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Effect of spatial and temporal stimulus parameters on the maturation of global motion perception

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ABSTRACT

There are discrepancies with respect to the age at which adult-like performance is reached on tasks assessing global motion perception. This is in part because performance in children depends on stimulus parameters. We recently showed that five-year-olds demonstrated adult-like performance over a range of speeds when the speed ratio was comprised of longer spatial and temporal displacements; but displayed immature performance when the speed ratio was comprised of shorter displacements. The goal of the current study was to assess the effect of these global motion stimulus parameters across a broader age range in order to estimate the age at which mature performance is reached. Motion coherence thresholds were assessed in 182 children and adults aged 7–30 years. Dot displacement (Δx) was 1, 5, or 30 min of arc; frame duration (Δt) was 17 or 50 ms. This created a total of six conditions. Consistent with our previous results, coherence thresholds in the youngest children assessed were adult-like at the two conditions with the largest Δx. Maturity was reached around age 12 for the medium Δx, and by age 16 for the smallest Δx. Performance did not appear to be affected by Δt. This late maturation may reflect a long developmental period for cortical networks underlying global motion perception. These findings resolve many of the discrepancies across previous studies, and should be considered when using global motion tasks to assess children with atypical development.

1. Introduction

Global motion perception is the ability to integrate locally-moving elements across a large region of visual space for an overall percept of motion direction. It is typically assessed using random dot stimuli in which a proportion of dots move together in a signal direction, while the remaining dots move in random directions. The proportion of signal dots is reduced to obtain a coherence threshold that is taken as an index of global motion sensitivity.

Global motion tasks recruit a network of cortical regions connected with V5/MT+ (Braddick, O'Brien, Wattam-Bell, Atkinson, & Turner, 2000; Braddick et al., 2001; Cornette et al., 1998; Dupont, Orban, De Bruyn, Verbruggen, & Mortelmans, 1994), and performance on a global motion task is taken as an indicator of the maturity of these networks. Discrepancies in the age at which global motion perception appears to be adult-like across studies may depend on the stimulus parameters these studies used to create an animation. For example, psychophysical coherence thresholds for direction discrimination have been shown to be adult-like at ages as young as three months (measured via eye movements; Blumenthal, Bosworth, & Dobkins, 2013), three years (Parrish, Giaschi, Boden, & Dougherty, 2005) or six years (Ellemberg, Lewis, Maurer, Brar, & Brent, 2002). Other studies have shown coherence thresholds to be immature at age two years (measured via eye movements; Yu et al., 2013) or five years (Ellemberg et al., 2003; Ellemberg et al., 2004; Ellemberg et al., 2010; Narasimhan & Giaschi, 2012), with adult-like performance reached by age 12 years (Hadad, Maurer, & Lewis, 2011) or age 14 years (Bogfjellmo, Bex, & Falkenberg, 2014). Similarly, motion-defined form tasks using similar random-dot stimuli, in which participants must detect a shape defined by a contrast in motion direction or coherence, have shown maturation by age 7 years (Hayward, Truong, Partanen, & Giaschi, 2011; Parrish et al., 2005), 10 years (Gunn et al., 2002), or 15 years (Schrauf, Wist, & Ehrenstein, 1999), depending on the stimulus.

There are many spatial and temporal parameters in a global motion stimulus that can produce a change in children's coherence thresholds when varied. Dot density is one such stimulus parameter. For example, children perform more adult-like when a stimulus contains more dots per square degree (Narasimhan & Giaschi,

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2012). Dot lifetime, or the number of frames for which a signal dot continues in the signal direction before being replotted in a random direction, may also play a role; limiting the lifetime of signal dots increases thresholds in control children (Manning, Charman, & Pellicano, 2015) and in adults (Festa & Welch, 1997; Pilly & Seitz, 2009), though no direct comparisons have been made between the two age groups to determine if they are impacted to the same extent. Dot speed is also important. For example, global motion perception is more immature for slow than for fast speeds (Bogfjellmo et al., 2014; Narasimhan & Giaschi, 2012). Moreover, a similar effect of speed on the maturation of motion perception has been found for first- and second-order global motion using Gabor patterns (Ellemberg et al., 2004; Ellemberg et al., 2010), grating direction discrimination (Falkenberg, Simpson, & Dutton, 2014), motion-defined form (Hayward et al., 2011), radial flow (Joshi & Falkenberg, 2015), dot rotation (Kaufmann, 1995), and speed discrimination (Ahmed, Lewis, Ellemberg, & Maurer, 2005; Manning, Aagten-Murphy, & Pellicano, 2012). Minimum velocity thresholds decrease with age for tasks using moving bars (Aslin & Shea, 1990) or motion-defined form (Giaschi & Regan, 1997; Parrish et al., 2005), suggesting a prolonged fine-tuning of mechanisms underlying slow motion perception even when mastery of a task at higher speeds has occurred. The delayed maturation of mechanisms responsible for slow speeds may leave these vulnerable to disruption by developmental disorders.

The speed of signal dot movement in deg/s, however, does not fully characterize the spatiotemporal displacement properties of a global motion stimulus. For example, coherence thresholds in adults can vary when the underlying spatial (Δx) and temporal (Δt) displacement parameters are changed but their ratio, and hence stimulus speed, remains the same (Arena, Hutchinson, & Shimozaki, 2012). Crucially, the effect of stimulus parameters on coherence thresholds can depend on the age of the observer. Young macaques show greater motion sensitivity for stimuli comprised of larger spatial displacements regardless of Δt (Kiorpes & Movshon, 2004). This indicates that development unfolds in a coarse-to-fine fashion such that sensitivity for smaller spatial displacements, regardless of speed, is improved during development. In turn, this leads to the prediction that children should perform more adult-like for larger spatial displacements. This finding was confirmed in our previous study comparing global motion coherence thresholds in children aged 4–6 years to adults on a range of spatiotemporal parameters (Meier & Giaschi, 2014): children demonstrated greater immaturities for small displacements, which correspond to slow speeds, and more adult-like responses for large displacements, which correspond to faster speeds. Importantly, performance for intermediate speeds was adult-like with large but not for smaller spatial displacements, a finding that resolves some previous inconsistencies about maturational age for global motion perception. These findings indicate that mature performance is reached at a later age for smaller spatial displacements, but provide no indication of what this age might be. Additionally, the pattern of coherence thresholds obtained in the previous study suggested that maturity at medium-to-small displacements may be reached earlier in life for stimuli presented with a shorter temporal displacement and further evidence is necessary to confirm whether this is the case.

The goal of the current study was to investigate global motion maturation in children and adults with typical visual development between seven and 30 years of age. In particular, we were interested in quantifying the age at which global motion perception can be considered mature across six different combinations of spatial and temporal stimulus parameters. This will expand upon our previous finding showing the effect of these stimulus parameters in younger children, and also provide normative data for future studies involving children with developmental visual disorders.

2. Methods

This work was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

2.1. Participants

Participants between the ages of seven and 30 years old were recruited from the community to participate. All participants had normal or corrected-to-normal vision and no reported visual, developmental or cognitive disorders. Informed consent was obtained from adults or parents, and assent was obtained from all children participating in this study. Data from some adult participants were collected for a prior study (Meier & Giaschi, 2014) that used the same stimuli used in the current study. In total, 217 participants were recruited to participate. Twenty-four participants (aged 7.2–22.7 years, M = 14.9 years) were excluded for poor visual acuity and/or poor stereoacuity (see criteria below); eleven participants (aged 7.1–23.4 years, M = 11.0 years) were excluded for failing to complete enough of the experiment within the hour either due to task misunderstanding or motivational difficulties. In all, data from 182 participants were used in the analysis.

2.2. Apparatus

An Intel Core i7 Macintosh Macbook Pro running MATLAB R2015a (The Mathworks, Inc.) equipped with the Psychophysics Toolbox extension version 3.0.12 (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) was used to generate the stimuli for this experiment. A BenQ XL2420T LED-backlit LCD Monitor at a resolution of 1920 × 1080 and a 60 Hz refresh rate was used to present the stimuli. Participants responded using a Gravis Gamepad Pro while viewing stimuli in a dimly-lit room at a viewing distance of 1 m.

2.3. Stimuli and experimental conditions

The stimulus animation parameters used in this study were the same as those used in our previous studies (Meier & Giaschi, 2014; Meier, Sum, & Giaschi, 2016) and were chosen to approximate those of Kiorpes and Movshon (2004). Each stimulus consisted of an array of 64 white (260 cd/m^2) dots, 1 arcmin diameter, on a black (0.7 cd/m^2) background. Stimuli subtended a 7.7 × 7.7 deg square area in the center of the screen, yielding a density of 1.1 dots/deg^2 in each frame (or 1.7% of area). Signal dots moved left or right. A white noise algorithm controlled dot movement: on each update of an animation frame, a dot was selected to be a signal dot with a probability equal to the coherence value, which could range from 0 to 1. The remaining dots were re-plotted in random locations. Thus, signal dot lifetime was determined probabilistically, such that the probability of each signal dot disappearing was equal to the stimulus coherence level on any given trial.

Two factors were examined in this study: Δx, the spatial displacement of the dots between each pair of animation frames; and Δt, the duration of each frame. The six conditions assessed here are identical to those used by Meier et al. (2016): three Δx values (1, 5, and 30 arcmin) were crossed with two Δt values (17 and 50 ms, equivalent to 60 and 20 Hz, respectively). This combination of parameters yielded signal dot speeds of 1, 5, and 30 deg/s in the Δt = 17 ms condition with a dot density over time of 66 dots/deg^2/s (36 animation frames total), and 0.3, 1.7, and 10 deg/s in the Δt = 50 ms condition with a dot density over time