Neuropsychological Trends

25
April 2019

Chronological age versus developmental age in evaluating patients' performances on motion perception tests

Ymie J. Van Der Zee[1, 2] - Peter L.J. Stiers[3, 4]
Lieven Lagae[4] - Johan J.M. Pel[5] - Heleen M. Evenhuis[1]

[1] Intellectual Disability Medicine, Department of General Practice, Erasmus MC, Rotterdam

[2] Royal Dutch Visio, Centre of expertise for blind and partially sighted people, Rotterdam

[3] Department of Neuropsychology & Psychopharmacology, Maastricht University, Maastricht

[4] Department of Woman & Child, Section Paediatric Neurology, K.U. Leuven, Leuven

[5] Vestibular and Ocular Motor Research Group, Department of Neuroscience, Erasmus MC, Rotterdam

DOI: http://dx.doi.org/10.7358/neur-2019-025-vand y.vanderzee@erasmusmc.nl

ABSTRACT

In neuropsychological assessments, a patient's raw score is frequently compared to a large general population normative sample. It is common to use the chronological age as entry of norm tables to assess a patient's current cognitive function. In individual patients with a developmental delay or cognitive impairment, this may result in misinterpretation of performance. The aim of this study was to test the impact of chronological and developmental age parameters on motion perception outcomes and to construct and evaluate normal motion perception limits for clinical practice. In the present study, the developmental age and four aspects of motion perception (biological motion, global motion, motion speed, motion-defined form) were assessed in 49 children with indications of brain damage and in 60 controls. Based on current results, we present the preliminary normal limits and we suggest the use the developmental age as entry of norm tables.

Keywords: motion perception assessment; normal limits; chronological age; developmental age; brain damage

1. Introduction

Congenital brain damage often leads to multiple disabilities, including impairments in cognitive functioning. The presence of a cognitive impairment might affect the performance on motion perception tasks. The visual perception of motion is essential for navigating and interpreting a dynamically changing visual environment. Valuable knowledge was obtained from a patient (LM) with selective impairments in visual motion perception. The patient reported the inability to see other people and vehicles moving around, to see facial movements and detect changes in the liquid level while pouring a cup of tea (Baker, Hess, & Zihl, 1991; Zihl, Von Cramon, & Mai, 1983). Later studies on the neural mechanisms of visual motion perception suggested that different aspects of visual motion are processed to a certain extent in parallel such as global motion, motion speed, motion-defined form, body motion, and that such aspects can be selectively impaired (Baker et al., 1991; Cowey & Vaina, 2000; McLeod, 1996; Vaina, Lemay, Bienfang, Choi, & Nakayama, 1990). As a result of these different aspects of motion perception, humans are able to process multiple local motion signals, e.g. to perceive and distinguish directional movement of dots in a display with random moving dots (global motion), to discriminate speed differences (motion speed), to recognize objects of fictive forms only through motion (motion-defined form) and to distinguish between humans, animals and their activities through their specific motion patterns only (biological motion).

Some studies on motion perception do control for an intellectual disability and/or developmental delay by matching on verbal and/or non-verbal IQ-test performances (Moore, Hobson, & Anderson, 1995; Reiss, Hoffman, & Landau, 2005), whereas others do not make a choice and report the performances of patients in relation to chronological age and (verbal) mental age (Atkinson et al., 2003; Del Viva, Igliozzi, Tancredi, & Brizzolara, 2006).

When controlling for mental age, normal performance levels can be found for biological motion in intellectually disabled individuals (Moore et al., 1995) and children with Williams Syndrome (Reiss et al., 2005), and for global motion in autism (Del Viva et al., 2006) and Williams Syndrome (Reiss et al., 2005) while the performances were still weak for motion-defined form in Williams Syndrome (Reiss et al., 2005) and for global motion in extremely prematurely born children, mainly without clear signs of brain damage (Benassi et al., 2017).

Since most controls were carried out on a group level, it remains unknown what the effect of the control for mental age is on the evaluation of individual results. A study by Atkinson et al. (2003) suggest that a significant reduction of 50-67% in weak performances can be expected for global motion (from 19/45 to 8/45) and motion-defined form (from 18/45 to 6/45).

Several studies in children with early brain damage suggest that non-

verbal/performance IQ is more affected than verbal IQ (Murias, Brooks, Kirton, & Iaria, 2014). Therefore, their global or verbal cognitive level of functioning might not be the best predictor or control factor for their performance level on a given task.

It might be a crucial factor to select the appropriate cognitive level, verbal or non-verbal, when evaluating the performances of specific neuropsychological tests in multiply disabled patients. A study on Fragile X Syndrome (Wouters, Fonteyne, & Stiers, 2006) suggests that specific verbal and non-verbal working memory problems can be detected if the verbal and non-verbal age equivalents, based on Verbal IQ and Performance IQ results, are used as input for norm tables of verbal tests and non-verbal tests, respectively. Specific impairments in dorsal stream functions, such as object recognition in suboptimal conditions (Stiers et al., 2001; Stiers & Vandenbussche, 2004) can be found in children with early brain damage by using the non-verbal mental age as entry of the present norm tables. The use of chronological age masks these specific neuropsychological deficits by a profile of weaknesses in several functions (Stiers et al., 2001; Wouters et al., 2006) and thereby dramatically increases the number of impairments in patients (Stiers et al., 2001). This suggests that outcomes of dorsal stream function tests, like motion perception test results, obtained in children with congenital brain damage could be either judged against chronological or non-verbal developmental age. The aim of this study was to contribute to the discussion what age parameter should be considered as entry of the norm tables when assessing individual patients in clinical practice.

We examined four aspects of visual motion perception in a group of typically developing children and children with brain damage: global motion, motion speed, biological motion, and motion-defined form. In this article, we focused on the relation between age parameters (chronological age and developmental age, i.e. the median age equivalent based on raw scores of nonverbal intelligence subtests) and motion perception outcomes. We hypothesized that motion perception scores are closely related to the non-verbal cognitive level. In typically developing children, both measures are reflected in their chronological age, suggesting that a clinician would be free to choose between chronological age and performance age in the construction of norm values. In children with brain damage, on the other hand, non-verbal cognitive level and chronological age are dissociated. For the children with brain damage, we hypothesized that motion perception performance is related to developmental age rather than to chronological age. Here, we set and evaluated preliminary norm values and considered the possible impact of the choice between the use of chronological age or performance age as the entry of the norm table in the evaluation of the performance of individual patients.

2. Method

2.1 Participants

The patient group consisted of 49 children (24 boys, 25 girls). The patients were recruited through rehabilitation centers in the Rotterdam area (Rijndam Rehabilitation Centre and Royal Dutch Visio, n = 19) and the Leuven University Hospital, Belgium (n = 30). Forty patients had abnormal imaging results and nine had normal or no imaging results but had indications of brain damage/dysfunction. The aetiology of brain damage was brain malformations in three children, hypoxic-ischemic encephalopathy in twenty-three cases (19 periventricular leukomalacia (PVL), 3 intraventricular haemorrhage (IVH), 1 PVL + IVH), perinatal asphyxia in five, intracranial haemorrhage in two, hydrocephalus in one and acquired brain injury in six (4 trauma, 1 meningitis, 1 tumour). Of the nine patients in whom no or normal imaging results were present, three had a genetic disorder (Velo-Cardio-Facial syndrome; Beckwith Wiedemann syndrome; 46XY + m), four had neurological signs such as cerebral palsy, one had visual problems not explained by ocular abnormalities and one was dysmature probably due to prenatal drug exposure. Five patients had ocular abnormalities other than refractive errors or oculomotor dysfunctions. No patient had ophthalmological abnormalities to such a degree that it would interfere with perceiving details of the motion stimuli (Stiers & Fazzi, 2010). At the moment of motion perception testing, chronological age ranged from 4.11 to 14.58 (M = 7.35, SD = 2.26 years).

The control group consisted of 119 typically developing children (54 boys, 65 girls) with no indication of neurological or visual impairments and normal or corrected to normal visual acuity. Controls were recruited through primary schools in the Netherlands (n = 79) and Belgium (n = 40). At the moment of motion perception testing, their chronological age ranged from 3.50 to 7.86 years (M = 5.47, SD = 1.05 years), which was significantly lower than that of the control group ($U(166) = 1141.5$, $Z = -6.19$, $p < .01$).

Studies were approved by the Ethics Committees of the Erasmus Medical Center and the Leuven University Hospital. For all participants informed consent was obtained from their parents or guardians.

2.2 Procedure

All Dutch and Belgian controls (n = 119) and the Dutch patients (n = 19) were tested at the children's primary schools. The Belgian patient group (n = 30) was

studied at the Leuven University Hospital. In the Dutch groups, motion perception tasks were presented in a fixed order: biological motion, motion-defined form, global motion, and motion speed. In a subgroup of Dutch controls, motion speed was not administered due to time constraints (n = 19). In the Belgian control and patient groups tasks were administered in a random order.

Task administration was done by trained senior psychology students or neuropsychologists. Tasks were presented on a 15-inch CRT monitor attached to a laptop. Participants were placed in front of the screen at approximately 40 cm.

2.3 Motion Perception tasks

Four different motion perception tasks were administered, covering the domains of global motion, motion speed, biological motion, and motion-defined form (Figure 1A-D). All stimuli consisted of white dots on a black background with a resolution of 640 x 480 and refresh rate 25 frames/s. In the global motion task, biological motion task and the motion speed task psychophysical thresholds were estimated by calculating the mean of the values of the last 4 of 8 reversals, using a 2up-1down staircase procedure. In these tasks, a correct answer was followed by a beep.

The global motion stimulus consisted of two random dot kinematograms (size 14.7 x 22.4 deg) containing 1103 white dots (dot size 0.07 deg, limited life time 130 ms) presented next to one another with a distance between them (size 3.3 deg). A variable proportion of dots (starting level 100%, scaling factor 0.33) in each kinematogram oscillated coherently in horizontal direction (reversal time 330 ms, velocity 6.7 deg/s). Participants had to locate a horizontal strip (size 14.7 x 7.5 deg) in the middle of one of the random dot kinematograms, where the coherent dots oscillated in the opposite direction. Because the proportion of coherent dots was constant throughout the random dot kinematograms, the strip could not be located by tracing the movement of single dots. The proportion of coherently moving dots or the coherence level determined the difficulty of the task and was used to calculate the coherence threshold. Participants were instructed to help a lost person to find his way in the snow (presentation = 15 s, answer time 5 s).

The motion-defined form stimuli consisted of objects hidden in a random dot kinematogram (size 20.6 x 16.0 deg, 5000 dots, dot size 0.13 deg, life time 200 ms, velocity 3.4 deg/s). Each object could be displayed in three successive conditions with decreasing level of difficulty (presentation max. 15 s). In all conditions, the dots outside the contour moved coherently in oblique direction. In the first condition, the dots in the contour of the object moved coherently downwards. In the second condition, the dots in the contour were standing still, and in the third condition there were no dots in the contour. After an

object was correctly identified, the trial was aborted and the next trial, with a new object, was started. If the object was correctly named or described in the first, second or third condition a score of 1, 0.5 or 0 was noted. If the object was not correctly identified in the third condition, the response was marked as inconclusive, and the item was not used in the computation of the visual motion perception score. Three subtasks, increasing in difficulty with six objects were presented. Objects in task 1 were circle, star, bear, banana, heart and fish; task 2: arrow, kangaroo, boat, guitar, ostrich and bag; task 3: beetle, seat, airplane, seahorse, car and shoe.

The biological motion stimulus consisted of a human-point light walker and a phase-scrambled point-light figure (both 11 dots, dot size 0.13 deg, dot lifetime 40 ms, stimulus height approx. 11 deg). The location of the human point-light walker (left or right of the screen), its position within the field and its walking direction (left or right) were randomized. Participants had to indicate the location of the human point-light walker (presentation max. 20 s, walking speed 48 cycl/min). Difficulty was increased by adding noise dots (starting level 1 dot added, scaling factor 0.075 and 0.150 from second reversal), and the threshold was the critical number of noise dots added.

The motion speed stimulus consisted of two identical contours of a car (car length approx. 17 deg) filled with leftwards moving dots (dot density 11 dots/deg^2, dot size 0.07 deg, lifetime 120 ms). Participants were asked to indicate the location of the fastest car (presentation time 10 s). A decrease in the speed difference of the dots in the cars made the task more difficult (starting speed difference 17.0 deg/s, scaling factor 0.33, 0.25 from fifth reversal) and the critical speed difference was the score for this task.

Before each task, example stimuli were used to familiarize participants with task elements and verify that they understood the task.

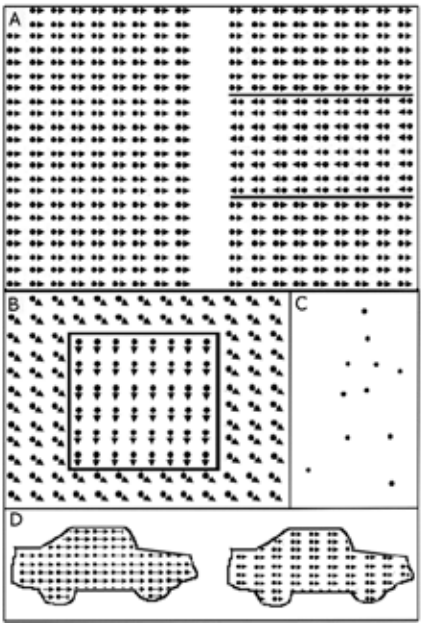

Figure 1. Schematic examples of motion perception tasks. The arrows indicate the motion direction of the dots, length of the area motion speed (longer is higher speed). In the real task, the background is black and dots are white and the borders are not defined by lines. A. Motion coherence task with target area on the right; B. Motion-defined form task, example item square; C. Biological motion: the single walker, walking to the right. Scrambled figure and distracter dots are not shown; D. Motion speed: dots in left car move faster

2.4 Developmental age

Because previous studies suggest that non-verbal cognitive ability and not verbal cognitive skill is predictive of perceptual performance (Ito et al., 1996; Ito et al., 1997; Stiers, De Cock, & Vandenbussche, 1998; Stiers, De Cock, & Vandenbussche, 1999; Stiers et al., 2005), we only studied non-verbal intelligence in addition to visual perception in patients and in a subset of controls. The data collection of IQ data in the control group was limited due to time constraints. Although the use of a single intelligence test is preferable, the

broad age range in the patient group and the cognitive consequences of the brain damage made this impossible. In addition, we decided to use recent intelligence results when available to keep the required effort of the patients as low as possible.

Non-verbal intelligence data were collected in 60 Dutch controls using the Snijders-Oomen non-verbal intelligence test (SON-R 2½ - 7). In the patient group, data were available for SON-R in 19, Wechsler preschool and primary scales of intelligence (WPPSI-R) in 24, Wechsler Intelligence Scale for Children III (WISC-III) in 5 and Wechsler Intelligence Scale for Children-revised (WISC-R) in 1 patient. All these tests have normative data for the Dutch speaking population of Belgium and The Netherlands.

The SON-R differs from the Wechsler tests in that the SON-R can be administered without using verbal instructions, which makes the assessment in children with hearing or language problems possible and feedback is provided after each item, which gives the child the possibility to learn. The effect of these differences on the outcomes is unknown, but because the correlation between SON-R IQ and WPSSI-R PIQ is 0.93 (Moore, O'Keefe, & Lawhon, 1998) and WISC-R PIQ is 0.79 (Nieuwenhuys, 1991), we considered these tests interchangeable for the developmental age estimation.

The developmental age was defined as the median age equivalent based on the raw subtest scores of the non-verbal intelligence scale. We used age equivalent tables published in the manuals of the different IQ tests to convert each raw subtest score to an age equivalent and then calculated the median age equivalent, see Table 1 for examples of the WPPS-R results. Because there was a time lag (M = 1.85, SD = 2.39 months) between the assessment of non-verbal intelligence and motion perception, the estimated developmental age was extrapolated from the time of intelligence assessment to the time of motion perception assessment.

*Table 1. Calculating developmental age in months from non-verbal IQ subtest age equivalents of the WPPSI-R in 4 different Belgian patients (BE04; BE02; BE11; BE07) * middle two values, values around the median*

	BE04	BE02	BE11	BE07
WPPSI-R subtests	(Raw test scores) Age equivalents in months according manual			
Object Assembly	(28)	(24)	(20)	(10)
	88*	66*	54*	33
Geometric designs	(47)	(48)	(34)	(15)
	68	69	57*	41
Block design	(20)	(18)	(10)	(8)
	57	54	43	39*
Mazes	(19)	(17)	(8)	(9)
	75*	67*	42	41
Picture completion	(23)	(18)	(22)	(10)
	92	58	83	40*
Animal Pegs	(58)	(56)	(58)	(50)
	96	84	96	67
Median age equivalent	81	66	56	40
Age IQ test	73.13	73.86	3.96	91.73
Age motion tests	73.13	73.86	96.89	3.72
Developmental age [a]	81	66	57.74	45.23
PIQ	102	83	62	-
VIQ	106	83	102	-

[a] Developmental age = (Median age equivalent/Age IQ test)*Age motion test

2.5 Statistical Analysis

We used IBM SPSS Statistics version 20, the data of the 60 Dutch controls and all patients and the Mann-Whitney test to study group performances. Because we assumed that patients performed equally well or worse than controls, we used the one-tailed significance and a *p*-value of .05.

To study the relation between the outcomes of the motion perception tasks and the age parameters chronological age and developmental age, we calculated the Spearman correlation and partial correlation. Outcomes of these analysis in controls were used to decide whether chronological age or developmental age should be used to set the normal limits. We ordered the performances of the controls from worst to best and computed the weighted average of the 5th, 10th, 25th, 50th and 75th percentile. We set the 5th percentile score as the cut-off value for abnormal performance and the 10th percentile score as the cut-off value for weak performance.

We then calculated the 95%-confidence interval for the found cut-off values based on 1000 bootstrap samples, with replacement from the original dataset. In addition, we calculated the 95%-confidence interval for the percentage excluded participants with the exact binomial method of Clopper-Pearson (Newcombe, 1998).

3. Results

3.1 Motion perception performance in relation to chronological and developmental age

Data were present on chronological age, PIQ and developmental age in the 60 Dutch controls, 25 boys and 35 girls. In the control group, the mean chronological age was 5.67 years (*SD* = 0.82), the mean PIQ 105 (*SD* = 14), and the mean developmental age 5.85 years (*SD* = 1.10). As expected, the Spearman correlation was high between chronological age and developmental age (r_s = .72, p < .01, *df* = 59) and absent between chronological age and PIQ (r_s = - .01, *ns*, *df* = 59), showing that mean PIQ is similar across age. In eight controls, one or two motion perception tasks were not completed due to reduced compliance. With respect to the biological motion task it was remarkable that several children mentioned that the phase-scrambled point-light figure looked like a dancing person when it was introduced.

In the patient group, one girl and one boy did not complete any of the motion perception tasks. The girl complained that she did not see anything moving. Ten patients completed all four tasks, 24 three, 7 two, and 6 one. Chronological age of these remaining 47 patients was 7.32 years (*SD* = 2.28), mean PIQ 78 (*SD* = 20, *n* = 40) and mean developmental age 5.38 years (*SD* = 1.42). The correlation between chronological and developmental age was modest (r_s = .41, p < .01) but significantly lower than in the control group (.41 versus .72, p < .01). The relation between chronological age and PIQ was absent (r_s = - .07, *ns*).

In Figure 2 the distribution of scores on the motion perception tasks in patients and controls are plotted. The boxplots and measures for skewness and kurtosis show that the data of most tasks are not normally distributed, except for the data of the patient group for the global motion and biological motion tasks. The distribution for the global motion task in the controls is near-normal. The non-normal distributions are skewed and sometimes leptokurtic (clustered about the center and thinner tails, except at the end points where the tails are thicker than in the normal distribution). The motion coherence level

in patients (*Mdn* = .45) did not differ significantly from controls (*Mdn* = .40), *U* = 1416.50, *z*= 1.56, *p* = .06, effect size *r* = 0.16. However, the patients (*Mdn* = .72) performed significantly worse than the controls (*Mdn* = .84) on the motion-defined form task, *U* = 861.50, *z*= -1.91, *p* = .03, *r* = -0.19. The performance on the biological motion task did not differ significantly (Mdn_{patients} = 8.12, Mdn_{controls} = 7.87), *U* = 813.50, *z*= -0.24, *ns*, *r* = 0.03. Unexpectedly, patients performed significantly better on the motion speed task ($Mdn_{patients}$ = 4.28 deg/s, Mdn_{controls} = 5.78), *U* = 507.50, *z*= -1.66, *p* = .05, effect size *r* = 0.19. The data of the patient group is more clustered and shows 1 outlier.

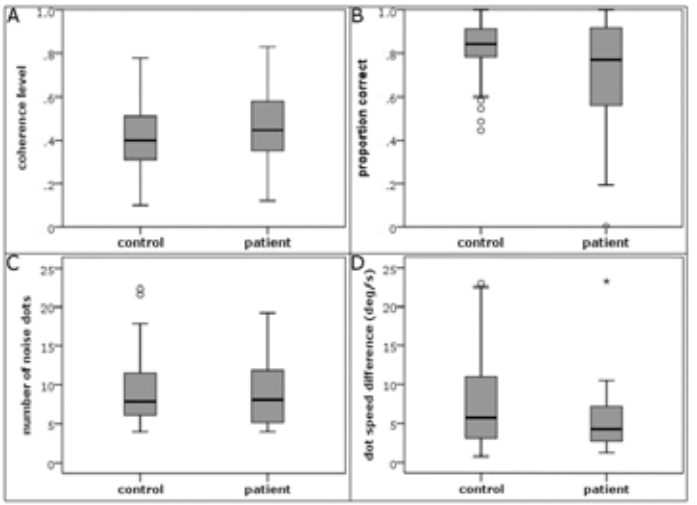

Figure 2. Motion perception performances in controls and patients. Boxplots: horizontal line is the median, the box represents the interquartile range (range between 25th and 75th percentile), the wishers represent the 95%-confidence interval, the circles are data points outside the confidence interval and the asterisk is an outlier in that group A. Motion coherence task; B. Motion-defined form task; C. Biological motion; D. Motion speed

Table 2 and 3 present the relation between motion perception outcomes and age parameters in controls and patients. The signs of the correlations indicate that on all motion perception tasks the performance tends to improve with increasing chronological and developmental age, except for biological motion in the patient group for which performance tends to deteriorate with increasing chronological age.

In the control group (Table 2), all correlations of motion perception performance with chronological age and with developmental age were significant. Similar results for chronological and developmental age in the control group are not surprising, given their strong intercorrelation. Therefore, we also studied the unique contribution of each age parameter to motion perception using the partial correlation. Chronological age explained some unique variance in the global motion scores (p = .02) whereas developmental age explained some unique variance in the motion speed scores (p = .03).

In the patient group (Table 3), correlations of motion perception performance with chronological age were non-significant. In contrast, the correlations with developmental age were significant and similar in magnitude to those found in controls. The partial correlations were also mainly significant for developmental age.

*Table 2. Controls: relation between motion perception task outcomes, chronological age and developmental age, as well as unique contribution of chronological age and developmental age to task outcomes * p ≤ .05 ** p ≤ .01*

		Spearman correlation		Spearman partial correlation	
	n	Chronological age	Developmental age	Chronological age [a]	Developmental age [b]
Global motion	57	- .43**	- .35**	- .27*	- .07
Motion-defined form	59	.39*	.40*	.16	.19
Biological motion	60	.31*	.27*	.17	.08
Motion Speed	53	- .34*	- .42**	- .07	- .27*

[a] *controlled for developmental age*

[b] *controlled for developmental age*

*Table 3. Patients: relation between motion perception task outcomes, chronological age and developmental age, as well as unique contribution of chronological age and developmental age to task outcomes. * p ≤ .05 ** p ≤ .01*

		Spearman correlation		Spearman partial correlation	
	n	Chronological age	Developmental age	Chronological age [a]	Developmental age [b]
Global motion	42	- .17	- .42**	.00	- .39**
Motion-defined form	8	.01	.32*	- .14	.34*
Biological motion	8	- .12	.48**	- .39 *	.59**
Motion Speed	5	- .18	- .33*	- .05	- .29

[a] *controlled for developmental age*

[b] *controlled for developmental age*

3.2 Normal limits

The results above show that in typically developing children the unique contribution of performance age over chronological age in visual motion perception performance is limited. Therefore, we had no reasons to deviate from common practice and calculated the normal limits based on controls' chronological age. As a result, we could use data of the entire control group (N = 119) including the controls without IQ data.

The control groups performed equally on the global motion task (*Mdn* = .40 vs .37) and the biological motion task (*Mdn* = 7.87 vs 9.42, effect size r=0.14). The control group with IQ data (*Mdn* = .84) performed significantly better than the control group without IQ data (*Mdn* = .77) on the motion-defined task, U = 2222.50, z= 2.79, p < .01, r = 0.26 and on the motion speed task (*Mdn*= 5.78 vs 9.40 deg/s), U = 635.50, z= -2.83, p < .01, r = 0.30. In Figure 3 the motion perception scores, obtained in the group with and without IQ information, are plotted relative to age. As the chronological age in the group without IQ data was slightly but significantly lower than in the group with IQ data (5.29 ±1.21 years vs. 5.66 ± 0.81 years; t(101.5) = 1.99, p = .05), there is a slight shift of the groups relative to the X-axis. This explains the differences in performance between the control groups.

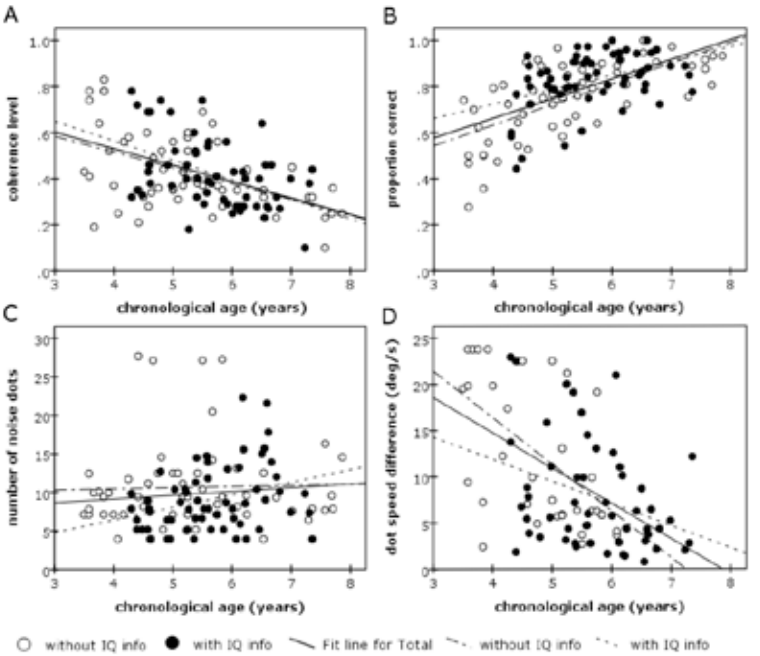

Figure 3. Performance of the control group with IQ (n = 60) information and the control group without IQ information (n = 59) on A. global motion, B. motion-defined form, C. Biological motion, D. motion speed

To construct age-specific cut-off criteria, the entire sample was optimally divided in three age groups with a minimum of 30 participants per group. The youngest group, group 1, consisted of 19 boys and 12 girls younger than 4.75 years with a mean age of 4.20 years (*SD* = 0.39; range = 3.50-4.67). Group 2 consisted of 17 boys and 26 girls with an age between 4.75 and 5.75 years with a mean age of 5.26 years (*SD* = 0.27; range = 4.75-5.74). Group 3, the oldest group, consisted of 18 boys and 27 girls aged 5.75 years and older with a mean age of 6.56 years (*SD* = 0.60; range 5.75-7.86).

The data of the global motion task was normally distributed in group 1 and 2. Skewness and kurtosis were within normality ranges in group 3 but the Shapiro-Wilks was significant (p = .05), suggesting a non-normal distribution. The data of the motion-defined form task was normally distributed for group 1

and 3. The data of the group 2 was skewed and the Shapiro-Wilks was near significant (p = .06). The data of the motion speed task had a non-normal distribution in all groups (Shapiro-Wilks ps < .01). In group 1, skewness and kurtosis were within normality ranges, the data in group 2 was skewed and the data of group 3 was more skewed, looked more like a lognormal distribution, but was also leptokurtic. Because of the different shapes of the distributions, we decided not to transform and normalize the data.

For the global motion and motion speed task, the 10th and 5th percentile cut-off values decreased by age. In the youngest group (n_1 = 31), the global motion cut-off coherence levels were 0.78 and 0.80, in the second group (n_2 = 39) 0.69 and 0.74, and in the oldest group (n_3 = 45) 0.46 and 0.56. 10th percentile cut-off values for the motion speed differences were 23.80, 20.00 and 12.49 deg/s and 5th percentiles cut-off values were 23.80, 21.53 and 19.87 (n_1 = 25; n_2 = 34; n_3 = 31). For the motion-defined form task, the proportion correct cut-off values increased by age from 0.45 in group 1 (n_1 = 31), 0.63 in group 2 (n_2 = 43) to 0.74 in group 3 (n_3 = 43) for the 10th percentile and from 0.33, 0.59 to 0.70 for the 5th percentile. The 5th percentile of the biological motion task coincided with the lowest score obtainable in all age groups, implying a bottom effect for this task. Therefore, presentation of cut-off values and clinical evaluation on this task is not useful.

3.3 Confidence intervals for task cut-off values and for the percentages of participants scoring below the 5th/10th percentile

To illustrate possible developmental trends, we fitted trendlines to the median scores of different age groups, cut-off values for the 5th and 10th percentile, and their confidence intervals in Figure 4. Because bootstrapping relies on the observed data, the upper bound (if data is ordered from worst to best performance) of the confidence intervals (illustrated with open grey triangles) coincided with the worst performance observed in each group for the 5th percentile and some, but not all groups, for the 10th percentile. For the remaining groups, the outcomes were near the 5th percentile score. The lower bound of the confidence intervals (illustrated with filled grey triangles) for the 5th percentile was near the outcomes of the 10th percentile and that for the 10th percentile coincided with or was near the outcomes for the 25th percentile in all groups for all tasks. As a result, the changes in the distributions over age, most notable for the motion speed task, are reflected in our plots: the increasing variance and skewness in the motion speed task resulted in a wider confidence interval, although group size changed from 25 to 34 and 31.

The exact binomial method of Clopper-Pearson showed that we might label 1% to 17-21% of the population as abnormal when using the 5th

percentile cut-off values of the global motion task and 2-4% to 24-26% as weak when using the 10th percentile cut-off values. The results for the motion-defined form are comparable. For the motion speed task, we might label 1% to 20-26% as abnormal and 2-3% to 26-31% as weak when using the cut-off values for the 5th and 10th percentile.

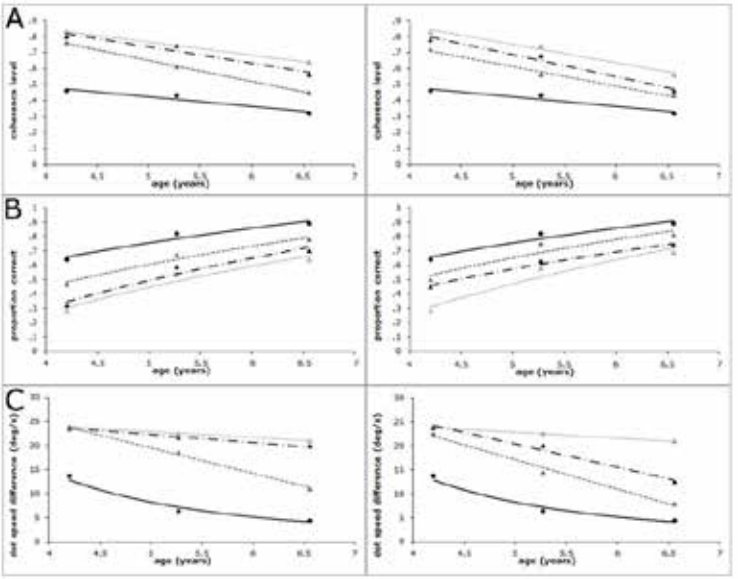

Figure 4. Confidence intervals for cut-off values for percentile 5 (left) and percentile 10 (right). Filled circle: median score; filled black triangle: cut-off value; grey triangles: confidence limits. The lines are fitted to illustrate possible trends. A. global motion, B. motion-defined form, C. motion speed

4. Discussion

This study shows that a child's level of non-verbal cognitive ability is indicative of the level of performance on a visual motion perception task. This non-verbal cognitive level is not the relative level in comparison to peers, but the absolute level of ability as reflected in the non-verbal cognitive complexity of the tasks that the child is able to perform. In typically developing children, this absolute level of non-verbal cognitive ability is directly related to the child's chronological age, which is a good proxy for it. In children with early brain damage, on the other hand, the level of non-verbal ability is often dissociated from chronological age (Abercrombie et al., 1964; Ballantyne, Scarvie, & Trauner, 1994; Bava, Ballantyne, & Trauner, 2005; Fedrizzi et al., 1993; Stiers et al., 1999). Our results show that in that case, the non-verbal cognitive level is predictive of visual motion perception performance. This is in line with previous studies on object and form perception abilities in neuropediatric populations, such as cerebral palsy (Ito et al., 1996; Koeda & Takeshita, 1992; Stiers et al., 1999), hypoxic-ischemic encephalopathy in premature infants and in birth asphyxia (Stiers et al., 1999) and spina bifida (Ito et al., 1997). The high correlations between PIQ and object or form perception scores reported, ranging from 0.33 to 0.85, imply that a lower perception score than expected from a child's chronological age is not as such an indication of a perceptual disability. This implies that, in general, the scores on visual motion perception tasks reflect a patient's global non-verbal cognitive level, in addition to a possible specific visual motion perception disability. Therefore, to evaluate perceptual ability in these children it is important to use their global non-verbal cognitive level, as expressed by the developmental age, as a baseline. Only in this way, it can be avoided to erroneously interpret non-verbal cognitive impairment manifested in the motion task performance as a motion perception impairment. Stiers and colleagues (1999) (see also Stiers et al. 2001; Stiers & Fazzi, 2010) suggest a simple and clinically feasible approach. In this approach, the scores on a set of non-verbal intelligence subtest is used to estimate the overall non-verbal performance level of a child. This performance level, expressed as an age equivalent, is used instead of chronological age to relate the child's visual motion score to the scores of the normative group.

Given that normative data for tests are usually based on participants' chronological age, the results in our study provide no reason for deviating from this practice; the gains of collecting IQ information in typically developing children seem to be minimal. We therefore state that motion perception performances in different chronological age groups of normally developing children should be used to set norm values for motion perception tasks.

A number of limitations to our study must be addressed. Four different motion perception tasks were included in our study. Unfortunately, the

biological motion paradigm was too difficult or even invalid for the age range of the typically developing children. The remarks of several children that the phase-scrambled point-light figure looked like a dancing person, suggests that top-down processes like expectations might have influenced the results and makes the construct validity of the task questionable.

It should be noted that the reliability of the estimated incidence of visual motion perception impairment will depend on the reliability of the statistical cut-offs used to define impairment. In the present study, the 95%-CI for the chosen cut-off scores were rather large, e.g. 1-16% for the 5th percentile in a group with a sample size of 43 and 1-26% in a group with a sample size of 25. Using currently applied cut-off values might therefore result in the overdiagnosis of motion perception abnormalities and weaknesses. Our bootstrap overdiagnosis results also showed that our cut-off values are not that precise yet. In addition, the results of the motion speed task showed that the distribution of data influenced the width of the confidence interval. With the increase in age, the distribution looked more like a lognormal distribution. To set normal limits more precisely, larger samples of typically developing children are needed. We advise to study the developmental trends and distribution in different age groups and age ranges before setting the percentile normal limit. Especially, in non-linear developmental trends with more steep development, smaller age ranges per norm group should be considered. Additionally, transformation of data might be needed to get more precise normal limits. Even if lognormally distributed data is present, it might be advantageous to perform a data transformation (Schoonjans, De Bacquer, & Schmid, 2011).

Finally, before clinical implementation can take place, we not only need accurate norm values, but also should evaluate the sensitivity and specificity of the tasks and assure ourselves that we assess clinically meaningful weaknesses. The question is whether children with weak motion perception show more problems in dynamic daily activities, such as pouring a drink, sport and traffic participation and social interactions. Although effects of weak motion perception might be less debilitating in developing children than reported by patient LM as mentioned in the introduction, studies in children and adults suggest that the ability to perceive motion might indeed influence daily functioning in several ways. The middle temporal area (MT) is essential in the perception of global motion, the segregation of the moving object from its background and fixating and following the object (Born, Groh, Zhao, & Lukasewycz, 2000). Smooth pursuit and global motion perception seem essential in controlling the water level while pouring a cup of tea and tracking a ball and/or predicting the ball's course before hitting or catching it (Land, 2006). Studies in adults demonstrate that performances on a motion-defined and a 3D speed discrimination task (Wilkins, Gray, Gaska, & Winterbottom, 2013) and a global motion task (Wood, 2002) predict car driving

performances. It was also shown that motion perception training can improve traffic performances (Wilkins et al., 2013). A study on biological motion perception and autism (Pelphrey & Carter, 2008) shows that superior temporal sulcus (STS) is not only selectively activated by biological motion stimuli, but its activity is also modulated by the perception of other people's intentions. Children with autism seem less able to distinguish biological and non-biological motion patterns. The authors suggested that this might have impaired their development of the theory-of-mind, the ability to interpret and predict other people's actions and intentions correctly, and social skills. Further imaging research (Yang et al., 2016) shows that activity in the brain network involved in biological motion perception predicts the effectiveness of treatment in children with autism, i.e. higher activity levels were associated with higher treatment effectiveness. Overall, the ability to perceive motion seems to have significant impact on daily functioning. Still, not many studies have investigated motion perception problems in dynamic daily activities. It remains a topic for important future research especially in children when they have reached school age. For example, are children that perform worse on a global motion task also slower or clumsier in activities of daily life or do they perform worse on (fast) ball sports in school? Or does a worse motion-defined form or global motion task performance relate to the ability to cross a street safely? Lastly, do children with brain damage that perform weak on motion perception tasks also have more problems with social interactions? Additional studies on motion perception performances and daily life functioning are necessary to answer these questions.

Acknowledgements

We thank the participating children and their parents, the schools (Eduard van Beinum, Openbare basisschool Charlois, De Bergse Zonnebloem, Visio-school); Rijndam Revalidatiecentrum, Rijndam Rehabilitation Centre; Royal Dutch Visio, Centre of expertise for blind and partially sighted people, all located in Rotterdam, the Netherlands for their cooperation in the data collection.

Funding

This study was supported by the K.U.Leuven Research Fund (K.U.Leuven Onderzoeksfonds) grants nr. OT/01/43, PDM/01/156 and PDM/03/251 and Royal Dutch Visio.

References

Abercrombie, M. L., Gardiner, P. A., Hansen, E., Jonckheere, J., Lindon, R. L., Solomon, G., & Tyson, M. C. (1964). Visual, Perceptual and Visuomotor Impairment in Physically Handicapped Children. *Perceptual and Motor Skills, 18*, 561-625.

Atkinson, J., Braddick, O., Anker, S., Curran, W., Andrew, R., Wattam-Bell, J., & Braddick, F. (2003). Neurobiological models of visuospatial cognition in children with Williams syndrome: measures of dorsal-stream and frontal function. *Developmental Neuropsychology, 23*(1-2), 139-172.

Baker, C. L., Jr., Hess, R. F., & Zihl, J. (1991). Residual motion perception in a "motion-blind" patient, assessed with limited-lifetime random dot stimuli. *The Journal of Neuroscience, 11*(2), 454-461.

Ballantyne, A. O., Scarvie, K. M., & Trauner, D. A. (1994). Verbal and Performance Iq Patterns in Children after Perinatal Stroke. *Developmental Neuropsychology, 10*(1), 39-50.

Bava, S., Ballantyne, A. O., & Trauner, D. A. (2005). Disparity of verbal and performance IQ following early bilateral brain damage. *Cognitive and Behavioral Neurology, 18*(3), 163-170.

Benassi, M., Bolzani, R., Forsman, L., Ådén, U., Jacobson, L., Giovagnoli, S., & Hellgren, K. (2017). Motion Perception and Form Discrimination in Extremely Preterm School-Aged Children. *Child Development*, *89*(6), e494-e506.

Born, R. T., Groh, J. M., Zhao, R., & Lukasewycz, S. J. (2000). Segregation of object and background motion in visual area MT: effects of microstimulation on eye movements. *Neuron, 26*(3), 725-734.

Cowey, A., & Vaina, L. M. (2000). Blindness to form from motion despite intact static form perception and motion detection. *Neuropsychologia, 38*(5), 566-578.

Del Viva, M. M., Igliozzi, R., Tancredi, R., & Brizzolara, D. (2006). Spatial and motion integration in children with autism. *Vision Research, 46*(8-9), 1242-1252.

Fedrizzi, E., Inverno, M., Botteon, G., Anderloni, A., Filippini, G., & Farinotti, M. (1993). The cognitive development of children born preterm and affected by spastic diplegia. *Brain and Development, 15*(6), 428-432.

Ito, J., Saijo, H., Araki, A., Tanaka, H., Tasaki, T., Cho, K., & Miyamoto, A. (1996). Assessment of visuoperceptual disturbance in children with spastic diplegia using measurements of the lateral ventricles on cerebral MRI. *Developmental Medicine & Child Neurology, 38*(6), 496-502.

Ito, J., Saijo, H., Araki, A., Tanaka, H., Tasaki, T., Cho, K., & Miyamoto, A. (1997). Neuroradiological assessment of visuoperceptual disturbance in children with spina bifida and hydrocephalus. *Developmental Medicine & Child Neurology, 39*(6), 385-392.

Koeda, T., & Takeshita, K. (1992). Visuo-perceptual impairment and cerebral lesions in spastic diplegia with preterm birth. *Brain and Development, 14*(4), 239-244.

Land, M. F. (2006). Eye movements and the control of actions in everyday life. *Prog Retin Eye Res, 25*(3), 296-324.

McLeod, P. (1996). Preserved and Impaired Detection of Structure From Motion by a 'Motion-blind" Patient. *Visual Cognition, 3*(4), 363 - 392.

Moore, C., O'Keefe, S. L., & Lawhon, D. (1998). Concurrent validity of the Snijders-Oomen Nonverbal Intelligence Test 2 1/2-7--Revised with the Wechsler Preschool and Primary Scale of Intelligence--Revised. *Psychological Reports, 82*(2).

Moore, D. G., Hobson, R. P., & Anderson, M. (1995). Person Perception - Does It Involve Iq-Independent Perceptual Processing. *Intelligence, 20*(1), 65-86.

Murias, K., Brooks, B., Kirton, A., & Iaria, G. (2014). A review of cognitive outcomes in children following perinatal stroke. *Dev Neuropsychol, 39*(2), 131-157.

Newcombe, R. G. (1998). Two-sided confidence intervals for the single proportion: comparison of seven methods. *Statistics in Medicine, 17*, 857-872.

Nieuwenhuys, M. (1991). A comparative study between Son-R, WISC-R and Raven-SPM. [Een vergelijkingsonderzoek SON-R, WISC-R en Raven-SPM]. (*Unpublished doctoral thesis*), University of Amsterdam, Amsterdam, The Netherlands.

Pelphrey, K. A., & Carter, E. J. (2008). Brain mechanisms for social perception: lessons from autism and typical development. *Ann N Y Acad Sci, 1145*, 283-299.

Reiss, J. E., Hoffman, J. E., & Landau, B. (2005). Motion processing specialization in Williams syndrome. *Vision Research, 45*(27), 3379-3390.

Schoonjans, F., De Bacquer, D., & Schmid, P. (2011). Estimation of population percentiles. *Epidemiology, 22*(5), 750-751.

Stiers, P., De Cock, P., & Vandenbussche, E. (1998). Impaired visual perceptual performance on an object recognition task in children with cerebral visual impairment. *Neuropediatrics, 29*(2), 80-88.

Stiers, P., De Cock, P., & Vandenbussche, E. (1999). Separating visual perception and non-verbal intelligence in children with early brain injury. *Brain and Development, 21*(6), 397-406.

Stiers, P., & Fazzi, E. (2010). Psychometric evaluation of higher visual disorders: strategies for clinical settings. In G. N. Dutton & M. Bax (Eds.), *Visual Impairment in Children Due to Damage to the Brain. Clinics in Developmental Medicine* (pp. 149-161). London: Mac Keith Press.

Stiers, P., Swillen, A., De Smedt, B., Lagae, L., Devriendt, K., D'Agostino, E., . . . Fryns, A. P. (2005). Atypical neuropsychological profile in a boy with 22q11.2 Deletion Syndrome. *Child Neuropsychol, 11*(1), 87-108.

Stiers, P., van den Hout, B. M., Haers, M., Vanderkelen, R., de Vries, L. S., van Nieuwenhuizen, O., & Vandenbussche, E. (2001). The variety of visual perceptual impairments in pre-school children with perinatal brain damage. *Brain and Development, 23*(5), 333-348.

Stiers, P., & Vandenbussche, E. (2004). The dissociation of perception and cognition in children with early brain damage. *Brain and Development, 26*(2), 81-92.

Vaina, L. M., Lemay, M., Bienfang, D. C., Choi, A. Y., & Nakayama, K. (1990). Intact "biological motion" and "structure from motion" perception in a patient with impaired motion mechanisms: a case study. *Visual Neuroscience, 5*(4), 353-369.

Wilkins, L., Gray, R., Gaska, J., & Winterbottom, M. (2013). Motion perception and driving: predicting performance through testing and shortening braking reaction times through training. *Invest Ophthalmol Vis Sci, 54*(13), 8364-8374.

Wood, J. M. (2002). Age and visual impairment decrease driving performance as measured on a closed-road circuit. *Hum Factors, 44*(3), 482-494.

Wouters, H., Fonteyne, A., & Stiers, P. (2006). Specific memory impairment in a multiple disabled male with fragile X syndrome and temporal lobe epilepsy. *Developmental Medicine & Child Neurology, 48*(5), 378-382.

Yang, D., Pelphrey, K. A., Sukhodolsky, D. G., Crowley, M. J., Dayan, E., Dvornek, N. C., . . . Ventola, P. (2016). Brain responses to biological motion predict treatment outcome in young children with autism. *Transl Psychiatry, 6*(11), e948.

Zihl, J., Von Cramon, D., & Mai, N. (1983). Selective disturbance of movement vision after bilateral brain damage. *Brain, 106*, 313-340.