



The maturation of global motion perception depends on the spatial and temporal offsets of the stimulus



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ABSTRACT

The typical development of motion perception is commonly assessed with tests of global motion integration using random dot kinematograms. There are discrepancies, however, with respect to when typically-developing children reach adult-like performance on this task, ranging from as early as 3 years to as late as 12 years. To address these discrepancies, the current study measured the effect of frame duration (Δt) and signal dot spatial offset (Δx) on motion coherence thresholds in adults and children. Two Δt values were used in combination with seven Δx values, for a range of speeds (0.3–38 deg/s). Developmental comparisons showed that for the longer Δt , children performed as well as adults for larger Δx , and were immature for smaller Δx . When parameters were expressed as speed, there was a range of intermediate speeds (4–12 deg/s) for which maturity was dependent on the values of Δx and Δt tested. These results resolve previous discrepancies by showing that motion sensitivity to a given speed may be mature, or not, depending on the underlying spatial and temporal properties of the motion stimulus.

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1. Introduction

The random dot kinematogram (RDK) is a commonly-used stimulus for assessing global motion perception. This stimulus has been used in clinical studies that compare the performance of patient populations (e.g., autism, Milne et al., 2002; preterm children, Taylor et al., 2009; dementia, Silverman et al., 1994) to healthy age-matched controls, and in cross-sectional studies that compare performance of aging populations to healthy young adult controls (e.g., Snowden & Kavanagh, 2006). This stimulus is also used to track the maturational trajectory of global motion perception in typically-developing children. However, there are discrepancies with respect to the age at which global motion perception matures to adult levels. Resolving these discrepancies was the main purpose of this study.

Estimates of the age at which global motion direction discrimination can be considered adult-like range from as young as 3 years to as old as 12. Parrish et al. (2005) compared coherence thresholds in children aged 3–12 and adults, and found no significant differences between thresholds, indicating global motion perception matures before age 3. Consistent with this, in clinical studies that included control groups of children and adults, no difference between control groups of 6-year-old children and adults were found

by Ellemberg et al. (2002), or Reiss, Hoffman, and Landau (2005) on a motion detection task. In contrast, Narasimhan and Giaschi (2012) found that 5- to 6-year-old children had immature global motion perception, and a study by Hadad, Maurer, and Lewis (2011) testing children aged 6–14 found that maturation did not occur until age 12. Studies using random Gabor kinematograms, which are similar to RDKs but with Gabor patches rather than dots, have also found significant differences in global motion perception between 5-year-olds and adults (Ellemberg et al., 2004, 2010).

Because each research group tends to create its own stimulus, it is likely that different stimulus parameters are driving performance differences in children and adults. However, the relationship between stimulus parameters and maturation is not obvious, from a simple review of the literature. For example, Parrish et al. (2005) and Ellemberg et al. (2002) used up/down direction discrimination and found early maturation, but so did Hadad, Maurer, and Lewis (2011), who found quite late maturation. Both Reiss, Hoffman, and Landau (2005) and Narasimhan and Giaschi (2012) used left/right directions, and also came to different conclusions about 5- to 6-year-olds. Studies also differ in the type of noise algorithm used (direction noise: Ellemberg et al., 2002; Hadad, Maurer, & Lewis, 2011; walk noise: Narasimhan & Giaschi, 2012; Parrish et al., 2005; white noise: Reiss, Hoffman, & Landau, 2005), and in the dot size and density used (small dots, dense stimulus: Parrish et al., 2005; small dots, varying densities: Narasimhan & Giaschi, 2012; large dots, sparse stimulus: Ellemberg et al., 2002; Hadad, Maurer, & Lewis, 2011; Reiss, Hoffman, &

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Landau, 2005), but these properties do not identify which studies found early or late maturation. Studies used a range of stimulus durations, but studies using short (400 ms; Narasimhan & Giaschi, 2012) and long (2000 ms; Hadad, Maurer, & Lewis, 2011) durations came to similar conclusions about development.

The studies also overlap in the speeds they tested, ranging from 1 to 18 deg/s. Mature performance was found for 1.2 deg/s (Parrish et al., 2005), 2.5 deg/s (Reiss, Hoffman, & Landau, 2005), and 18 deg/s (Elleberg et al., 2002); and immature performance was found for 1 and 4 deg/s (Narasimhan & Giaschi, 2012), and 4 and 18 deg/s (Hadad, Maurer, & Lewis, 2011). However, there is evidence to suggest that the underlying spatial and temporal parameters used to create a speed matter more than simply their ratio (e.g., Arena, Hutchison, & Shimozaki, 2012; Elleberg et al., 2010; Kiorpes & Movshon, 2004; reviewed below). This may account for some conflicting conclusions on when global motion perception is adult-like.

Studies of preschool-aged children indicate sensitivity to fast motion matures earlier in life than sensitivity to slow motion. For example, Narasimhan and Giaschi (2012) found global motion direction discrimination thresholds in 5-year-olds were more immature at a speed of 1 deg/s than at 4 deg/s. Similarly, using random Gabor kinematograms, Elleberg et al. (2004) found children at this age were very immature at stimuli with speeds of 1.5 deg/s, and less so at 6 and 9 deg/s. Speed discrimination thresholds in 5-year-old children are also immature, but more so for reference speeds of 1.5 deg/s than for 6 deg/s (Ahmed et al., 2005). Children do not show adult-like thresholds in speed discrimination tasks until age 11 for reference speeds of 6 deg/s, and thresholds for speeds of 1.5 deg/s are still immature at this age (Manning, Aagten-Murphy, & Pellicano, 2012). In motion-defined form tasks, children aged 4–6 show adult-like coherence thresholds for stimuli moving at 5 deg/s, but are immature at 0.9 deg/s and even more so at 0.1 deg/s (Hayward et al., 2011). Some early developmental disorders have been shown to disrupt performance on motion tasks at slow speeds only, indicating a protracted sensitive period for damage. For example, Hayward et al. found that children with amblyopia had elevated thresholds for the motion-defined form task in the affected and unaffected eyes at 0.1 deg/s, but not at 0.9 or 5 deg/s, and Edwards et al. (2004) found elevated global motion direction discrimination thresholds in children with dyslexia for speeds of 0.24 and 1.2 deg/s, but not 7.3 deg/s.

The speed of a motion stimulus is calculated as the ratio $\Delta x/\Delta t$, where Δx represents the spatial offset of signal dots in an RDK, and Δt represents the temporal interval between subsequent animation frames. There is evidence to suggest that a measure of speed alone may not be the most informative indicator of coherence thresholds. In three direction-discrimination experiments with adults, Arena, Hutchison, and Shimozaki (2012) held Δx , Δt , or speed constant while varying the other two parameters. When Δt was held constant at 107 ms and Δx was varied from 4 to 64 arcmin, they found thresholds were increased for spatial offsets greater than about 18 arcmin. When Δx was held constant at 37.5 arcmin and Δt varied from 27 to 427 ms, thresholds were slightly increased for times greater than 250 ms. When speed was held constant at 2.5 deg/s, participants had increased coherence thresholds for larger values of Δx and Δt (32 arcmin/213 ms) than smaller ones (16 arcmin/107 ms and below). These results suggest that a stimulus made with larger values of Δx and Δt will yield higher thresholds than one with lower values of Δx and Δt , even when they travel at the same speed. Consistent with this, Elleberg et al. (2010) investigated thresholds in 5-year-old children and adults with random Gabor kinematograms, holding speed constant at 1.5 deg/s, and testing $\Delta x/\Delta t$ values of 6 arcmin/66 ms, 30 arcmin/333 ms, and 60 arcmin/666 ms. In general, as displacements increased, thresholds increased in both

groups. Children were immature at all displacements, but least so at the smallest Δx and Δt values tested. These results caution against characterizing motion stimuli simply by the speed ratio, and point to the importance of investigating the effects of not only speed, but Δx and Δt , on performance during development.

Few studies have examined coherence thresholds as a function of Δx and Δt during human development, but evidence from developing macaques suggest these parameters matter. A longitudinal study by Kiorpes and Movshon (2004) demonstrated in young macaques that coherence thresholds for a given speed vary depending on underlying values of Δx and Δt . For example, a 40-week old macaque could best discriminate stimuli created using Δx values of about 7–12 arcmin, meaning discrimination was optimal for speeds from 1 to 4 deg/s when Δt was 19 ms, speeds from 3 to 6 deg/s when Δt was 37 ms, and speeds from 7 to 11 deg/s when Δt was 56 ms. In other words, psychophysical tuning curves obtained from developing macaques have the same peak when plotted as a function of Δx , but not when plotted as a function of speed. While overall coherence thresholds decreased from 3 weeks to 3 years of age, optimal Δx values also decreased, from 15 to 40 arcmin around 3 weeks to 6–8 arcmin at about 3 years (approximately equivalent to ages from 3 months to 12 years in human development; Boothe, Dobson, & Teller, 1985). Even at 3 years, thresholds were best expressed as a function of Δx rather than speed. A similar pattern was found in macaques studied by Kiorpes et al. (2012).

If the optimal value of Δx decreases with age, this may have important implications for studies of global motion perception with children who are still developing. As smaller values of Δx yield slower speeds, this is a potential mechanism for why sensitivity to slow speeds takes longer to develop in human children. These results also suggest that thresholds measured in two studies that use the same signal dot speeds may vary widely, depending on the value of Δx used in the RDK stimulus. Children may appear more or less mature for a given speed, depending on the Δx used by the experimenter. The goal of this experiment was get a better understanding of how changes in Δx and Δt impact motion coherence thresholds.

The values selected in this experiment were chosen to closely match those used by Kiorpes and Movshon (2004), who tested an approximately logarithmic progression of Δx values from 1 to 60 arcmin, and Δt values of 19 ms, 37 ms, and 56 ms. In pilot studies with adults it was determined that some people have difficulties seeing motion from Δx displacements greater than 40 arcmin at longer values of Δt , so a range from 1 to 38 arcmin was used. Two Δt values, 17 ms and 50 ms, were selected to be similar to the shortest and longest tested by Kiorpes and Movshon (2004).

2. Methods

2.1. Participants

Children (4–7 years old) and adults (18–30 years old) were recruited for this experiment. As assessed through self- or parental-report, all participants were free of any visual, neural, developmental, or cognitive disorders that might impact performance or interfere with binocular vision. Stereo and visual acuities for each participant were assessed before the experiment began.

A total of 33 children were recruited (22 female; M age = 5.6 years; SD = 0.9, range 4.0–7.0). All children had a stereoacuity score on the Randot Preschool Stereoacuity Test (Stereo Optical Co., Inc.) that was better than the normal limit for their age (200 arcsec for 4–5 year olds, 100 arcsec for 6 year olds; Birch et al., 2008), and monocular visual acuity scores at 6 m on the Regan high-contrast letter chart (Regan, 1988) that were better than the normal limit

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