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Dynamic stability during running gait termination: Predictors for successful control of forward momentum in children and adults

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ABSTRACT

Reported differences between children and adults with respect to COM horizontal and vertical position to maintain dynamic stability during running deceleration suggest that this relationship may not be as important in children. This study challenged the current dynamic stability paradigm by determining the features of whole body posture that predicted forward velocity and momentum of running gait termination in adults and children. Sixteen adults and 15 children ran as fast as possible and stopped at pre-determined location. Separate regression analyses determined whether COM posterior and vertical positions and functional limb length (distance between COM and stance foot) predicted velocity and momentum for adults and children. COM posterior position was the strongest predictor of forward velocity and momentum in both groups supporting the previously established relationship during slower tasks. COM vertical position also predicted momentum in children, not adults. Higher COM position in children was related to greater momentum; consistent with previously reported differences between children and adults in COM position across running deceleration. COM vertical position was related to momentum but not velocity in children suggesting that strategies used to terminate running may be driven by demands imposed not just by velocity, but also the mass being decelerated.

1. Introduction

Previous work found that adults and children use different control strategies to modulate forward momentum during a maximal effort running gait termination task (Cesar & Sigward, 2015). When compared with adults, children used fewer and longer steps, positioned their center of mass (COM) higher and less posterior, and exhibited greater anterior-posterior (A-P) COM excursion. In addition, children approached the termination task at a higher relative velocity than adults. These strategies, characterized by the use of spatiotemporal and whole body (COM) position and velocity variables, suggest that children exhibit mechanics more similar to running and more characteristic of a less stable strategy for deceleration than adults. However, despite less stable mechanics, children and adults achieved similar success with no differences in the number of trials that resulted in loss of stability. These differences suggest that the relationship established between COM position and velocity in adults for dynamic stability during the termination of forward movement may not apply to children.

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Previous studies characterizing dynamic stability in adults suggest that the relationship between COM position and velocity is tightly regulated by the central nervous system for maintenance of balance during dynamic tasks (Jian, Winter, Ishac, & Gilchrist, 1993). The relationship between COM position and velocity in the horizontal plane, referred to as COM state, modeled for dynamic tasks indicates that for a given COM forward velocity, there is a limited range of COM positions posterior to the base of support (BOS) that are able to be brought to zero without loss of dynamic stability (Pai, 2003). In the terminating step, if the COM forward velocity is too great or is not positioned posterior enough, it will fall outside this range and dynamic stability will not be maintained. Loss of dynamic stability during this step would results in a forward fall or the need to take an additional step. The strength of this relationship in adults, across different tasks suggests that modulation of the A-P COM position and velocity is critical for dynamic stability. Several studies have demonstrated this relationship across a variety of functional tasks including walking gait termination, sit to stand, and reactive tasks such as waist-pull perturbations and support-surface translations (Iqbal & Pai, 2000; Pai & Lee, 1994; Pai, Maki, Iqbal, McIlroy, & Perry, 2000; Pai & Patton, 1997; Pai, Rogers, Patton, Cain, & Hanke, 1998; Patton, Pai, & Lee, 1999). When considering a running gait termination task (Cesar & Sigward, 2015), the differences in COM A-P position between children and adults throughout running termination described above suggest that this relationship during the terminating step may not apply to tasks performed at faster velocities or may not be as important in children for maintenance of stability.

Interpretation of the reported differences between children and adults is challenged by the nature of the task and underlying anthropometric differences. While walking gait mechanics are modeled as an inverted pendulum, running gait are described as a spring mass system (Farley, Glasheen, & McMahon, 1993). In contrast to the inverted pendulum, the COM position moves from a higher to a lower vertical position after ground contact in a spring mass model. These differences suggest that the vertical position of the COM may also be important for dynamic stability in children and adults during running. Moreover, the use of knee flexion or lower limb flexion contributes to termination of forward movement during walking gait (Iqbal & Pai, 2000) and may be even more important for modulation of the COM vertical position during running gait termination. Additionally, the regulation of the relationship between horizontal COM position and velocity for dynamic stability has only been established during tasks performed at slower velocities. It is not clear how strong this relationship is during tasks performed at faster speeds. Children approached the termination task at a faster relative velocity than adults (84.9% of their maximum sprint velocity versus 76.9%, respectively). While this represented a less than 10% difference in approach velocity between groups, it translated into a near 3 times greater momentum for the adults as a result of their larger mass (Cesar & Sigward, 2015). To date the relationship between horizontal COM position and velocity has been only established in adults. It is not known how the mass of the individual (and the consequent forward momentum) influences this relationship. Given the difference in anthropometrics between children and adults, the less stable strategy previously described in children may in fact be appropriately stable.

The purpose of this study was to challenge the current dynamic stability paradigm by increasing the speed at which gait termination is performed in children and adults. We aimed to determine which features of whole body posture (COM posterior and vertical positions, and functional length of lower limb) predict the demands to control forward velocity at the last, terminating step of successful running gait termination in adults and children. Velocity and momentum at initial contact of the terminating step were used to represent the demands to control forward velocity as they were brought to zero during this step. It was hypothesized that COM posterior position would predict forward velocity and momentum during running gait termination for adults and children. Also, it was hypothesized that COM vertical position and lower limb length would be stronger predictors in children compared with adults.

2. Methods

2.1. Participants

Thirty-one physically active individuals participated in the study, consisting of 16 young adults and 15 typically developing children (Table 1). These were the same individuals who participated in our previous study (Cesar & Sigward, 2015). They were included in the study if they were healthy without complaints associated with lower extremity or spine injuries. Also, adults and children had to be engaged in physical activity for a minimum of 150 min and 420 min per week, respectively, according to the Physical Activity Guidelines for Americans (USDHHS, 2008). This criterion was confirmed with the Children's Physical Activity Questionnaire (Chinapaw, Mokkink, van Poppel, van Mechelen, & Terwee, 2010; Nor Aini, Poh, & Chee, 2013). To avoid the potential influence of sex related difference in performance, only male subjects were

Table 1
Participants' characteristics. Values are mean ± SD (range).

	Adults	Children
Age (yr)	27.13 ± 3.98 (21–34)	8.87 ± 1.46 (7–11)
Mass (kg)	73.96 ± 7.89 (56.15–92.17)	32.02 ± 7.26 (22.41–46.18)
Height (m)	1.77 ± 0.09 (1.51–1.87)	1.35 ± 0.12 (1.22–1.69)
COM height (m)	0.95 ± 0.05 (0.87–1.05)	0.66 ± 0.07 (0.59–0.87)