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Frequency domain analysis of ground reaction force in preadolescents with and without Down syndrome

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ABSTRACT

Children with Down syndrome (DS) display less stable and coordinated gait patterns in the time domain than their healthy peers. However, little is known about whether this group difference exists in the frequency domain. The purpose of this study was to investigate differences in vertical ground reaction force (GRF) in the frequency domain between preadolescents with and without DS. Twenty children at 7–10 years of age with and without DS participated in this study. Participants walked on an instrumented treadmill at two speeds with and without external ankle load. Vertical GRF was collected and the data was processed through a Fourier transform. Frequency content variables included fundamental frequency, power of the first five harmonics, and the frequency and number of harmonics at 95%, 99% and 99.5% of total power. Preadolescents with DS had a similar fundamental frequency as their healthy peers even though the DS group walked at slower speeds. The DS group displayed a different power spectrum of the first five harmonics and had the lower frequency and number of harmonics at 99% and 99.5% of total power. However, walking at a faster speed with external ankle load helped the DS group produce a power spectrum more similar to healthy children. Frequency content of vertical GRF provides additional assessment parameters in functional gait evaluation of children with DS. Treadmill intervention at a faster speed and with external ankle load appears to be clinically promising and needs further investigation.

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1. Introduction

Down syndrome (DS) is the most common genetic disease and affects about 1 out of 700 new births in the United States (Parker et al., 2010). The presence of an extra chromosome 21 not only delays physical growth, but also markedly hinders motor, cognitive and social development in children with DS. Preadolescence has been considered as perhaps an optimal period when persons with DS show their best motor capability (Ulrich, Haehl, Buzzi, Kubo, & Holt, 2004). However, even during preadolescence, children with DS still display less stable and coordinated movement patterns than their healthy peers. For instance, preadolescents with DS walk at a slower self-selected speed over the ground and display a shorter stride

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length, but a wider step width than typically developing children (Rigoldi, Galli, & Albertini, 2011; Ulrich et al., 2004). While walking on a treadmill, preadolescents with DS show greater variability in the center-of-mass and joint angle excursions (Black, Smith, Wu, & Ulrich, 2007; Kubo & Ulrich, 2006) and adopt a compensatory variability-partitioning strategy to accommodate this greater variability (Black et al., 2007).

Previous studies using a kinetic perspective demonstrate that children with DS produce a lower ground reaction force (GRF) (Rigoldi et al., 2011) and a lower ankle plantar-flexion moment and power (Cioni, Cocilovo, Rossi, Paci, & Valle, 2001; Galli, Rigoldi, Brunner, Virji-Babul, & Giorgio, 2008; Rigoldi et al., 2011) than their healthy peers during overground walking. By using an instrumented treadmill and investigating the pattern of vertical GRF, our previous study found that children with DS produced a less efficient vertical propulsion than their healthy peers during treadmill walking; however, walking at a faster speed with an external ankle load helped children with DS increase vertical propulsive force and impulse (Wu & Ajisafe, 2014). Despite the valuable knowledge obtained from these kinematic and kinetic studies in the time domain, little study has been conducted in the frequency domain to understand the frequency content of kinetic variables in children with and without DS.

A frequency domain analysis usually uses a Fourier transform to describe a periodic movement and helps reveal the characteristics of various anatomical components governing the periodic pattern (Jacobs, Skorecki, & Charnley, 1972). GRF is considered as the kinetic manifestation of the summation of many oscillatory anatomical components such as joints, muscles, and nerves, among others, during walking. Since each anatomical component has its own frequency of activity, a frequency domain analysis of GRF helps reveal the amplitude and power of these components in a frequency spectrum. Such an analysis has been shown to be clinically important in identifying potential gait abnormalities in children with cerebral palsy (White, Agouris, & Fletcher, 2005), adults with knee joint disease (Schneider & Chao, 1983), adults with multiple sclerosis (Wurdeman, Huisinga, Filipi, & Stergiou, 2011), and elderly people with peripheral arterial disease (McGrath, Judkins, Pipinos, Johanning, & Myers, 2012). It is therefore logical to apply this frequency analysis to the GRF data collected from children with DS and develop additional parameters for functional gait evaluation in this population.

A Fourier transform represents the GRF data with many harmonics, each of which has a different frequency. Fourier (harmonic) coefficients of the first three to five harmonics were found to primarily determine the shape of the GRF curve and help reveal an abnormal pattern in persons with diseases (Alexander & Jayes, 1980; Fineberg et al., 2013; Schneider & Chao, 1983; White et al., 2005). Other common variables include the frequency and the number of harmonics essential for reconstructing the GRF data at a certain accuracy level. Adults with knee joint disease require a lower number of harmonics than healthy peers (Schneider & Chao, 1983), whereas children with cerebral palsy need a higher number of harmonics when reconstructing the GRF data at 95% of the total amplitude (White et al., 2005). The frequency corresponding to 99% or 99.5% of the GRF total power was found to be lower in clinical populations than in healthy controls (McGrath et al., 2012; Stergiou, Giakas, Byrne, & Pomeroy, 2002; Wurdeman et al., 2011). With different levels of accuracy of data reconstruction used in a frequency domain analysis, it is important to investigate what level of accuracy would differentiate the frequency content of GRF between children with and without DS.

Preadolescents with DS have shown the capability of adapting to a faster treadmill speed and an external ankle load although their vertical GRF pattern was not comparable to that of their healthy peers (Wu & Ajisafe, 2014). Healthy adults were found to increase the amplitude of the second harmonic while walking overground at a faster speed (Crowe, Samson, Hoitsma, & van Ginkel, 1996). It is not known if preadolescents with and without DS would have a similar response during treadmill walking. Inclusion of external ankle load has been shown to be an important training component in treadmill intervention with infants with DS (Ulrich, Lloyd, Tiernan, Looper, & Angulo-Barroso, 2008; Wu, Looper, Ulrich, Ulrich, & Angulo-Barroso, 2007; Wu, Ulrich, Looper, Tiernan, & Angulo-Barroso, 2008). However, no study has been conducted to investigate how external ankle load would affect the frequency content of vertical GRF between preadolescents with and without DS. Therefore, the purpose of this study was to investigate the frequency content of vertical GRF between preadolescents with and without DS during treadmill walking at different speeds with and without external ankle load. Given their slower and less coordinated movement patterns, we hypothesized that children with DS might display a different power spectrum in the first five harmonics and have a lower frequency and number of harmonics for reconstructing the GRF data at 95%, 99% and 99.5% of total power.

2. Methods

2.1. Participants

Twenty children at 7–10 years of age with and without DS participated in this study. The DS group was recruited through the Down Syndrome Association of Atlanta and the local parent support groups. The age- and sex-matched typically developing (TD) group was recruited from the local community through advertisement and personal contact. All the participants in this study were Caucasian except one Hispanic and one African American in the DS group. Table 1 presents the physical characteristics of each group. The DS group was shorter in height than the TD group, but the two groups had similar body masses. This study was approved by the university's institutional review board. A written informed consent was obtained from all the participants and their parents or guardians before their participation.