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Full Length Article

Age-dependent adaptations to anticipated and non-anticipated perturbations after balance training in children

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ABSTRACT

Postural control undergoes rapid changes during child development. However, the influence of balance training (BT) on the compensation of perturbations has not yet been investigated in children. For this purpose, young (6.7 ± 0.6 years) and old children (12.0 ± 0.4 years) were exposed to externally induced anticipated (direction known) and non-anticipated (direction unknown) perturbations on a free swinging platform before and after either child-oriented BT (INT; young: n = 12, old: n = 18) or regular physical education (CON; young: n = 9, old: n = 9). At baseline, old children exhibited less platform sway after perturbations than young children ($p = .004$; $\eta_p^2 = 0.17$). However, no differences were found between anticipated and non-anticipated perturbations. After training, INT reduced the platform sway path while CON remained stable (−11.1% vs. +2.7%; $p < .001$; $\eta_p^2 = 0.26$). Furthermore, the young INT group adapted statistically similarly in anticipated and non-anticipated situations (−7.9% vs. −12.6%; $p = .556$; $r = 0.33$), whereas the old INT group tended to improve more in anticipated perturbations (−15.1% vs. −8.2%; $p = .052$; $r = 0.51$). Thus, the maturity of the postural system seems to influence the extent of training adaptations in anticipated perturbations. Furthermore, this study provides evidence that BT can improve postural responses to external perturbations in children and may represent a useful intervention to prevent falls.

1. Introduction

It was previously shown that children display a high risk of falling (Granacher, Muehlbauer, Gollhofer, Kressig, & Zahner, 2011) with negative consequences for health care costs (Kahl, Dortschy, & Ellsasser, 2007; Mathers & Penm, 1999; Moorin & Hendrie, 2008). Furthermore, the ability to counteract external perturbations was shown to predict the risk of falls in older adults (Sturnieks et al., 2013). It might therefore be assumed that the ability to compensate externally or internally induced postural perturbations is also essential for children to reduce the risk of falls; especially as the quality of such responses is considered to be low in young children (Westcott & Burtner, 2004). With respect to non-anticipated externally induced perturbations, it was shown that postural responses of children are maturing with age. After sudden toe-up rotations, the onset of the anterior tibialis muscle – which is not activated by a stretch reflex but essential to restore position in this movement – was demonstrated to decrease from the age of 14 months to the age of 15 years (Haas, Diener, Bacher, & Dichgans, 1986). Furthermore, the variability of postural responses after

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non-anticipated external perturbations was shown to be higher in children under the age of 7 when compared with older children or adults (Berger, Quintern, & Dietz, 1985; Forssberg & Nashner, 1982; Shumway-Cook & Woollacott, 1985; Woollacott, Debu, & Mowatt, 1987).

Regarding anticipated perturbations in children, most studies investigated the development of anticipatory postural adjustments (APA), which are characterized by feedforward activities in postural muscles already before the onset of a voluntary movement (e.g. arm rising). For instance, when children were asked to stand on tiptoe as soon as possible after an acoustic cue, the time needed to initialize the anticipatory forward shift (i.e. APA) decreased with age (Haas, Diener, Rapp, & Dichgans, 1989). Additionally, young children under the age of 8 years were shown to display inconsistent anticipatory patterns in comparison to older children when performing a self-initiated arm rising task (Hay & Redon, 2001; Riach & Hayes, 1990). This suggests that younger children have limited abilities to generate adequate APAs to self-induced perturbations when comparing with older children or adults.

On the other side, responses to externally induced anticipated perturbations were shown to be modulated based on the preparatory setting (or central set) in adults (Horak, Diener, & Nashner, 1989; Wälchli, Tokuno, Ruffieux, Keller, & Taube, 2017). The preparatory setting is defined as a neural readiness state based on the predictability of a stimulus and the generation of an adequate response to it (Smith, Jacobs, & Horak, 2012). There exists to our knowledge only one study which investigated the preparatory setting in children (Hay & Redon, 1999). In this study, children held a load in their horizontally outstretched arms. The load was removed either through a self-initiated release (anticipated) or externally lifted up (non-anticipated). Six to 8-year-olds showed highly variable responses and therefore a less efficient anticipatory strategy in the voluntary releasing task when compared with older children (9–10 years) and adults. The authors assumed that "…high-level anticipatory control and information-processing mechanisms… (Hay & Redon, 1999, p. 161)" are less matured in young children compared to older children or adults.

However, a design where anticipated and non-anticipated perturbations were both triggered externally to assess the preparatory setting – without any influence of APAs – has not yet been investigated in children. Therefore, the first aim of the present study was to analyze postural responses of children exposed to externally induced anticipated (prior knowledge about the direction) and non-anticipated perturbations (direction not previously known). We hypothesized that the older children (11–13 years) perform better than the younger children (6–7 years) in both, anticipated and non-anticipated perturbations. For this purpose, the overall ability to counteract perturbations, i.e. performances in all 4 directions together was analyzed in a first step. Subsequently, performances in the 4 directions were compared separately between the young and the old group to get a more detailed insight. Regarding the preparatory setting, postural sway was expected to be reduced in anticipated perturbations (i.e. previous information about the direction) when compared with non-anticipated perturbations.

Moreover, evidence is missing whether balance training (BT) can positively influence the postural responses to perturbations in children. Better postural responses to anticipated translational perturbations were previously reported in 13 year old adolescents after ice skating training (Keller, Röttger, & Taube, 2014) and in adults after classical BT (Taube et al., 2007). Furthermore, infants (36–40 weeks) improved the postural response pattern after platform perturbations when exposed to intense perturbation training (Sveistrup & Woollacott, 1997). Similar findings were reported for 20–40 weeks old infants in perturbed sitting balance, where postural response modulation increased after two months of toy reaching training (Hadders-Algra, Brogren, & Forssberg, 1996). However, BT-induced adaptations to perturbations with altered preparatory setting have never been investigated in children between 4 and 13 years of age. Therefore, the second aim of the present study was to evaluate the age-dependent trainability of anticipated and non-anticipated perturbations in children.

2. Methods

Parents and children were previously informed about the study protocol and gave their written consent. Ethical principles of the Helsinki Declaration were respected and the local ethics committee permitted the realization of the present study (87/14). Other parts of this study were published earlier (Wälchli, Ruffieux, Mouthon, Keller, & Taube, 2018).

2.1. Participants

Initially, 25 young (YOUNG) and 28 old children (OLD) without any motor difficulties started the experiment after parents had reported no neurological and/or orthopedic impairments for their participating children. An intervention (INT) and a control group (CON) were analyzed for both ages. The INT groups consisted of regular school classes and children of the CON groups attended other schools in the same region. Only 48 children could be taken into the final analysis due to leisure time injury (OLD-INT: 1) or incomplete data (YOUNG-INT: 3; YOUNG-CON: 1; see Table 1).

2.2. Perturbations

A two-dimensional free swinging platform (Posturomed, Haider, Bioswing, Pullenreuth, Germany) was used to assess postural stability after either anticipated (direction known) or non-anticipated (direction not known) postural perturbations in four different directions (anterior, posterior, left, right). Perturbation onset was induced manually by the experimenter and was entirely unpredictable for the participants. The tests were executed in double leg stance with feet together, arms akimbo and a natural head position while looking at a given point (Kapteyn et al., 1983). To induce a perturbation, the platform was moved away from its middle position by servomotors and was swinging freely after the release. Acceleration (2.15 m/s^2), peak velocity (0.22 m/s) and distance (2 cm) of the perturbations were kept constant throughout the experiment. A reflecting marker was placed on the platform