Gestalt perception in children with visual impairments: item-specific performance and looking behaviour

van der Zee, Y., Kooiker, M., Talamante Ojeda, M., & Pel J. Gestalt perception in children with visual impairments: item-specific performance and looking behavior. *Accepted for publication in Developmental Neuropsychology*

ABSTRACT

Visual closure is the ability to visualize a complete whole when an incomplete picture is presented. The aim of the present study was to investigate the Kaufman Gestalt closure task in children with cerebral and ocular visual impairments. Looking behaviour was assessed by an eye tracker system to quantify the number and duration of fixations. We found that children with visual impairments due to cerebral damage show weaker Gestalt perception and had different looking patterns than children with ocular or without visual impairments. Children with brain damage performed significantly worse on the animate items than the group without brain damage.

INTRODUCTION

Neuropsychology aims to understand how behaviour and cognition are influenced by brain functioning. Especially the effect of mental processes on behaviour, such as attention, memory, and perception, are assessed in standardized neuropsychological tests. During such tests the processing of visual information plays an important role, because neuropsychological tests often consist of and employ visual representations. Dependent on the task at hand, a participant can be asked to discriminate details, to name forms and objects and to interpret relations within and between pictures. Thus, besides understanding a given instruction and being able to give a verbal or motor response, participants should be able to create a meaningful representation of the world from visual elements. An underlying premise is that simple visual elements are integrated into a whole, also known as a Gestalt, and that the given representations are visually organized through the same principles, or laws, of perceptual grouping.[1, 2] Examples of Max Wertheimer's classical grouping principals are proximity and visual closure.[2, 3] The proximity principle means that elements that are closer to each other are more likely to be perceptually grouped than more distant elements. The visual closure principle is the ability to visualize a complete whole when presented with incomplete information or a partial picture, thus elements that form a closed figure tend to be grouped together.[3] It was shown that visual closure is essential in the identification of incomplete drawings,[4] of global letters[5] and of hierarchically organized figures.[6]

In adults without neurological impairment, the bilateral temporo-parietal junction (TPJ), the bilateral anterior cingulate cortex (ACC), and the precuneus (PC), primarily on the left side, became activated in a recognition task.[6] Presumably, perceptual grouping depends on the integrity of a large brain network and brain damage may result in poorer performance. Indeed, damage in the right occipital lobe[4] and the medial parietal lobe, i.e. the precuneus (PC)[5] resulted in weaker recognition performance. In adults, Gestalt perception, visual illusions or hierarchical letters are used to test aspects of the principle grouping. In children, the subtest Gestalt Closure of the Kaufman Assessment Battery for Children second edition (KABC-II) is frequently used. This test is an object recognition task with incomplete representations and is a subtest of the Simultaneous Processing scale. Despite the importance of these aspects of visual information processing, not many studies have addressed Gestalt perception performance in visually impaired children. A population-based cohort study of very preterm children showed that at an age

of 5 years, children born premature had lower scores than full-term controls on multiple scales, including the simultaneous processing scale.[7] Exclusion of participants with cerebral palsy (9%), an indication of brain damage, visual impairments (1% of the population had low vision, a visual acuity <3/10) and hearing impairment (<1%) had no influence on the results.[7] These data suggested that prematurity combined with brain damage did not explain differences in performances. Yet, the number of children with impairments was too small to draw definite conclusions.

As stated, perceptual grouping of simple visual elements (e.g., lines and arcs) into simple forms and shapes helps to create meaningful representations of the world. In this process, visual attention plays a very important role. The frontoparietal network is essential for both bottom-up attention (externally driven and involving stimuli that are salient because of their inherent properties relative to the background) and top-down attention (internally driven on prior knowledge, willful plans and current goals).[8] Based on event-related potential patterns, it was shown that visual objects organized according to Gestalt principles were prioritized over competing non-Gestalt stimuli in a bottom-up and automatic fashion.[9] However, these electrophysiological responses (~150 ms after stimulus onset) only relate to the first steps of perceptual grouping of simple visual elements, and are not directly associated with the process of perceptual grouping that results in perception. Alternatively, visual attention can be quantified from infancy onwards using visually-guided eye movement responses. Differences in interactions between eye movement responses and salience in target areas have been found in children at risk of cerebral and ocular visual impairments compared to typically developing children.[10] Specifically, in children at risk of cerebral visual impairments (CVI), higher reaction times to large and high contrast stimuli were found in combination with poorer fixation stability.[11] These children might have problems with bottom-up regulated visual attention orienting, not only in visually-guided response tasks but also in visual recognition tasks, like Gestalt Closure.

The aim of the present study was to investigate the role of visual attention orienting in the Kaufman Gestalt closure task in children with cerebral and ocular visual impairments. Digitized Gestalt items were shown one-by-one on a monitor with an integrated eye tracker. Each participant was asked to name the complete image that each item represented. For analysis purposes, we grouped the items in animate (i.e. humans and animals) and inanimate objects (i.e. everything else). For each item, eye movement responses were collected to calculate the number of gaze shifts and fixation durations. We

hypothesized that children with visual impairments score lower on Gestalt Closure performance than age-matched American controls and that gaze fixation duration on visual elements of the Gestalt (area of interest) in children at risk of CVI is longer than in children with OVI.

METHODS

Participants

For this study, a database was used that consisted of 122 clients of a rehabilitation centre for visually impaired and blind people. The experimental procedures were approved by the local Medical Ethical Committee (MEC 2012-097) and adhered to the tenets of the declaration of Helsinki (2013). The parents of all children gave written informed consent. Of the total cohort of 122 patients, 72 patients underwent the Gestalt Closure test. The remaining 51 patients had either a developmental level below 3 years old, or the task was not performed due to a time limitation. The chronological age of the selected patients (42 male, 30 female) ranged from 4y6m to 13y8m (M = 9y8m, SD = 2y5m). Four patients had syndromes: one CHARGE-syndrome, one Down syndrome, one Noonan syndrome, one Sotos syndrome. Forty-four (60%) had nystagmus as main diagnosis or as a symptom of another diagnosis, like albinism. Based on the information in the medical records about ocular abnormalities, brain damage, presence of paresis and visual diagnosis, the children were divided in three different groups: ocular visual impairments (OVI), ocular and cerebral visual impairment (OCVI) or cerebral visual impairments (CVI).

Group 1: Ocular visual impairment (OVI)

Of the 72 patients, 38 (23 males, 15 females) were included in group 1. Twenty-three patients had iris or retinal abnormalities: iris coloboma (n = 1); aniridia combined with lens luxation and glaucoma (n = 1); uveitis and retinopathy of prematurity (ROP; n = 1); ocular or oculocutaneous albinism (n = 10); cone/rod dysfunction (n = 6); CMV retinitis (n = 1); retinitis pigmentosa (n = 1); retinoschisis (n = 1). Ten patients had lens abnormalities: hypermetropia (n = 2); high myopia (n = 2); cataract (n = 6). Four patients had congenital nystagmus and the cause of visual problems was unknown in two patients. A total of twenty-three patients had nystagmus, twelve patients had strabismus and twenty-one wore glasses. Visual acuity ranged from 0.05 to 0.80 (Snellen equivalent). Thirty-one patients had a visual acuity equal to or lower than 0.3 (cut-off for low vision), of whom eight could be considered

legally blind (visual acuity ≤0.1). Of the remaining seven patients six had a subnormal visual acuity (< 0.8) and one had a normal visual acuity (≥ 0.8). Behavioural problems were mentioned in nine patients: 3 had no diagnosis, one had an autism spectrum disorder (ASD), two had attention deficit hyperactivity disorder (ADHD), one had ASD and ADHD, one had ADHD and oppositional defiant disorder (ODD), one had an attachment disorder. In eleven patients no estimation of the cognitive level was present. Of the remaining patients three had a mild cognitive impairment (50 < TIQ < 70), four functioned at a borderline cognitive level (70 < TIQ < 89), six at a below average level (70 < TIQ < 89) and seven at an average level (TIQ ≥ 90). The chronological age of the OVI group ranged from 4y8m to 13y7m (*M* = 9y9m, *SD* = 2y5m).

Group 2: Ocular and cerebral visual impairment (OCVI)

Fourteen patients (7 males, 7 females) were included in group 2. Eight had ocular abnormalities and brain damage. Six had no brain damage but were included based on the clinical signs and diagnosis of CVI, in the addition to the presence of ocular abnormalities. In Table 1 the etiological categories for the brain damage and the distribution of cognitive level of the CVI and OCVI group are presented. Present ocular abnormalities were: nystagmus (*n* = 7); myopia (*n* = 1); ocular albinism (*n* = 2); optic nerve atrophy (*n* = 1); cataract (*n* = 1) and retinitis pigmentosa (*n* = 2). Seven children had strabismus and eleven wore glasses. Visual acuity ranged from 0.10 to 0.60. Ten were visually impaired (visual acuity: ≤ 0.3), one could be considered legally blind (visual acuity: ≤ 0.1). The other four had a subnormal visual acuity. The (estimated) level of cognitive functioning ranged from a mild intellectual disability (50 < TIQ < 70) to an average level (90 < TIQ < 110). Behavioural problems were mentioned in four patients: one had no diagnosis, three had ADHD. The chronological age of the OCVI group ranged from 5y11m to 13y7m (*M* = 9y6m, *SD* = 2y7m).

Group 3: Cerebral visual impairment (CVI)

Twenty patients (12 males, 8 females) were included in group 3. Some patients had multiple causes. Two patients had no objectified brain damage but were included based on the clinical diagnosis of CVI, one patient had a developmental coordination disorder (DCD) and in two patients a paresis was present, suggesting the presence of some type of brain dysfunction or damage. Of the patients with dysgenesis of the brain one patient had septo-optic dysplasia, a condition characterized by the underdevelopment of the optic nerve and the absence of the septum pellucidum (midbrain structure); one had Arnold-

Table 1. Aetiology of brain damage and estimated cognitive levels in children in the groups OCVI (*n* = 14) and CVI (*n* = 20).

	OCVI	CVI
	***n* (%)**	***n* (%)**
Aetiology of brain damage		
No imaging data	6 (43)	5 (24)
Perinatal	8 (57)	12 (57)
Asphyxia	3 (21)	3 (15)
Hypoxic-ischemic encephalopathy (HIE)[a]	2 (14)	6 (30)
Dysgenesis/agenesis	2 (14)	2 (10)
Postnatal brain damage		
Acquired brain damage[b]	-	4 (20)
Peri- and/or postnatal		
Hydrocephalus	-	1 (5)
Mild atrophy	1 (7)	-
Estimated cognitive level		
Average (TIQ ≥ 90)	4 (29)	4 (20)
Below average (70 < TIQ < 89)	2 (14)	6 (30)
Borderline (70 < TIQ < 89)	4 (29)	3 (15)
Mild impairment (50 < TIQ < 70)	2 (14)	4 (20)
Moderate impairment (TIQ < 50)	-	2 (10)
No data	2 (14)	1 (5)

[a] Hypoxic-ischemic encephalopathy (HIE) includes different categories for perinatal brain damage, i.e. Periventricular leukomalacia (PVL), Intraventricular haemorrhage (IVH), Cerebral Vascular Accident (CVA) or combinations of these categories; [b] Acquired brain damage consists of different categories, i.e. CVA, meningitis and tumour.

Chiari malformation, a condition of characterized by the malformation of the cerebellum and/or brainstem. One patient had iris coloboma, as a symptom of the CHARGE syndrome combined with hydrocephalus, and one patient had a cone dysfunction.

Eight patients had nystagmus, fourteen had strabismus and eight wore glasses. Visual acuity ranged from 0.05 to 1.00. Ten were visually impaired (visual acuity ≤0.3), of whom three could be considered legally blind (visual acuity ≤ 0.1). Of the remaining ten patients six had a subnormal visual acuity (visual acuity < 0.8). Behavioural problems were mentioned in five patients: four had no diagnosis, one of them had ASD. The (estimated) level of cognitive functioning ranged from a moderate intellectual disability (TIQ < 50) to an average level (90 < TIQ < 110) and cognitive level was unknown in one patient. The chronological age of the CVI group ranged from 4y6m to 13y10m (*M* = 9y8m, *SD* = 2y5m).

The mean age and the distribution of visual acuity levels of the three different groups did not differ significantly. The distributions of the estimated cognitive level did significantly differ ($\chi^2(2) = 11.29$, $p < .01$) between groups: post-hoc analyses showed a higher mean cognitive level of the OVI group than of the two other groups.

Procedures

The subtest Gestalt Closure of the Kaufman Assessment Battery for children second edition (KABC-II) consisted of one example item and 37 tests items of increasing difficulty.[12] The items contained incomplete black figures on a white background and represent 12 animate objects (7 animals including a dinosaur and 5 human faces or activities), and 25 inanimate objects. The normal clinical procedure would be to start with the example item followed by the age appropriate items. Here, we showed all items on a 24-inch monitor with an integrated infrared eye-tracking system (Tobii T60-XL, Tobii Corporation, Sweden). In-between each item, a neutral display was shown with a fixation point to let the child refocus on the centre of the monitor. The system measured gaze position of each eye separately using cornea reflection and compensated for free head movements. Each child sat at approximately 60 cm distance from the monitor. The visual angle towards the monitor was approximately 30x24 degrees (1280 x 1024 pixels). Eye movement responses were recorded with a sampling rate of 60 Hz and the latency of the system was approximately 25 ms. The experiments were conducted in a quiet room with ambient light conditions. Prior to starting the Gestalt Closure test a standardized 5-point calibration procedure of both eyes was performed. Item presentation time was dependent on the child's verbal response, i.e. the examiner pushed the spacebar after the first answer to each item and thereby ended the item presentation. The examiner also noted whether the answer was correct. After 4 consecutive errors the assessment was stopped. All data were stored off-line.

DATA ANALYSIS

Performance data

Firstly, we scored items the standard way, i.e. recognition was either correct or incorrect. The items after discontinuation were assumed to be too difficult and therefore scored as incorrect. Raw scores, i.e. the total correct items up to four consecutive incorrect answers, were noted and the American norm values

for the age group 4-14 years old were used to classify the performances,[12] based on scaled scores (M = 10; SD = 3): scaled scores 1-5 (expected: 9%) = weak; 6-7 = below average (expected: 16%); 8-11 = average (expected: 50%); 12-13 above average (expected: 16%); 14-19 = superior (expected: 9%). Secondly, a simple item analysis was done by calculating the percentage of patients that correctly recognized each item. This way, we were able to check whether items increased in difficulty as reported in the original population. For the analysis of the subgroups, i.e. the animate and inanimate items, we calculated the percentage of correct items with respect to the total number of items presented in that subgroup.

Eye tracking data

Gaze data was analyzed off-line using Tobii Studio 3.2 analysis software (Tobii, Danderyd, Stockholm, Sweden). Patients with at least 40% gaze data measured during the assessment were selected for further analysis to ensure reliability of the eye movement responses. For each stimulus, an area of interest (AOI) was defined that corresponded with the size and the location of the Gestalt item. The eye movement patterns relative to these AOIs were obtained to calculate 1) the mean and total time spent within the AOI and 2) the number of times gaze went in and out of the AOI. A lower mean and/or total time within the AOI might be the result of efficient information processing, i.e. fast recognition, or caused by the presence of nystagmus, attentional problems or a lack of effort.

Statistical analysis

We used IBM SPSS Statistics version 20 for statistical analyses. Non-parametric tests were used, since data were not normally distributed, even not after data transformation. To compare groups with ordinal (number of items shown; scaled scores) and skewed data (percentage correct of presented items), Kruskal Wallis and Mann-Whitney U-tests were used. To test for differences in performance while controlling for differences in cognitive level, we used the partial Spearman correlation test. Binomial tests were used the compare the expected percentage of weak, average and superior performers with the actual percentages found in the patient groups. Finally, an explorative correlation analysis was done between weak overall performance, visual acuity, nystagmus and eye tracker results. p-Values ≤ .05 were considered significant.

RESULTS

The collection of the performance scores of one patient with albinism in the group OVI (n_{OVI} =37, 22 males, 15 females) failed, resulting in a total group of seventy-one tested patients (M_{age}= 9y9m, *SD* = 2y5m; 41 males, 30 females).

Overall performance

Scaled scores

Analysis of the scaled scores showed that the distributions of scores significantly differed across groups ($\chi^2(2) = 8.65$, $p = .01$). The group CVI performed significantly worse (*Mdn* = 2) than the group OVI (*Mdn* = 9; *U* = 197.5, $p < .01$). Compared to the normal distribution of the scaled scores in the norm population, half of the patients in the group CVI performed extremely weak. A scaled score of 5 is expected in 9% of the population, yet, this scaled score of 5 or lower was found in 9/37 (24%) of the OVI patients, 5/14 (36%) of the OCVI patients and 12/20 (60%) CVI patients (*p*s < .01). Despite these weak performances, still 12/37 (32%) of the OVI patients, (7/14) (50% of the OCVI patients and only 12/37 (32%) of the CVI patients performed on an average level ($p = .05$ and $p < .01$). The percentage of patients that performed at a superior level was not higher than expected. The Spearman rho correlations between the patient groups and 1) the scaled item scores (r_s = -.31) and 2) the proportion weak performers (r_s = .32) were significant (*p*s = .02). Controlling for the cognitive level, group differences in scaled scores were only near significant ($r_{s,cognitive\ level}$ = -.25, $p = .07$), but group differences in the proportion of weak performers remained significant ($r_{s,cognitive\ level}$ = .26, $p = .05$). This suggests that the performance of the group CVI remains significantly weaker after correction for differences in cognitive level.

Item scores

The item scores showed a monotone decrease with increasing number of presented items, suggesting that test difficulty increased per presented item (Figure 1). Notably, the percentage correct animate items, especially the animal items, deviated from this general pattern. We found that the animal items were more difficult to recognise or to name than the inanimate items. The most difficult items were the dinosaur (item 7; 44% correct) and the elephant (item 18; 39% correct).

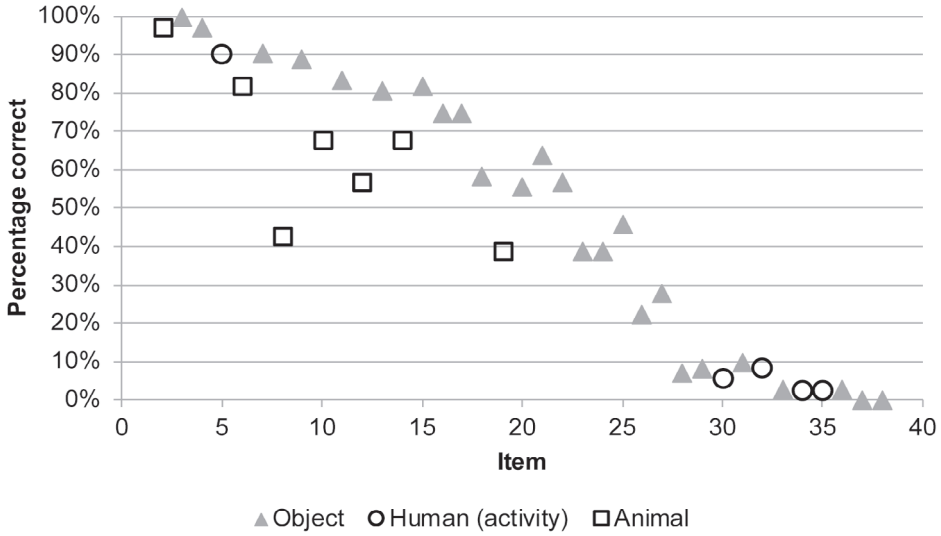

Figure 1. Percentage of correct answers per item-group: inanimate objects and animate objects, human (activity) and animals.

Analysis of the percentage correct answers of the presented items showed that significant differences on performances were indeed present ($\chi^2(2) = 7.28$, $p = .03$), see also Figure 2. The group CVI (*Mdn* = 59.94) performed significantly worse than the group OVI (*Mdn* = 73.33; *U* = 215.0, $p = .01$). The difference between the groups CVI and OCVI (*Mdn* = 67.95) and OCVI and OVI were not significant. Significant negative correlations ($r_s = -.34$, $p = .01$; $r_{s.cognitve\ level} = -.29$, $p = .03$) were found between the percentage correctly recognized items and the patient groups, indicating that cognitive level does not explain the group difference found.

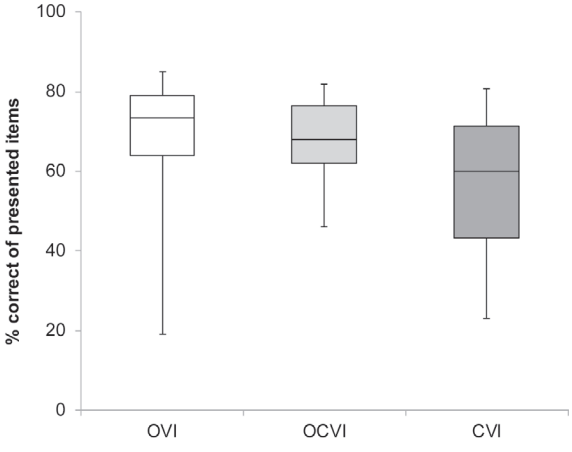

Figure 2. Distribution of percentage correct answers given the number presented items in the different patient groups.

Animate items

Analysis of the number of animate items presented showed that the number of presented animal items differed across groups ($\chi^2(2) = 6.82$, $p = .03$), suggesting differences in performances. In the groups OVI and the OCVI, only 1 patient was presented less than 7 items (the total number of animal items) (OVI: 2 items; OCVI: 5 items). In the group CVI, 7 patients were presented less than 7 items; less than 3 items were presented to 5 patients, less than 5 items to 1 patient and less than 6 items were presented to 3 patients. The number of presented items was significantly different between the groups OVI and the CVI ($U = 290.0$, $p < .01$). Analysis of the percentage correct answers of the presented items showed that significant differences in performances were indeed present ($\chi^2(2) = 13.45$, $p < .01$), see also Figure 3. The groups CVI ($Mdn = 50.00$) and OCVI ($Mdn = 64.29$) performed significantly worse than the group OVI ($Mdn = 85.71$; $U = 171.5$, $p < .01$ and $U = 158.00$, $p = .03$). The difference between the groups CVI and OCVI was not significant. A significant negative correlation ($r_s = -.43$, $p < .01$) was found between the percentage correctly recognized animals and the patient groups. This indicates that children with brain damage tend to perform worse than children without brain damage (OVI) on the animal items. Importantly, this correlation remained significant when controlling for differences in cognitive level ($r_{s.\,cognitve\ level} = -.38$, $p < .01$).

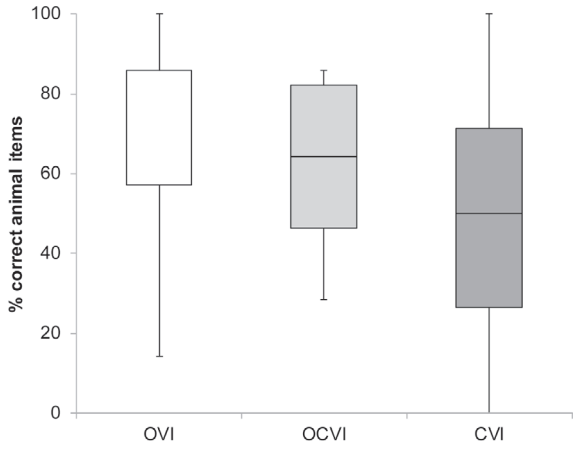

Figure 3. Distribution of percentage correct answers given the number presented animal items (max 7 items) in the different patient groups.

Inanimate items

To test whether the same pattern of group differences was also present in recognising the inanimate items, we first selected 7 inanimate items with approximately the same performance score as the 7 animal items. We selected

item 2, 10, 16, 19, 20, 23 and 24. The median difference in performance between these two item sets was -1% (range -6% to +4%). Thus, compared to the animate items, these selected inanimate items were a bit easier to recognize. Again, the number of presented inanimate items varied from 1 to 7 in the groups OVI an CVI and 2 to 7 in the group OCVI. The distribution of the number of presented inanimate items significantly differed across the groups ($\chi^2(2) = 11.45$, $p < .01$). In the group CVI, a significantly smaller number of items was presented ($Mdn = 5$) than in the group OVI ($Mdn = 7$; $U = 212.5$, $p < .01$). The percentage correct answers, however, to the inanimate items was not significantly different between the groups ($Mdn_{OVI} = 85.71$, $Mdn_{OCVI} = 71.43$ $Mdn_{CVI} = 60.00$; $p = .13$). Correlations between performance and groups were not significant ($r_s = -.21$, $r_{s.cognitve\ level} = -.19$). Thus, children with CVI tend to perform in a similar way as the children with OCVI and OVI on inanimate items.

Gaze patterns

Group characteristics

Of the seventy-two patients forty-five patients had at least 40% gaze data. The group OVI consisted of 20 patients (12 males, 8 females). The chronological age ranged from 5y0m to 13y7m (*M* = 9y10m, *SD* = 2y7m). Thirteen patients had iris or retinal abnormalities: iris coloboma (n = 1); ocular or oculocutaneous albinism (*n* = 9); cone/rod dysfunction (*n* = 2); retinitis pigmentosa (*n* = 1). Three patient had lens abnormalities: high myopia (*n* = 1), Stickler Syndrome); cataract (*n* = 2). Three patients had congenital nystagmus and the cause of visual problems was unknown in one patient. The group included 4 patients with a weak performance on the Gestalt test.

The group OCVI consisted of 11 patients (5 males, 6 females). The chronological age ranged from 6y5m to 13y7m (*M* = 9y7m, *SD* = 2y8m). Aetiology of brain damage was: asphyxia (*n* = 3), dysgenesis (*n* = 1), periventricular leukomalacia (*n* = 1), intraventricular haemorrhage (*n* = 1), atrophy (*n* = 1). Imaging data was not available for four patients. Present ocular abnormalities were: nystagmus (*n* = 5); ocular albinism (*n* = 2); optic nerve atrophy (*n* = 1); and retinitis pigmentosa (*n* = 2), unknown (*n* = 1). The group included 3 patients with a weak performance on the Gestalt test.

The group CVI consisted of 14 patients (10 males, 4 females). The chronological age ranged from 4y6m to 13y10m (*M* = 10y2m, *SD* = 2y6m). Aetiology of brain damage was: asphyxia (*n* = 3), Arnold-Chiari malformation (*n* = 1), periventricular leukomalacia (*n* = 2), cerebral vascular incident (*n* = 3),

tumour (*n* = 1). No imaging data was present in four patients. This group included 8 patients with a weak performance on the Gestalt test.

The mean age and the estimated cognitive level of the three different groups did not differ significantly, see Table 2. Group differences were present in the distributions of the visual acuity ($\chi^2(2) = 7.27$, $p = .03$) and nystagmus ($\chi^2(2) = 12.22$, $p < .01$). Post-hoc analyses showed a higher visual acuity and fewer patients with nystagmus in the group CVI than of the two other groups (*p*s ≤.02). Visual acuity in the groups OVI and OCVI were considered comparable.

Table 2. Group characteristics of children with at least 40% gaze data in the groups OVI (n = 20), OCVI (n = 11) and CVI (n = 14).

	OVI	OCVI	CVI	
Characteristic	***n* (%)**	***n* (%)**	***n* (%)**	***p*-value**
Glasses	9 (45)	8 (73)	6 (43)	
Strabismus	7 (35)	4 (36)	10 (71)	.09, *ns*
Nystagmus	15 (75)	11 (100)	5 (36)	<.01
Visual acuity				.03
≥ 0.8	1 (5)		4 (29)	
0.5-0.8	4 (20)		3 (21)	
0.4-0.5		3 (27)	3 (21)	
≤ 0.3	15 (75)	8 (73)	4 (29)	
Cognitive level				.07, *ns*
Average (TIQ ≥ 90)	7 (35)	4 (36)	1 (7)	
Below average (70 < TIQ < 89)	2 (10)	1 (9)	4 (29)	
Borderline (70 < TIQ < 89)	3 (15)	3 (27)	3 (21)	
Mild impairment (50 < TIQ < 70)	2 (10)	1 (9)	3 (21)	
Moderate impairment (TIQ < 50)			2 (14)	
No data	6 (30)	2 (18)	1 (7)	

p-values < .05 indicate statistically significant group differences

Item characteristics

In one CVI patient, no eye tracking data was available during the presentation of the 7 animal and 7 selected inanimate items. In the remaining group of 44 patients, eye tracking data during the presentation of the animal items was present for at least 4 items in 20/20 OVI patient, 11/11 OCVI patients and 11/13 CVI patients. To control for individual differences in the number of items, we used mean individual outcomes for group comparisons. Overall, no significant group differences on the number of visits and the median visit duration of each visit within the area of interest (AOI) were found, but we did find a significant difference in the total visit duration ($\chi^2(2) = 6.38$, $p = .04$), see Table 3. This indicates that children with CVI tend to need more time

to analyse the Gestalt to formulate an answer. Analysis of individual animal items showed that children with CVI tend to be a bit slower on 6 of 7 items, but differences were not significant. Of the 7 selected inanimate items, eye tracking data of at least 4 items were available in 20/20 OVI patients, 10/11 OCVI patients and 12/13 CVI patients. Here, no significant group differences were found, see Table 4.

Finally, explorative correlation analyses were done between weak overall performance, visual acuity, nystagmus and eye tracker results of the animal items within the patient groups. The correlations between weak overall performance, visual acuity and nystagmus were not significant, except the correlation between weak overall performance and visual acuity in the group CVI (r_s = -.63, p = .02). This suggest that weak performers within the group CVI have lower visual acuities. Within the group OVI we found that the weak performers tend to stay shorter within the AOI (r_s = -.52, p = .02), children with lower visual acuity visit the AOI more often (r_s = -.59, p < .01), children with higher visual acuity seem to stay longer within the AOI (r_s = .43, p = .06) and children with nystagmus need in total more time to analyse and respond (r_s = .47, p = .03). Within the group CVI we found that weak performers tend to visit the AOI more often (r_s = .63, p = .03), and need in total more time to analyse and give a response (r_s = .72, p < .01). This indicates that weak score of these children was not the result of a lack of effort.

Table 3. Outcomes of eye tracking data (number of visits of area of interest, median visit duration and total visit duration) on animal items in the groups OVI (n = 20), OCVI (n = 11) and CVI (n = 13).

	OVI	**OCVI**	**CVI**	***p*-value**
Mean				
# visits AOI	7 (1-33)	10 (3-15)	6 (2-28)	*ns*
Median visit duration	0.7 (0.1-3.4)	0.7 (0.1-3.3)	1.3 (0.1-4.7)	*ns*
Total visit duration	3.7 (1.0-6.7)	3.8 (0.5-12.0)	8.4 (0.2-14.4)	*.04*
Butterfly				
n	20	11	11	
# visits AOI	4 (1-15)	2 (1-12)	3 (1-13)	*ns*
Median visit duration	0.4 (0.1-3.5)	1.3 (0.1-3.6)	1.2 (0.2-6.1)	*ns*
Total visit duration	2.4 (0.1-3.5)	2.2 (0.1-5.2)	2.7 (0.8-13.1)	*ns*
Dog				
n	20	11	13	
# visits AOI	3 (1-19)	2 (1-11)	2 (1-22)	*ns*
Median visit duration	1.0 (0.1-3.5)	0.6 (0.1-3.4)	1.7 (0.1-5.6)	*ns*
Total visit duration	2.6 (0.7-7.0)	2.4 (0.1-4.4)	3.0 (0.1-20.7)	*ns*

Table 3. Outcomes of eye tracking data (number of visits of area of interest, median visit duration and total visit duration) on animal items in the groups OVI (*n* = 20), OCVI (*n* = 11) and CVI (*n* = 13). (continued)

	OVI	OCVI	CVI	*p*-value
Dinosaur				
n	20	11	12	
# visits AOI	8 (1-47)	7 (1-25)	5 (1-63)	*ns*
Median visit duration	0.7 (0.1-6.2)	0.8 (0.1-11.8)	2.4 (0.3-7.2)	*.08*
Total visit duration	5.1 (1.8-26.6)	5.5 (0.6-11.8)	6.1 (1.6-30.2)	*ns*
Fish				
n	20	10	10	
# visits AOI	3.0 (1-90)	5.5 (1-24)	7.0 (1-44)	*ns*
Median visit duration	0.7 (0.1-4.4)	1.0 (0.1-3.2)	0.80 (0.3-6.4)	*ns*
Total visit duration	2.8 (0.1-7.6)	2.9 (0.1-22.5)	6.35 (1.18-19.96)	*ns*
Turtle				
n	20	10	12	
# visits AOI	10 (1-13)	10 (4-34)	8.5 (1-27)	*ns*
Median visit duration	0.4 (0.1-4.0)	0.3 (0.1-6.0)	0.8 (0.1-7.0)	*ns*
Total visit duration	3.2 (0.4-17.6)	5.6 (1.4-24.2)	5.3 (0.5-29.0)	*.10*
Pig				
n	19	10	10	
# visits AOI	7.0 (1-29)	4.0 (1-17)	4.0 (1-12)	*ns*
Median visit duration	0.3 (0.1-3.8)	0.6 (0.1-4.2)	1.6 (0.3-9.0)	*.03*
Total visit duration	2.6 (0.1-7.4)	2.9 (0.1-23.0)	4.0 (1.9-18.0)	*.12*
Elephant				
n	20	10	9	
# visits AOI	7 (2-44)	15 (2-35)	5 (1-94)	*ns*
Median visit duration	0.4 (0.1-1.1)	0.3 (0.1-1.2)	0.6 (0.2-3.6)	*.03*
Total visit duration	3.4 (0.1-6.7)	5.0 (0.1-16.3)	5.6 (1.0-43.0)	*ns*

AOI = area of interest. *p*-values indicate statistically significant differences in eye tracking parameters between patient groups.

Table 4. Outcomes of eye tracking data (number of visits of area of interest, median visit duration and total visit duration) of the seven selected object items in the groups OVI (*n* = 20), OCVI (*n* = 11) and CVI (*n* = 12).

	OVI	OCVI	CVI	*p*-value
Mean				
# visits AOI	6 (1-34)	5 (2-13)	6 (2-19)	*ns*
Median visit duration	1.0 (0.2-5.0)	1.3 (0.1-2.6)	1.3 (0.1-4.2)	*ns*
Total visit duration	3.0 (0.8-7.8)	4.2 (0.6-5.9)	4.7 (1.0-14.8)	*ns*

AOI = area of interest. *p*-values indicate statistically significant differences in eye tracking parameters between patient groups.

DISCUSSION

Neuropsychological assessment in children often includes subtests that examine the ability to integrate visual elements into a (meaningful) whole, i.e. perceive gestalts. This is the first study to address Gestalt perception in visually impaired children. This study about performances and looking behaviour on a Gestalt Closure test (KABC-II) in groups of children with visual impairments, i.e. children with brain damage or clinical signs of cerebral visual impairment (CVI), children with ocular abnormalities and brain damage (OCVI) and children ocular abnormalities (OVI), shows that children with visual impairments more often performed weak than age-matched controls of the American norm population, and that children with brain damage performed worse than children without brain damage. The proportion of weak performers in the groups CVI (60%) and OCVI (36%) was significantly higher than that in the group OVI (24%). Differences remained significant even after controlling for differences in cognitive level. Eye movement patterns revealed that weak performance on animate items in the CVI group was associated with longer fixations and more re-fixations.

Literature on Gestalt performance in children, including fragmented picture recognition, hierarchical figures and embedded figures, covers many conditions, such as autism spectrum disorder (ASD),[13] schizophrenia[14, 15] and intellectual disability syndromes.[16] These reports may provide insights into mechanisms and networks underlying our current results. For example, our finding that children with a (partly) cerebral cause for their visual impairment more often perform weak on Gestalt Closure is related to findings in children with brain damage in general, who were found to have worse visuomotor Gestalt performance (i.e. Bender Gestalt test) than children without brain damage.[17] More specific, PVL is an important underlying cause of CVI in children, and children with PVL showed poor results on a Closure subtest of a visual perception battery.[18]

Neuroimaging studies showed that performance in visual closure tasks is associated with activity in object-related processing areas, including the lateral occipital cortex and inferior temporal areas.[19, 20] For example, patients' impaired perceptual closure performance was associated with a diminished closure-related ERP negativity, of which the neural source has been attributed to visual association areas.[21] Furthermore, two studies on Gestalt perception in schizophrenia patients showed a relation of reduced neural connectivity in visual cortical areas and impaired perceptual closure. Although no studies about Gestalt performance in visually impaired children could be found, one

study showed that early visual deprivation in patients with congenital cataract aged 9-23 years was related to impairments in holistic (face) processing. [22] Our current results in a more general population of children with visual impairments confirms that in children who have experienced some sort of visual deprivation early in life, holistic visual processing in general seems to be affected.

Notably, children with brain damage (groups CVI and OCVI) performed significantly worse on the animate items than the group without brain damage (OVI). Differences between groups on the inanimate items were smaller and non-significant, suggesting that the overall difference can mainly be attributed to the weak performance on the animal items. The gaze data collected with the eye tracker reveals that the CVI children with weak performances fixate these Gestalt items longer and even re-fixate them more often. This suggests that this difference in performance may not attributed to a lack of effort. Further analysis on the 7 animal items, items earlier in the test than the 7 selected object items but with a comparable difficulty level, shows that weak performers within the group OVI spend less time within the area of interest (AOI) per visit. There was no relation with visual acuity or nystagmus, which suggests there is another reason why they perform weak. Maybe children with OVI have learned other strategies, for example to guess more often to save time and energy or to perform as fast as children without a visual impairment. In order to study this hypothesis a control group should be added, and reaction times and performances should be compared.

It has been shown that processing of either animate or inanimate pictures can be selectively impaired in patients with damage to anterior visual areas. [23-25] More recently, fMRI studies found clusters of voxel population vectors that were associated with animate and inanimate categories located anterior to retinotopic visual areas.[26, 27] However, in these studies, images of hundreds of well-defined objects were presented to the subjects. In the present study, visual processing of each item involved perceptually grouping of closely projected elements to visualize a complete object, even when presented incomplete information. To our surprise, we found a significantly worse performance for naming the animate items in children with confirmed or suspected brain damage. We could not find any support for our finding in literature. At this point, we do not know if the differences we found between animate and inanimate object recognition in children with cerebral visual impairments are related to possible damage to the associated processing areas in the brain, e.g. the occipital face area (OFA) and the extra-striate body area (EBA).[26]

The available imaging data lack the detailed information that is required to obtain insight in these specific regions.

This study has some limitations that need to be addressed. Firstly, the Kaufman Gestalt closure task contains a fixed number of 37 items. We applied the classic stopping rule, i.e. we stopped testing, when a subject gave 4 consecutive incorrect answers. As a result, the total number of tested items was different between the subjects. For the between group comparisons per item, we were able to control for this by calculating the correct items with respect to the total number of items presented within each subject. The comparison of the performance scores between the animate and inanimate items, however, inevitably led to two different subgroups of patients. Secondly, in a majority of the patients, only the global cognitive functioning was scored using total IQ. We are aware of the fact that more exact data on verbal and non-verbal IQ is preferable to control for differences in developmental level between groups. Thirdly, the performance of the children in the present study was compared with American norm group. We did investigate any cultural differences. Some of the items were typical American illustrations, such as a land map of the US. These items were not judged too strictly – and were not selected for further item analysis. Fourthly, we did not check after the Gestalt closure test whether children could name standard drawings of the same objects. Especially for the animate items, this would have been a valuable control condition. Lastly, the size of the area of interest dependent on the size of the Gestalt closure item. As a result, some AOI's were larger than others but not more than ~20%. Presumably, this had some influence on the number of re-fixations, especially for the small Gestalt closure items. In addition, we attempted to investigate whether a subject fixated the different elements within the Gestalt closure item to create an overview or that this was obtained with one central fixation. Due to the variability in gaze behaviour, we were not able to find a consistent pattern. In a future study, we would like to address this question using a fixed set of Gestalt closure items of equal sizes and a higher resolution eye tracker. Lastly, the quality of each eye tracking study depends on the quality of the recorded gaze patterns. In our group, 45 of the 72 patients (63%) had at least 40% valid gaze data. In the present study, the investigator was able to keep track of the gaze tracking quality. Still, we applied this rather strict criterion because we needed good continues gaze tracking data during item presentation to be able to calculate the presented gaze parameters.

In the present study we presented data on Gestalt perception performance in combination with looking behaviour in visually impaired children. Further research is necessary to address causality of the results: did a different way

of looking result in worse perceptual performance, or did poor perception lead to a different looking pattern? We would like to stress that the analysis of eye movement patterns during perception tasks adds value for the visual testing of 'non-verbal children' and may provide a link to later visual training.

CONCLUSIONS

This study showed that children with visual impairments more often performed weak on the Kaufman Gestalt closure task than chronologically age-matched controls, and that children with brain damage performed worse than children without brain damage. Notably, children with brain damage (groups CVI and OCVI) performed significantly worse on the animate items than the group without brain damage (OVI). Based on the looking patterns obtained with the eye tracker, we can conclude that weak Gestalt performance of the children in the CVI group is not the result of intellectual disability or a lack of effort, but instead seems a pure perceptual dysfunction.

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