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Research article

Global motion perception is associated with motor function in 2-year-old children

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ABSTRACT

The dorsal visual processing stream that includes V1, motion sensitive area V5 and the posterior parietal lobe, supports visually guided motor function. Two recent studies have reported associations between global motion perception, a behavioural measure of processing in V5, and motor function in pre-school and school aged children. This indicates a relationship between visual and motor development and also supports the use of global motion perception to assess overall dorsal stream function in studies of human neurodevelopment. We investigated whether associations between vision and motor function were present at 2 years of age, a substantially earlier stage of development. The Bayley III test of Infant and Toddler Development and measures of vision including visual acuity (Cardiff Acuity Cards), stereopsis (Lang stereotest) and global motion perception were attempted in 404 2-year-old children (± 4 weeks). Global motion perception (quantified as a motion coherence threshold) was assessed by observing optokinetic nystagmus in response to random dot kinematograms of varying coherence. Linear regression revealed that global motion perception was modestly, but statistically significantly associated with Bayley III composite motor ($r^2 = 0.06$, $P < 0.001$, $n = 375$) and gross motor scores ($r^2 = 0.06$, $p < 0.001$, $n = 375$). The associations remained significant when language score was included in the regression model. In addition, when language score was included in the model, stereopsis was significantly associated with composite motor and fine motor scores, but unaided visual acuity was not statistically significantly associated with any of the motor scores. These results demonstrate that global motion perception and binocular vision are associated with motor function at an early stage of development. Global motion perception can be used as a partial measure of dorsal stream function from early childhood.

1. Background

The two-systems theory of visual processing describes two interconnected cortical processing streams; the dorsal stream and the ventral stream [10]. The dorsal stream includes V1, motion sensitive area V5 (also known as the middle temporal area or MT) and the posterior parietal lobe. The ventral stream also includes V1 and projects to the inferior temporal lobe via visual areas such as V4. The distinction between these two pathways is based on their function. In general terms, the dorsal stream supports motion perception and visually guided motor function (visuomotor integration), whereas the ventral stream supports form processing and object recognition (see [9] for an overview).

The dorsal stream vulnerability hypothesis proposes that the dorsal stream is more susceptible to the effects of abnormal neurodevelopment than the ventral stream [6]. This is based on evidence that motion integration (a dorsal stream function) but not form integration (a ventral stream function) is impaired in children with conditions such as Williams Syndrome or a history of preterm birth [see [2,6,11] for reviews]. In these studies, motion integration, also known as global motion perception, is typically measured using random dot kinematograms that are constructed from two groups of dots; a signal group that move in a

Abbreviations: CHYLD, children with hypoglycaemia and their later development; NICU, neonatal intensive care unit

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coherent direction and a noise group that move randomly. The observer judges the direction of coherent motion and the signal to noise ratio is varied to estimate a motion coherence threshold (the lowest signal to noise ratio required for a particular level of task performance). Combining local motion signals into a coherent, global perception of motion involves area V5 in the dorsal stream [7,22,24,26].

Until recently it has been unclear whether motion coherence thresholds provide an index of overall dorsal stream function or whether they simply reflect motion processing. However, we and others have recently demonstrated modest but statistically significant associations between motion coherence thresholds and motor development in children [5,8]. We found an association between motion coherence thresholds and standardized clinical measures of visuomotor integration and gross (but not fine) motor function in a group of 606 4.5-year-old children born at risk of abnormal neurodevelopment [8]. Similarly, Braddick et al. [5] found that motion, but not form coherence thresholds were associated with visuomotor integration and posterior parietal lobe development in a group of 154 normally developing 5–12 year olds. Together, these results support the overall concept of a dorsal processing stream and indicate that motion coherence thresholds do provide a partial index of dorsal stream function.

Building on this prior work, the primary aim of this study was to assess whether a relationship between motion coherence thresholds and motor function is present at an earlier stage of child development, 2 years of age. Such a relationship would suggest that both functions of the dorsal stream develop in parallel and that motion coherence thresholds can be used to estimate dorsal stream function early in life.

Our secondary aim was to assess the strength of association between motor function, stereopsis and unaided binocular visual acuity at 2 years of age. Binocular vision [1], and, to a lesser extent, visual acuity [15] have each been associated with motor function in normally developing pre-school and school age children. In our previous study, we observed a significant association between stereopsis and motor function at 4.5 years of age [8]. Visual acuity was not significantly associated with fine or gross motor function at 4.5 years, but there was an association with overall motor function. It is unknown whether these associations exist at an earlier stage of neurological development.

2. Methods

2.1. Participants

Participants were recruited as part of the Children with Hypoglycaemia and their Later Development (CHYLD) study, a prospective cohort study designed to investigate the relationship between neonatal hypoglycaemia and long-term neurodevelopment. Infants were recruited before or shortly after birth to one of two parallel studies (BABIES, N = 102 and Sugar Babies, N = 514) if they had one or more risk factors for neonatal hypoglycaemia, including being born to a diabetic mother, preterm (< 37 weeks), small (< 10th centile or < 2500 g) or large (> 90th centile or > 4500 g) [13,14]. Infants with serious congenital malformations or terminal conditions were excluded. The cohort was recruited from 2006 to 2010 at Waikato Hospital, New Zealand, a regional public hospital with approximately 5500 births annually. Cohort characteristics and neonatal glycemic monitoring and management have been reported [12–14]. We anticipated considerable variability in motor development within the CHYLD study cohort because conditions present in the cohort such as neonatal hypoglycaemia [18], late preterm birth [20] and intrauterine growth restriction [17] can influence motor development. Such variability would facilitate the detection of even weak associations between motion coherence thresholds and motor function. The CHYLD study was approved by the Health and Disability Ethics Committee. Written informed consent was obtained at study entry and at follow-up.

2.2. Assessment at 2 years of age

At 2 years' corrected age (± 4 weeks) all children in the CHYLD Study who were born ≥35weeks' gestation were invited to participate in a comprehensive neurodevelopmental assessment, including neurological status, Bayley Scales of Infant Development (Bayley-III), executive function, vision screening and global motion perception, as previously described [21]. Bayley-III provides composite scores for cognitive, language, and motor ability, with standardised means (standard deviation [SD]) of 100 (15) [4]. The motor score is a composite of fine and gross motor subtest scores, each with a standardised mean (SD) of 10 (3). Fine motor tests include reaching and grasping activities whereas gross motor tests include measures of locomotion, coordination and balance.

Vision screening included unaided binocular visual acuity measurement (Cardiff Acuity Cards), stereopsis (Lang Stereotests), alignment and motility (including cover test, 20^{Δ} base-out test), and non-cycloplegic autorefraction (Suresight™ Autorefractor, Welch Allyn, Skaneateles Falls, NY) [28]. A Vision Impairment Score assigned one point for each of the following: internal or external ocular health problem, strabismus, abnormal motility, absence of stereopsis, binocular visual acuity worse than 0.5 logMAR. Children were assigned a Refractive Error Score consisting of one point for each of the following: hyperopia (mean sphere [M] ≥ +4.00 dioptre [D]), myopia (M ≤ −1.00 D), astigmatism (cylinder [C] ≤ −1.50 D in any meridian), and anisometropia (difference in M between eyes of ≥3.00 D in either the most positive or negative meridian) [25].

Global motion perception was measured from optokinetic nystagmus (OKN) responses to random dot kinematograms (RDK) of varying coherence, as previously described [28]. In brief, RDK stimuli created in Matlab (MathWorks, Matick, MA) were presented within a circular aperture (radius 8.3°) on a cathode ray tube and consisted of 250 white dots (138 cd/m^2, diameter 0.5°, speed of 8°/s) on a grey background (42 cd/m2, dot density = 1.16 $dots/deg^2$). Signal dot direction (left or right) was randomized and noise dots had a random direction. Dots had a limited lifetime with a 5% chance of being randomly relocated on each frame. Stimuli were presented for 8 s at coherence levels of 100%, 84%, 68%, 52%, 36% and 20%, in descending order across consecutive trials. The sequence was repeated until the child could no longer be encouraged to look at the monitor. Eye movements were recorded at 50 Hz using a high definition camera (Sony HDR-CX7EK; Sony Corporation, Tokyo, Japan) and motion coherence threshold corresponding to 63% correct was determined from a Weibull fit to the proportion of correct responses at different coherence levels [28].

A subset of the children who completed the 2-year assessment also completed a 4.5-year assessment. Data from these children were reported in our recent study into the association between global motion perception and motor function at 4.5 years of age [8].

2.3. Statistical analysis

Analysis was performed with SAS software, version 9.4 (SAS Institute, Cary, NC). Bayley-III composite and subtest scores, and motion coherence thresholds were converted to z-scores. Socioeconomic status was determined from the New Zealand Deprivation Index [3]. Linear regression was used to assess the relationship between motion coherence and Bayley-III motor z-scores. Multivariate analysis was used to test for potentially confounding effects of vision problems (Vision Impairment Score ≥1) and Bayley-III language score. The Bayley-III language score was used to represent cognitive ability because many of the tasks involved in assessing the Bayley-III cognitive score include visual-motor activities. Interaction tests were used to investigate if the relationship between motion coherence and Bayley-III motor z-scores was affected by sex, low socioeconomic status (≤3rd decile), neonatal hypoglycaemia (blood glucose concentration < 2.6 mmol/L) or being