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Age-related changes in postural sway in preschoolers

Evi Verbecque [a,*], Paula Hentschel Lobo da Costa [b,c], Pieter Meyns [d,f], Kaat Desloovere [e,f], Luc Vereeck [a], Ann Hallemans [a,c,g]

[a] Department of Rehabilitation Sciences and Physiotherapy, Faculty of Medicine and Health Science, University of Antwerp, Belgium
[b] Department of Physical Education, Federal University of São Carlos, Brazil
[c] Department of Functional Morphology, Faculty of Sciences, University of Antwerp, Belgium
[d] Department of Rehabilitation Sciences & Physiotherapy, Faculty of Medicine and Health Sciences, University of Ghent, Belgium
[e] Department of Kinesiology, Faculty Kinesiology and Rehabilitation Sciences, KU Leuven, Belgium
[f] Department of Rehabilitation Sciences, Faculty of Kinesiology and Rehabilitation Sciences, KU Leuven, Belgium
[g] Multidisciplinary Motor Centre Antwerp, Antwerp, Belgium

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ABSTRACT

Objectives: The present study aimed to investigate age-related differences of postural sway in 3- to 6-year-old typically developing children in different sensory conditions and subsequently to provide reference values for global descriptive sway parameters in preschoolers.

Methods: Ninety-six typically developing children, between 3 and 5 years of age, participated in this cross-sectional study. Postural sway was measured for 40 s in four conditions (eyes open/eyes closed on stable ground/foam) by using a force plate. Global descriptive sway parameters were calculated and analysed using a 2 × 2 × 3 (surface × vision × age group) MANOVA ($p < 0.05$) in the children that were able to complete the task (40 s).

Results: When sensory information was altered, a significantly smaller number of 3- and 4-year-olds was able to complete the task. Significant main effects of vision ($p < 0.05$), surface ($p < 0.001$) and an interaction effect between vision and surface ($p < 0.05$) on all postural sway parameters were found. A significant main effect of age was found for antero-posterior amplitude ($p = 0.047$), medio-lateral root mean square ($p = 0.012$) and area ($p = 0.009$) between 3- and 5-year-olds and 4- and 5-year-olds. No interaction effects (surface × vision × age group) were found.

Conclusions: During natural stance, the amount of postural sway distinguishes 5-year-olds from 3- and 4-year-olds, highlighting the need for age-specific reference values for specific balance-related sway parameters (e.g. RMS_ml). Regarding test conditions with altered sensory input, a larger number of 5-year-old children are able to perform more difficult tasks. Nevertheless, if 3- or 4-year-olds are able to perform the more difficult tasks, their performance can be compared to the older children.

1. Introduction

To achieve and maintain an upright standing position, sufficient postural control is required [1,2]. Postural control can be defined as achieving a desired body position, such as upright standing and maintaining this position in any static (maintaining a posture) or dynamic (performing a motor skill) situation [1–4]. Therefore, postural *control* is a necessity to ensure stability of the body during widely differing motor tasks allowing skilled movement [2]. This requires perception of body and head position in space in relation to the environment, as well as perception of the position of body segments in relation to each other based on sensory information [1–4]. This information, obtained through the auditory, visual, vestibular and somatosensory systems, is processed in the brain, involving the selection of an appropriate balance strategy leading to an adequate motor output [1]. This output is provided by the motor system, which is responsible for the activation of the appropriate movement patterns in response to perturbations of balance [3–5].

The assessment of postural control in children can be performed in different ways, varying from functional to technical approaches, and is of great importance because it provides

* Corresponding author at: Universiteitsplein 1, 2610 Wilrijk, Belgium. Tel.: +32 3 265 18 06.
E-mail addresses: evi.verbecque@uantwerpen.be, evi.verbecque@gmail.com (E. Verbecque).

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information on functioning and motor development [2,3]. Functional tests assess the ability to perform a task, but in contrast to technical tests, they do not quantify the movements of a child while it maintains his or her posture nor do they provide information on the influence of sensory input [6]. The most common technical measure of postural control is the characterisation of postural sway by measuring centre of pressure (COP) displacements. This technique has two main advantages compared to the functional tests: (1) measuring postural sway ensures a very accurate quantitative measure (COP displacement) of maintaining a certain posture during a certain timeframe and (2) environmental factors, that challenge different sensory systems, can be easily implemented in the test battery (e.g. measuring postural sway with eyes open/closed on a firm/foam surface) [7]. To investigate the role of sensory information in postural control several approaches have been reported in literature. Furthermore, opinions differ on its development in children. Forssberg and Nashner [8] stated that it is probably sensory integration that occurs during development of postural control, rather than the dominance of a specific modality, as was reported by Shumway-Cook and Woollacott [9]. Sensory integration refers to reweighting multiple sensory inputs to maintain one's posture [8,10,11]. To assess sensory integration, Foudriat et al. [12] applied the Sensory Organization Test in children, in which sway- and/or visual referencing can be used to alter sensory input. This test examines a child's ability to integrate multiple sensory inputs for postural control [12]. However, according to Bair et al. [10], this technique would not be sufficient to quantify the sensory fusion process. They stated that the most adequate way to evaluate sensory integration during postural control, is by using a moving room [10]. Several recent studies have shown indeed, that this type of assessment actually provides information on sensory reweighting during postural control [10,11]. Nevertheless, moving room assessment requires specific and expensive equipment. From a clinical point of view, an easily applicable and fast way to determine whether a child's postural control is sufficient, would be enough. Therefore, static posturography, measuring spontaneous postural sway, in which global descriptive sway parameters (e.g. sway amplitude and sway velocity) are measured and this in different sensory conditions (e.g. standing with eyes open or closed on stable ground or foam) could provide enough information to determine whether a child's postural control deviates from what is normal.

In previous studies, different age categories have been investigated and all authors suggest that an important first *transitional* phase with regard to the amount of postural sway occurs in young children [13–16]. The exact age of these *young children*, however, varies depending on the investigating authors. A literature review on reference values and developmental changes of postural sway during bipedal stance, revealed that preschoolers (children between the ages 3 and 6) are usually addressed as one group, and that reference values for postural sway parameters in this group are scarce [13,17–21]. Due to developmental changes in postural control during the preschool years, it could be expected that age-related differences of sway parameters can be identified, hence the relevance for age-specific reference values. Therefore the aim of this study is twofold: (1) to investigate age-related differences of postural sway in 3- to 6-year-old typically developing children in different sensory conditions and (2) to provide reference values for global descriptive sway parameters in preschoolers. It is hypothesised that postural sway measures will differ between 3-, 4- and 5-year-olds, reflected by a decrease in the amount of sway with increasing age. Also, withdrawal or alteration of specific sensory information is expected to disturb younger children significantly more than older children, leading to increased sway.

2. Methods

2.1. Participants

A cross-sectional study was performed investigating postural sway in a sample of 96 children, consisting of 3-year-olds (43.2 (3.9) months), 4-year-olds (53.2 (3.8) months) and 5-year-olds (64.8 (3.3) months). The children were recruited from three regular preschools in the city of Antwerp, Belgium. Data were collected between October 2013 and April 2014. This study was approved by the local ethical committee of the University of Antwerp (B300201316328). Prior to the assessment of postural sway, a questionnaire was completed by the parents, which was used to identify the presence of developmental problems and to map features of the child's birth, use of aids such as glasses, orthoses and cochlear implants. Children were excluded from the study if they had any known developmental or neuromotor disorder, severe visual or hearing impairment, used aids (except for glasses), had cochlear implantations, or when there was a lack of cooperation.

2.2. Test procedure and protocol

To examine postural sway during upright bipedal stance, subjects stood barefoot on a force plate (0.4×0.5 m, 1000 Hz, model OR 6-5-2000, Advanced Medical Technology Inc., Massachusetts, USA), with a standardised distance of 10 cm between the medial borders of the feet, for 40 s watching a film (iPad 2, 9.7 in. multi-touch screen) at eye level or with their eyes closed. Postural sway was measured in four non-randomised test conditions:

condition 1: EO; standing on firm surface with eyes open
condition 2: EC; standing on firm surface with eyes closed
condition 3: FEO; standing on a foam with eyes open
condition 4: FEC; standing on a foam with eyes closed

During each trial the subjects were asked to keep both arms along their body and stand as still as possible. A medium density foam pad ($12 \times 45 \times 45$ cm, NeuroCom International Inc., Clackamas, USA; 60 kg/cm^3) was used in conditions 3 and 4. Each condition was explained in advance to each child and performed once as single trial measurements for postural sway have been shown to provide a representative sample of postural control in children [22]. The trial was stopped if the child didn't understand or didn't follow the instructions, only then a second trial was performed. All subjects were permitted to rest between trials or conditions. Two therapists (EV, PHLC) tested all subjects. Throughout the entire test, one investigator stayed close to the subject to prevent falling, without interfering with his/her performance. The children were verbally encouraged by the investigator if needed.

2.3. Variables of interest

Demographic data (age, gender, height, use of aids) were used to describe the sample. The COP positions were calculated from the ground reaction forces (F_x, F_y, F_z) and appropriate moments of force around the x (Mx) and y (My) axes using formula 1 and 2 (Table 1). The first 10 s of each trial were discarded to avoid transients [23], leaving 30 s for analysis.

The COP amplitudes in antero-posterior (COP_ap) and medio-lateral directions (COP_ml), velocities (COPv_ap, COPv_ml), root mean squared error (RMS_ap, RMS_ml) and path (COP_path) were calculated using a custom made Matlab scripts (version 2013b for Windows, Mathworks) based on formula 3–9 according to Duarte and Freitas (Table 1) [24]. A second order low pass butterworth filter with a cut-off frequency of 12.5 Hz was used for filtering the COP.