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Impact of multilevel joint contractures of the hips, knees and ankles on the Gait Profile score in children with cerebral palsy

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ABSTRACT

Background: Children with cerebral palsy are at risk of developing muscle contractures, often contributing to pain, structural deformities and mobility limitations. With the increasing use of gait indices to summarise the findings of three dimensional gait analysis (3DGA), the purpose of this study is to determine whether there is a relationship between multilevel joint contractures and the Gait Profile Score in children with cerebral palsy.

Methods: The Gait Profile Score, calculated from 3D gait analysis, and passive range of motion, strength and spasticity of the hips, knees and ankles in the sagittal plane were measured in 145 children with cerebral palsy (mean age:11 years,4 months; SD:2 years,10 months) (83 males) enrolled in the NSW Paediatric Gait Analysis Service Research Registry from 2011 to 2016. The relationships between these physical measures and the Gait Profile Score were explored using bivariate and multivariate correlations.

Findings: Reduced hip extension, knee extension and ankle dorsiflexion (knee extended) range of motion were correlated with a higher (worse) Gait Profile Score ($r = -0.348$ to -0.466, $p < .001$). Children with all joints contracted had a significantly higher Gait Profile Score (mean 17.5°, SD 6.2°) than those with no contractures (mean 11.0°, SD 2.3°) or ankle contractures only (mean 12.8°, SD 5.1°) ($p < .05$). Knee flexion weakness, reduced hip extension and ankle dorsiflexion (knee extended) range of motion predicted 47% of the Gait Profile Score.

Interpretation: The Gait Profile Score is a sensitive measure for demonstrating the relationship between multilevel sagittal plane joint contractures and kinematic gait. Clinically, this supports the use of the Gait Profile Score as a simplified measure to understand the contribution of contractures to functional gait limitations. Monitoring knee flexion strength, and hip extension and ankle dorsiflexion (knee extended) range of motion may assist clinicians in prioritising interventions to improve gait in this population.

1. Introduction

Cerebral palsy is a group of non-progressive disorders characterised by abnormalities of movement and posture. This is caused by an injury to the developing central nervous system in utero, during delivery or in the first 2 years of life (Koman et al., 2004). The neural damage manifests peripherally as abnormal muscle tone, muscle weakness and decreased motor control, leading to secondary musculoskeletal impairments such as contractures, pain and structural deformities (Heyrman et al., 2014).

Increased stiffness or shortening of the soft tissues surrounding a joint, such as the muscles, ligaments and joint capsule may indicate the presence of a contracture in children with cerebral palsy (Attias et al., 2016). Contractures present as an inability to achieve full passive range of motion in a joint and often contribute to pain, structural deformities and limitations in mobility (Keenan et al., 2004). Spasticity and muscle weakness can result in the development of contractures by causing abnormal and prolonged static positions (Darrah et al., 2014). Management of spasticity, through botulinum toxin injections and intrathecal baclofen, has seen a decline in the severity of contractures (Hägglund et al., 2005). Surgical management is considered when a contracture is significantly impacting on the child's quality of life or ability to walk comfortably, and non-surgical management, such as serial casting and ankle-foot orthoses have ceased to be effective

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(Novak et al., 2013).

Three dimensional gait analysis (3DGA) is considered best practice when assessing the walking ability of children with cerebral palsy (Desloovere et al., 2006). 3DGA generates kinematic and kinetic graphs representing the deviations in the lower limbs throughout the gait cycle compared to a healthy population (Abel et al., 2003; Baker et al., 2009). 3DGA data is used with the physical examination measures to determine which impairments may be contributing to gait abnormalities (Orendurff et al., 1998). These gait data provide clinicians with further information to help justify whether operative management is appropriate for a child's long-term function. 3DGA is also used to assess outcomes following surgery and can aid in directing any future management of the child (Cimolin & Galli, 2014).

3DGA generates a large and complex dataset, often presenting a barrier to its effective use in clinical decision making. The Gillette Gait Index (GGI), Gait Deviation Index (GDI) and Gait Profile Score (GPS) (Cimolin & Galli, 2014) are single indices used to summarise 3DGA kinematics. These indices can enhance clinical interpretation and provide patients, families and clinicians with a better understanding of the 3DGA results (Thomason et al., 2013). Whilst the GGI, GDI and GPS all score the overall quality of the patient's kinematic gait, the GPS has the advantage of including gait variability scores (GVS). The GPS and nine GVS domains are presented in degrees and calculated as the root mean square difference between the participants' kinematic data and an averaged normative reference dataset, with a higher score indicating a greater deviation from normal. The GPS scores the patients overall gait quality whereas the nine GVS domains score the quality of movement at the pelvis, hips, knees and ankles in their relevant anatomical planes of movement (Baker et al., 2009). The GVS scores can indicate which joint movement abnormalities are likely to contribute to an elevated (worse) GPS. The GPS has been validated and shown to be reliable for use in the cerebral palsy population (Baker et al., 2009; Baker et al., 2012; Beynon et al., 2010). Previous studies have shown that the GPS is sensitive to detecting changes following gastrocnemius lengthening (Ferreira et al., 2014) and single event multi-level surgery (Thomason et al., 2013; Rutz et al., 2013; Firth et al., 2013).

To date, only the impact of single joint range of motion on joint angles, moments and power at specific time points during the gait cycle has been explored (Desloovere et al., 2006; Orendurff et al., 1998; McMulkin et al., 2000). These studies have found that range of motion accounts for up to 25% of the variance in specific gait measures (Orendurff et al., 1998; McMulkin et al., 2000), with strength and spasticity being slightly better at predicting these variables (Desloovere et al., 2006). The influence of multilevel joint contractures on the GPS is yet to be explored. Whilst the interaction between musculoskeletal impairments in different anatomical planes in children with cerebral palsy is highly complex, the impact of impaired muscle length is commonly described by changes in sagittal plane gait patterns (Rodda et al., 2004). With the increasing use of gait indices in clinical practice, it is necessary to determine whether these indices can represent the severity of clinical impairments in children with cerebral palsy. This would further support the use of the GPS as a tool to aid interpretation and clinical decision making following 3DGA, and as an outcome measure following management of these physical impairments. Clinically, this may guide clinicians in further understanding the contribution of contractures to decreased walking ability in individual patients, and as such the relevance of managing these impairments.

The primary aim of this study is to investigate the relationship between sagittal plane multilevel joint contractures and the GPS in children with cerebral palsy. The secondary aim was to assess whether there is an interaction between patient characteristics, the physical examination measures and the GPS and all GVS domains. The final aim was to assess, when combined, which impairments were most likely to contribute to an elevated GPS (ipsilateral limb) score. Therefore, allowing the authors to evaluate the use of the GPS in quantifying the association between contracture, and other physical impairments, on kinematic gait in this population.

2. Methods

2.1. Participants

Children, and their carers, who attended the Paediatric Gait Analysis Service of New South Wales (NSW) from January 2011 to July 2016 and provided informed written consent were eligible for inclusion in this study (Sydney Children's Hospitals Network Human Research Ethics Committee LNR/12/SCHN/146). From 289 participants with a diagnosis of cerebral palsy enrolled in the Paediatric Gait Analysis Service of NSW Research Registry, 145 children were included. Eligible participants were 18 years or younger and classified as a Gross Motor Function Classification System (GMFCS) level I-III (Baker et al., 2009; Rosenbaum et al., 2008). Previous surgery warranted exclusion from this study. If a child met the inclusion criteria and attended multiple visits, their most recent visit was included.

2.2. Data collection

The physical examination measures were adapted from the Hugh Williamson Gait Laboratory, Royal Children's Hospital Melbourne Physical Assessment Protocol (Keenan et al., 2004). Range of motion was measured using a universal goniometer and included hip extension (Modified Thomas Test), knee extension, hamstring length (popliteal and true popliteal angle) and ankle dorsiflexion (knee extended and flexed). A contracture was defined as any angle below the minimum range of normative reference values collected from 50 typically developing children in the same Gait Laboratory (mean age: 9 years, 10 months; SD: 3 years, 10 months; 15 males) (Mudge et al., 2014). Spasticity and muscle strength were also measured. Spasticity of the hamstrings (true popliteal angle), gastrocnemius and soleus were assessed using the Modified Tardieu Scale (Gracies et al., 2010). If spasticity was present, the catch angle was measured using a universal goniometer. Muscle strength was measured using manual muscle testing, following the Medical Research Council (MRC) scale (Vanhoutte & Faber, 2012). The original scoring system using 4−, 4 and 4+, was modified to 3+, 4 and 4+ to grade movement against gravity with slight, moderate and strong resistance throughout range. Muscle weakness was defined as any score below $4^{+}/5$.

The children underwent 3DGA using a Vicon MX system (Vicon Motion Systems Ltd., Oxford, UK) with eight infrared video cameras and three AMTI force plates (Advanced Mechanical Technology Inc., Watertown, Massachusetts, USA). Sixteen retro-reflective markers were attached to the pelvis and lower limbs following the Plug-In Gait protocol for marker placement (Davis et al., 1991). The participants walked barefoot at a self-selected speed along an 8 m walkway. Kinematic and spatiotemporal data were collected throughout the gait cycle.

2.3. Data processing

The kinematic data graphs generated by 3DGA were normalised to a percentage of the gait cycle. The averaged values of six consistent trials from each limb were analysed. The GPS and the nine GVS domains were calculated using MATLAB 2016b, and presented in the movement analysis profile (MAP) (Baker et al., 2009). The GPS and GVS domains represent the root mean square difference between the participants' kinematic data and the averaged normative reference dataset (Wojciechowski et al., 2014), with a higher score indicating a greater deviation from normal (Baker et al., 2009). Spatiotemporal measures (walking speed, cadence, stride and step length) were scaled to non-dimensional values using leg length (Hof, 1996). Single and double support were presented as a percentage of the gait cycle.