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Global motion perception is independent from contrast sensitivity for coherent motion direction discrimination and visual acuity in 4.5-year-old children

Arijit Chakraborty[1], **Nicola S. Anstice**[1], **Robert J. Jacobs**[1], **Nabin Paudel**[1], **Linda L. LaGasse**[2], **Barry M. Lester**[2], **Trecia A. Wouldes**[3], **Jane E. Harding**[4], and **Benjamin Thompson**[1,5]

[1]School of Optometry and Vision Science, University of Auckland, New Zealand [2]Brown Center for the Study of Children at Risk, Warren Alpert Medical School at Brown University, USA [3]Department of Psychological Medicine, University of Auckland, New Zealand [4]Liggins Institute, University of Auckland, New Zealand [5]School of Optometry and Vision Science, University of Waterloo, Canada

Abstract

Global motion processing depends on a network of brain regions that includes extrastriate area V5 in the dorsal visual stream. For this reason, psychophysical measures of global motion perception have been used to provide a behavioural measure of dorsal stream function. This approach assumes that global motion is relatively independent of visual functions that arise earlier in the visual processing hierarchy such as contrast sensitivity and visual acuity. We tested this assumption by assessing the relationships between global motion perception, contrast sensitivity for coherent motion direction discrimination (henceforth referred to as contrast sensitivity) and habitual visual acuity in a large group of 4.5-year-old children (n = 117). The children were born at risk of abnormal neurodevelopment because of prenatal drug exposure or risk factors for neonatal hypoglycaemia. Motion coherence thresholds, a measure of global motion perception, were assessed using random dot kinematograms. The contrast of the stimuli was fixed at 100% and coherence was varied. Contrast sensitivity was measured using the same stimuli by fixing motion coherence at 100% and varying dot contrast. Stereoacuity was also measured. Motion coherence thresholds were not correlated with contrast sensitivity or visual acuity. However, lower (better) motion coherence thresholds were correlated with finer stereoacuity (rho=0.38, p=0.004). Contrast sensitivity and visual acuity were also correlated (rho= −0.26, p=0.004) with each other. These results indicate that global motion perception for high contrast stimuli is independent of contrast sensitivity and visual acuity and can be used to assess motion integration mechanisms in children.

Correspondence: Ben Thompson, School of Optometry and Vision Science, University of Waterloo, 200 Columbia Street West, Waterloo, Ontario, ON 2Nl, Canada, ben.thompson@uwaterloo.ca, +1 519 888 4567 x 39398.

Keywords

Visual development; extrastriate visual cortex; preschool vision assessment; at risk infant

Introduction

A well-established theory of functional organization across visual brain areas suggests that visual information is processed within two distinct pathways: the ventral stream and the dorsal stream (Goodale & Milner, 1992). The ventral stream receives parvocellular input and includes V2, V4, and the inferior temporal cortex. The dorsal stream, on the other hand, receives magnocellular input and includes V2, V3a, V5 (the homologue of the macaque middle temporal area; MT), and the posterior parietal lobe (de Haan & Cowey, 2011; Goodale & Milner, 1992; Goodale, 2013; Grinter, Maybery, & Badcock, 2010). Functionally, the ventral stream has been shown to underpin object recognition, whereas the dorsal stream supports object localization and visuomotor control (Almeida, Mahon, & Alfonso, 2010; Goodale, 2013; Johnson & Grafton, 2003; Rizzolatti & Matelli, 2003), although there is significant cross-talk between the two pathways (Cloutman, 2013; Himmelbach & Karnath, 2005; Zanon, Busan, Monti, Pizzolato, & Battaglini, 2010).

The dorsal stream vulnerability hypothesis proposes that neurodevelopmental problems have a greater impact on dorsal than ventral stream development (Braddick, Atkinson, & Wattam-Bell, 2003; Spencer et al., 2000). Much of the evidence for this hypothesis comes from the measurement of global motion perception, which involves the integration of local motion signals. Global motion perception is measured typically using random dot kinematograms (RDKs), which consist of two populations of moving dots; a signal population that move in the same direction and a noise population that move randomly. The observer identifies the direction of the signal dots and the relative proportion of signal to noise in the stimulus is varied to measure a psychophysical ‘motion coherence’ threshold (Newsome & Pare, 1988). Neurophysiological (Andersen, 1997; Edwards & Badcock, 1994), neuroimaging (Braddick et al., 2001; Klaver et al., 2008), lesion (Newsome & Pare, 1988; Rudolph & Pasternak, 1999) and brain stimulation studies (Cai, Chen, Zhou, Thompson, & Fang, 2014; Kaderali, Kim, Reynaud, & Mullen, 2015; Salzman, Britten, & Newsome, 1990) have shown that the perception of global motion in RDKs involves dorsal stream extrastriate area MT/V5 in macaques and humans, although a range of other brain areas may also be involved (Braddick et al., 2001).

Impairments in global motion perception due to abnormal visual cortex development have been reported in adults with strabismic and anisometropic amblyopia (Simmers & Bex, 2004; Simmers, Ledgeway, Hess, & McGraw, 2003; Simmers, Ledgeway, Mansouri, Hutchinson, & Hess, 2006) and children with deprivation amblyopia (Ellemberg, Lewis, Maurer, Brar, & Brent, 2002). Furthermore, in support of the dorsal stream vulnerability hypothesis, impaired global motion perception has been observed in children with William’s syndrome (Atkinson et al., 1997), dyslexia (Raymond & Sorensen, 1998), autism (Brieber et al., 2010; Manning, Charman, & Pellicano, 2013; Manning & Charman, 2015) a history of preterm birth (Taylor, Jakobson, Maurer, & Lewis, 2009), and fetal alcohol syndrome

(Gummel, Ygge, Benassi, & Bolzani, 2012). However, not all neurodevelopmental studies report visual deficits that are consistent with the dorsal stream vulnerability hypothesis (Bertone & Faubert, 2006; Bertone, Mottron, Jelenic, & Faubert, 2003).

In addition to motion integration, global motion perception also relies on accurate processing of local motion signals (Simoncelli & Heeger, 1998). Therefore, global motion deficits may originate from abnormal processing of local motion, abnormal motion integration or both. One technique for separating these possibilities is to measure motion coherence thresholds for RDKs presented at a range of different contrast levels (Simmers, Ledgeway, & Hess, 2005; Simmers, Ledgeway, Hess, & McGraw, 2003). This approach is based on psychophysical data indicating that contrast thresholds for the detection of global motion in RDKs are limited by local mechanisms that are sensitive to motion direction (Morrone, Burr, & Vaina, 1995). Specifically, contrast thresholds for direction discrimination of coherent RDKs do not exhibit spatial summation, whereas motion coherence thresholds benefit from spatial summation. In macaques, cells in V1 that project to MT are tuned for motion direction, have high contrast sensitivity and may support the processing of local motion signals in global motion stimuli (Movshon & Newsome, 1996). By extension, human V1 may be involved in the local processing of motion in RDKs. In adult observers with normal vision, motion coherence thresholds remain stable over a broad range of dot contrasts and then rapidly increase for contrasts that are sufficiently low to impair local motion processing (Hess, Hutchinson, Ledgeway, & Mansouri, 2007). Using the same technique of measuring motion coherence thresholds at different stimulus contrasts, Allen et al. (2010) investigated global motion perception in elderly observers. A deficit in global motion perception was observed in the older observers. Reduced contrast sensitivity rather than impaired motion integration was found to be the key factor. Similarly, Blumenthal et al. (2013) found no difference in motion coherence thresholds for 3 and 7 month old infants when the stimulus dots were presented at a fixed multiple of their contrast threshold for coherent motion direction discrimination. The authors suggest that previous reports of global motion development in infancy (Banton & Bertenthal, 1996; Mason, Braddick, & Wattam-Bell, 2003; Wattam-Bell, 1994; Wattam-bell, 1996) reflect changes in local motion processing rather than motion integration.

However, deficits in motion integration that are not due to impaired or underdeveloped local motion processing have also been reported (Raymond & Sorensen, 1998; Schellekens, Van Wezel, Petridou, Ramsey, & Raemaekers, 2013). For example, adults with amblyopia exhibit global motion deficits that are independent from stimulus contrast and therefore likely reflect abnormal development of extrastriate areas such as V5 (Simmers, Ledgeway, Mansouri, Hutchinson, & Hess, 2006; Simmers & Bex, 2004; Simmers et al., 2005, 2003). Global motion impairments in studies of dorsal stream vulnerability are also interpreted typically in the context of abnormal motion integration (Atkinson et al., 1997; Brieber et al., 2010; Palomares & Shannon, 2013). Many of these studies were conducted with preschool or school aged children and used high contrast stimuli in order to minimize any effects of reduced acuity or contrast sensitivity deficits on task performance (Gummel et al., 2012; Manning & Charman, 2015). However, the influence of contrast dependent local motion processing on global motion perception is largely unknown in this population. A number of studies have measured both contrast sensitivity and global motion perception in children

with neurodevelopmental disorders, but different stimuli were used for each type of task (Cornelissen, Richardson, Mason, Fowler, & Stein, 1995; Pellicano, Gibson, Maybery, Durkin, & Badcock, 2005; Pellicano & Gibson, 2008). This is because the studies were designed to target different stages of dorsal stream processing and not explore the relationship between local and global motion processing. For example, Pellicano et al., (2005) and Pellicano & Gibson (2008) tested global motion perception with RDKs and contrast sensitivity by measuring detection thresholds for a low spatial frequency, high temporal frequency stimulus that was designed to target early magnocellular processing. Tasks designed to target different stages of dorsal stream processing do not correlate well with one another (Dakin & Frith, 2005; Goodbourn et al., 2012), and therefore current data do not directly address the question of whether contrast sensitivity impacts global motion perception in children.

The relationships between motion coherence thresholds and clinical measures of vision such as visual acuity and stereopsis have also been investigated. Visual acuity, which involves processing in V1 (Duncan & Boynton, 2003) and relies on parvocellular function (Merigan, Katz, & Maunsell, 1991), was not significantly correlated with motion coherence thresholds in children (Ho et al., 2005) or adults (Simmers et al., 2003) with strabismic, anisometropic or mixed amblyopia. Similarly, Ellemberg et al. reported a dissociation between acuity deficits and global motion deficits in a group of children and young adults with deprivation amblyopia (Ellemberg et al., 2002). More recently, Giaschi et al. have reported deficits for a form-from-motion task designed to target global motion processing in a group of children with amblyopia that persisted despite visual acuity improvements following occlusion therapy (Giaschi, Chapman, Meier, Narasimhan, & Regan, 2015).

Results that are consistent with the dissociation between visual acuity and motion coherence thresholds in patients with amblyopia have also been found in observers with normal vision. For example, motion coherence thresholds are unaffected by stimulus manipulations that significantly impair visual acuity such as low lighting conditions (Grossman & Blake, 1999) and optical defocus (Trick & Silverman, 1991; Trick, Steinman, & Amyot, 1995). Furthermore, no relationship between visual acuity and motion coherence thresholds was found in a group of 2-year old children born at risk of neonatal hypoglycaemia (Yu et al., 2013). Therefore the available data suggest that global motion processing is largely independent of visual acuity.

Stereoacuity has been linked to processing in both the dorsal and ventral streams (Anzai, Chowdhury, & DeAngelis, 2011; Neri, 2005; Parker, 2007; Uka & DeAngelis, 2004; Umeda, Tanabe, & Fujita, 2007). Within the dorsal stream, areas that are sensitive to global motion such as V3A and MT/V5 have also been found to exhibit sensitivity to retinal disparity (Anzai et al., 2011; Cottereau, McKee, & Norcia, 2012; DeAngelis & Uka, 2003; DeAngelis, 1998; Rokers, Cormack, & Huk, 2009). This may provide the basis for the correlations between finer stereoacuity and lower motion coherence thresholds that have been reported in a number of populations such as young children born at risk of neonatal hypoglycaemia (Yu et al., 2013) and children with a low birth weight (MacKay et al., 2005). However, the inverse relationship has also been reported whereby poorer stereopsis was

related to lower (better) motion coherence thresholds in children with amblyopia (Ho et al., 2005).

Building on this previous work we investigated the relationship between contrast sensitivity for direction discrimination with fully coherent RDKs and motion coherence thresholds for high contrast RDKs in a group of one hundred and twenty five 4.5-year-old children born at risk of abnormal neurodevelopment. The children were enrolled in one of two longitudinal follow up studies that included optometric screening at 4.5 years of age. Therefore, we were also able to assess the relationship between motion coherence thresholds and both visual acuity and stereoacuity.

2. Materials and methods

2.1 Subjects

One hundred and twenty five children aged 54 (±2) months took part in the study. Of these, one hundred and seventeen (94%; 59 boys, 58 girls) were able to complete all psychophysical and clinical tests and were therefore included in the final analyses. The children were participants in one of two large-scale, multidisciplinary follow-up studies; the Children with Hypoglycemia and their Later Development (CHYLD) study or the Infant, Development, Environment and Lifestyle (IDEAL) study. Both study protocols included a comprehensive developmental assessment at 4.5 years of age. Our data were collected as part of this assessment. The Northern Y Regional Health and Disability Ethics Committee approved both study protocols. The IDEAL study was also approved by Auckland and Waitemata District Health Boards and their Māori ethics committees. All caregivers gave informed consent and the study was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki).

The CHYLD study was designed to assess the neurodevelopmental outcomes of children who were born with one or more of the following risk factors for neonatal hypoglycemia; child of a diabetic mother, being small (< 2.5 Kg or < 10^{th} centile) or large (> 4.5 Kg or > 90^{th} centile) at birth or late preterm birth (≥ 32 weeks' gestation) (McKinlay et al., 2015). The IDEAL study participants included children who were exposed prenatally to methamphetamine and controls matched for birth weight, socio-economic status, ethnicity and level of maternal education (LaGasse et al., 2011; Wouldes et al., 2013, 2014). Although children were recruited into the IDEAL study on the basis of methamphetamine exposure, all children were exposed to socioeconomic risk factors and the majority of the children, including controls, experienced prenatal exposure to a range of drugs including alcohol, marijuana and nicotine.

Both neonatal hypoglycaemia and prenatal drug exposure can affect the visual cortex. Diffusion-weighted imaging has revealed restricted diffusion in the occipital lobes of infants with neonatal hypoglycaemia, possibility indicating myelin edema (Tam et al., 2008). Abnormal visual evoked potentials were also reported (Tam et al., 2008). Furthermore, severe neonatal hypoglycaemia (not present in our study cohort) can cause occipital lobe injury and cortical visual impairment (Burns, Rutherford, Boardman, & Cowan, 2008; Yalnizoglu, Haliloglu, Turanli, Cila, & Topcu, 2007). Prenatal drug exposure has also been

linked to visual evoked potentials that indicate impaired cortical processing of visual information (Hamilton et al., 2010; McGlone et al., 2013). Although the specific effects of neonatal hypoglycaemia and prenatal drug exposure were not the focus of our research question in this study, we anticipated that the children from these two cohorts would vary sufficiently in their contrast sensitivity for coherent motion direction discrimination and global motion perception to allow for any relationships between these two factors to be detected.

2.2. Stimuli

Random dot kinematograms consisted of 100 circular dots (dot diameter 0.24°, dot density 1.27 dot/deg^2) presented within a circular aperture (10° diameter) at a viewing distance of 60 cm. Dots were displaced by 0.1° every 17ms to achieve a speed of 6°/second. The stimuli were presented for 1 second. These parameters were chosen on the basis of previous studies that have investigated global motion perception in children (Narasimhan & Giaschi, 2012; Gunn et al., 2002; Lewis & Maurer, 2005). Dots had a limited lifetime, whereby each dot had a 5% chance of disappearing on each frame and being redrawn in a random location. The mean lifetime was 300 msec. Bright dots were presented on a grey background (45 cd/m^2) and dot contrast was defined using the Michelson equation: $(L_{dots} - L_{background}) / (L_{dots} + L_{background})$.

Motion coherence thresholds were measured using a RDK constructed from dots presented at maximum brightness (137 cd/m^2; Michelson contrast of 0.51). Signal dots moved coherently upwards or downwards and noise dots moved in random directions. Contrast thresholds for coherent motion direction discrimination were measured using a fully coherent (signal dots only) RDK with variable dot contrast.

All stimuli were presented on a 15” Dell cathode ray tube (CRT) monitor (model: E771p) with a 120 Hz refresh rate and 1024×768 resolution. Stimuli used for motion coherence threshold measurement were generated using MATLAB 2013a and psychtoolbox-3 (Pelli, 1997). Stimuli used to measure contrast thresholds for coherent motion direction discrimination were generated using Psykinematix software (Beaudot, 2009) which allows for a 10.8-bit contrast resolution by using a bit-stealing algorithm (Kontsevich & Tyler, 1999). The stimuli were matched for all parameters described above. All RDK stimuli were viewed binocularly.

2.3. Procedure

Observers viewed the stimuli using their habitual vision corrections. Motion coherence thresholds were measured first, followed by an optometric screening and then contrast thresholds for coherent motion direction discrimination were measured.

2.3.1. Motion coherence thresholds—Prior to threshold measurement, children were familiarized with the stimuli and task. First, the children were presented with 100% coherent (all signal dots), high contrast RDKs moving up or down. After 4 successive correct responses at the 100% coherence level, the experimenter manually varied the direction and coherence of the RDK to demonstrate the appearance of RDKs with different coherence

levels. Once the child was familiar with the stimulus and task, a 2-down-1-up adaptive staircase test was used to vary the coherence of the RDK to measure a motion coherence threshold (contrast was fixed at 100% of maximum). The staircase began at 100% coherence and had a proportional step size of 50% until the first reversal and 25% thereafter. The staircase was terminated after 5 reversals and the threshold was calculated by averaging the last 4 reversals.

2.3.2. Contrast thresholds for coherent motion direction discrimination—A second familiarization session was conducted prior to the measurement of contrast thresholds for coherent motion direction discrimination. Participants viewed a fully coherent RDK at 70% of maximum contrast. Motion direction was varied (up/down) until the participant was able to correctly identify the motion direction on four consecutive trials. Dot contrast was then manually varied to demonstrate the appearance of the stimulus at different contrast levels. A contrast threshold for coherent motion direction discrimination was then measured using a 2-down-1-up adaptive staircase that varied dot contrast (RDK coherence was fixed at 100%). The starting contrast was 70% of maximum and the staircase employed a proportional step size of 50% before the first reversal and 25% thereafter. The staircase ran for 5 reversals and the threshold was calculated as the mean of the last 4 reversals.

2.3.3. Optometric examination—A comprehensive vision screening was conducted to rule out any significant ocular pathology. Monocular and binocular habitual visual acuities were tested using the crowded linear Lea symbols test in the CHYLD cohort and the crowded Keeler logMAR test in the IDEAL cohort. Subsequent references to visual acuity should be interpreted as the better eye's monocular visual acuity. Stereoacuity was measured using the graded circles portion of the stereo fly test. Ocular motility was assessed using a cover test, a broad H-test, a 20-prism base out test and near point of convergence. Ocular health was assessed using the red reflex test, external inspection and pupillary evaluation. Children were tested with their habitual refractive correction, if any.

2.4. Statistical Analysis

Contrast thresholds for coherent motion direction discrimination were converted to log contrast sensitivity. Data were analyzed using SPSS v22 (IBM Corp, Armonk, NY, USA). The Shapiro-Wilk test was used to assess whether data were normally distributed and parametric (ANOVA) or nonparametric (Kruskal Wallis, Mann-Whiney U and Spearman's rank correlation coefficients) statistical tests were chosen accordingly. Data are reported as mean and standard deviation or median and range.

3. Results

Distributions for motion coherence thresholds, log contrast sensitivity for motion direction discrimination, better eye visual acuity and stereoacuity are shown in Fig 1. Motion coherence thresholds (Fig 1A, median 49%, range 11% to 86%), better eye visual acuity (Fig 1C, median 0.06 logMAR, range −0.06 logMAR to 0.30 logMAR) and stereoacuity (Fig 1D, median 63" of arc, range 25" to 300" of arc) were not normally distributed. Log contrast sensitivity (Fig 1B) was normally distributed with a mean of 1.7 + 0.2 logCS.

3.1. Correlations involving motion coherence thresholds

Motion coherence thresholds and log contrast sensitivities were not correlated significantly (rho= −0.06, p= 0.52; Fig 2A). Motion coherence thresholds were also not correlated with visual acuities (rho=0.005, p=0.96, Fig 2B).

To further test for any relationships between motion coherence threshold and contrast sensitivity for coherent motion direction discrimination, motion coherence thresholds (MCT) were divided into quartiles (Q) (Q1=MCT < 31.75%, Q2=MCT ≥ 31.75% to < 48.75%, Q3=MCT ≥ 48.75% to < 59.75% and Q4=MCT ≥ 59.75%; Fig 3A). Contrast sensitivity did not vary significantly across motion coherence threshold quartiles (ANOVA, $F_{3,113}$=1.42, p=0.24) (Fig 3A). Similarly, visual acuity (Fig 3B) did not vary significantly across each of the motion coherence threshold quartiles (Kruskal Wallis $\chi^2(3) = 0.81$, $p = 0.85$).

Motion coherence thresholds were correlated moderately and statistically significantly with stereoacuity (rho= 0.38, p=0.004) whereby lower (better) motion coherence thresholds were associated with lower (better) stereoacuity scores. In agreement with this correlation, stereoacuity varied significantly across the four quartiles of motion coherence threshold [Kruskal Wallis, $\chi^2(3) = 16.5$, $p = 0.001$; Fig 3C], with a significant difference between the stereoacuity scores for children in the first and fourth quartiles of motion coherence thresholds (*post hoc* Mann-Whitney, U=193.5, p<0.001).

3.2. Correlations among contrast sensitivity for direction discrimination, visual acuity and stereoacuity

A statistically significant positive correlation was observed between better eye visual acuity and contrast sensitivity for coherent motion direction discrimination (rho= −0.26, p=0.004). Furthermore, visual acuity varied significantly across the four quartiles of contrast sensitivity (Q1=logCS < 1.58, Q2= logCS ≥ 1.58 to < 1.76, Q3= logCS ≥ 1.76 to < 1.88 and Q4= logCS ≥ 1.88, $\chi^2(3) = 9.67$, p=0.022; Fig 4), with a statistically significant (but clinically small) difference between the visual acuities of children in the first and fourth quartiles of contrast sensitivity (U=239, p=0.004, difference = 0.08 logMAR). No significant relationships were found between visual acuity and stereopsis or contrast sensitivity and stereopsis.

4. Discussion

The aim of this study was to assess whether motion coherence thresholds in preschool age children were independent from contrast thresholds for coherent motion direction discrimination measured using the same stimuli. This question is important as studies investigating the dorsal stream vulnerability hypothesis often interpret elevated motion coherence thresholds as evidence for abnormal motion integration in extrastriate visual areas (Raymond & Sorensen, 1998; Schellekens et al., 2013), but elevated thresholds could be related to impairments at earlier stages of visual processing.

In our large group of 4.5-year-old children born at risk of abnormal neurodevelopment, we found no evidence for a relationship between contrast thresholds for coherent motion

direction discrimination and motion coherence thresholds for the same RDK stimuli. Motion coherence thresholds were also unrelated to visual acuity, as has previously been reported for patients with amblyopia (Ellemberg et al., 2002; Simmers et al., 2003). This suggests that motion coherence thresholds for high contrast RDKs are independent of normal variations in contrast sensitivity for direction discrimination and acuity in children. Therefore, elevated motion coherences thresholds for high contrast RDK stimuli are likely to reflect abnormal motion integration, a visual function that has been linked to dorsal stream extrastriate visual areas such as V5. This is in agreement with recent work using equivalent noise techniques indicating that integration processes limit global motion perception in 5–11 year old children and not local motion processing (Manning, Dakin, Tibber, & Pellicano, 2014). Our results are also consistent with previous work demonstrating that, in adults, motion coherence thresholds are constant across a wide range of stimulus contrasts (Hess et al., 2007).

The absence of a relationship between contrast thresholds for coherent motion direction discrimination and motion coherence thresholds in our group of 4.5-year-old children is not consistent with studies that have reported a link between contrast sensitivity and global motion perception. Blumenthal et al. (2013) found that motion coherence thresholds were dependent on contrast thresholds for direction discrimination in infants 3–7 months of age. Furthermore, they argued that motion integration mechanisms function at adult levels by 3 months of age and that apparent maturation of global motion perception is primarily a result of contrast sensitivity development. The discrepancy between the results of Blumenthal et al., (2013) and those we report here could result from a number of factors. Contrast sensitivity develops significantly between early infancy (3–7 months as assessed by Blumenthal et al., 2013) and childhood (4.5 years of age, as assessed in the current study). Therefore it is possible that stimulus contrast has a more pronounced effect on global motion processing for young infants than for 4.5-year-old children whose contrast sensitivity is closer to adult levels (reviewed in Daw, 2003). In addition, Blumenthal et al., (2013) used an eye movement based measure of global motion perception, which may involve both cortical and subcortical mechanisms in children below the age of 2 years (Lewis, Maurer, Chung, Holmes-Shannon, & Van Schaik, 2000).

Although motion coherence thresholds were not correlated with contrast sensitivity for coherent motion direction discrimination or acuity, there was a moderate and statistically significant correlation with stereoacuity. This is consistent with a previous study of the CHYLD study cohort at 2 years of age, which reported a moderate and significant correlation between an eye-movement-based motion coherence threshold measure and stereo acuity (Yu et al., 2013). Neurophysiological recordings from macaques have identified cells in MT that encode both global motion and retinal disparity (DeAngelis & Uka, 2003; Felleman & Essen, 1987; DeAngelis, 1998). If human V5 also supports both global motion perception and disparity processing, these correlations may reflect parallel development of these two important visual functions. We also observed a weak but statistically significant correlation between better eye visual acuity and contrast sensitivity for coherent motion direction discrimination suggesting a partial relationship between these two measurements of spatial (visual acuity) and spatio-temporal (RDK contrast sensitivity) vision. Although both visual acuity (Duncan & Boynton, 2003) and motion direction encoding (Movshon &

Newsome, 1996) involve V1, these two processes primarily rely on parvocellular and magnocellular inputs from the LGN respectively, and therefore the neural basis for this relationship is unclear.

In summary, motion coherence thresholds for high contrast RDK stimuli were independent from contrast sensitivity for coherent motion direction discrimination and visual acuity in our sample of 4.5-year-old children. This suggests that motion coherence thresholds measured with high contrast RDK stimuli reflect the function of motion integration mechanisms within extrastriate areas of the visual cortex. In practical terms, the results indicate that RDK stimuli can be used to investigate motion integration in studies of dorsal stream development and function.

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Highlights

- Global motion was unrelated to contrast sensitivity and acuity in preschool children
- Global motion was correlated with stereoacuity
- High contrast stimuli assess motion integration in at-risk pediatric populations

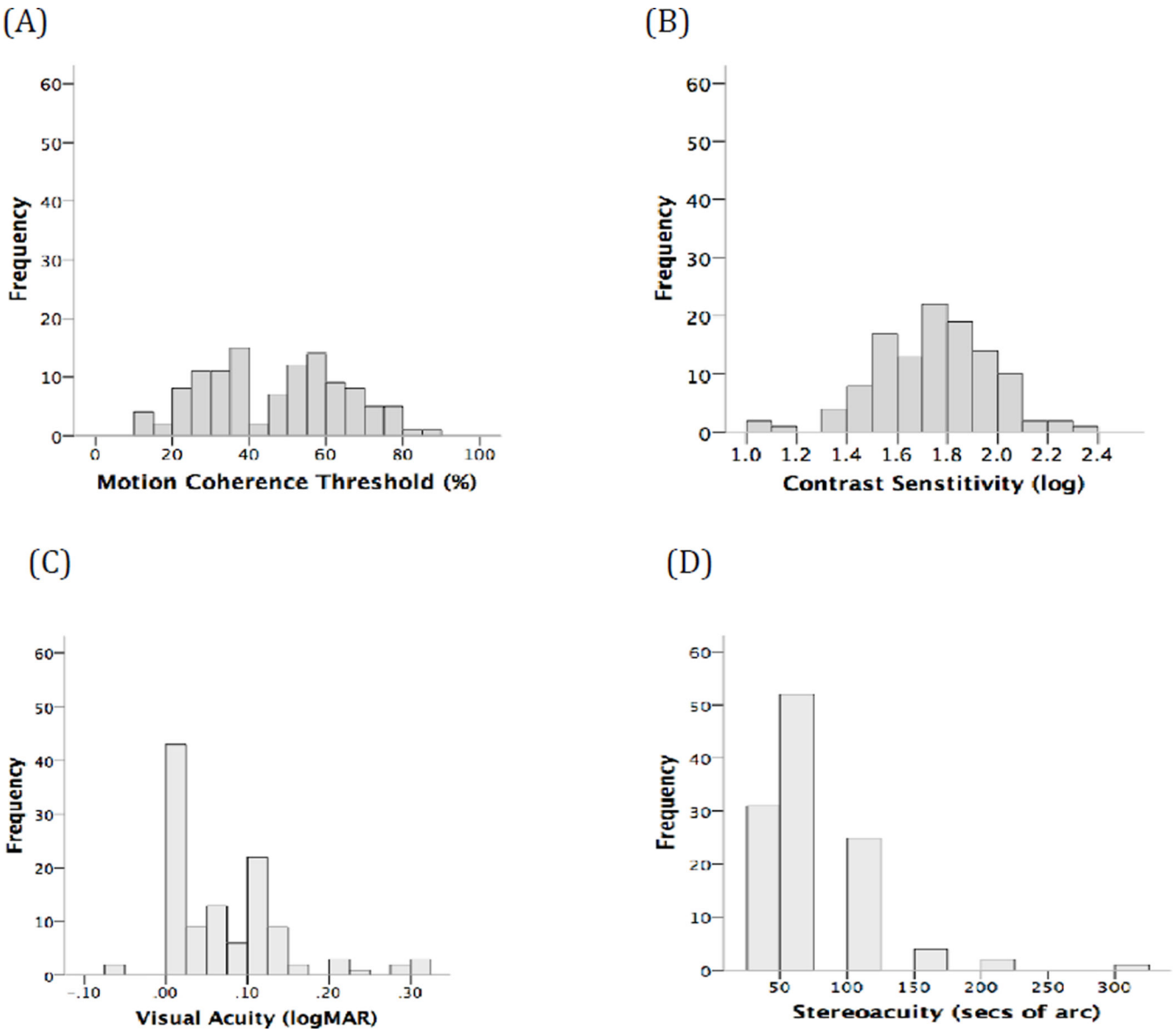

Figure 1.

Distribution (n = 117) of (A) motion coherence thresholds (B) log contrast sensitivity for coherent motion direction discrimination (C) visual acuity and (D) stereoacuity.

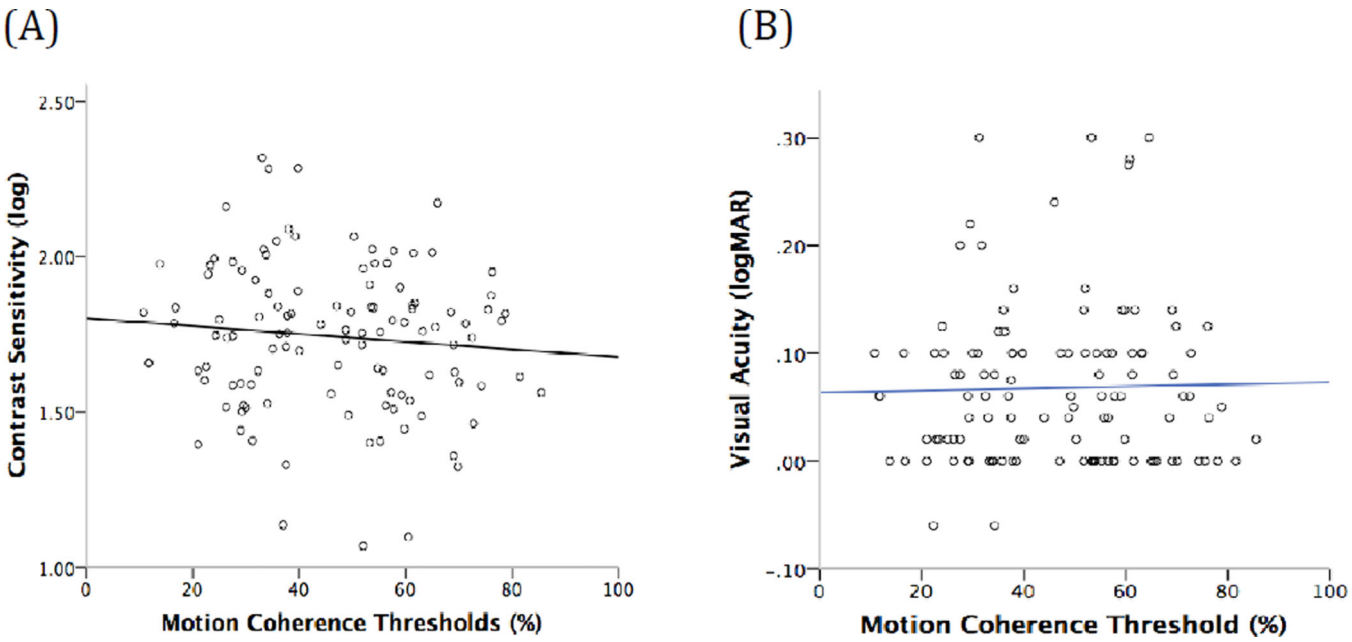

Figure 2.

Relationships between motion coherence thresholds and (A) contrast sensitivity for coherent motion direction discrimination and (B) visual acuity.

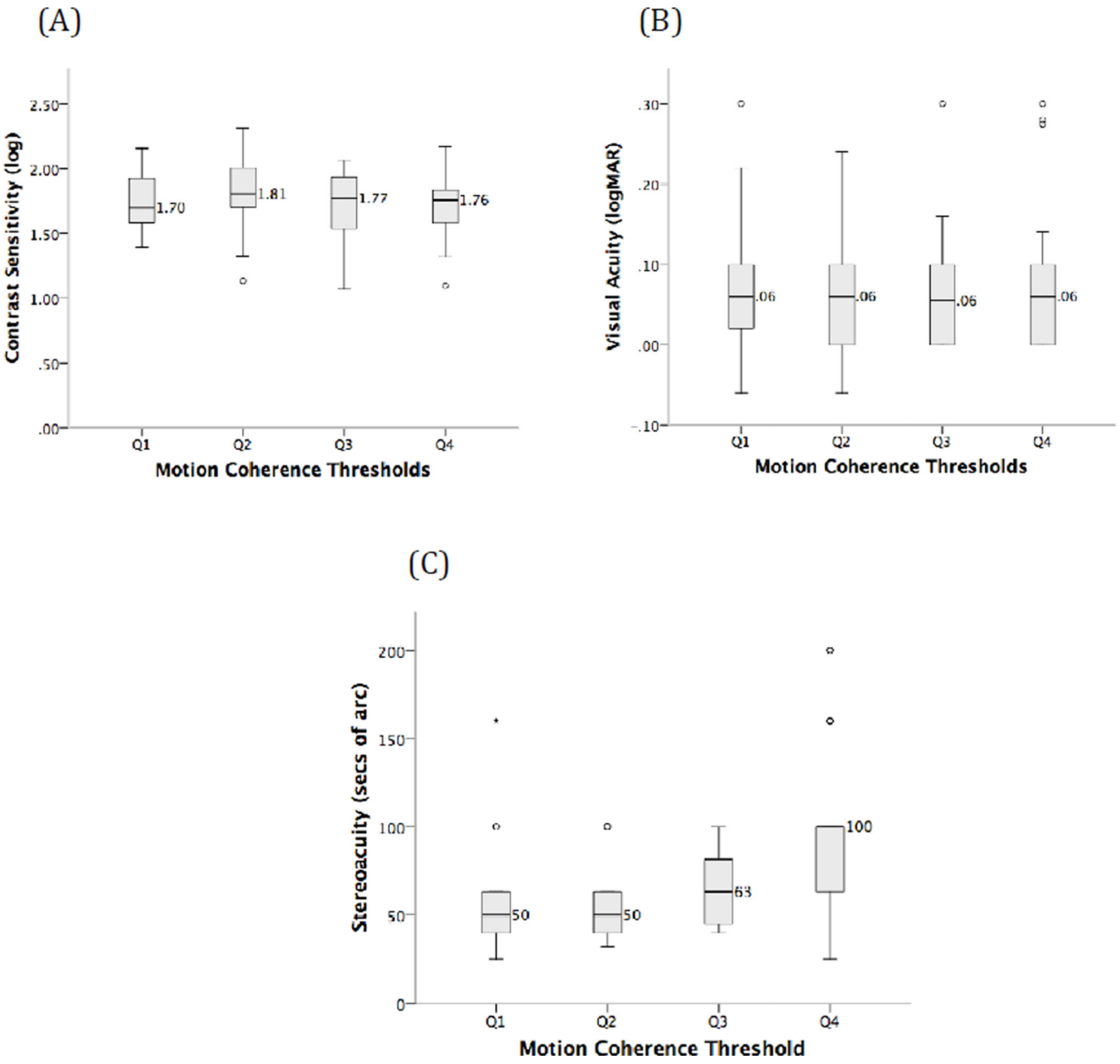

Figure 3.

Comparison of (A) log contrast sensitivity for coherent motion direction discrimination, (B) visual acuity, and (C) stereoacuity across four quartiles of motion coherence threshold. In panel A, horizontal lines indicate the mean log contrast sensitivity for each quartile of motion coherence threshold. Mean log contrast sensitivity values are given to the right of each data point. The error bars show standard deviation and open circles indicate outliers (values larger or smaller than 1.5 times the interquartile range). In panels B and C, horizontal lines indicate medians with the median value given to the right of each data point. In these panels, error bars show the range and open circles indicate outliers. Absent error

bars indicate that no data points (excluding outliers) fell outside of the relevant box plot boundary.

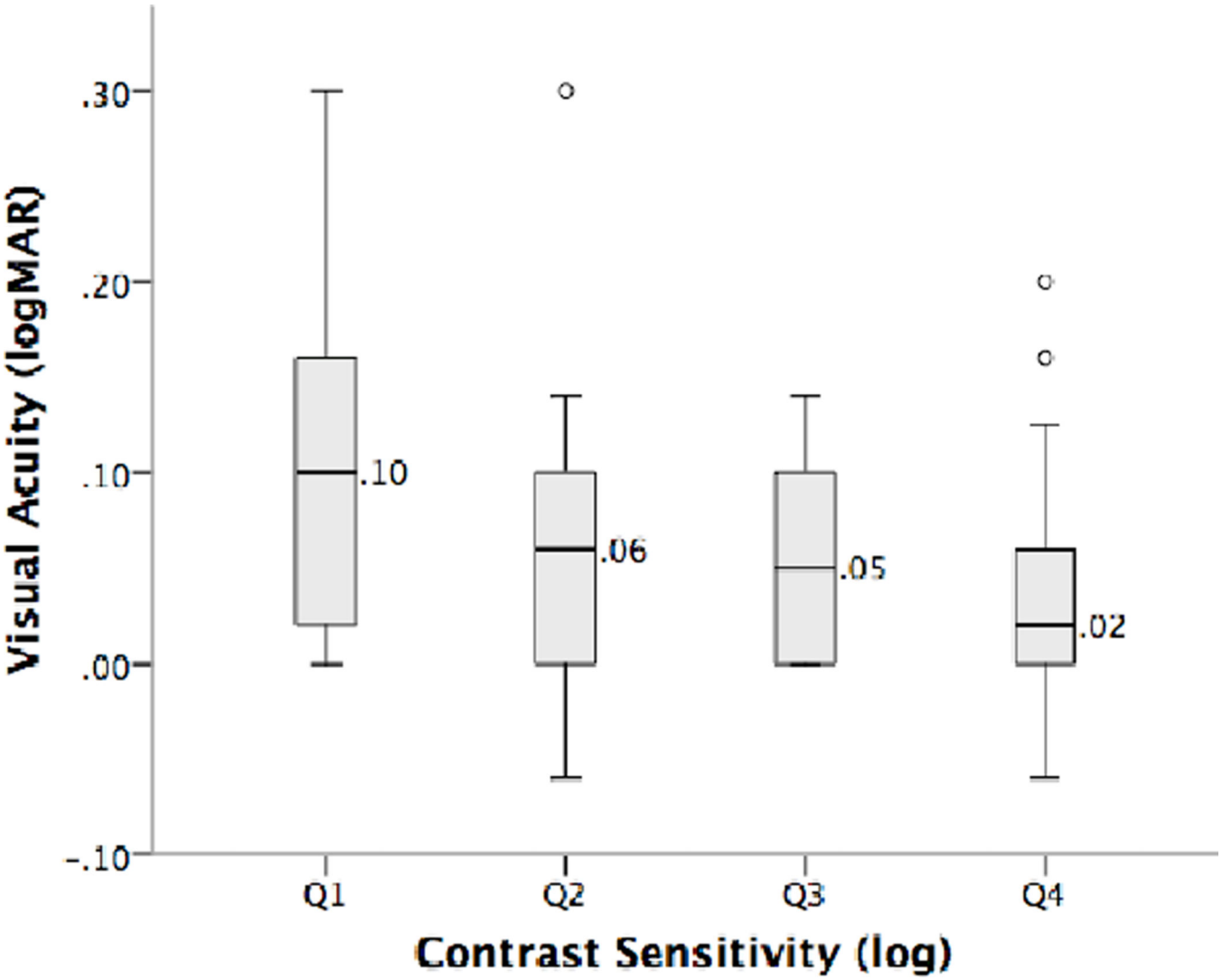

Figure 4.
Variation in visual acuity as a function of log contrast sensitivity for coherent motion direction discrimination quartile. Data are shown as in Figure 3B.