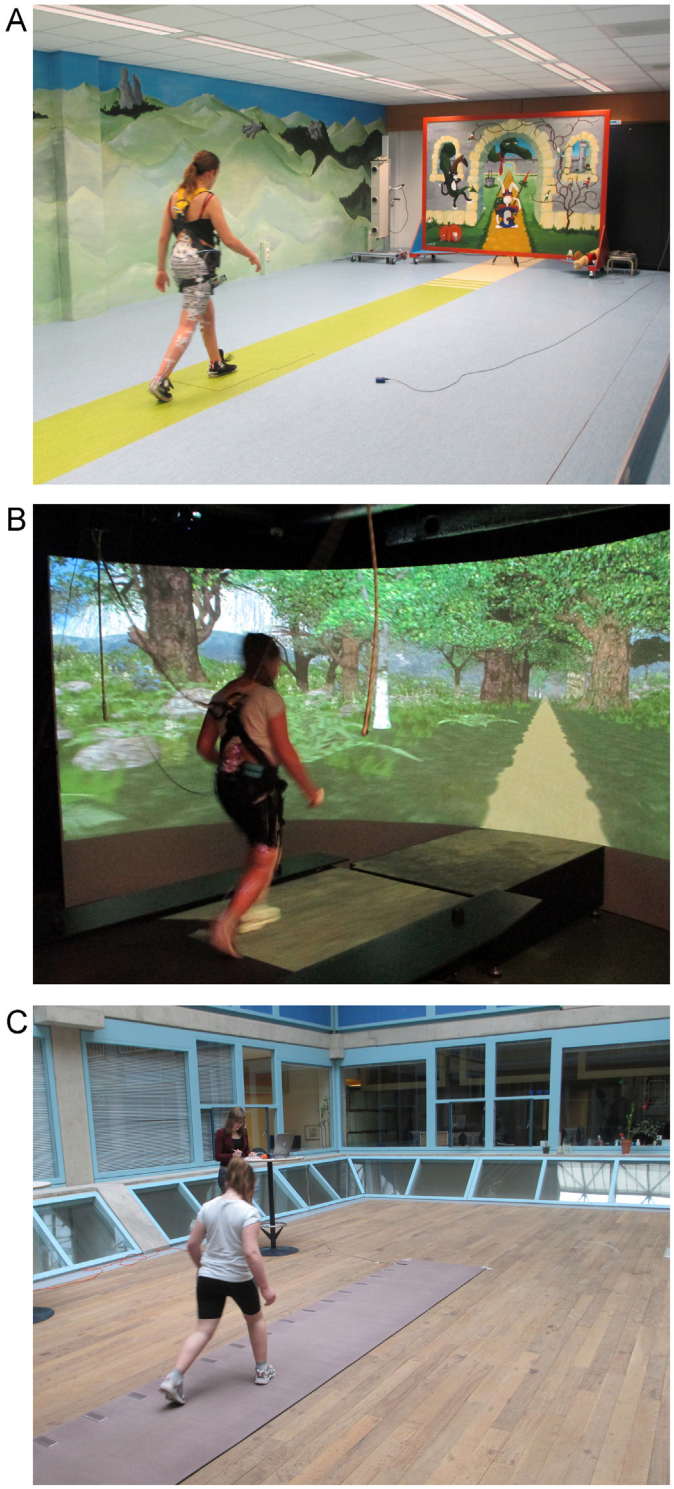

Fig. 1. Pictures of the three different conditions: (A) conventional gait lab (CGL); (B) self-paced treadmill walking in a virtual environment (TM+); (C) natural walking (NW) in an indoor courtyard over a GaitRite measurement mat.

Subsequently, as part of a larger protocol, four different 3-min trials were collected in random order (i.e. with and without SP mode and with and without a virtual environment), of which the last minute of the trial with virtual environment and in SP mode was evaluated. Subjects wore a safety harness over legs and shoulders loosely hanging from the ceiling, to prevent injury in case of an accidental fall.