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Global motion perception is related to motor function in 4.5-year-old children born at risk of abnormal development

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ABSTRACT

Global motion perception is often used as an index of dorsal visual stream function in neurodevelopmental studies. However, the relationship between global motion perception and visuomotor control, a primary function of the dorsal stream, is unclear. We measured global motion perception (motion coherence threshold; MCT) and performance on standardized measures of motor function in 606 4.5-year-old children born at risk of abnormal neurodevelopment. Visual acuity, stereoacuity and verbal IQ were also assessed. After adjustment for verbal IQ or both visual acuity and stereoacuity, MCT was modestly, but significantly, associated with all components of motor function with the exception of fine motor scores. In a separate analysis, stereoacuity, but not visual acuity, was significantly associated with both gross and fine motor scores. These results indicate that the development of motion perception and stereoacuity are associated with motor function in pre-school children.

1. Introduction

A primary role of human vision is the guidance of motor functions such as reaching, grasping and locomotion. In fact, a dominant theory of visual processing posits two parallel streams; one specialized for object recognition (the ventral stream) and one for visuomotor control or "vision for action" (the dorsal stream) (Goodale & Milner, 1992). The ventral stream receives predominantly parvocellular input from the lateral geniculate nucleus and projects to the inferior temporal lobe via V1 and ventral extrastriate areas such as V4 (Livingstone & Hubel, 1988; Van Essen & Gallant, 1994). Conversely, the dorsal stream receives magnocellular input and projects from V1 to regions of the posterior parietal lobe involved in visuomotor control. The dorsal stream involves motion-sensitive extrastriate areas such as V3a, and V5 (Braddick et al., 2001; Goodale & Milner, 1992).

The dorsal stream is of interest from a child development perspective because it may be particularly susceptible to the effects of abnormal neurodevelopment (the dorsal stream vulnerability hypothesis) (Braddick, Atkinson, & Wattam-Bell, 2003; Grinter, Maybery, & Badcock, 2010; Spencer et al., 2000). Furthermore, visuomotor control is a key domain of preschool development that is related to later performance in areas such as learning, writing and mathematics (Becker, Miao, Duncan, & Mcclelland, 2014; Kurdek & Sinclair, 2001).

Visual areas that are typically included in definitions of the dorsal stream (V1, V3A and V5, also known as the middle temporal area or MT) form a motion processing hierarchy within the visual cortex (Movshon & Newsome, 1996). This involves the representation of local motion signals in V1 and the integration of these signals in V3A and V5 to enable perception of coherent or global motion.

Global motion perception is typically measured using random dot kinematograms (RDKs), which consist of two populations of moving dots; signal dots that move in a common coherent direction and noise dots that move randomly. The observer's task is to detect the direction of the coherent signal dots and the relative

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proportion of signal to noise in the stimulus can be varied to estimate a motion coherence threshold (the percentage of signal dots required for a particular level of task performance) (Newsome & Pare, 1988). It is well established that V5, a component of the dorsal stream, plays a central role in detecting coherent motion in RDKs (Cai, Chen, Zhou, Thompson, & Fang, 2014; Chen, Cai, Zhou, Thompson, & Fang, 2016; Newsome & Pare, 1988; Rudolph & Pasternak, 1999). However, the extent to which performance on a global motion task reflects the function of higher-level dorsal stream areas such as the posterior parietal cortex is unclear.

Visuomotor control refers to the visual guidance of motor actions, a function that is supported by the posterior parietal lobe (Cavina-Pratesi et al., 2010; Tunik, Frey, & Grafton, 2005). Examples of visually guided actions include reaching, grasping and object manipulation. The accuracy and kinematics of visually guided actions can be assessed with a high degree of accuracy using infrared motion tracking systems (Grant, Melmoth, Morgan, & Finlay, 2007; Melmoth, Finlay, Morgan, & Grant, 2009). Alternatively, there are several well-validated standardized clinical test batteries of motor function that include visuomotor tasks. One example is the Beery-Buktenica Developmental Test of Visual–Motor Integration (Beery VMI) (Beery & Beery, 2010). The visuomotor control aspect of this test (referred to as the visual motor integration component) involves copying visually presented stimuli using a pencil and paper. Other examples are the Movement Assessment Battery for Children (M-ABC) (Schoemaker, Niemeijer, Flapper, & Smits-Engelsman, 2012; Smits-Engelsman, Fiers, Henderson, & Henderson, 2008) and the Peabody Developmental Motor Scales – 2 (PDMS-2) (Rasa, Rashedi, Hosseini, & Sazmand, 2011; Tavasoli, Azimi, & Montazari, 2014). The assessment of fine motor skills within these test batteries involves activities such as bead threading, coin posting and using building blocks. Gross motor function assessment includes ball catching along with predominately motor tasks such as balancing and jumping.

The primary aim of this study was to examine the relationship between global motion perception and standardized measures of motor function in preschool children. An association between global motion perception and motor function would indicate a link between the development of abilities supported by V5 and the posterior parietal lobe respectively, in accordance with the concept of a dorsal processing stream. Such an association would also support the current practice of using global motion perception as an index of general dorsal stream function (Atkinson et al., 1997; Chakraborty, Anstice, Jacobs, LaGasse, et al., 2015; Guzzetta et al., 2009; MacKay et al., 2005; Manning, Charman, & Pellicano, 2013; Palomares & Shannon, 2013).

Several studies have reported concurrent global motion and motor function deficits in children with abnormal neurodevelopment, for example due to William's syndrome (Atkinson et al., 1997) or Dravet syndrome (Ricci et al., 2014). In these studies, motor function was assessed using a card posting task (Atkinson et al., 1997) or the Beery VMI (Ricci et al., 2014). These findings are consistent with an association between global motion perception and visuomotor control. In some cases, the same children exhibited normal performance on tests of global form perception that were designed to target the ventral processing stream (Atkinson et al., 1997). This suggests the presence of a specific dorsal stream impairment in certain neurodevelopmental disorders (Braddick et al., 2003; Grinter et al., 2010).

More recently, the relationship between global motion perception and visuomotor control has been investigated in a group of normally developing children (Braddick et al., 2016). Braddick et al. measured global motion perception, global form perception and performance on the visual-motor integration component of the Beery VMI in 154 children aged 5–12 years. Greater sensitivity to global motion perception was modestly but significantly associated with better visuomotor control ($R^2 = 0.06$). No such relationship was found for global form perception. Furthermore, an association between greater sensitivity to global motion and a greater proportion of cortical area devoted to the posterior parietal lobe was evident from structural MRI data. Global motion perception was also associated with measures of mathematical ability that involve the posterior parietal lobe. These results support the idea that global motion perception provides at least a partial index of overall dorsal stream function.

In this study, we assessed the relationship between global motion perception and performance across a range of well validated, standardized tests of motor function (see Section 2.4, neurodevelopmental assessment). The study involved a large group of pre-school children born with neurodevelopmental risk factors and assessed in a consistent fashion at a consistent age, and with a wide range of motor function outcomes. The children were recruited from two large-scale multidisciplinary studies; Children with Hypoglycemia and their Later Development (CHYLD) and Infant Development Environment and Lifestyle (IDEAL). The studies were designed to investigate the impact of neonatal hypoglycemia (CHYLD) and prenatal drug exposure (IDEAL) on child development. Both study protocols involved a comprehensive assessment of neurodevelopment at 4.5 years of age, including visual-motor integration and fine and gross motor function.

We expected that motor function would vary considerably within this group of children because both neonatal hypoglycemia (Lucas, Morley, & Cole, 1988) and prenatal drug exposure (Wouldes et al., 2014) affect motor development. Specifically, moderate levels of neonatal hypoglycaemia (glucose concentration <2.6 mm/l) have been associated with lower gross motor scores on the Bayley motor scale at 18 months of age (Lucas et al., 1988). In addition, 1 to 3-year-old children with prenatal exposure to methamphetamine had lower scores on the Peabody Developmental Motor scale than closely matched children without methamphetamine exposure (Wouldes et al., 2014).

We reasoned that this variability would allow for the detection of any association between global motion perception and visuomotor control that may exist. Additional benefits of studying this group included the ability to control for the effect of age (all children were assessed at 4.5 years) and the fact that the children had not yet started school, which may substantially influence development (Camilli, Vargas, Ryan, & Barnett, 2010). Furthermore, verbal IQ (V-IQ) scores from the Wechsler Preschool and Primary Scale of Intelligence (WPPSI)-III (Welscher, 2002) were available and could be used to control for the potentially confounding effect of cognitive development on performance of the global motion task (Jakobson, Frisk, & Downie, 2006; Manning et al., 2013). The V-IQ score was chosen as it does not involve any measures of visual processing (Jarrold, Baddeley, & Hewes, 1998).

The secondary aim of this study was to investigate the relationships between clinical measures of visual function (stereopsis and visual acuity) and visuomotor control in the same group of children. Disorders of binocular vision such as amblyopia and strabismus disrupt normal development of visually guided reaching and grasping (Grant & Conway, 2014; Grant & Moseley, 2011; Grant, Suttle, Melmoth, Conway, & Sloper, 2014; Grant et al., 2007; Mazyn, Lenoir, Montagne, Delaey, & Savelsbergh, 2007; Melmoth et al., 2009; O'Connor, Birch, Anderson, & Draper, 2010b; Suttle, Melmoth, Finlay, Sloper, & Grant, 2011) and impair performance on standardized tests of fine motor function (Caputo et al., 2007; Drover, Stager, Morale, Leffler, & Birch, 2008; Hrisos, Clarke, Kelly, Henderson, & Wright, 2006; Rogers, Chazan, Fellows, & Tsou, 1982; Webber, Wood, Gole, & Brown, 2008; Webber, Wood, & Thompson, 2016). However, the relationship between stereoacu-