

An assessment tool for visual perception deficits in Cerebral Visual Impairment (CVIT 3-6): Development and normative data of typically- developing children

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Abstract

Aim. To develop an assessment tool that measures a wide range of visual perceptual deficits common in Cerebral Visual Impairment (CVI) and to provide normative data from typically developing children between 3 and 6 years old.

Method. Test development reflected cross-talk between vision research and clinical relevance for CVI. The Children's Visual Impairment Test for 3 to 6 year olds (CVIT 3-6) includes 14 subtests covering four domains of visual perception: object recognition, degraded object recognition, motion perception and local-global processing. Normative data were collected from 301 typically developing children (average age: 4y8m; 148 girls). A questionnaire was administered to parents about pregnancy duration, birth and developmental problems.

Results. Average total CVIT 3-6 performance was 60.1 (SD = 5.5) out of 70. The cut-off score for normal visual perception (53) was set at the 10th percentile of scores in typically developing children. Multiple regression indicated CVIT 3-6 visual perception scores increase with age for children born \geq 36 weeks gestational age ($\beta = -18.03$, 95%CI = [-31.31, -4.75])

Interpretation. CVIT 3-6 (<https://psytests.be/clinicians/test-centrum/cvi-t.php>) is a tool for assessing a wide range of visual perceptual deficits common in CVI. Age-dependent normative data are available because we found performance to increase with age.

Running footer

CVIT 3-6 development and normative data

What the paper adds

- A test for visual perceptual deficits common in cerebral visual impairment
- Normative data of 301 typically developing 3- to 6-year-olds
- Visual perceptual functions improve with age in full-term typically developing children

Cerebral Visual Impairment, Cortical Visual Impairment or CVI is a neurological condition characterized by deficits in visual perception due to underlying brain malfunctioning rather than an ocular disease. It is nowadays the most common cause of blindness or low vision certificates¹. Neurobiological causes include periventricular leukomalacia and periventricular haemorrhagic infarcts, lesions typically seen in children born preterm, and resulting in a clinical picture of cerebral palsy^{1,2}. However, many other causes of either structural or functional brain damage³ and genetic conditions⁴ have been described. The diversity in neurobiological causes is also reflected in the wide range of behavioural deficits these children experience⁵. At the level of low visual functions, deficits include reduced visual acuity, reduced contrast sensitivity, and visual field defects. Ventral stream impairments include difficulties in recognition of objects, faces, shapes and letters, and visual memory. Dorsal visual stream dysfunctions result in impairments in visually guided actions, visual attention, motion perception, visual search and handling complex 2D and 3D scenes^{1,6}.

Now more than ever, there is an increased need for improved accuracy in assessing and diagnosing CVI, due to its hazardous effect on development and learning^{1,6}. In addition, early diagnosis is warranted, given the fact that neuroplasticity is at its greatest at a young age^{7,8}. Diagnosis of CVI is challenging, however, in children aged under six and particularly in those having a mental, language or motor deficit. The diverse range of symptoms described above asks for a multidisciplinary diagnostic process that acts at several levels of visual impairment⁹. A neuropsychological profile of the child is key to characterize higher level visual functioning. Although test protocols for functional vision assessment in children have been published^{10,11}, the currently available neuropsychological visual perception tests have several limitations. First of all, many tests are designed for adults and are therefore not adjusted to the cognitive level of the child or do not reflect their interests (e.g. Visual Object and Space Perception, Birmingham Object Recognition Battery)^{12,13}. Consequently, normative data for children under six years old are rarely available. Another limitation follows from the comorbidity of CVI with Cerebral Palsy¹⁴, making it difficult for some children to interact with test materials

because of their motor impairment (e.g. Visual Motor Integration¹⁵, Developmental Test of Visual Perception (DVTP¹⁶ Copying, DVTP eye-hand coordination) or speech impairments (e.g. L94¹⁷: 'What do you see in the picture?'). Furthermore, low-level visual impairments like strabismus, amblyopia or low visual acuity, should not be the main determinant of the test outcome. Test materials often confound several visual functions making it difficult to pin-point which visual functions are impaired in a child. For instance in the Figure-Ground task of the DVTP, a child needs to segregate an object from the background, detect the target object, recognise the object, and name the object correctly (see also the visual perception subtests (16-18 and 19-22) of ABCDEFV¹⁰). Lastly, many of these tests lack evaluation of recognition of everyday objects (e.g. DTVP, TVPS) or if they include it, images are solely presented as black and white line drawings (e.g. L94¹⁷), reducing the ecological validity of the test.

We aim to develop an assessment tool that provides an answer to the limitations above. Our tool is intended to be an assessment tool for visual perception impairments common in CVI, so we target a broad range of visual perception functions, but do not aim to test visual functions in depth. Following initial assessment of a patient with our tool, the assessment can be followed-up by more specialised in-depth tests of certain visual functions identified through CVIT 3-6, with existing tests like VMI, L94 or DTVP if no motor or speech problems are present, with VOSP or BORB at an older age, or custom-made tests. This paper describes the development and the normative sample of the CVIT 3-6. The reliability and validity is described in a companion paper.

Study 1: Development of CVIT 3-6

Guiding principles

The development of the Children's Visual Impairment Test for 3 to 6 year olds or CVIT 3-6 (<https://psytests.be/clinicians/test-centrum/cvi-t.php>) reflects a cross-talk between vision sciences and clinical experience. In-depth knowledge of hierarchical visual processing in the

brain and the sub-processes involved in visual perception¹⁸ informed decision making in our choice of subtests. The overall range of subtests was selected in order to cover most of the key processes in visual perception, from the grouping of individual elements to the assignment of figure-ground relationships¹⁹, but at the same time be short enough to fit into a standard clinical appointment. Stimulus and task choice was influenced by our perceptual organisation screening test for adults with brain-damage, L-POST²⁰, that has been successfully validated²¹.

The tool adopts a rigorous testing method (matching-to-sample, see further) that is previously used in toddlers ²². We also used well-controlled stimuli that were developed in a lab-based context. For instance, the stimuli of the degraded object perception subtests were derived from the Snodgrass-Vanderwart stimulus set²³ that is well studied and for which normative data are available^{23–27}. The theoretical basis and stimuli of each subtest are detailed in the Supplementary materials.

Beside the already reported clinical needs, clinical input highlighted the need for a test that relates to visual impairments experienced in daily life. For instance, children with CVI often have difficulties with crowded environments which motivated the choice for a subtest on scene perception. This is also reflected in a bias towards subtests that are clinically relevant but currently lacking in existing visual perception tests like motion perception. Last, a simple and flexible comparison with normative data is recommended for ease of use in a clinical context and ability to discriminate a child's visual perceptual abilities.

Procedural aspects

CVIT 3-6 can be administered on any device with an Internet connection (<https://psytests.be/clinicians/test-centrum/cvi-t.php>). Scores are automatically calculated and presented graphically at the end of the test (Figure 1). Cut-off scores are set at the 10th percentile of the normative sample. By default, a child's performance is compared with the whole normative sample, but the appropriate age range can be customized.

All trials in CVIT 3-6 follow a matching-to-sample paradigm. The child is asked to indicate which of the three alternative stimuli presented at the bottom of the screen is perceived as most similar to the target stimulus at the top of the screen (Figure 2). Several modalities to answer are available (pointing, tapping, via a computer mouse or verbally) to allow children with motor or speech problems to be assessed. A minimum screen resolution of 1000 by 800 pixels, minimum screen size of approximately 9 inch (23cm), and full-screen viewing is recommended to avoid having to scroll to view all stimuli.

Each subtest consists of two practice trials during which specific instructions are presented on the screen. To progress to the next trial, each practice trial has to be solved correctly. Following the practice trials, five test trials are presented in which no additional instructions nor feedback is given.

The subtests are presented in a fixed order (as described in the Supplementary materials). The fixed order is especially important for the Object and Scene Perception subtests for which performance on the subtests can depend on each other and a randomized order would improve or impair the subtest scores in some instances. Test administration can be split up over several sessions if required, but the Object and Scene Perception subtests must be completed within one session.

Subtests

CVIT 3-6 includes 14 subtests that can be categorized in four themes or subscales. All subtests are described in detail in the Supplementary materials. The first theme 'Object and Scene Perception' is inspired by clinical needs and has high ecological validity. The three subtests evaluate object recognition in natural viewing conditions in the presence of distractors: Object Recognition, Scene Perception, and Object Recognition in Context. The second theme 'Degraded Object Recognition' evaluates object recognition when limited visual information of the object is available. In each of the five subtests, the objects are degraded in distinct ways: Silhouettes, Full Line Drawings, Fragmented Outlines, Object in Noise, and

Unconventional Viewpoints. Our third theme 'Motion Perception' evaluates different levels of motion processing in three subtests: Coherent Motion Perception, Kinetic Object Segmentation, and Biological Motion. The last theme of CVIT 3-6 focuses on 'Global-Local Perception'. The three subtests (Overlapping Figures, Embedded Figures, and Missing Parts) in this theme evaluate whether local and global information of objects (parts and wholes) can be processed independently.

Development process

In six consecutive pilot studies with a total of 100 typically developing children, test instructions, test length, stimuli, and the number of subtests were optimized until the average performance for each subtest exceeded 80 percent. In addition, all the images were found to be recognizable with a visual acuity of 0.2.

Study 2: Normative data

Following development, we collected normative data from typically developing children between 3 and 6 years old. This enabled us to determine the average total score on CVIT 3-6 and average scores on the subscales and subtests in the general population. In addition, we calculated the 10th percentile of each subscale and subtest scores and set this as a cut-off for normal visual functioning. The 10th percentile is recommended in clinical contexts because this test is intended as an assessment tool to highlight potential problems for further testing. Furthermore, we evaluate the effect of age, gender, pregnancy duration, birth weight, and multiple birth on CVIT 3-6 scores.

Methods

Participants

A Dutch version of CVIT 3-6 was administered in 387 children in Flemish schools. Parents received an information sheet explaining the aim of the study and the procedures involved. Parents who agreed for their children to participate in the study were asked to sign

the consent form and return a health questionnaire. All procedures were approved by the Medical Ethical Committee of University Hospitals Leuven.

To create our normative sample, data from suboptimal test conditions were excluded: technical problems (n=11) or a small screen size that could not fit all stimuli at once (n=2). Subsequently, data from these children with parent-reported visual problems were excluded from the normative sample (n=18). In addition, if parents reported developmental problems, the child's data were also excluded (n=8). Lastly, children outside our targeted age range were removed from the sample (n=47). This resulted in a normative sample of 301 participants. We have chosen to include preterm born children without reported visual or developmental problems to reflect a typically developing population.

Instruments

CVIT 3-6 was administered in every child to assess visual perception functions (<https://psytests.be/clinicians/test-centrum/cvi-t.php>).

A questionnaire asked for biographical information (date of birth and gender). In addition, we asked to report the pregnancy duration, birth weight, birth length, and whether the child was part of a multiple birth. Further, a yes/no filter question about developmental problems was included. If answered 'yes' to this question, parents were asked to describe the developmental problem(s). The same question format was used to report visual problems.

Data analysis

To characterize the normative sample, we calculated descriptive statistics (frequencies, mean, SD) for biographic and birth information. Descriptive statistics (mean, SD, median, minimum, maximum, interquartile range) on CVIT 3-6 performance and test duration were calculated for all children and per age group (6 month intervals). Subsequently, we evaluated a linear regression model with main effects of age, gender, pregnancy duration, birth weight, multiple birth and interactions between age and gender, age and pregnancy duration, and between pregnancy duration and birth weight. To avoid multicollinearity, birth length was not included

in the regression model ($r_{\text{birth weight, birth length}}=.79$). For the regression analysis, 16 subjects were excluded because their pregnancy duration was not reported.

Results

Our normative sample consisted of 148 girls and 153 boys (mean age=4 years, 8 months; SD=9.7 months). Descriptive statistics on pregnancy duration, birth weight and birth length are reported in Table 1. 290 children were a single birth, while the remaining 11 children were part of multiple births.

The average total score on CVIT 3-6 was 60.1 with a standard deviation of 5.5. With a maximum score of 70 (14 subtests, max 5 correct in each) and minimum of 45, the distribution was slightly skewed. The median in our sample was 60, with an interquartile range of [56, 64]. The 10th percentile cut-off for normal developing visual perception was 53. Summary statistics for the subscales and subtests for all children are reported in Table 2 and per age group in Tables S1-S6 in Supporting Materials. The median time to complete the test decreases slightly with age (13 min for 3-4 year olds, 11 min for 4-5 year olds, 10 min for 5-6 year olds).

The regression model explained a significant amount of variance in CVIT 3-6 scores ($F(8, 276)=26.69, p<.001, R^2=0.44, R^2_{\text{adjusted}}=0.42$). We observed a main effect of age ($\beta=-18.03, t(276)=-2.66, p=.008$) and pregnancy duration ($\beta=-3.42, t(276)=-3.29, p=.001$), as well as a significant interaction between them ($\beta=0.56, t(276)=3.26, p=.001$) on the total CVIT 3-6 score. To interpret these effects, we calculated the estimated slopes for age and corresponding confidence intervals for each reported pregnancy duration (from 28 to 42 weeks, in steps of 1 week). The slopes of age inform us about the direction and size of the effect of age on CVIT 3-6 scores for children with a certain pregnancy duration. Estimated slopes for age did not significantly differ from zero for children with a pregnancy duration under 36 weeks ($n = 25$). For children with a longer pregnancy duration, slopes are positive and CVIT 3-6 scores increased significantly with age (Figure 3). In addition, we observed a significant main effect of birth weight ($\beta=-0.01, t(276)=-2.43, p=.016$) and a significant

interaction between birth weight and pregnancy duration ($\beta=0.0003$, $t(276)=2.51$, $p=.013$), which was driven by one child born before 31 weeks gestational age with a relative low birth weight and high CVIT 3-6 score (without this outlier: $\beta=0.0002$, $t(275)=1.54$, $p=.12$, see also Figure 3). The other variables gender ($\beta=-4.07$, $t(276)=-1.40$, $p=.164$), multiple birth ($\beta=0.35$, $t(276)=0.26$, $p=.798$) and the interaction between age and gender ($\beta=0.78$, $t(276)=1.25$, $p=.213$) did not significantly predict CVIT 3-6 scores.

Discussion

We have developed an online computerized assessment tool for visual perception functions in Cerebral Visual Impairment for children with a developmental age between 3 and 6 years old (<https://psytests.be/clinicians/test-centrum/cvi-t.php>). CVIT 3-6 covers a wide range of mid and high level visual functions. Our normative sample includes 301 typically developing children. We calculated a cut-off score for normal visual perception for the total score on CVIT 3-6 and for the subscale scores. The 5th and 10th percentile are most commonly used as cut-off scores in clinical test with skewed normative data. With CVIT-3-6 being an initial assessment tool, we want to minimise false negatives rather than false positives (in other words increase sensitivity with reduced specificity) and have chosen a lower cut-off.

Multiple regression indicated CVIT 3-6 scores increase with age. Therefore, it is advisable to compare individual CVIT 3-6 scores to the appropriate age group. Age-dependent normative tables are provided with this paper and a direct visual comparison with an age-dependent matched group is available in the online test. We recommend the use of the online age-dependent comparison because a more precise comparison is possible and additional normative data are likely to become available in the future.

Compared to other visual perception tests like Beery-VMI or DVTP, CVIT 3-6 performance does not require perfect motor or cognitive abilities as rough pointing abilities are sufficient to perform the testing. In addition, our tool assesses the perception of coloured images and images of every day scenes, which makes the test more ecologically valid than

for instance L94 and TVPS. Furthermore, our normative sample includes data for children under 6 years old with about 100 children for each age group, which is considerable more than for a similar recently developed tool, the Battery for the Evaluation of Visual Perceptual and Spatial processing in children (BEVPS), with 35-36 children per age group, starting from 5 years old²⁸. High performance of typically developing children on CVIT 3-6 (median 4 or 5 out of 5 in all but two subtests) makes differentiation between patients possible with only five items per subtest compared to for instance 30-50 in the BEVPS²⁸, making our tool more suitable for clinical practice. Last, CVIT 3-6 is the first test to include motion perception tasks, a task that is currently lacking in any of the paper and pencil tests and a common problem in CVI in clinical experience.

Limitations of CVIT 3-6 include the relatively poor performance of the normative group on two out of 14 subtests: the Global Motion Detection and the Missing Parts test. Pilot studies with typically developing children indicated that average performance increased from 55-60% in the early versions (n=13) to 80% in the final version (n=13) with changes in instructions and representation of motion direction (arrows). However, in our normative sample, average performance is 58% and 56% on these subtests. This makes the differentiation between impaired and unimpaired performance more difficult. Furthermore, we observed increased performance on CVIT 3-6 with age for children born after 36 weeks of pregnancy. This seems to indicate that preterm born children do not improve their visual functions with age, while full term born children do. However, these conclusions are derived from a small group of 25 preterm children. A longitudinal study in a larger group with formal assessment of visual and developmental problems seems more appropriate to investigate this effect than our small study with self-reported data. The effect of age on CVIT 3-6 scores can also suggest that understanding the concepts 'same' and 'different' and ability to perform a matching to sample task increases with age^{29,30}. By comparing a child's performance to age-dependent normative data age effects can be taken into account.

In our companion paper, we have shown that CVIT 3-6 total score has high test-retest reliability but reliability for the subscale scores is lower and subscale scores should be interpreted cautiously. We demonstrated excellent internal validity via confirmatory factor analyses and showed that CVIT 3-6 specifically measures visual perception functions and is not mediated by intellectual abilities or visual acuity [please insert a reference to our companion paper here].

Besides aiding the diagnosis of CVI, our tool can potentially detect deficits in visual perception in other developmental conditions that have previously been related to impaired development in visual functions like William's syndrome, autism spectrum disorders, developmental dyslexia, Fragile X, congenital cataract, amblyopia, nystagmus, and other anterior pathway disorders^{31,32}.

In summary, the CVIT 3-6 is a valuable tool in the assessment of for visual perception impairments common in Cerebral Visual Impairment.

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Conflict of interest

The authors report no conflicts of interests.

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388

389 *Figure 1.* Screenshot of results of a demo patient. The bar shows the number of correct trials for each
390 subtest. The percentile for this score compared to the normative database is shown in the right column.
391 Subtests for which the demo patient obtains a score below the 10th percentile are presented with red
392 bars. In addition, the total score and the number of failed subtests is given (colour version available
393 online).

394

395 *Figure 2.* Example trial from the subtest ‘Silhouettes’ illustrating the matching-to-sample paradigm used
396 in all trials. Each subtest is preceded by two examples with specific instructions. In the Silhouettes
397 subtest these instructions are ‘Which image at the bottom is the shadow of the image at the top?’ (Pilot
398 studies indicated that ‘shadow’ - although indeed not very accurate - is easier for children to understand
399 than ‘silhouettes’. Colour version available online)

400

401 *Figure 3.* CVIT 3-6 scores in our normative sample. (A) Distribution of the scores. Scatterplots of total
402 CVIT 3-6 scores in function of (B) age and (C) birth weight. Children born before 36 weeks (B) or 31
403 weeks (C) gestational age are plotted as yellow triangles. For the latter subgroup of children the
404 relationship between age and CVIT 3-6 scores differs from the children with a longer pregnancy duration
405 (blue squares). (colour version available online)

406

Table 1. Descriptive statistics for pregnancy duration, birth weight, and birth length

	<i>Min</i>	<i>Max</i>	<i>IQR</i>	<i>Mdn</i>	<i>n</i>
Pregnancy duration (in weeks gestational age)	28	42	38-40	39	285
Birth weight (in kg)	0.75	4.97	2.97-3.67	3.36	298
Birth length (in cm)	34	59	48-52	50	292

Note. *Mdn* = median, *IQR* = Interquartile range

Table 2. Descriptive Statistics for Scores on CVIT 3-6

	<i>M</i>	<i>SD</i>	<i>Min</i>	<i>Max</i>	<i>Mdn</i>	<i>IQR</i>	<i>Pc₁₀</i>	<i>Skewness</i>
Total	60.1	5.5	45	70	60	56-64	53	-0.30
Object Recognition	9.2	1.2	1	10	10	9-10	8	-2.40
Object Recognition	5	0.2	3	5	5	5-5	5	-6.92
Scene Perception	4.7	0.7	1	5	5	5-5	4	-2.27
Object Recognition in Context	4.5	0.8	0	5	5	4-5	3	-1.99
Degraded Object Recognition	23.8	1.4	19	25	24	23-25	22	-1.24
Full line drawings	4.5	0.7	2	5	5	4-5	4	-1.32
Silhouettes	4.9	0.3	3	5	5	5-5	5	-3.18
Fragmented outlines	4.8	0.5	3	5	5	5-5	4	-2.04
Object in Noise	4.8	0.4	3	5	5	5-5	4	-2.13
Unconventional Viewpoints	4.7	0.6	2	5	5	5-5	4	-1.94
Motion perception	10.8	2.6	3	15	11	9-13	7	-0.26
Global Motion Detection	2.9	1.7	0	5	3	2-5	1	-0.23
Kinetic Object Segmentation	4	1.3	0	5	5	3-5	2	-1.17
Biological Motion	3.9	1.2	0	5	4	3-5	2	-0.99
Global Local	11.4	2.3	5	15	12	10-13	9	-0.41
Overlapping Figures	4	1	0	5	4	3-5	2	-0.92
Embedded Figures	4.7	0.6	1	5	5	4-5	4	-2.26
Missing Parts	2.8	1.4	0	5	3	2-4	1	0.03

Note. *M* = mean, *SD* = standard deviation, *Mdn* = median, *IQR* = Interquartile range, *Pc₁₀* = 10th percentile.