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# The analysis of three-dimensional ground reaction forces during gait in children with autism spectrum disorders

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ABSTRACT

Minimal information is known about the three-dimensional (3D) ground reaction forces (GRF) on the gait patterns of individuals with autism spectrum disorders (ASD). The purpose of this study was to investigate whether the 3D GRF components differ significantly between children with ASD and the peer controls. 15 children with ASD and 25 typically developing (TD) children had participated in the study. Two force plates were used to measure the 3D GRF data during walking. Time-series parameterization techniques were employed to extract 17 discrete features from the 3D GRF waveforms. By using independent *t*-test and Mann-Whitney *U* test, significant differences ($p < 0.05$) between the ASD and TD groups were found for four GRF features. Children with ASD demonstrated higher maximum braking force, lower relative time to maximum braking force, and lower relative time to zero force during mid-stance. Children with ASD were also found to have reduced the second peak of vertical GRF in the terminal stance. These major findings suggest that children with ASD experience significant difficulties in supporting their body weight and endure gait instability during the stance phase. The findings of this research are useful to both clinicians and parents who wish to provide these children with appropriate treatments and rehabilitation programs.



**What this paper adds?**

This paper presents a quantitative assessment of the 3D GRF gait patterns among children with ASD. Based on the 3D GRF gait features that were carefully and thoroughly examined in this study, children with ASD were found to exhibit several significant gait impairments in the 3D GRF gait patterns as compared to the age-matched typically developing children. These recent findings suggest that children with ASD had impairments during their stance phase of walking which could be associated with difficulties during weight-acceptance and gait instability. The significant differences of the 3D GRF gait features showed that these features could further be utilized as possible indicators in identifying gait deviations in children with ASD.

## 1. Introduction

Autism spectrum disorders (ASD) are permanent neurological disorders typically identified in the early years of childhood. Children with ASD primarily suffer from impairments in social communication and social interaction, in addition to exhibiting unusual patterns of behavior (American Psychiatric Association, 2013). Other additional characteristics that sup-

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port the diagnosis of ASD are the existence of movement and motor deficits which include irregular motor signs, clumsiness, and abnormal gait (American Psychiatric Association, 2013). According to Torres and Donnellan (2015) researchers across disciplines have recognized movement and sensory disturbances as the backbone symptoms of this disorder.

A considerable amount of literature revealed a wide range of movement disturbances and gait deviations in individuals with ASD (Kindregan, Gallagher, & Gormley, 2015). For example, several evidences of movement disturbances that influenced gait were observed during the developmental age of children and young teenagers with ASD, namely temporal-spatial and kinematic gait disturbances (Vilensky, Damasio, & Maurer, 1981); clumsiness (Ghaziuddin & Butler, 1998; Hallett et al., 1993); unstable and imbalanced movements (Ambrosini, Courchesne, & Kaufman, 1998); irregular locomotion and motor disturbances (Esposito, Venuti, Apicella, & Muratori, 2011; Nayate et al., 2012; Vernazza-Martin et al., 2005); poor coordination and postural abnormalities (Nobile et al., 2011; Rinehart et al., 2006); higher cadence plus abnormal joint kinematics and kinetics (Calhoun, Longworth, & Chester, 2011); and various alterations of temporal-spatial gait features (Weiss, Moran, Parker, & Foley, 2013). These evidences showed that children with ASD exhibited various types of movement disturbances which affected their daily physical activities particularly gait.

Gait is a human style of walking of naturally moving the body forward from one location to another (Perry, 1992). Walking involves movements of the limbs in a repetitive sequence while concurrently preserving stance stability (Perry, 1992; Whittle, 2007). Gait can be assessed quantitatively to produce temporal-spatial, kinematic, and kinetic parameters that can be used for an examination of any deviation from a normal walking pattern (Chester, Biden, & Tingley, 2005).

Temporal and spatial parameters refer to gait parameters that are related to time and distance such as walking speed, stride time, and stride length. Kinematic describes the way the body moves without reference to the causes of the motion, whereas kinetic outlines the forces and moments involved to produce motion (Whittle, 2007). The most essential force in gait analysis is the ground reaction force (GRF), which is the force exerted by the ground on the foot. GRF supports the body against gravity and accelerates the center of mass of the body during walking (Baker, 2013).

In routine gait analysis, GRF can be measured in three-dimensional (3D) space using force plate which is normally embedded in the middle of a walkway. Assessment of the 3D GRF in the medial-lateral, anterior-posterior, and vertical directions provides a detail interpretation of the weight acceptance and the single-limb-support tasks during the stance phase of walking (Perry, 1992). Any significant deviation in the discrete features of the 3D GRF could be a sign of weight-bearing stability and preservation during walking progression (Perry, 1992). Therefore, an investigation of the 3D GRF components is expected to be more effective in identifying specific locomotion characteristics (Giakas & Baltzopoulos, 1997; McCrory, Chambers, Daftary, & Redfern, 2011; Williams, Gibbs, Meadows, & Abboud, 2011).

To the best of the researchers' knowledge, there were only two studies that investigated GRF patterns in individuals with ASD which were conducted by Hallett et al. (1993) and Ambrosini et al. (1998). In Hallett et al.'s (1993) study, adult subjects were used and the researchers found that all five adults with ASD had showed a reduction of dynamic vertical forces despite the fact that the vertical GRF gait patterns were normal. Another study by Ambrosini et al. (1998), which used children samples, also showed similar results whereby relatively normal GRF patterns were found in all eight children who were diagnosed with ASD. However, seven of the subjects in Ambrosini et al.'s (1998) study demonstrated a decrease in the second vertical force peak during the terminal stance. These results showed that both studies were in agreement that individuals with ASD were associated with cerebellar disorder, and that gait impairments could be interpreted as neurological disturbances of the motor system (Ambrosini et al., 1998; Hallett et al., 1993).

Despite these important findings, many uncertainties regarding the GRF patterns in children with ASD still exist due to small sample size employed and also due to the absence of quantitative data to support the findings of both studies. Based on these gaps, this study endeavored to investigate whether the 3D GRF components during walking differ significantly between children with ASD and typically developing (TD) age-matched control group based on quantitative methods. From here, this study hypothesized that several significant differences would be observed in the 3D GRF gait patterns between children with ASD and TD children. A detailed and comprehensive assessment of the 3D GRF would provide useful information on the ASD gait impairments to important parties such as clinicians and parents. This would also promote better invention and planning of appropriate treatments and rehabilitation programs for ASD patients requiring therapies.

## 2. Methodology

### 2.1. Participants

In this study, 15 children with ASD ($N_1 = 15$) and 25 typically developing (TD) age-matched control children ($N_2 = 25$) ranging from 4.3 to 12.4 years of age were examined. Prior to the recruitment of the participants, a statistical power calculation was conducted with an assumption to acquire a large effect size of 0.95 using a significance level of 0.05 and a power of 0.80 to detect its effect (Cohen, 1988). The effect size indicates the real magnitude of the disparity between scores and permits easier comparison with other studies (Mayers, 2013). The allocation ratio of TD to ASD groups ($N_2/N_1$) was specified to 1.68 in order to achieve the desired effect size specification. This resulted in a total sample size of 40 children recruited for the study. The calculation of power analysis was performed using the G*Power version 3.1.9.2 (Faul, Erdfelder, Lang, & Buchner, 2007).

Twelve ASD participants were recruited from the center of local national autism society and four were chosen from the local community. In order to get participants from the local community, an advertisement calling for parents with ASD

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