Human Movement Science 46 (2016) 52–62

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Contribution of binocular vision to the performance of complex manipulation tasks in 5–13 years old visually-normal children

Fatimah Alramis [a], Eric Roy [a], Lisa Christian [b], Ewa Niechwiej-Szwedo [a,*]

[a] Department of Kinesiology, University of Waterloo, 200 University Ave. W., Waterloo N2L 3G1, Ontario, Canada
[b] School of Optometry and Vision Science, University of Waterloo, 200 University Ave. W., Waterloo N2L 3G1, Ontario, Canada

ARTICLE INFO

Article history:
Received 19 June 2015
Revised 17 December 2015
Accepted 17 December 2015
Available online 23 December 2015

Keywords:
Fine motor skills
Development
Binocular vision
Stereopsis

ABSTRACT

Individual studies have shown that visuomotor coordination and aspects of binocular vision, such as stereoacuity and dynamic vergence control, continue to improve in normally developing children between birth and early teenage years. However, no study has systematically addressed the relationship between the development of binocular vision and fine manipulation skills. Thus, the aim of this cross-sectional study was to characterize performance of complex manipulation tasks during binocular and monocular viewing. Fifty-two children, between 5 and 13 years old, performed 2 manipulation tasks: peg-board and bead-threading under randomized viewing conditions. Results showed that binocular viewing was associated with a significantly greater improvement in performance on the bead-threading task in comparison to the peg-board task and the youngest children showed the greatest decrement in task performance under the monocular viewing condition when performing the bead-threading task. Thus, the role of binocular vision in performance of fine manipulation skills is both task- and age-dependent. These findings have implications for assessment of visuomotor skills in children with abnormal binocular vision, which occurs in 2–3% of otherwise typically developing children.

1. Introduction

Performance of skillful manipulations with our hands requires the ability to see in depth. There are multiple monocular depth cues that the brain can use to determine an object's location and properties, such as shape, size, and orientation (Howard, 2012). But, being able to use both eyes provides two important binocular depth cues: stereopsis and ocular vergence. Stereopsis involves the ability to combine two slightly disparate retinal images into a single image that is perceived in depth (Howard & Rogers, 2002). On the other hand, ocular vergence involves coordinated, disjunctive eye movements performed when looking at objects at different distances in depth. The ability to integrate these different depth cues is not innate but begins to develop during the first year of life, and continues to mature into the second decade (Daw, 2006; Nardini, Bedford, & Mareschal, 2010). During this maturation period, children also develop fine motor skills. Although individual studies have examined the developmental trajectory of binocular vision and visuomotor skills separately, only a few studies have examined the role of binocular vision in the development of fine motor skills (Grant, Suttle, Melmoth, Conway, & Sloper, 2014; Suttle, Melmoth, Finlay, Sloper, & Grant, 2011; Watt, Bradshaw, Clarke, & Elliot, 2003). Thus, the focus of this

* Corresponding author.
E-mail addresses: falramis@uwaterloo.ca (F. Alramis), eroy@uwaterloo.ca (E. Roy), lisa.christian@uwaterloo.ca (L. Christian), eniechwi@uwaterloo.ca (E. Niechwiej-Szwedo).

http://dx.doi.org/10.1016/j.humov.2015.12.006

cross-sectional study was to examine the contribution of binocular vision during the performance of two manipulation tasks involving precision grasping, placement, and action sequencing in primary school-aged children.

Research has shown that stereopsis emerges between 3–5 months of age in normally developing infants (Atkinson, 1984; Braddick, 1996; Held, Birch, & Gwiazda, 1980) and continues to improve across the childhood period (Simons, 1981). Visually-normal preschool children (3–6 years old) attain a stereoacuity threshold between 60–120 s of arc (Afsari et al., 2013; Ciner et al., 2014), and achieve adult levels (i.e., <10 s of arc) later than 14 years of age (Giaschi, Narasimhan, Solski, Harrison, & Wilcox, 2013). Ocular vergence also emerges during the first few weeks after birth and continues to develop during childhood (Aslin, 1977; Bharadwaj & Candy, 2008; Horwood & Riddell, 2013; Yang, Bucci, & Kapoula, 2002; Yang & Kapoula, 2004). Infants at 6 months of age are capable of executing convergent eye movement to re-fixate the target upon introduction of 5 and 10 diopter base-in prisms (Aslin, 1977). However, the fine-tuning of vergence eye movements continues throughout the childhood period. For example, Yang and colleagues (Yang & Kapoula, 2004; Yang et al., 2002) found that vergence latency was prolonged in children and adult-like vergence latency was attained around 10–12 years of age. Because depth perception is important for the performance of skillful hand movements (Drover, Stager, Morale, Leffler, & Birch, 2008; O'Connor, Birch, Anderson, & Draper, 2009; Webber, Wood, Gole, & Brown, 2008), this relatively prolonged developmental trajectory of binocular visual functions (i.e., stereopsis and vergence) may have implications for the development of fine motor skills.

Visuomotor coordination skills include a variety of movements such as reaching, grasping, and manipulating. Pioneering studies by von Hofsten (Bertenthal & Von Hofsten, 1998; Von Hofsten, 1984), Hay and colleagues (Bard, Hay, & Fleury, 1990; Bourgeois & Hay, 2003; Hay, 1979; Olivier, Hay, Bard, & Fleury, 2007), and Smyth, Peacock, and Katamba (2004) have identified at least 3 stages that characterize the development of reaching and grasping movements in primary school-aged children. The first developmental stage, evident in children younger than 7 years, is characterized by a ballistic movement, increased spatial and temporal variability, and reduced accuracy of reaching. Several studies have shown that visual feedback of the hand does not significantly alter movement kinematics (Hay, 1979; Smyth et al., 2004), which indicates that children at this developmental stage rely on visual information to plan their reach and grasp; but, the presence of visual feedback during movement execution does not improve performance. Around the age of 8 years, children begin to rely on visual feedback during movement execution. The lack of visual input during reach execution results in longer movement times and reduced accuracy, which indicates that visual feedback provides a critical source of information to plan and execute movements at this developmental stage. Following this stage, children's reaching movements begin to resemble an adult-like pattern, which is characterized by a higher peak acceleration and velocity, while errors in the spatial trajectory and variability are reduced. It has been suggested that children at this developmental stage begin to integrate predictive control and visual feedback during movement execution (Bard et al., 1990; Hay, 1979). However, studies by Smyth et al. (2004) have shown that fully adult-like reach control, based on the integration of predictive and feedback control mechanisms, does not emerge until children are older than 10 years. Specifically, children are not able to use visual information as efficiently as adults to integrate reaching, grasping, and lifting movements.

Several recent studies have postulated that improvements in motor control emerge when children learn to rely on predictive control (Contreras-Vidal, Bo, Boudreau, & Clark, 2005); (Babinsky, Braddick, & Atkinson, 2012). Current theoretical and experimental findings suggest that predictive control requires an internal model for movement control, that is, a neural representation of action or an internal simulation of the sensory-motor transformation (Sabes, 2000; Shadmehr, Smith, & Krakauer, 2010; Wallace et al., 2007; Wolpert, 2007). The internal model can be used to predict the motor and sensory consequences of a movement, which is referred to as state estimation. Because of the delays associated with the processing of afferent, movement-related feedback, state estimation during movement execution allows more effective control. That is because the prediction can be integrated with current sensory feedback to detect errors in the trajectory (dynamic state estimation) (Izawa & Shadmehr, 2008). Recent studies have shown age-related improvements in state estimation during the execution of goal-directed arm movements (King, Oliveira, Contreras-Vidal, & Clark, 2012). Indeed, the ability to engage in online control to correct limb trajectory when the target is displaced, which reflects accurate state estimation, was only evident in the older group of children, between 10–12 years old. Whereas, the younger children (6–8 years) were less accurate and more variable in making corrections. Interestingly, a recent study found an association between the ability to engage in online control and the performance on a motor imagery task (Fuelscher, Williams, & Hyde, 2015). Overall, these studies indicate that optimal sensorimotor control is dependent on the development of internal neural representation of action, which likely depends on the maturation of the sensory systems and task-specific experiences.

Although the role of visual feedback in the control of upper limb movements in children has been examined extensively, only three studies to date assessed the role of binocular vision during reaching and grasping movements performed by visually-normal children aged 5–12 years (Grant et al., 2014; Suttle et al., 2011; Watt et al., 2003). The study by Watt et al. focused on visually-normal children, while the studies by Grant et al. and Suttle et al. focused on children with abnormal binocular vision and included visually-normal children as a control group. All three studies examined reach and grasp kinematics and found age-dependent differences in reaching behavior during binocular and monocular viewing. In particular, kinematic measures during monocular viewing indicated that children younger than 7 years old had more difficulty appropriately scaling their movements for distance and object size; however, there was no difference in overall movement duration between binocular and monocular viewing. In contrast, binocular vision provided important sensory information during movement execution for the older children. These studies provide important information about the role of binocular vision during the performance of a single prehension movement. However, most of our daily activities consist of more