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Visual tasks and stance width influence the spatial magnitude and temporal dynamics of standing body sway in 6- to 12-year old children

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1. Introduction

Children learn to control body balance in sitting and, later, in standing. Our knowledge of the emergence of adult-like control of the quantitative kinematics of upright posture is incomplete. Some researchers have examined childrens' postural responses to dynamic visual stimuli, using the moving room paradigm (e.g., Bertenthal & Bai, 1986; Chung & Stoffregen, 2011; Lee & Aronson, 1974; Schmuckler, 1997; Stoffregen, Schmuckler, & Gibson, 1987), to motion of the surface of support (Berger, Trippel, Assaiante, Zijlstra, & Dietz, 1995), or to vibration of the ankle (Cuisinier, Olivier, Vaugoyeau, Nougier, & Assaiante, 2011). Several studies have examined the kinematics of unperturbed stance in pre-adolescent children but have not examined variations across age (e.g., Blanchard et al., 2005; Bucci, Ajrezo, & Wiener-Vacher, 2015; Mickle, Munro, & Steele, 2011; Schmid, Conforto, Lopez, & D'Alessio, 2007). Studies that have examined postural kinematics as a function of age in pre-adolescent children have not varied the tasks that children performed during stance (e.g., Kirshenbaum, Riach, & Starkes, 2001; Rival, Ceyte, & Olivier, 2005), or have compared only the presence versus absence of saccades (Ajrezo, Wiener-Vacher, & Bucci, 2013).

We evaluated posture in children aged 6- to 12-years. We selected this age range, in part, because we required children who were old enough to understand and follow experimental instructions. We examined the influence on postural control of visual tasks performed during stance. We crossed our manipulation of visual tasks with a variation in the distance between the feet in stance. Each of these variations affects the kinematics of standing sway in adults, and we were interested to determine their developmental course. In the following sections, we motivate our study in terms of the existing literature.

1.1. Suprapostural tasks

The spatial magnitude of standing body sway is often modulated by variations in supra-postural visual tasks (Woollacott & Shumway-Cook, 2002). Schärli, van de Langenberg, Murer, and Müller (2013) varied supra-postural visual tasks in a cross-sectional study of postural kinematics in participants ranging in age from 6 to 35 years. Participants either fixated a stationary dot, or freely watched a film. Recordings of head movements verified that children moved their heads more (in yaw) when viewing the film than when looking at a stationary dot. The task variation influenced several parameters of postural kinematics (as recorded using a force plate), but these effects may have arisen from the fact that viewing of the film was associated with significant increases in motion of the head, which would tend to displace the COP independent of any other factors. In the present study, we varied supra-postural tasks in a way that is not associated with changes in head movement.

Chang, Wade, Stoffregen, Hsu, and Pan (2010) examined standing body sway during performance of visual tasks in children

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7–10 years old. In one task, children maintained their gaze on a small target, while in the other task, they counted designated digits in a block of numbers. In the body's AP axis, the spatial magnitude of sway during performance of the digit counting task was reduced, relative to sway during performance of the simple gaze task. Bucci et al. (2015), reported a similar effect in the context of reading, in a study in which posture and eye movements were recorded among children 6.3–15.5 years old. Overall, the spatial magnitude of sway decreased with increasing age. The spatial magnitude of postural sway during saccades, and during reading was reduced relative to the spatial magnitude of sway during pursuit eye movements. There were no statistically significant interactions between visual tasks and age. Similarly, Chen, Tsai, Stoffregen, and Wade (2011) evaluated the spatial magnitude of standing body sway in children 9–10 years old. They found that the spatial magnitude of sway was reduced during performance of visual signal detection tasks that encouraged stationary fixation. Chen et al., did not record eye movements.

The cognitive and visual tasks used by Chen, Tsai, Stoffregen, and Wade (2012) were designed to minimize the use of eye movements. Other research (e.g., Ajrezo et al., 2013; Stoffregen, Bardy, Bonnet, & Pagulayan, 2006) has shown that horizontal saccades (derived from recordings of eye movement), in the absence of any higher cognitive task, can be sufficient to reduce the spatial magnitude of postural sway. Stoffregen et al. (2006) found that, when the eyes were open, the spatial magnitude of adults' standing body sway was reduced during horizontal eye movements. Ajrezo et al. (2013) conducted a similar study in children aged 5.8–17.6 years. They compared sway during fixation versus horizontal saccades (moving the eyes to fixate flashing targets on either side of a screen). Ajrezo et al. reported that children reduced the spatial magnitude of sway during saccades. In the present study, we combined the use of a complex cognitive task based on reading with a cross-sectional study of the effects of age in children.

1.2. Stance width

In adults, stance width (the distance between the feet) affects the kinematics of standing body sway (e.g., Day, Steiger, Thompson, & Marsen, 1993; Yu, Chung, Hemingway, & Stoffregen, 2013). Generally, the spatial magnitude of sway is reduced when the feet are apart, and is increased when the feet are together. Yu et al. (2013) identified a statistically significant interaction between stance width (5 cm vs. 17 cm vs. 30 cm) and variation of visual tasks (counting target letters vs. looking at a blank target).

Mickle et al. (2011) varied stance width in a study of 9 year-old children. The spatial magnitude of sway was greater for narrow stance width than for wider stance width, consistent with effects reported in adults. We sought to replicate this effect, but also to test for possible interactions between stance with and visual supra-postural tasks, and to consider these interactions across a range of ages. Research relating childrens' postural sway to visual tasks has not included variations in stance width (e.g., Ajrezo et al., 2013).

In the present study, we tested a cross-sectional sample of children ranging in age from 6- to 12-years. Within-participants, we co-varied stance width and supra-postural visual tasks. Our primary aim was to evaluate the evolution of postural support for supra-postural visual activity. Our co-variation of visual tasks and stance width made it possible for us to detect interactions between these factors, such as have been observed among adults (Stoffregen, Villard, Chen, & Yu, 2011; Yu et al., 2013). Such interactions might evolve across development differently from the evolution of either factor, taken singly.

Research on standing body posture often relies on the "quiet stance paradigm", in which participants are expressly instructed to minimize postural sway (e.g., Woollacott & Shumway-Cook, 2002). This instruction has been employed in many studies of postural sway in children (e.g., Cuisinier et al., 2011; Rival et al., 2005; Schmid et al., 2007). The instruction to stand "as still as possible" is not representative of situations outside the laboratory (e.g., cf. Olivier, Palluel, & Nougier, 2008; Stoffregen, Hove, Bardy, Riley, & Bonnet, 2007; Stoffregen, Smart, Bardy, & Pagulayan, 1999). In part for this reason, following previous studies (e.g., Chang et al., 2010; Chen et al., 2012; Stoffregen, Pagualayan, Bardy, & Hettinger, 2000), we asked participants to stand comfortably, rather than making any attempt to minimize sway.

1.3. Spatial magnitude versus temporal dynamics

Most studies of postural control in children have analyzed only the spatial magnitude of sway (e.g., Ajrezo et al., 2013; Bucci et al., 2015). Increasingly, this practice has come into question as we have come to understand the importance of the temporal dynamics of movement. The temporal dynamics of movement differ qualitatively from the spatial magnitude of movement, such that one cannot be extracted from the other (e.g., Harbourne & Stergiou, 2003). In part for this reason, the spatial dynamics of movement have implications for the interpretation of empirical findings.

For example, reduction in the spatial magnitude of postural sway often is interpreted as an increase in postural stability. This interpretation is widely applied in adult contexts, and has been extended to interpretation of results found in children (e.g., Ajrezo et al., 2013). In dynamic systems theory, the stability of movement is not defined in terms of its spatial magnitude. In the present study, we separately evaluated the spatial magnitude and the temporal dynamics of postural sway, so that we might better understand the evolution of these distinct aspects of postural activity among children. Variations in suprapostural tasks of the kind used in the present study have been shown to yield qualitatively different effects on the spatial magnitude and temporal dynamics of postural sway in adults (e.g., Koslucher et al., 2012). Some studies have examined both spatial and temporal metrics in childrens' posture, but have not included variations in suprapostural tasks, or in stance width (e.g., Gouleme, Ezane, Wiener-Vacher, & Bucci, 2014; Newell, Slobounov, Slobounova, & Molenaar, 1997). In the present study, we asked how about both the spatial magnitude and temporal dynamics of childrens' postural sway might vary with age, suprapostural tasks, and stance widths.