

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

5 Kathleen Vancleef ^{1,2,3}, Postdoctoral Research Fellow, PhD

6 Eva Janssens ^{2,5}, Research Assistant

7 Yasmine Petré ², Master student

8 Johan Wagemans ^{2,3}, Professor, PhD

9 Els Ortibus ^{4,5}, Paediatric Neurologist, MD, PhD

10

11 ¹ *Department of Experimental Psychology, University of Oxford, Oxford, United Kingdom*

12 ² *Brain and Cognition, KU Leuven, Leuven, Belgium*

13 ³ *Leuven Brain Institute (LBI), KU Leuven, Leuven, Belgium*

14 ⁴ *Faculty of Medicine, Department of Development and Regeneration and Department of
15 Biomedical Sciences, KU Leuven, Leuven, Belgium*

16 ⁵ *Centre for Developmental Disabilities, University Hospitals Leuven, Leuven, Belgium*

17 Word count: 3075

18

19 Corresponding author: Kathleen Vancleef

20 Current address: Department of Experimental Psychology, New Radcliff House, Walton
21 Street, Oxford, OX2 6GG, United Kingdom

22 Current Email: kathleen.vancleef@psy.ox.ac.uk

23 Abstract

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

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

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

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

40 Running footer

41 CVIT 3-6 development and normative data

42 What the paper adds

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

46

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

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

74 because of their motor impairment (e.g. Visual Motor Integration¹⁵, Developmental Test of
75 Visual Perception (DVTP¹⁶ Copying, DVTP eye-hand coordination) or speech impairments
76 (e.g. L94¹⁷: 'What do you see in the picture?'). Furthermore, low-level visual impairments like
77 strabismus, amblyopia or low visual acuity, should not be the main determinant of the test
78 outcome. Test materials often confound several visual functions making it difficult to pin-point
79 which visual functions are impaired in a child. For instance in the Figure-Ground task of the
80 DVTP, a child needs to segregate an object from the background, detect the target object,
81 recognise the object, and name the object correctly (see also the visual perception subtests
82 (16-18 and 19-22) of ABCDEFV¹⁰). Lastly, many of these tests lack evaluation of recognition
83 of everyday objects (e.g. DTVP, TVPS) or if they include it, images are solely presented as
84 black and white line drawings (e.g. L94¹⁷), reducing the ecological validity of the test.

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

94

95 Study 1: Development of CVIT 3-6

96 Guiding principles

97 The development of the Children's Visual Impairment Test for 3 to 6 year olds or CVIT
98 3-6 (<https://psyttests.be/clinicians/test-centrum/cvi-t.php>) reflects a cross-talk between vision
99 sciences and clinical experience. In-depth knowledge of hierarchical visual processing in the

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

106 The tool adopts a rigorous testing method (matching-to-sample, see further) that is
107 previously used in toddlers²². We also used well-controlled stimuli that were developed in a
108 lab-based context. For instance, the stimuli of the degraded object perception subtests were
109 derived from the Snodgrass-Vanderwart stimulus set²³ that is well studied and for which
110 normative data are available²³⁻²⁷. The theoretical basis and stimuli of each subtest are detailed
111 in the Supplementary materials.

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

119 Procedural aspects

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

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

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

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

142 Subtests

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

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

157 Development process

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

162 Study 2: Normative data

163 Following development, we collected normative data from typically developing children
164 between 3 and 6 years old. This enabled us to determine the average total score on CVIT 3-
165 6 and average scores on the subscales and subtests in the general population. In addition,
166 we calculated the 10th percentile of each subscale and subtest scores and set this as a cut-off
167 for normal visual functioning. The 10th percentile is recommended in clinical contexts because
168 this test is intended as an assessment tool to highlight potential problems for further testing.
169 Furthermore, we evaluate the effect of age, gender, pregnancy duration, birth weight, and
170 multiple birth on CVIT 3-6 scores.

171 Methods

172 Participants

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

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

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

186 Instruments

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

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

194 Data analysis

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

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

204 Results

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

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

216 The regression model explained a significant amount of variance in CVIT 3-6 scores
217 ($F(8, 276)=26.69, p<.001, R^2=0.44, R^2_{\text{adjusted}}=0.42$). We observed a main effect of age ($\beta=-$
218 $18.03, t(276)=-2.66, p=.008$) and pregnancy duration ($\beta=-3.42, t(276)=-3.29, p=.001$), as well
219 as a significant interaction between them ($\beta=0.56, t(276)=3.26, p=.001$) on the total CVIT 3-6
220 score. To interpret these effects, we calculated the estimated slopes for age and
221 corresponding confidence intervals for each reported pregnancy duration (from 28 to 42
222 weeks, in steps of 1 week). The slopes of age inform us about the direction and size of the
223 effect of age on CVIT 3-6 scores for children with a certain pregnancy duration. Estimated
224 slopes for age did not significantly differ from zero for children with a pregnancy duration under
225 36 weeks ($n = 25$). For children with a longer pregnancy duration, slopes are positive and
226 CVIT 3-6 scores increased significantly with age (Figure 3). In addition, we observed a
227 significant main effect of birth weight ($\beta=-0.01, t(276)=-2.43, p=.016$) and a significant

228 interaction between birth weight and pregnancy duration ($\beta=0.0003$, $t(276)=2.51$, $p=.013$),
229 which was driven by one child born before 31 weeks gestational age with a relative low birth
230 weight and high CVIT 3-6 score (without this outlier: $\beta=0.0002$, $t(275)=1.54$, $p=.12$, see also
231 Figure 3). The other variables gender ($\beta=-4.07$, $t(276)=-1.40$, $p=.164$), multiple birth ($\beta=0.35$,
232 $t(276)=0.26$, $p=.798$) and the interaction between age and gender ($\beta=0.78$, $t(276)=1.25$,
233 $p=.213$) did not significantly predict CVIT 3-6 scores.

234 Discussion

235 We have developed an online computerized assessment tool for visual perception
236 functions in Cerebral Visual Impairment for children with a developmental age between 3 and
237 6 years old (<https://psyttests.be/clinicians/test-centrum/cvi-t.php>). CVIT 3-6 covers a wide
238 range of mid and high level visual functions. Our normative sample includes 301 typically
239 developing children. We calculated a cut-off score for normal visual perception for the total
240 score on CVIT 3-6 and for the subscale scores. The 5th and 10th percentile are most commonly
241 used as cut-off scores in clinical test with skewed normative data. With CVIT-3-6 being an
242 initial assessment tool, we want to minimise false negatives rather than false positives (in other
243 words increase sensitivity with reduced specificity) and have chosen a lower cut-off.

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

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

254 for instance L94 and TVPS. Furthermore, our normative sample includes data for children
255 under 6 years old with about 100 children for each age group, which is considerable more
256 than for a similar recently developed tool, the Battery for the Evaluation of Visual Perceptual
257 and Spatial processing in children (BEVPS), with 35-36 children per age group, starting from
258 5 years old²⁸. High performance of typically developing children on CVIT 3-6 (median 4 or 5
259 out of 5 in all but two subtests) makes differentiation between patients possible with only five
260 items per subtest compared to for instance 30-50 in the BEVPS²⁸, making our tool more
261 suitable for clinical practice. Last, CVIT 3-6 is the first test to include motion perception tasks,
262 a task that is currently lacking in any of the paper and pencil tests and a common problem in
263 CVI in clinical experience.

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

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

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

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

293 Acknowledgments

294 We would like to thank the participating schools, children, and parents. We are also grateful
295 for the input from the clinical team of Centre for Developmental Disabilities (University
296 Hospitals Leuven, Belgium) during development of CVIT 3-6. Silke Bäumer, Anne Ballet, and
297 Kerensa Nelissen assisted in piloting early versions of CVIT 3-6. We thank Rudy
298 Dekeerschieter and Christophe Bossens for their support in programming the tool. The work
299 was supported by long-term structural funding from the Flemish Government to JW
300 (METH/08/02 and METH/14/02).

301 Conflict of interest

302 The authors report no conflicts of interests.

303 References

- 304 1. Ortibus EL, De Cock PP, Lagae LG. Visual Perception in Preterm Children: What Are
305 We Currently Measuring? *Pediatr Neurol*. 2011;45(1):1–10.
- 306 2. Dutton GN, Bax M. Visual impairment in children due to damage to the brain. Mac
307 Keith; 2010. 352 p.
- 308 3. Khetpal V, Donahue SP. Cortical visual impairment: Etiology, associated findings, and
309 prognosis in a tertiary care setting. *J Am Assoc Pediatr Ophthalmol Strabismus*.
310 2007;11(3):235–9.
- 311 4. Bosch DGM, Boonstra FN, de Leeuw N, Pfundt R, Nillesen WM, de Ligt J, et al. Novel
312 genetic causes for cerebral visual impairment. *Eur J Hum Genet*. 2016;24(5):660–5.
- 313 5. Fazzi E, Signorini SG, Bova SM, La Piana R, Ondei P, Bertone C, et al. Spectrum of
314 Visual Disorders in Children With Cerebral Visual Impairment. *J Child Neurol*.
315 2007;22(3):294–301.
- 316 6. Lueck AH, Dutton GN. Vision and the brain: understanding cerebral visual impairment
317 in children. Lueck AH, Dutton GN, editors. New York, NY: American Foundation for
318 the Blind Press; 2015.
- 319 7. Fiori S, Guzzetta A. Plasticity following early-life brain injury: Insights from quantitative
320 MRI. *Semin Perinatol*. 2015;39(2):141–6.
- 321 8. Martín MBC, Santos-Lozano A, Martín-Hernández J, López-Miguel A, Maldonado M,
322 Baladrón C, et al. Cerebral versus Ocular Visual Impairment: The Impact on
323 Developmental Neuroplasticity. *Front Psychol*. 2016;7:1958.
- 324 9. Zihl J, Dutton GN. *Cerebral Visual Impairment in Children*. Vienna: Springer Vienna;
325 2015. 341 p.
- 326 10. Atkinson J, Anker S, Rae S, Hughes C, Braddick O. A test battery of child

- 327 development for examining functional vision (ABCDEFV). *Strabismus*. 2002 Jan
328 8;10(4):245–69.
- 329 11. Rossi A, Gnesi M, Montomoli C, Chirico G, Malerba L, Merabet LB, et al. Neonatal
330 Assessment Visual European Grid (NAVEG): Unveiling neurological risk. *Infant Behav*
331 *Dev*. 2017 Nov 1;49:21–30.
- 332 12. Warrington EK, James M. *The Visual Object and Space Perception Battery*. Bury St.
333 Edmunds, United Kingdom: Thames Valley Test Company; 1991.
- 334 13. Riddoch MJ, Humphreys GW. *Birmingham Object Recognition Battery*. London,
335 United Kingdom: Psychology Press; 1993.
- 336 14. Fazzi E, Signorini SG, La Piana R, Bertone C, Misefari W, Galli J, et al. Neuro-
337 ophthalmological disorders in cerebral palsy: ophthalmological, oculomotor, and visual
338 aspects. *Dev Med Child Neurol*. 2012 Aug;54(8):730–6.
- 339 15. Beery KE, Buktenica NA, Beery NA. *The Beery-Buktenica Developmental Test of*
340 *Visual-Motor Integration*, 6th edition. Minneapolis, MN: NSC Pearson; 2010.
- 341 16. Colarusso RP, Hammill DD. *Motor-free Visual Perception Test (MVPT-3)*. 3rd Editio.
342 Novata,CA: Academic Therapy Publications; 2003.
- 343 17. Stiers P, Van Den Hout BM, Haers M, Vanderkelen R, De Vries LS, van
344 Nieuwenhuizen O, et al. The variety of visual perceptual impairments in pre-school
345 children with perinatal brain damage. *Brain Dev*. 2001;23(5):333–48.
- 346 18. Wagemans J, Wichmann FA, Op de Beeck HP. Visual perception I: Basic principles.
347 In: Lamberts K, Goldstone R, editors. *Handbook of cognition*. London, United
348 Kingdom: Sage Publications; 2005. p. 3–47.
- 349 19. Wagemans J, Elder JH, Kubovy M, Palmer SE, Peterson MA, Singh M, et al. A
350 century of Gestalt psychology in visual perception: I. Perceptual grouping and figure-
351 ground organization. *Psychol Bull*. 2012 Nov;138(6):1172–217.

- 352 20. Torfs K, Vancleef K, Lafosse C, Wagemans J, De-Wit L. The Leuven Perceptual
353 Organization Screening Test (L-POST), an online test to assess mid-level visual
354 perception. *Behav Res Methods*. 2014;46(2):472–87.
- 355 21. Vancleef K, Acke E, Torfs K, Demeyere N, Lafosse C, Humphreys G, et al. Reliability
356 and validity of the Leuven Perceptual Organization Screening Test (L-POST). *J*
357 *Neuropsychol*. 2015 Sep;9(2):271–98.
- 358 22. Pitchford NJ, Mullen KT. The role of perception, language, and preference in the
359 developmental acquisition of basic color terms. *J Exp Child Psychol*. 2005
360 Apr;90(4):275–302.
- 361 23. Snodgrass JG, Vanderwart M. A standardized set of 260 pictures: norms for name
362 agreement, image agreement, familiarity, and visual complexity. *J Exp Psychol Hum*
363 *Learn*. 1980;6(2):174–215.
- 364 24. Rossion B, Pourtois G. Revisiting Snodgrass and Vanderwart's Object Pictorial Set:
365 The Role of Surface Detail in Basic-Level Object Recognition. *Perception*. 2004 Feb
366 25;33(2):217–36.
- 367 25. Panis S, De Winter J, Vandekerckhove J, Wagemans J. Identification of Everyday
368 Objects on the Basis of Fragmented Outline Versions. *Perception*. 2008
369 Feb;37(2):271–89.
- 370 26. Sassi M, Machilsen B, Wagemans J. Shape Detection of Gaborized Outline Versions
371 of Everyday Objects. *Iperception*. 2012 Dec;3(10):745–64.
- 372 27. Wagemans J, Winter J De, Beeck HP Op de, Ploeger A, Beckers T, Vanroose P.
373 Identification of everyday objects on the basis of silhouette and outline versions.
374 *Perception*. 2008;37:207–44.
- 375 28. Schmetz E, Rousselle L, Ballaz C, Detraux J-J, Barisnikov K. The BEVPS: A new test
376 battery to assess visual perceptual and spatial processing abilities in 5–14 year-old

- 377 children. *Appl Neuropsychol Child*. 2017;1–17.
- 378 29. Beving B, Eblen RE. “Same” and “Different” Concepts and Children’s Performance on
379 Speech Sound Discrimination. *J Speech Hear Res*. 1973;16(3):513–7.
- 380 30. Glucksberg S, Hay A, Danks JH. Words in Utterance Contexts: Young Children Do
381 Not Confuse the Meanings of “Same” and “Different.” *Child Dev*. 1976;47(3):737.
- 382 31. Braddick O, Atkinson J, Wattam-Bell J. Normal and anomalous development of visual
383 motion processing: motion coherence and ‘dorsal-stream vulnerability.’
384 *Neuropsychologia*. 2003;41(13):1769–84.
- 385 32. Grinter EJ, Maybery MT, Badcock DR. Vision in developmental disorders: Is there a
386 dorsal stream deficit? *Brain Res Bull*. 2010;82(3–4):147–60.
- 387

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

407 *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

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

409

410 *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

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

412

413