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Determinants of gait as applied to children with cerebral palsy

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Abstract

In the present study, we quantified the isolated contributions of eight determinants of gait on the vertical center of mass (CoM) displacement of both typically developing children and children with cerebral palsy (CP). The role of these determinants, on vertical excursion, has never been examined for children or children with CP. We hypothesized that the relative contributions of the determinants to vertical CoM excursion of children with CP would be the same as the age-matched controls. We found that based on the similarities in the determinants effect on gait between the controls and adults reflect that children of this age walk with a mature gait. When applied to subjects with CP the determinant analysis found similar, but slightly exaggerated effects of those of the controls. All determinants that negatively affect CoM excursion were significantly worse in the children with CP, while those determinants that decreased excursion were varied. Heel rise, single support knee flexion, and pelvic obliquity had similar effects for on both groups. Pelvic rotation resulted in more excursion reduction in the controls, while leg inclination was more beneficial in reducing the CP groups excursion. The main cause for increased vertical excursion of the CoM in the children with CP was the increased knee flexion of both legs during double support. This excessive lowering of the CoM means that extra work is done to raise the CoM over the single support leg. The situation is aggravated by the fact that the CoM was lifted higher than typical because of the heel lifting during single support. Although these determinants allow quantification of the effects of gait kinematics and provide some useful information for gait they are limited in their ability to quantify the dynamics and kinetics of gait that are important for individuals with walking disabilities.

Keywords: Gait parameters; Determinants of gait; Center of mass; Vertical displacement; Cerebral palsy

1. Introduction

During walking the body center of mass (CoM) moves up and down, reaching a maximum during single limb support and a minimum during double limb support. The work required for this vertical movement of the CoM is approximately 50% of the total work for walking [1,2]. For persons with neuromuscular disorders such as stroke or cerebral palsy, the CoM vertical excursion may be increased. To date little work has been done to quantify the contributions of the body kinematics resulting in the increased CoM excursion experienced by children with CP. Understanding the kinematic conditions resulting in CoM vertical excursion may provide insights for specific treatments.

Saunders et al. [3] in their classic paper on human walking sought to identify kinematic characteristics or ‘‘gait determinants’’ that impact on the excursion of the body CoM. They empirically identified three determinants: pelvic rotation, pelvic obliquity, and single support knee flexion which would minimize the vertical displacement of the CoM. Saunders et al. proposed that pelvic rotation would raise the CoM at its low point in double limb support while pelvic obliquity and knee flexion would lower the high point of CoM excursion during single limb stance. The

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coordinated action of the knee and ankle were described as being important to smoothing the CoM transition between its high and low points resulting in a low amplitude sinusoidal CoM motion.

Recent quantitative research has modified our understanding of the relative contributions of gait determinants on CoM vertical motion. Gard and Childress [4–6] found that pelvic obliquity and single support knee flexion did not significantly reduce the CoM excursion in walking at comfortable speeds. Other studies estimated that pelvic rotation accounts for only a 10% reduction in CoM excursion [7,8]. Della Croce et al. [7] defined five new determinants: ipsi-, contra-lateral knee flexion, and heel rise in double limb support at CoM minimum and leg inclination, and heel rise at CoM maximum in single limb support, to more completely explain the CoM vertical excursion. Ipsi-, contra-lateral knee flexion, in double support, and heel rise, in single support, differ from the other determinants in that their action increases rather than decreases the excursion of the CoM. Of these new determinants they found that heel rise during double limb support had the greatest impact and resulted in approximately a 66% reduction of CoM excursion.

The roles of the above eight determinants on vertical excursion have never been examined or quantified for children or children with cerebral palsy (CP). The large metabolic cost of walking experienced by children with CP draws interest to the vertical excursion of their CoM. Children with CP walk with a gait which characteristically uses two to three times as much energy as typically developing children [9], while walking at a slower self selected comfortable pace [10]. Our studies have demonstrated that the potential/kinetic energy exchange, a major energy saving mechanism of gait, is less efficient in children with CP [11]. This poor energy exchange is in part created by a larger CoM vertical excursion, and thus potential energy variation, than is seen in typically developing children. Cavagna et al. [12] have shown that potential energy is a reliable predictor of total biomechanical energy. Kerrigan et al. [13] also demonstrated that the vertical excursion of the CoM reliably predicts the oxygen consumption during walking. By examining the effect of determinants on CoM, we hope to gain insight into the high metabolic cost of gait in children with CP.

In the present study, we used the methodology of Della Croce et al. [7] to quantify the isolated contributions of the eight determinants of gait on the vertical CoM displacement of both typically developing children and children with CP. Such a comparison provides insight into the walking patterns of children with CP and their increased energy required for ambulation. We hypothesized that CoM vertical excursion would be increased in CP but that the relative contributions of the determinants to vertical CoM excursion of children with CP would be the same as the age-matched controls because the children with CP employ a similar reciprocating walking strategy.

2. Methods

2.1. Subjects and procedures

The kinematic data of 23 children were collected and analyzed. This group of children consisted of two populations. The first group of age-matched controls was comprised of 13 children without known musculoskeletal, neurological, cardiac, or pulmonary pathology, and included six females and seven males averaging 12.4 ± 2.8 years of age, 149.0 ± 17.3 cm in height, and 46.1 ± 17.0 kg in mass. The second group consisted of 10 children diagnosed with spastic diplegic CP. These subjects were community ambulators who did not use walking aids. They included two females and eight males averaging 10.0 ± 3.6 years of age, 139.5 ± 22.0 cm in height, and 36.3 ± 14.1 kg in mass. All tests were conducted in the Motion Analysis and Motor Performance Laboratory at the University of Virginia. Subject assent and parental consent was approved by the University of Virginia's Human Investigation Committee and was obtained for all subjects.

A full body marker set of 38 markers was attached to all 10 of the cerebral palsy subjects and 6 of the controls. The other 7 controls were part of a database collected before the 38 marker set was adopted and used reduced marker sets consisting of pelvis and lower extremity markers. Subjects were instructed to walk barefoot along the 10 m laboratory walkway at their self selected comfortable walking speed. Three-dimensional kinematic data were collected using a six camera Vicon Motion Analysis System (Oxford Metrics, UK) at 120 Hz. Each subject completed a minimum of five trials assuring there would be sufficient trials with clean continuous walking. The measurement volume of the Vicon system allowed for the capture of two to five steps per trial. The determinant analysis was applied to each step and the values averages.

For each subject, the length of the shank and thigh segments and the geometry of the pelvis were estimated during a static standing trial. Shank length was defined as the distance between ankle joint center and knee joint center, thigh length was defined as the distance between the knee joint center and the hip joint center, pelvis width was defined as the distance between the hip joint centers. The CoM vertical position during walking was estimated differently with respect to the marker set used. For subjects with full body marker sets the CoM was calculated using the full body multi-segment kinematics model [14]. The CoM for subjects whose data were collected using only the lower body marker set was estimated using the sacral marker. Previous studies have demonstrated the pattern of vertical displacement for these two methods are nearly identical [13,15,16]. We found no difference between the excursions of the sacral marker and the computed CoM for the controls with full body marker sets ($P > 0.60$) or between the excursion of the sacral marker of the controls with lower body marker set and that of the CoM in the full body marker set ($P > 0.20$).