Gait & Posture 39 (2014) 953–957

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Can we unmask features of spasticity during gait in children with cerebral palsy by increasing their walking velocity?

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ARTICLE INFO

Article history:
Received 2 August 2013
Received in revised form 28 November 2013
Accepted 15 December 2013

Keywords:
Cerebral palsy
Walking velocity
Spasticity
Gait

ABSTRACT

Background and aim: Spasticity is a velocity dependent feature present in most patients with cerebral palsy (CP). It is commonly measured in a passive condition. The aim of this study was to highlight markers of spasticity of gastrocnemius and hamstring muscles during gait by comparing the effect of increased walking velocity of CP and typical developing (TD) children.
Methods: 53 children with spastic CP and 17 TD children were instructed to walk at self-selected speed, faster and as fast as possible without running. Kinematics, kinetics and electromyography (EMG) were collected and muscle length and muscle lengthening velocity (MLV) were calculated. To compare the data of both groups, a linear regression model was created which resulted in two non-dimensional gait velocities. A difference score (DS) was calculated between the high and low velocity values for both groups.
Results: 103 gait parameters were analyzed of which 16 had a statistically significant DS between TD and CP groups. The spastic gastrocnemius muscle presented at high velocity with a higher ankle angular velocity, plantar flexion moment, power absorption and increased EMG signal during loading response. The spastic hamstrings demonstrated at high velocity a delayed maximum knee extension moment at mid-stance and increasing hip extension moment and hip power generation. The hamstrings also presented with a lower MLV during swing phase.
Conclusions: A limited number of gait parameters differ between CP and TD children when increasing walking velocity, giving indirect insight on the effect of spasticity on gait.

1. Introduction

Children with cerebral palsy (CP) present with varying motor deficits, including neuromotor impairments and pathological gait patterns. Spasticity is one of the most present and disabling neuromotor problems. Lance [1] defined spasticity as "a motor disorder characterized by a velocity-dependent increase in tonic stretch reflexes (muscle tone) with exaggerated tendon jerks, resulting from hyperexcitability of the stretch reflex, as one component of the upper motor neuron syndrome". Spasticity is commonly evaluated in a passive condition, either by clinical scales such as the modified Ashworth Scale [2] (MAS) or the Tardieu scale [3], or in laboratory settings using biomechanical and electrophysiological methods [4–7]. The latter provide more objective measures, but still lack functional aspects. In particular, passive measurement may not reflect the effect of spasticity on gait. More-over, CP patients have a multifaceted disorder and different studies highlight the complex relationship between spasticity and gait leaving the interactions largely uncovered [8–10].

In line of the original definition of spasticity which stresses the velocity dependency, it has been suggested that signs of spasticity during gait may be highlighted by increasing the walking velocity [11,12]. Walking faster will change the gait pattern both in CP and in typically developing (TD) children [11–15]. Indirect insight into the effect of spasticity on gait can be achieved by studying the differences in effect of increased walking velocity on gait in CP and TD children.

Abbreviations: 3D, three dimensional; CP, cerebral palsy; DS, difference score; EMG, electromyography; GC, gait cycle; GMFCS, gross motor function classification scale; LR, loading response; IC, initial contact; MAS, modified Ashworth scale; ML, muscle length; MLV, muscle lengthening velocity; rms, root mean square; TD, typical developing.

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http://dx.doi.org/10.1016/j.gaitpost.2013.12.024

A number of previous studies indicated that in TD children, several aspects of gait appear to be sensitive to walking speed [13–15]. However, the effect of walking speed on gait of CP children has only been studied for a few gait parameters. For example, Van der Krogt et al. demonstrated the effect of walking speed on muscle-tendon length and lengthening velocity of spastic plantar flexors and hamstrings [11,12].

The aim of this study was to highlight markers of spasticity of gastrocnemius and hamstring muscles in gait analysis data by comparing the effect of increased walking velocity in CP and TD children. We studied the impact of increased walking velocity on kinematic, kinetic and EMG parameters and on muscle length (ML) and muscle lengthening velocity (MLV).

2. Methods

2.1. Subjects

Fifty-three patients diagnosed with spastic CP (28 boys, 25 girls; mean age 9.8 y ± 3.0 y) and 17 TD children (11 boys, 6 girls, mean age 10.46 y ± 2.36 y) volunteered for this study. All children's parents signed an informed consent form, approved by the local Ethics Committee of the hospital.

Children with CP were selected from the list of planned gait analyses of the Clinical Motion Analysis Laboratory of the University Hospital of Leuven, based on the following inclusion criteria: (1) spastic CP, (2) ambulatory status, (3) aged between 4 and 17 years old and (4) the presence of a catch angle as measured by the Tardieu Scale [3] in gastrocnemius and hamstrings in the same lower limb. Children presenting with the following criteria were excluded: dystonia and/or athetosis, severe cognitive impairment, previous orthopedic surgery, Intrathecal Baclofen pump or botulinum toxin-A treatment less than 6 month prior to evaluation. The TD children were children of colleagues of the research team of the Clinical Motion Analysis Laboratory or siblings of patients and had no medical history of cardio-vascular, neurological or musculoskeletal disorders.

In children with CP, the most affected side was selected based on the MAS scores. For 10 patients the MAS scores were symmetrical; their side was selected according to Tardieu score. In case of symmetrical MAS and Tardieu, the right side was selected. For the TD group, the right side was selected unless no kinetics were available or in case of bad quality electromyographic (EMG) signal, in which case the left was selected.

2.2. Study design

The evaluation involved a clinical examination and a three-dimensional (3D) gait analysis. The clinical examination included evaluation of range of motion (ROM), bony alignment, MAS [2], Tardieu scale [3], strength and selectivity [16] of both lower limbs.

The gait data were collected using an 8 camera VICON system, operating at 100 Hz, with 15 reflective markers located at specific anatomical landmarks of the lower limbs, according to the lower limb Vicon PluginGait marker configuration (VICON, Oxford Metrics, Oxford, UK). The ground reaction forces were recorded using two AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, Massachusetts) integrated in the walkway. Surface EMG was collected for 8 lower extremity muscle groups bilaterally. However, this study only reported the results of gastrocnemius and medial hamstrings. The surface EMG (Zerowire, Cometa, Milan, Italy) was recorded at a sample rate of 1500 Hz and filtered through a bandpass filter (20–500 Hz) (Nexus, Vicon, Oxford Metrics Group, UK).

All children walked barefoot along a 10 m walkway. First, they were instructed to walk at a self-selected walking speed; secondly, to walk faster; and finally to walk at the fastest speed they could achieve without running. At least 3 successful trials were collected at each speed condition. A trial was considered successful when there was good marker visibility and an overall artifact-free EMG signal.

2.3. Data analysis

Three dimensional kinematic data were calculated for the pelvis, hip, knee, ankle and foot bilaterally, decomposed in the sagittal, coronal and transverse plane. Kinetic analysis included the net internal moments and joint power for hip, knee and ankle. All kinematic and kinetic analyses were based on the lower limb PlugInGait model (VICON, Oxford Metrics, Oxford, UK). Two gait cycles (GC) per trial were determined using kinematic and kinetic data. Gait cycle events of initial contact and toe off were visually determined using Nexus software (Vicon, Oxford Metrics Group, Oxford, UK).

An additional visual quality control of the all EMG, kinetic and kinematic signals was carried out in custom-made MATLAB software (Mathworks®, Natick, MA, USA), prior to further data analysis. In the same software, the root mean square (rms) was calculated from the raw surface EMG signals. Average rms-EMG values were calculated by dividing the rms-EMG signal by a given time phase during the GC including: (1) 0–100% GC, (2) 0–20% GC, (3) stance phase, (4) swing phase and (5) 80–100% GC. These values were then normalized to the averaged maximum rms-EMG value of the gait cycles collected at self-selected walking speed, to enable comparison between subjects and between different velocities.

Muscle lengths were estimated using the musculoskeletal model introduced by Delp [17], using the lower limb segment and joint kinematics as input data. The algorithms of muscle length estimations were created through a custom-made bodybuilder program (VICON). All muscle lengths were expressed as a percentage of the corresponding muscle length in the anatomical position. The derivative of the muscle length was then calculated to obtain the muscle lengthening velocity (MLV).

From the continuous waveforms organized in gait cycles for kinematics, kinetics and muscle lengths a set of discrete parameters were selected based on clinical relevance. These included maxima, minima and mean values, ROM and the timing of maxima and minima within the GC and/or for sub-phases (stance and swing) and several specific parameters (including kinematic and kinetic values at specific events such as initial contact and toe off and ROM values for specific sub-phases such as loading response and push-off). For EMG the mean square roots of EMG of the gastrocnemius and hamstrings for the full gait cycle as well as for specific sub-phases (stance, swing, and first and last 20% of the gait cycle) were calculated. Finally, EMG and muscle length parameters were combined into EMG ratios, which are the averaged rms EMG values in swing divided by the maximum muscle lengthening velocity in swing, calculated for gastrocnemius and hamstrings [18]. All these parameters were automatically extracted from the waveforms using custom-made MATLAB software (Mathworks®, Natick, MA, USA). Gait parameters in TD children were also expected to change with increasing walking velocity and this effect was important to consider when studying pathological gait [13]. To allow focusing on comparable walking speed between CP and TD children, the gait velocities were first rendered to dimensionless using the scheme proposed by Hof [19], $\tilde{v} = v/\sqrt{g}/\text{leg}$, in which v is the walking speed, g the acceleration of gravity and $l$leg the leg length (Fig. 1). Per subject, the value of each gait parameter for each of the nine trials (three per velocity condition: self-selected speed, faster and fastest; two gait cycles per trial), were plotted against dimensionless velocity. Subsequently, a linear regression model was fitted through all data