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Development of the Parental Questionnaire for Cerebral Visual Impairment in Children Younger than 72 Months

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Background and Purpose Cerebral visual impairment (CVI) is an underdiagnosed condition in children, and its assessment tools have focused on older children. We aimed to develop a parental questionnaire for cerebral visual impairment (PQCVI) for screening CVI in young children.

Methods The PQCVI comprised 23 questions based on a modified version of Houliston and Dutton's questionnaire for older children. The PQCVI with neurocognitive function tests was applied to 201 child–parent pairs with typically developing children younger than 72 months (age 32.4±20.1 months, mean±standard deviation). The children were classified into six age groups. The normative data, cutoff scores, and internal reliability were assessed and item analysis was performed. We referred to the total score for all questions as the cerebral visual function (CVF) score.

Results The normative data showed that the CVF score and the scores corresponding to ventral-stream and dorsal-stream visual functions plausibly increased with age. The scores rapidly reached 90% of their maximum values up to the age of 36 months, after which they increased slowly. Cronbach's alpha for all questions across all age groups was 0.97, showing excellent consistency. The item difficulty and item discrimination coefficients showed that the questions were generally adequate for this age stage.

Conclusions The PQCVI items produced reliable responses in children younger than 72 months. The rapid increase in scores before the age of 3 years supports the importance of early identification of CVI. Following additional clinical verification, the PQCVI may be useful for CVI screening.

Key Words vision disorders, development, neurodevelopmental disorders, preschool children, early diagnosis.

INTRODUCTION

Cerebral visual impairment (CVI) encompasses various conditions related to problems in higher-order visual processing caused by injury to the retrogeniculate pathways and brain structures.[1,2] Children with cerebral or cortical visual problems have difficulties in recognizing people, objects, depth, and movement, simultaneous perception, orientation and navigation, and in performing visual field tests.[1,3,4] Problems with higher visual functions may be outstanding or unnoticed, and may lead to the underdevelopment of motor coordination and cognitive abilities, possibly even affecting socioemotional development.[5,6] Thus, early detection and intervention of CVI is important for preventing negative consequences.

There are various causes of CVI, including periventricular leukomalacia (PVL) or hypoxic ischemic encephalopathy in premature infants, hydrocephalus, meningoencephalitis, trauma, and genetic disorders. CVI is an important cause of visual impairment in children with

various disabilities. It is found in 40–50% of children with cerebral palsy and in 21–47% of children born prematurely.[7] CVI may exist in patients without organic disease and with normal brain imaging findings.[8,9]

CVI remains an underdiagnosed condition in children. Routine eye examinations and cognitive function tests might not detect abnormalities in higher visual functions. Undiagnosed patients may be considered clumsy and have delayed visuospatial learning. Therefore, CVI-specific screening tools for the early detection of such children are required.[5,8]

Typical currently used diagnostic tools for visuospatial disability in children and adults are the Developmental Test of Visual Perception (DTVP), Beery–Buktenica Developmental Test of Visual–Motor Integration (Beery VMI), and Motor-Free Visual Perception Test (MVPT). Most tests require the motor performance of patients (DTVP and VMI) and are aimed at subjects older than 4 years (DTVP and MVPT). The scores on these tests may be more affected by general intelligence than pure visual perception ability. Considering that it is not easy to examine young children, structural interviews of parents or caregivers who observe children over a long time can also be helpful.

There are few CVI-specific tests for younger children. The ABCDEFV (A test Battery of Child Development for Examining Functional Vision) for children aged 0–36 months and computerized assessment tools for visual perception deficits in preschool children, such as the L94 and CVIT 3-6 (Children's Visual Impairment Test for 3- to 6-year-olds), are used both clinically and in research.[9-12] For clinical ease of use, shortened screening tools such as Five Questions, CVI Inventory, and CVI Questionnaire have been developed.[13-15] These are parental questionnaires with adequate reliability and validity, but the target age of most surveys is over 5 years, and the available normative data are insufficient.

In Korea, the National Health Screening Program for Infants and Children (NHSPIC) of the National Health Insurance Service provides a periodic health screening program for children younger than 72 months from across the country.[16] Although the national birth rate is decreasing in Korea, the survival rate of low-birthweight infants has increased more than tenfold since the 1960s.[17] For children who have a high risk of developing CVI, such as those with PVL caused by prematurity or cerebral palsy, additional screening for CVI could be helpful in its early detection.[18-20]

With this background, a taskforce of the Korean Child Neurology Society (KCNS) was convened to develop a CVI screening tool for use in children younger than 72 months. The taskforce developed a parental questionnaire for cerebral visual impairment (PQCVI) based on Houliston and Dutton's questionnaire that was previously developed for cognitive visual problems in children with hydrocephalus.[14] In the present study, the newly developed PQCVI was administered to children with typical development who were younger than 72 months. The normative data, cutoff scores, internal reliability, and item analysis of the PQCVI were assessed.

METHODS

Development of the PQCVI

The KCNS taskforce for the development of a CVI screening tool had met periodically and critically reviewed the original questionnaire. The important considerations addressed in the reviews were whether the tool was appropriate for evaluating CVI in young children and the cultural suitability of the questions. The original questionnaire used in Houliston and Dutton's research was targeted at children aged 5–12 years.[14] The KCNS taskforce sorted the questions by age and modified them for use in infants and younger children, which resulted in the questionnaire being modified to 23 questions. Some questions were combined (e.g., questions 10 and 11, and 13 and 14 of Houliston and Dutton's study were combined into questions 12 and 23, respectively, of our study) or split (from question 17 of Houliston and Dutton's study were split into questions 3 and 8 of our study).[14] New questions for younger children were added (questions 6 and 7 of our study). The final version used in the present study was written in Korean.

Table 1 lists the PQCVI questions translated into English in the order from that with the highest mean score to the lowest mean score. Nine questions (questions 1, 4, 5, 10, 11, 13, and 19–21) were assumed to mainly reflect ventral-stream function, and 13 questions (questions 2, 3, 6–8, 12, 14–18, 22, and 23) were assumed to mainly reflect dorsal-stream function. Question 9 was related to binocular vision.

Parents were asked to choose an answer for each question that corresponded to their child's behavior on the following scale: never, 1; occasionally, 2; most of the time, 3; always, 4; and don't know, 5. Each answer from 1 to 4 was scored as the corresponding points, while answer 5 ("don't know") was excluded from the scoring. We designated the total score for the 23 questions as the cerebral visual function (CVF) score in this questionnaire (range, 23–92). The scores for 9 questions related to ventral-stream cerebral visual function (vCVF) (range, 9–36) and 13 questions related to dorsal-stream cerebral visual function (dCVF) (range, 13–52) were analyzed separately.

Subjects

The PQCVI was developed and then administered to subjects from December 2016 to March 2018. Volunteer child–parent pairs who visited for the NHSPIC were enrolled. They were

Table 1. Parental questionnaire for cerebral visual impairment (PQCVI)

The questions below are related to the visual perception-related behavior of your child. Read these questions and choose the best answer for your child: never, 1; occasionally, 2; most of the time, 3; always, 4; or don't know, 5. The items in this list are ordered from the highest to the lowest mean score.	
Question	**Answer**
1. Does your child recognize mother/father' face before you speak?	(1) (2) (3) (4) (5)
2. Does your child reach out and grasp objects?	(1) (2) (3) (4) (5)
3. Is your child able to see slow-moving objects (e.g., a rolling ball)?	(1) (2) (3) (4) (5)
4. Does your child recognize the faces of other family members?	(1) (2) (3) (4) (5)
5. Does your child recognize familiar objects (e.g., cup, shoes, or doll)?	(1) (2) (3) (4) (5)
6. Does your child find objects covered by a blanket or paper?	(1) (2) (3) (4) (5)
7. Does your child pick up a small object with their thumb and index finger?	(1) (2) (3) (4) (5)
8. Is your child able to see fast-moving objects (e.g., a moving car)?	(1) (2) (3) (4) (5)
9. Does your child eat food from parts of a large plate rather than only from one part?	(1) (2) (3) (4) (5)
10. Does your child recognize other people in photographs?	(1) (2) (3) (4) (5)
11. Does your child recognize themself in photographs?	(1) (2) (3) (4) (5)
12. Does your child find their way well to rooms or the toilet at home?	(1) (2) (3) (4) (5)
13. Does your child recognize friends' faces?	(1) (2) (3) (4) (5)
14. Can your child easily find their way to doorways or along corridors?	(1) (2) (3) (4) (5)
15. Does your child judge the height of steps without missing their footing?	(1) (2) (3) (4) (5)
16. Does your child recognize objects when they themselves are moving quickly?	(1) (2) (3) (4) (5)
17. Can your child find objects on a blanket with a complex pattern?	(1) (2) (3) (4) (5)
18. Does your child remember well where they put things at home?	(1) (2) (3) (4) (5)
19. Can your child differentiate shapes (e.g., triangles, rectangles, and circles)?	(1) (2) (3) (4) (5)
20. Can your child gather or match colors?	(1) (2) (3) (4) (5)
21. Can your child name colors?	(1) (2) (3) (4) (5)
22. Can your child find objects in a complex picture?	(1) (2) (3) (4) (5)
23. Does your child easily find their way in new surroundings?	(1) (2) (3) (4) (5)

recruited from 11 hospitals across the country. The inclusion criteria were children younger than 72 months within the normal development ranges on the Korean Developmental Screening Test (K-DST) for infants and children, and having normal visual acuity in vision screening.[21] The exclusion criteria were children already diagnosed with a neurodevelopmental disorder, development quotient (DQ) <70 or intelligence quotient (IQ) <70, or ophthalmological, visuospatial, hearing, or motor problems, or other disabilities. The subjects were divided into six age groups: 1) <12 months, 2) 12–23 months, 3) 24–35 months, 4) 36–47 months, 5) 48–59 months, and 6) 60–71 months. All research protocols were approved by the Institutional Review Board of Ilsan Hospital (NHIMC 2017-05-004). Written informed consent was obtained from parents for both themselves and on behalf of their children.

Administration of PQCVI and neuropsychological tests

The PQCVI and developmental screening using the K-DST were administered to all of the included children. DQ and IQ were determined using the Korean version of Bayley Scales of Infant Development-II (age <42 months), the Korean version of the Wechsler Preschool and Primary Scale of Intelligence (K-WPPSI), and K-WPPSI-IV (age ≥42 months). K-Beery VMI-6 (age 30–48 months) and K-DTVP-II (age ≥48 months) were applied to assess visuospatial function. The subjects with abnormal results on K-DTVP-II or K- Beery VMI-6, a visuospatial index (VSI) of <70 on K-WPPSI-IV, or statistically significant differences in verbal IQ (VIQ) and performance IQ (PIQ) on the K-WPPSI test (VIQ exceeding PIQ by >12, and PIQ <90) were excluded from the analysis due to the likely presence of visuospatial dysfunction. All neuropsychological tests were conducted by child psychologists at each hospital.

Statistical analyses

Demographic and normative data for the study population are presented as mean±standard deviation (SD) values for continuous variables and as frequencies with percentages for categorical variables. Normative outcomes were compared between age groups using the Kruskal–Wallis test, and Bonferroni correction was applied to the post-hoc comparison. Cutoffs for the CVI scores were obtained by estimating the scores corresponding to mean minus 2 SDs and mean minus

1 SD for each age group. As a measure of the item internal consistency, Cronbach's alpha for items was calculated according to the range of ages.

The item response theory (IRT) was adapted to measure the reliability of the questionnaire.[22,23] For each item, the unique item characteristic curve (ICC), which represents the probability of answering correctly according to the subject's ability, was constructed for all age groups together and for each age group separately. The ICC of an item was analyzed to estimate the item difficulty coefficient (β) and the item discrimination coefficient (α). β measures the difficulty of an item, and it generally ranges from -2 to +2, with a larger value indicating that the item is more difficult. α measures the discrimination capability of an item, and it generally ranges from 0 to +2, with a larger value indicating that the item has a better discrimination capability.

The IRT analysis was conducted using R software (version 3.4.0, R Foundation for Statistical Computing, Vienna, Austria), while all other statistical analyses were performed using the Statistical Package for the Social Sciences (version 24.0, IBM Corp., Armonk, NY, USA). All p values <0.05 were considered statistically significant.

RESULTS

Subject characteristics

Initially 205 children were enrolled. Four children were excluded because they did not meet the inclusion criteria (VSI on K-WPPSI-IV of 67 in one child, VIQ and PIQ mismatch of >12 with PIQ <90 on K-WPPSI in two children, and K-Beery VMI score <70 on K-DTVP-II in one child). Finally, the data of 201 children aged 32.4±20.1 months (89 males and 112 females) were analyzed. Detailed demographic data and neurocognitive function test results are presented in Table 2, Supplementary Table 1 (in the online-only Data Supplement).

Normative data

The scores for each of the 23 questions and the CVF scores according to age group are listed in Table 3. The CVF scores increased with the children's age, being 41.2±10.5, 66.2±14.3, 85.1±5.0, 87.2±5.5, 89.8±2.7, and 89.1±2.9 in Groups A–F, respectively, and 74.0±20.2 for all subjects. The mean CVF scores increased rapidly from Group A to Group C, approaching 90% of their maximum values (Fig. 1A, Table 3). The mean CVF score was highest in Group E, which was higher than Group F, but the difference was not statistically significant. The mean CVF score differed significantly between age groups in the overall test (p<0.001). Post-hoc analysis showed significant increases from Group A to Group B (p<0.001) and from Group B to Group C (p=0.001) (Fig. 1B).

Table 2. Demographic data of the subjects

Age group	Age range, months	Number of subjects	Sex (male:female)	Age, months (mean±SD)
A	<12	38	18:20	7.7±2.2
B	12–23	46	19:27	17.0±3.4
C	24–35	31	11:20	29.0±3.2
D	36–47	29	17:12	41.1±4.0
E	48–59	29	14:15	52.8±3.5
F	60–71	28	10:18	65.1±3.2
Total	≤71	201	89:112	32.4±20.1

SD: standard deviation.

The mean scores for each question (range, 1.0–4.0 points) increased as age increased. When the maximal score of each question was 4.0 points, the score corresponding to 90% (near-mastered) was 3.6. After 36 months, the mean score of each question was >3.6 points for almost all questions (Table 3).

As for the CVF scores, both the vCVF and dCVF scores increased rapidly from Group A to Group C, and then reached a near plateau [Fig. 1A, Supplementary Table 2 (in the online-only Data Supplement)]. The vCVF and dCVF scores also differed significantly between the overall age groups (p<0.001 for both). Post-hoc analyses of the vCVF and dCVF scores showed that there were considerable increases from Group A to Group B (p=0.066 and p=0.002, respectively) and Group B to Group C (p<0.001 and p=0.008).

There were no significant differences between male and female children in total CVF scores or vCVF and dCVF scores.

Cutoff scores for CVI

In each age group, cutoffs for CVI scores were set at the mean minus 2 SDs and the mean minus 1 SD (Table 3). In-depth evaluation was recommended for subjects with a score of the less than the mean minus 2 SDs. For subjects with a score between the mean minus 2 SDs and the mean minus 1 SD, follow up evaluation was recommended. Detailed cutoffs for the total CVF, vCVF, and dCVF scores are presented in Table 3 and Supplementary Table 2 (in the online-only Data Supplement).

Item internal consistency

Cronbach's alpha for assessing internal consistency of the questionnaire was calculated for all subjects and according to the different age groups. For all subjects, Cronbach's alpha for all 23 questions was 0.97, which indicated excellent consistency. Cronbach's alpha values for all subjects for the 9 questions related to vCVF and the 13 questions related to dCVF showed good consistency (0.84) and excellent consistency (0.96), respectively. The Cronbach's alpha values in each age group are presented in Table 4.

Table 3. Normative scores on the PQCVI according to age group

	Age group*						
	A	B	C	D	E	F	Total
PQCVI score							
Question							
1	3.7±0.6	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.3
2	3.7±0.7	4.0±0.2	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	3.9±0.3
3	3.7±0.7	3.9±0.4	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	3.9±0.4
4	3.3±1.0	3.8±0.4	4.0±0.0	4.0±0.0	4.0±0.2	4.0±0.2	3.8±0.5
5	2.9±1.2	3.9±0.4	4.0±0.0	4.0±0.0	4.0±0.0	4.0±0.0	3.8±0.7
6	2.7±1.1	3.8±0.4	4.0±0.2	3.9±0.3	4.0±0.0	3.9±0.3	3.7±0.7
7	2.7±1.1	3.8±0.4	4.0±0.0	3.9±0.3	4.0±0.0	4.0±0.0	3.7±0.7
8	3.1±1.0	3.7±0.5	3.9±0.3	4.0±0.2	4.0±0.2	4.0±0.0	3.7±0.6
9	2.8±1.2	3.7±0.5	4.0±0.2	4.0±0.2	4.0±0.2	3.9±0.4	3.7±0.7
10	1.5±0.9	3.8±0.5	4.0±0.2	4.0±0.2	4.0±0.0	4.0±0.2	3.6±1.0
11	1.3±0.9	3.5±0.8	3.9±0.3	4.0±0.2	4.0±0.2	4.0±0.0	3.5±1.1
12	1.5±1.0	3.3±1.1	4.0±0.2	4.0±0.2	3.9±0.3	4.0±0.2	3.4±1.1
13	1.5±0.9	3.0±1.1	3.8±0.5	3.9±0.3	4.0±0.2	4.0±0.0	3.3±1.1
14	1.3±0.8	3.0±1.2	3.8±0.5	3.9±0.3	3.8±0.4	3.9±0.3	3.2±1.1
15	1.0±0.2	2.5±1.0	3.7±0.4	3.8±0.4	4.0±0.0	4.0±0.2	3.1±1.2
16	1.1±0.4	2.5±1.1	3.5±0.6	3.8±0.5	4.0±0.2	3.9±0.3	3.1±1.2
17	1.5±0.9	2.9±1.2	3.5±0.6	3.7±0.5	3.9±0.4	3.9±0.4	3.1±1.1
18	1.1±0.6	2.9±1.1	3.5±0.6	3.8±0.4	3.7±0.5	3.6±0.6	3.1±1.2
19	1.0±0.0	2.1±1.1	3.6±0.7	4.0±0.2	4.0±0.0	4.0±0.0	3.0±1.3
20	1.0±0.0	1.8±1.0	3.6±0.7	3.9±0.3	3.9±0.4	4.0±0.0	2.9±1.3
21	1.0±0.0	1.4±0.7	3.3±0.9	3.8±0.6	4.0±0.0	4.0±0.0	2.7±1.4
22	1.0±0.0	1.9±1.0	3.2±0.8	3.6±0.6	3.6±0.5	3.7±0.5	2.7±1.2
23	1.0±0.2	1.7±1.0	2.8±0.9	3.4±0.7	3.4±0.7	3.4±0.7	2.5±1.2
Total	2.0±1.1	3.1±0.8	3.7±0.3	3.9±0.2	3.9±0.2	3.9±0.2	3.4±0.4
CVF score†	41.2±10.5	66.2±14.3	85.1±5.0	87.2±5.5	89.8±2.7	89.1±2.9	74.0±20.2
Cutoff CVF scores							
Mean minus 1 SD	31	52	80	82	87	86	54
Mean minus 2 SDs	23	38	75	76	84	83	34

Normative data are mean±SD values.
*Age group: A, <12 months; B, 12–23 months; C, 24–35 months; D, 36–47 months; E, 48–59 months; F, 60–71 months, †CVF score is the sum for the 23 questions.
CVF: cerebral visual function, PQCVI: parental questionnaire for cerebral visual impairment, SD: standard deviation.

Item response analysis

Item response analysis was performed for all subjects and for each age group (Table 5). For all subjects, the β values for the 23 items were between -2.05 and 1.11, and the α values were between 1.78 and >2.00. In Groups A to F, each item corresponding to its age stage generally showed β values between -4.67×10^{8} and +2.00 and α values between 0.0 and >2.00 (Table 5). These β and α values were considered to be adequate given that items required different levels of development and were implemented at different ages. The overall ICC varied with age according to a sigmoid pattern.

DISCUSSION

After the first descriptions of visual perception disorders in children with brain injuries in the 1980s, CVI has been defined differently by authors in several conditions.[1-3,8,24,25] In a recent systematic review, Sakki et al.[25] proposed that CVI could be defined as "A verifiable visual dysfunction which cannot be attributed to disorders of the anterior visual pathways or any potentially co-occurring ocular impairment."[8] Children with CVI can present with difficulties in recognition, text reading, spatial memory, handwriting, object discrimination, spatial exploration, sequential movement, attention, motor planning, and spatial reasoning. CVI could

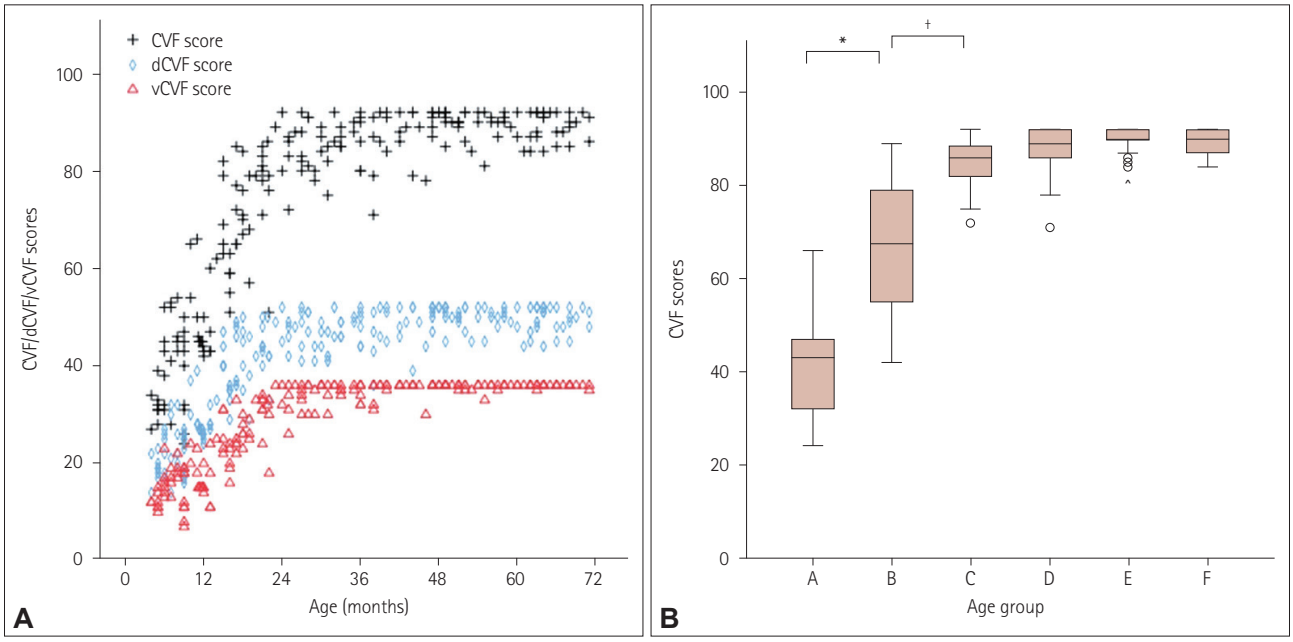

Fig. 1. Graphs of scores on the parental questionnaire for cerebral visual impairment according to age and age group. A: Scatter plots of scores for cerebral visual function (CVF) (black crosses), dorsal-stream cerebral visual function (dCVF) (blue diamonds), and ventral-stream cerebral visual function (vCVF) (red triangles) according to age. B: Box plots of the CVF scores according to age group. The mean CVF scores differed significantly between age groups in the overall test ($p<0.001$). Post-hoc analysis showed significant increases from Group A to Group B (*$p<0.001$), and from Group B to Group C ($^{\dagger}p=0.001$). Age group: A, <12 months; B, 12–23 months; C, 24–35 months; D, 36–47 months; E, 48–59 months; F, 60–71 months.

Table 4. Cronbach's alpha values for the PQCVI questions according to age group

Age group*	Cronbach's alpha		
	CVF score†	vCVF score‡	dCVF score§
A	0.903	0.800	0.737
B	0.920	0.919	0.829
C	0.808	0.746	0.756
D	0.849	0.773	0.787
E	0.776	0.671	0.494
F	0.675	0.590	-0.043
Total	0.974	0.840	0.955

*Age group: A, <12 months; B, 12–23 months; C, 24–35 months; D, 36–47 months; E, 48–59 months; F, 60–71 months, †CVF score is the sum for the 23 questions, ‡vCVF score is the sum score for the nine questions related to vCVF (questions 1, 4, 5, 10, 11, 13, and 19–21), §dCVF score is the sum score for the 13 questions related to dCVF (questions 2, 3, 6–8, 12, 14–18, 22, and 23).
CVF: cerebral visual function, dCVF: dorsal-stream cerebral visual function, PQCVI: parental questionnaire for cerebral visual impairment, vCVF: ventral-stream cerebral visual function.

influence the future development in various domains, learning, and social interaction.[1,3-6]

Several screening tools for CVI have been developed. The CVI Inventory reported by Macintyre-Beon et al.[26] comprises 51 questions tested in children with CVI (aged 5–16.5 years) and school children. The subsections of the CVI Inventory include visual fields, perception of movement, search, guidance of movement, attention, crowded scenes, recognition, and navigation.[26] The CVI Questionnaire reported by Orbitus et al.[15] comprises 46 questions answered by parents. This questionnaire estimates the visual attitude, ventral stream, dorsal stream, and other factors in children aged 3–17 years. Houliston and Dutton's questionnaire comprises 22 questions and was applied to children older than 5 years with hydrocephalus.[14] That questionnaire includes questions about difficulties related to visual perception that parents usually complain of and questions about visual field defects and visual inattention. A questionnaire for children younger than 24 months was developed by Pueyo et al.[27] However, it is not a screening tool and was developed to help in ophthalmological assessments of visual behavior. The CVI screening questionnaires described above were mostly developed for older children, whereas the present PQCVI was designed to assess the usefulness of CVI screening in children younger than those covered by the existing tools.

The present study found that the PQCVI scores increased with age. The mean CVF score already approached nearly half (44.8%) of the maximum score by the age of 12 months, over two-thirds (72.0%) at 12–23 months, 92.5% at 24–35 months, and approached the maximum score up to 71 months (Table 3, Fig. 1). The patterns in vCVF and dCVF scores were similar. Thus, our data show that there is significant development of higher visual functions until 5–6 years old, and the

Table 5. Item difficulty (β) and item discrimination (α) coefficients of the PQCVI according to age group

Question	Age group*						
	A	B	C	D	E	F	Total
1	-1.204/2.671	5.998×10^{7}/0.000	-1.133×10^{8}/0.000	-2.045×10^{8}/0.000	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	-2.045/22.149
2	-0.375/2.447	-1.365/1.546	-1.133×10^{8}/0.000	-2.045×10^{8}/0.000	-1.048/54.359	-3.029/1.177	-1.511/2.263
3	-0.971/5.201	-2.346/1.638	-1.133×10^{8}/0.000	-2.045×10^{8}/0.000	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	-1.949/3.972
4	0.604/1.514	-1.540/1.274	-2.926/1.409	-3.104/0.775	-4.678×10^{8}/0.000	-2.181/1.041	-1.131/1.775
5	0.311/3.687	-1.046/3.194	-1.133×10^{8}/0.000	-1.808/2.433	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	-1.100/3.476
6	-0.901/3.866	-1.345/29.238	-1.133×10^{8}/0.000	-2.045/0.000	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	-1.807/3.761
7	0.115/4.013	-0.631/1.704	-1.334/2.211	-4.656/0.776	-1.734/2.193	-2.124×10^{8}/0.000	-0.997/2.352
8	0.289/4.636	-0.457/1.639	-4.502/0.807	2.446/-0.136	-1.048/54.359	-1.412/1.492	-0.876/2.145
9	0.159/5.049	-1.328/1.625	-1.133×10^{8}/0.000	-2.045×10^{8}/0.000	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	-1.190/4.319
10	1.453/3.074	-0.440/2.628	-1.723/48.314	-1.724/50.591	-4.678×10^{8}/0.000	-4.563/0.739	-0.629/4.724
11	1.479/2.948	0.189/3.667	-1.780/1.678	-1.724/50.591	-1.048/54.359	-2.124×10^{8}/0.000	-0.399/5.858
12	3.088/1.265	0.774/4.056	-1.888/1.206	-1.382/30.129	-1.048/54.359	-2.124×10^{8}/0.000	-0.154/6.616
13	6.115×10^{6}/0.000	1.449/3.231	-9.650×10^{-1}/1.363	-1.724/50.591	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	0.000/198.004
14	6.115×10^{6}/0.000	1.877/45.932	-2.160×10^{-1}/0.834	-7.570/24.728	-4.678×10^{8}/0.000	-2.124×10^{8}/0.000	0.207/5.177
15	6.115×10^{6}/0.000	2.027/1.802	-8.560×10^{-1}/1.259	-1.173/2.498	-9.050×10^{-1}/2.208	-2.124×10^{8}/0.000	0.150/4.919
16	6.115×10^{6}/0.000	1.355/14.385	-6.620×10^{-1}/35.012	-1.386/1.666	-4.678×10^{8}/0.000	-1.360/29.921	0.064/4.872
17	6.115×10^{6}/0.000	1.203/3.228	-5.700×10^{-2}/31.172	-1.167/4.275	-1.734/2.193	-1.019/40.799	0.093/5.221
18	3.088/1.265	0.654/3.035	-1.800×10^{-2}/1.649	-6.420/12.578	-6.610×10^{-1}/35.510	-0.977/2.179	0.143/2.681
19	6.115×10^{6}/0.000	2.073/1.721	3.140×10^{-1}/3.741	-1.400/2.166	7.400×10^{-2}/10.720	-0.460/2.154	0.690/3.360
20	1.383/42.794	0.521/2.654	-1.490×10^{-1}/1.324	-8.330/2.036	-4.700×10^{-2}/26.860	-0.771/1.283	0.179/2.089
21	1.041/59.869	-0.357/2.654	-3.750/1.005	-1.724/50.591	-1.358/1.635	-1.360/30.801	-0.571/3.533
22	1.041/59.869	0.381/2.452	-2.856/0.713	-1.382/29.946	-6.710×10^{-1}/2.614	-1.233/2.576	-0.249/2.935
23	6.115×10^{6}/0.000	3.417/0.920	1.610/1.394	1.880/2.216	2.250×10^{-1}/1.062	0.548/22.210	1.109/2.294

Data are β/α values.
*Age group: A, <12 months; B, 12–23 months; C, 24–35 months; D, 36–47 months; E, 48–59 months; F, 60–71 months.
PQCVI: parental questionnaire for cerebral visual impairment.

basis of CVF is formed before the age of 3 years.

In the dual-stream hypothesis of visual information processing, the ventral stream comprises the occipitotemporal pathway to the anterior temporal cortex. Ventral-stream function is responsible for visual recognition and visual memory, and is related to face and object recognition (also called the "what" pathway).[28,29] It works in cooperation with the dorsal stream when solving complex visual problems. Integrating the ventral and dorsal streams in terms of color, speed, and form provide the information necessary for intermediate object representations in the dorsal stream.[30] In addition, direct evidence of the involvement of crosstalk networks between ventral and dorsal streams in skilled hand actions has been demonstrated by white-matter tractography.[31]

The recognition of faces is examined by questions 1 (parent), 4 (family), and 13 (friends) of the PQCVI. The average scores for questions related to the recognition of parents, family, and friends increased sequentially with age, and the recognition of friends was nearly mastered by 24–36 months. The sequential recognition of faces may be the basis of pretend play with other people emerging at approximately 18 months and parallel play with friends appearing at approximately 24 months.[32] Recognition of photographs is reviewed by questions 10 (other people) and 11 (themself). The sequential development of face and photograph recognition may also be related to the development of socioemotional behavior and self-concept.

The recognition of shape and objects is examined by questions 5 (object) and 19 (shape). The ability to recognize familiar objects developed earlier, and was accomplished before 24 months. However, shape recognition developed later, and was not nearly mastered until 36 months. This shows that mental representations began with individual objects and then progressed to abstract forms.

The matching and naming of colors are examined by questions 20 and 21, respectively. The score was slightly lower for color naming than for color matching, but both abilities were nearly mastered after 36 months. Color preferences are known to develop as early as 3 months,[33] while the ability to match colors develops at approximately 28 months.[32] Delayed success with matching and naming colors relative to the acquisition of color vision is related to cognition and language de-

velopment.

The dorsal stream comprises the occipitoparietal pathway and is responsible for spatial working memory, visually guided action, and navigation (also called the "where" or "how" pathway).[28] The dorsal stream is more vulnerable in children with periventricular white-matter injuries, autistic spectrum disorders, and Williams syndrome.[7,29,34] Questions 2 (reaching and grasping) and 7 (pincer grasping) examine visually guided action and depth perception, both of which relate to fine motor development. Parietopremotor pathways mediate reaching and grasping and visually guided actions.[28] In healthy children, reaching and grasping is possible at approximately 4 months, and pincer grasping is possible at 9–12 months. Our results show that reaching and grasping is nearly mastered before 12 months, while pincer grasping is nearly mastered after 12 months.

Motion perception is examined by questions 3 (slow-moving object), 8 (fast-moving object), and 16 (while self-moving). Motion perception is controlled by interactions between the visual and vestibular systems. The motion perception process is attributed to both ventral-stream function (stimuli duration) and dorsal-stream function (perceived vection).[35] In our study, the abilities to perceive the motions of slow-moving and fast-moving objects were achieved before 12 months and after 12 months, respectively, while self-moving was perceived after 36 months.

Orientation and navigation are examined by questions 12 (finding the way around the home), 14 (finding the way to doorways), and 23 (finding the way in new surroundings). Several reports have classified navigation as a ventral-stream function.[15,29] A recent study aimed at identifying a neural framework suggested that ventral-stream information and dorsal-stream information converged and were integrated in the medial temporal lobe. The dorsal stream is crucial for navigation using encoded landmarks.[28] Finding the way around the home was nearly mastered before 36 months, and finding the way in new surroundings developed latest, with the full score not being approached until 71 months.

Figure-ground and simultaneous perceptions are examined by questions 17 (finding an object in a complex pattern) and 22 (finding an object in a complex picture). Finding an object in a complex pattern was nearly mastered by 36–47 months, whereas finding an object in a complex picture was more difficult, not being almost mastered until 60–71 months.

Visuospatial memory is examined by questions 6 (finding covered objects) and 18 (finding an object in the home). The retrosplenial cortex in the dorsomedial parietal area is important for learning landmark locations and spatial memory,[28,36] and is related to object permanence. The milestone of remembering covered objects usually occurs at approximately 10 months.[32] In the present study, finding covered objects was nearly mastered after 12 months. The ability to find objects in the home was the best at 36–47 months, after which this ability slightly, but not significantly, decreased. However, it is unclear whether this function truly deteriorated, and so this function should be further evaluated.

Cognitive visual function has been considered difficult to evaluate before the age of 5 years. Higher visual functions might not be distinguished from general cognitive functions at this age. The behavior lists of the PQCVI include visual perception and practical abilities in everyday life. These questions may differ qualitatively from the items in traditional visuospatial function tests, which are more relevant to general cognitive functions or problem-solving. Most of the PQCVI items are easily observed behaviors but are practically related to cognitive visual function. Our results suggest that CVF can be assessed in young children using a parental questionnaire.

The main limitation of this study was that the effects of cognitive function on the PQCVI results could not be explained. Future studies should investigate such associations and follow-up subjects for the later manifestation of CVI, specifically in those with low CVF scores.

In summary, we have tested the PQCVI, which is a new CVI screening tool for children younger than 72 months. The PQCVI was found to be feasible to use, and its internal reliability and item analyses are adequate. Normative data showed a progressive pattern of the development of basic cerebral visual functions, and most functions were nearly mastered by 36 months. These results support the importance of early detection and early intervention for CVI before the age of 36 months, especially in high-risk children.

Supplementary Materials

The online-only Data Supplement is available with this article at https://doi.org/10.3988/jcn.2021.17.3.354.

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Conflicts of Interest

The authors have no potential conflicts of interest to disclose.

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