HAPC #1336710, VOL 0, ISS 0

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APPLIED NEUROPSYCHOLOGY: CHILD
https://doi.org/10.1080/21622965.2017.1336710

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# BEVPS: A new test battery to assess visual perceptual and spatial processing abilities in 5–14 year-old in children

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**ABSTRACT**
This study aims to examine the different levels of visual perceptual object recognition (early, intermediate, and late) defined in Humphreys and Riddoch's (1987a) model as well as basic visual spatial processing in children using a new test battery (BEVPS). It focuses on the age sensitivity, internal coherence, theoretical validity, and convergent validity of this battery. French-speaking, typically developing children ($n = 179$; 5 to 14 years) were assessed using 15 new computerized subtests. After selecting the most age-sensitive tasks though ceiling effect and correlation analyses, an exploratory factorial analysis was run with the 12 remaining subtests to examine the BEVPS' theoretical validity. Three separate factors were identified for the assessment of the stimuli's basic features (F1, four subtests), view-dependent and -independent object representations (F2, six subtests), and basic visual spatial processing (F3, two subtests). Convergent validity analyses revealed positive correlations between F1 and F2 and the Beery-VMI visual perception subtest, while no such correlations were found for F3. Children's performances progressed until the age of 9–10 years in F1 and in view-independent representations (F2), and until 11–12 years in view-dependent representations (F2). However, no progression with age was observed in F3. Moreover, the selected subtests, present good-to-excellent internal consistency, which indicates that they provide reliable measures for the assessment of visual perceptual processing abilities in children.

**KEYWORDS**
Child; development; object recognition; visual perceptual processes

## Introduction

Visual perception refers to the processes involved in the detection and recognition of visual information and determines the way in which something is seen, known, and understood (Dutton & Lueck, 2015). Indeed, visual perception is fundamental to the development of cognitive, academic, and social skills (Chokron, Cavézian, & de Agostini, 2010).

As object recognition is involved in all daily activities, it is evidently an important aspect of visual perceptual processing. Several theoretical models on visual object recognition have been elaborated from behavioral data collected in healthy and brain-damaged adults. One of the most renowned theoretical frameworks is Humphreys and Riddoch's model (Humphreys & Riddoch, 1987a), which distinguishes two processing stages in visual object recognition. First, the pre-semantic processing stage allows an object to be correctly perceived based on visual input and to be associated with structural knowledge. Second, the semantic processing stage allows the elaborated percept to be associated with semantic and functional knowledge about objects and to be named. Each processing stage encompasses multiple sub-processing steps that can be selectively impaired following a brain lesion (Rumiati, Humphreys, Riddoch, & Bateman, 1994). Studies with brain-damaged adults showed a clear dissociation between pre-semantic and semantic processing stages, in case of right or left lateralized lesions (Warrington & Taylor, 1978), and in cases of integrative agnosia (Butter & Trobe, 1994; De Renzi & Lucchelli, 1993; Humphreys & Riddoch, 1987a).

This paper will focus on the pre-semantic processing stage including four levels (Charnallet, 1998; Humphreys & Riddoch, 1987a, 2006). The first level known as "early analysis" regroups the processes involved in the treatment of basic shape components and in the parallel coding of the local and global features of the object (internal details and contours). In the second level called "intermediate analysis," local and global traits are integrated to form a complete and flexible representation of objects (Humphreys & Riddoch,

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2006; Riddoch et al., 2008). The parallel processes at work in intermediate analysis enable figure-ground discrimination and visual closure, and allow local and global perceptual features to be grouped into a global view-dependent representation of the object. These processes play a crucial role in the perceptual organization of the visual world by allowing us to use individual objects while ignoring background information. The third processing level known as "late analysis" leads to the elaboration of a 3D-object structures representation that is a view-independent representation of the object. As a result, objects that are presented from different points of view could be matched with episodic representations stored in memory at each encounter with this object, on the basis of one or more distinctive characteristics (i.e., main axis, critical distinctive features, Q3 Humphreys & Riddoch, 1987). The fourth, pre-semantic processing level, allows access to stored knowledge on the physical characteristics of forms and objects, and to match these with a prototypical representation stored in the long-term memory (Humphreys & Riddoch, 2006; Peissig & Tarr, 2007). These two last processing levels are regrouped into the name "late analysis" as they both included mnesic representations.

As can be seen in the aforementioned section, the pre-semantic stage involves different processing levels that allow the construction of an elaborated percept based on the view-dependent and independent representations of object and, on the access to stored structural knowledge. In contrast, the semantic stages include the access to stored semantic and functional knowledge in long-term memory, and the object naming (Humphreys & Riddoch, 1987a, 2006; Riddoch et al., 2008).

Based on their theoretical model and clinical observations of subgroups of brain-damaged adults, Humphreys and Riddoch (1993) developed the Birmingham Object Recognition Battery (BORB) to characterize specific patterns of impairments. However, while the BORB is a useful screening tool for the assessment of a large number of perceptual processes, some processes are not examined with this tests battery. For example, in terms of intermediate processing, only figure-ground discrimination is evaluated, and no test is proposed to assess visual closure and local-global processing abilities. Moreover, some BORB's drawings are unattractive or represent objects that are little or not at all known to children (e.g., thimble). Finally, the efficient use of objects and the interaction with them also depends on spatial processing skills such as the object's location and its spatial orientation (Chaix & Albaret, 2014; Dutton, 2015; Schmetz & Rousselle, 2016), but these are not represented in Humphreys and Riddoch's (1987a) model.

Considering the importance of object recognition abilities in daily life and learning, it is surprising that no tools simultaneously assess the different visual perceptual processing levels and visual spatial processing skills in children. Such tools are crucial for the precise assessment of visual perceptual and spatial impairment in children, as they could help to determine whether and how these deficits influence cognitive development and learning abilities. In fact, many different visual perceptual tasks (mainly based on adult theoretical models) are currently used to assess these abilities in typically developing (TD) and brain-damaged children. However, to the best of our knowledge, no study has assessed all visual perceptual and spatial processing abilities simultaneously using consistent methodology.

Table 1 presents a review of existing literature on the assessment of visual perceptual and spatial processing in TD children and reveals that none of the assessment tools allow a complete evaluation of the different visual perceptual processes. For each study, the table reports the age of participants, the clinical comparison group, and the assessment tools used in reference to the different pre-semantic processing levels of Humphreys and Riddoch's model. Q4

Three studies used the original BORB subtests to assess early, intermediate, and late perceptual processing in 7- to 11-year-old TD children, and children with neuro-developmental pathologies (Gillet, Chabernaud, Batty, Barthélémy, & Jambaqué, 2009; Joy & Brunsdon, 2002; Swain, Joy, Bakker, Shores, & West, 2009). These studies highlighted the difficulties faced by participants in different clinical groups compared to TD children matched for chronological or mental age. Joy and Brunsdon (2002) found that a child with a developmental visual agnosia without brain lesion shows deficits in all three processing levels. Swain et al. (2009) showed that children with myelomeningocele and hydrocephalus diagnosed at birth display deficits in both early and late processing levels, in particular in the length judgment and the object constancy subtests. Conversely, Gillet et al. reported that children with autism showed equal performances in the different levels of analyses, except in orientation and location processing in these children, showed higher performances than TD children matched on mental age. Unfortunately, clinical groups were very small and could not reflect the heterogeneity of cognitive processing present in children with different neuro-developmental pathologies. Moreover, the developmental trajectory of these processes was not examined in TD children. It should be also noted that early processes were assessed with all four BORB subtests, while intermediate processes were assessed with only one subtest (figure-ground discrimination).

**Table 1.** Studies on visual perceptual and spatial processing in TD children.

| Study | Population | Ages | Tasks | Analysis level |
|---|---|---|---|---|
| Bova et al. (2007) | 115 TD children | 6 to 11 years 5 months | Poppelreuter Ghent test | Intermediate |
| | | | Street completion test | Intermediate |
| | | | Unusual perspectives | Late |
| | | | Unusual lighting | Late |
| | | | Imaginary figures | Late |
| Bezrukikh and Terebova (2009) | 898 TD children | 5 to 7 years | DTVP II: Figure-ground discrimination | Intermediate |
| | | | DTVP II: Constancy of shape | Late |
| | | | DTVP II: Position in space | Spatial |
| Vilayphonh et al. (2009) | 111 TD children | 5 years | EVA overlapping figures | Intermediate |
| | | | EVA fruit puzzles | Late |
| | | | EVA shape and letter matching | Early |
| Pisella et al. (2013) | 96 TD children | 4 to 12 years | Length comparison | Early |
| | | | Size comparison | Early |
| | | | Angle comparison | Early |
| | | | Position | Spatial |
| Stiers et al. (2001) | 327 TD children | 2 years 9 months to 6 years 6 months | L94: Visual matching | Early |
| | | | L94: De Vos task | Intermediate |
| | | | L94: Overlapping figures | Intermediate |
| | | | L94: Matching block designs | Spatial |
| | | | L94: Line drawings occluded by noise | Intermediate |
| | | | L94: Unconventional object views | Late |
| Weber et al. (2004) | 30 TD children | 8 to 12 years | VOSP: Incomplete letters, shape decision, progressive silhouettes | Intermediate |
| | | | VOSP: Silhouettes | Late |
| | | | VOSP: Position discrimination, number location, cube analysis | Spatial |
| Joy and Brunsdon (2002) | 6 TD children (matched to a child with agnosia) | 7 years | BORB: Size, length, orientation and localization | Early |
| | | | BORB: Overlapping figures | Intermediate |
| Gillet et al. (2009) | 8 TD children (matched to autistic children) | 5 years | BORB: Size, length, orientation, localization | Early |
| | | | BORB: Overlapping figures | Intermediate |
| | | | BORB: Object decision | Late |
| Swain et al. (2009) | 21 TD children (matched to children with spina bifida) | 8 to 11 years | BORB: Size, length, orientation, localization | Early |
| | | | BORB: Overlapping figures | Intermediate |
| | | | BORB: Object decision | Late |

Over the last ten years, a series of other batteries have been set up and used to examine the typical development of visual perceptual processes during childhood. For example, the Visual Object and Space Perception Battery (VOPS; Warrington & James, 1991), allowing the assessment of intermediate and late perceptual processing levels as well as spatial processing, was developed for adults, and then was used to collect normative data for a German-speaking population of TD children aged between 8 and 12 years (Weber, Pache, Lütschg, & Kaiser, 2004). Likewise, both the Developmental Test of Visual Perception, third edition (DTVP III, Hammil, Pearson, & Voress, 2013) and the L94 visual perceptual battery (Stiers, De Cock, & Vandenbussche, 1999) were specifically created to assess intermediate and late visual perceptual processing and visual spatial processing in 4- to 12-year-old English-speaking children and 2.5- to 7-year-old Flemish-speaking children, respectively. The different subtests assess the intermediate and late processing levels, but again neglect to evaluate the early processing components. Moreover, Stiers et al. tested TD children using the L94 visual perceptual battery to collect normative data, but the typical developmental trajectory was not systematically examined. The Test of Visual Perceptual Skills (TVPS 3, Martin, 2006), standardized for English-speaking children and adolescents aged between 4 and 19 years, includes different subtests assessing intermediate and late visual perceptual processing, as well as visual memory and visual spatial processing. No test for the assessment of early visual perceptual processing component is included in those four batteries of tests.

Recently, Chokron (2015) developed the Evaluation of Visual Attention Processing (EVA), a battery of tests designed to screen for visual attention disorders in 4- to 6-year-old French-speaking children (Vilayphonh et al., 2009). This battery includes subtests that assess various neurovisual processing (e.g., visual pursuit, visual fields), visual cognitive abilities (e.g., visual memory for shapes, selective visual attention) and certain visual perceptual abilities (e.g., figure-ground discrimination, shape matching) and thus constitute a useful assessment of neurovisual processes. However, it does not provide a complete screening of visual perceptual processing.

Finally, Pisella et al. (2013) developed a battery with six tasks inspired by the BORB and VOSP subtests and tested French-speaking children between the ages of 4 and 12 years. These tests assess only the early level of perceptual processing (e.g., length, surface) and basic spatial characteristics (e.g., localization, orientation).

None of the aforementioned studies provides a systematic assessment of the development of different visual perceptual and spatial processes in the same sample of children. Among the studies examining the visual perceptual or spatial processes (Table 1), very few reported data on the developmental course of these processes in children. As a result, there is currently no model that depicts the developmental trajectory of visual perceptual and spatial processing abilities in children or that gives indications on the hierarchy of the different visual perceptual processes in this population. Some studies reported that visual object recognition develops gradually with age in TD children (Bezrukikh & Terebova, 2009; Bova et al., 2007). Pisella et al. (2013) show a significant development of early analysis processes between the ages of 4 and 12 years with the assessment of length, size, position, and angle comparisons. Bova et al. (2007) highlighted that several processes of visual perception such as figure-ground discrimination (intermediate) as well as object constancy and view-independent object recognition (late) develop only after the age of 6 years. Some of these processes such as the perception of visual closure continue to progress after the age of 11 years. In adulthood, objects can be recognized from partial views, different points of views, or partially occluded views, indicating that the different levels of processing have matured. Pereira and Smith (2009) showed that very young children are able to recognize simple objects when presented as a whole, while 2 year olds can recognize familiar objects by processing only local parts or prototypical details of these objects. From the age of 5 years, children can recognize objects by processing local parts and a global shape as well as from outline drawings.

In summary, the different batteries of tests used to assess the typical development of visual perceptual and spatial processes in TD children provide some information regarding the developmental trajectory of the underlying processes. However, no study to date has simultaneously assessed the different processing levels of the pre-semantic stage as well as basic visual spatial processing skills in the same sample of children with typical or atypical development. Furthermore, most batteries of tests are narrow in scope; they include only a few items and provide a global score for each process without contrasting the different presentation conditions and levels of difficulties (no individual score for each condition is available). As a result, the global view of the developmental trajectories of the specific processes of visual perception remains fragmented and incomplete.

In light of these findings and concerns, the aim of the present study is to assess the different processing levels of the pre-semantic stage defined in the Humphreys and Riddoch's model (1987) as well as the basic visual spatial Q5 processing (essential for optimal object manipulation and interaction) in TD children using a new computerized battery of tests. Mainly inspired by the BORB, the subtests were supplemented with others in order to complete the assessment of intermediate visual perceptual processing such as visual closure and local-global processing abilities. The involvement of praxis, visual construction, motor, and language functions is strictly limited. It is hoped that this new tool will be of use in future studies on visual perceptual disorders in children with neuro-developmental pathologies such as Cerebral Palsy who are at risk for associated disorders such as motor disabilities, oculomotor deficits, reduced short-term memory abilities, and language impairments.

To assess the different levels of the pre-semantic processing stage (i.e., analysis of basic visual features, view-dependent and view-independent object representations, and access to structural knowledge), and basic visual spatial processes (spatial location and evaluation of distances), all BEVPS (Battery for the Evaluation of Visual Perceptual and Spatial processing in children) subtests were administered to a sample of TD children aged between 5 and 14 years. The distribution of performances was examined separately according to age and visual perceptual and spatial processing levels in order to select the most appropriate tasks by removing any that were considered too long, difficult, easy, or redundant. Exploratory factorial analysis was also performed to assess the latent factor structure of our different subtests. Finally, convergent validity was examined between the performances for our subtests using a valid test (i.e., Visual Perception subtest of the Beery-Buktenica Developmental Test of Visual-Motor Integration, VMI, 2010).

## Methodology

### Participants

This explorative study included 179 TD children aged between 5 and 14 years 11 months divided into five age groups (Table 2). The criteria for exclusion were the following: the presence of a neuro-developmental disorder (including Cortical Visual Impairment) or a

**Table 2.** Distribution of typically developing children.

| Ages | Number of children (girls-boys) | | Mean age |
|---|---|---|---|
| 5–6 years | 19 | 17 | 5 years 11 months |
| 7–8 years | 17 | 19 | 7 years 11 months |
| 9–10 years | 18 | 18 | 9 years 10 months |
| 11–12 years | 17 | 18 | 12 years 1 month |
| 13–14 years | 18 | 18 | 13 years 11 months |

medical pathology resulting in school absenteeism, the repetition of a grade in school, a learning disability, and an uncorrected eye disorder. Children included in the sample were drawn from middle-class schools in the Walloon Region, Belgium, and were tested by examiners trained to apply the method and guidelines for the administration of the tests. Informed consent was obtained from the participants and their parents in accordance with the Declaration of Helsinki.

### Materials

The new tests battery is administered on a laptop with a 15.6-inch screen. Before presenting each item, a screen appeared with a central fixed point for a duration fixed at 1200 ms to respect the speed processing of information of the youngest children and children with neuro-developmental pathologies. Responses were recorded using the Superlab 4.5 software (Cedrus Corporation, San Pedro– USA). To respond, the child had to press one of three colored switches (6 cm in diameter each yellow on the left, blue in the middle, and red on the right) corresponding to the correct response. The three switches were embedded in a wooden support and placed on the table in front of the laptop (Figure 1).



### Tasks and stimuli

We have created fifteen subtests with new attractive drawings using Paint.net free software (dotPDN LLC), Gimp free software (The GIMP Team), and Publisher software (Microsoft Office 2013) to assess the different visual perceptual and spatial processes in children. The subtests were classified into three groups: (a) visual perceptual processing subtests (divided into early, intermediate, and late processing stages), (b) visual spatial processing subtests, and (c) control subtests. The subtests could be *matching* tasks, which required the child to choose the stimulus corresponding to a target from three possibilities; *naming* tasks, in which the child had to name the stimulus; or *binary decision* task, which required the child to classify the stimulus into two categories.

Figure 1. Computer with the three response switches.

To target the processes of interest, the presentation of the items and the modality of responses were designed to reduce as much as possible the involvement of other cognitive processes such as working or long-term memory, praxis and motor skills, visual constructional aptitudes, and language abilities. In all tasks, no time limit was placed on the stimuli presentation so as to ensure that each child had sufficient time to see all items presented on the screen and avoid memory-based responses. This methodological choice was made to use these subtests in comparative studies with children presenting different neuro-developmental pathologies. The use of large switches instead of a keyboard aimed to limit the involvement of motor and praxis functions. Testing only involved perceptual processing, thus avoided visual constructional skills. While the instructions were given in the form of short sentences, the examiner also touched the target and the stimuli on the screen to explain the purpose of the subtest. One point was given for each correct response.

A series of subtests was designed to examine the different processing levels of the pre-semantic stage described in Humphreys and Riddoch's (1987a) model. Table 3 reports the different tasks used to assess each processing level as well as those for visual spatial processing (15 in total).

### Visual perceptual processing: Early analysis

The subtests examining the early level of analysis assessed the processing of local basic shape components and global features of the stimuli. Except for the detection of visual features, all other subtests in this early level of analysis (i.e., surface, length, orientation, position) were matching tasks inspired by the BORB (Humphreys & Riddoch, 1993). In each subtest, items varied according to three levels of difficulty, and within each level, the items were presented in increasing order of difficulty, with more and more subtle differences to be gradually perceived.

#### Surface

This subtest assessed the ability to estimate the surface area occupied by objects. Children were presented with four drawings of black silhouettes of everyday objects

**Table 3.** Repartition of visual perceptual processing subtests according to Humphreys and Riddoch's model (1987) as well as visual spatial processing subtests. Q6

| Visual perceptual processing | | | Visual spatial processing |
|---|---|---|---|
| Early analysis | Intermediate analysis | Late analysis | Basic components |
| Surface | Overlapping figures | Object constancy | Location in a box |
| Length | Hierarchical figures | Object decision | Topology |
| Orientation | Incomplete figures | Object completion | Evaluation of distances |
| Position | White figures | | |
| Detection of visual features | | | |

(one target and three possible answers) and asked to select one of the three silhouettes that corresponded to the target silhouette presented at the top of the screen (Figure 2a). Items varied in terms of the percentage difference in surface area between the distractors and the target (from 1% to 15%). For each item, the percentage difference was equal for both distractors, with each one either over- or underestimating the surface of the target. Three items were presented for each percentage difference in surface area, with a total of 45 items in the whole task.

### Length

This subtest assessed the ability to estimate the length of objects. Children were asked to select one of the three pencils that corresponded to the length of the target pencil (Figure 2b). In half of the items, the pencils were placed horizontally, and in the other half, vertically. As their length did not vary locally at the pencil lead, the children had to analyze the length globally. Moreover, in the vertical presentation, the three pencils were aligned at their midpoint. Similarly to the surface subtest, items varied with regard to the percentage difference in the length between the distractor and the target (from 1% to 15%). For each item, the percentage difference in the length was equal for both distractors, with each one either over- or underestimating the target length. Three items were presented for each percentage difference in length, with a total of 45 items in the whole task.

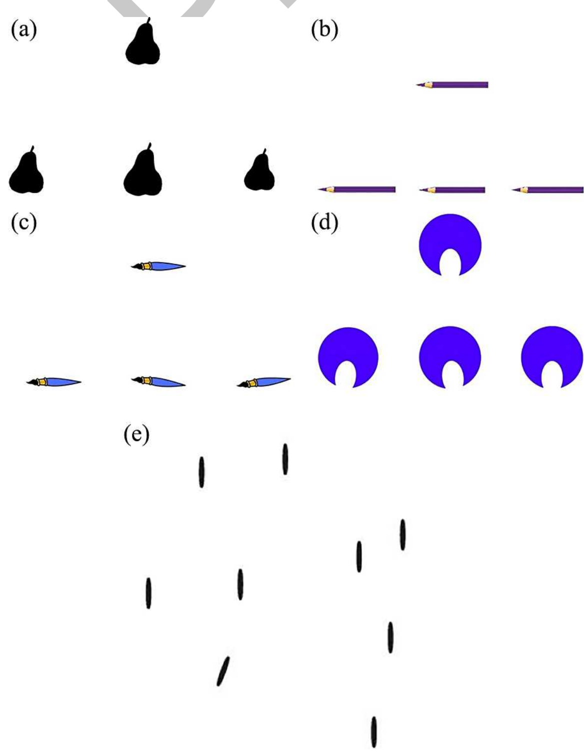


**Figure 2.** Examples of items found in the subtests for the early processing stage. (a) Surface, (b) Length, (c) Orientation, (d) Position, and (e) Detection of visual features.

### Orientation

This subtest assessed the ability to understand the orientation of objects. Children were asked to select one of three paintbrushes that corresponded to the orientation of the target paintbrush presented at the top of the screen (Figure 2c). The paintbrushes were placed horizontally, vertically, or in an oblique position (±45° from the vertical axis). For each item, the two distractors were presented with either a clockwise or counterclockwise rotation of 1°, 3°, 5°, 7°, 9°, 11°, 13°, or 15° from the target position, with the amount of deviation being equal for both distractors. A total of 64 items were presented in this subtest, with eight items for each 1° rotation (two horizontal, two vertical, two oblique to the left, and two oblique to the right).

### Position

This subtest assessed the ability to evaluate the relative position of objects. Children were presented with discs with a semi-circular opening. They were asked to select one of three discs that corresponded to the position of the target disc (Figure 2d). The opening of the target was oriented horizontally for half of the trials (left/right counterbalanced) and vertically for the other half (top/down counterbalanced). For each item, the two distractors presented either a clockwise or counterclockwise rotation of 1° to 15° from the position of the target, with the amount of deviation being equal for both distractors. Four items were presented for each 1° rotation, with a total of 60 items in the whole task.

### Detection of visual features

This subtest assessed the perception of line orientations as based on the protocol in the study of Ballaz, Boutsen, Peyrin, Humphreys, and Marendaz (2005). The subtest was divided into two detection tasks (Figure 2e). Children had to decide (a) whether an oblique line was hidden among a set of vertical lines (oblique detection) and, inversely, (b) whether a vertical line was presented among a set of oblique lines (vertical detection). The size of the display increased in complexity with three, six, and then nine lines. For each display size, 16 items were presented, with a total of 48 items in each of the two detection tasks.

## Visual perceptual processing: Intermediate analysis

The subtests examining the intermediate level of analysis assessed a child's ability to integrate local and global traits into a view-dependent representation of an object. Four subtests were proposed to each participant: (a) overlapping figures to assess figure-ground discrimination abilities, (b) hierarchical figures to test local-global perceptual processing, (c) incomplete figures to assess visual closure on everyday objects, and (d) white figures to examine visual closure on geometrical shapes. In the overlapping and incomplete figures subtests, items belonged to four different semantic categories (utensils, furniture, clothing, and animals) and were selected based on the ability of a 5-year-old child to name the objects or animals. For each picture, the success rate was between 95% and 100% (Cannard et al., 2006).

### Overlapping figures

This subtest assessed the ability to discriminate between figure and ground. Children were presented with two, three, or four overlapping black outline drawings on a white background and were asked to identify the overlapping figures. This subtest included two tasks administered in the following order: a naming task in which participants had to name the different objects (Figure 3a) and a matching task in which participants

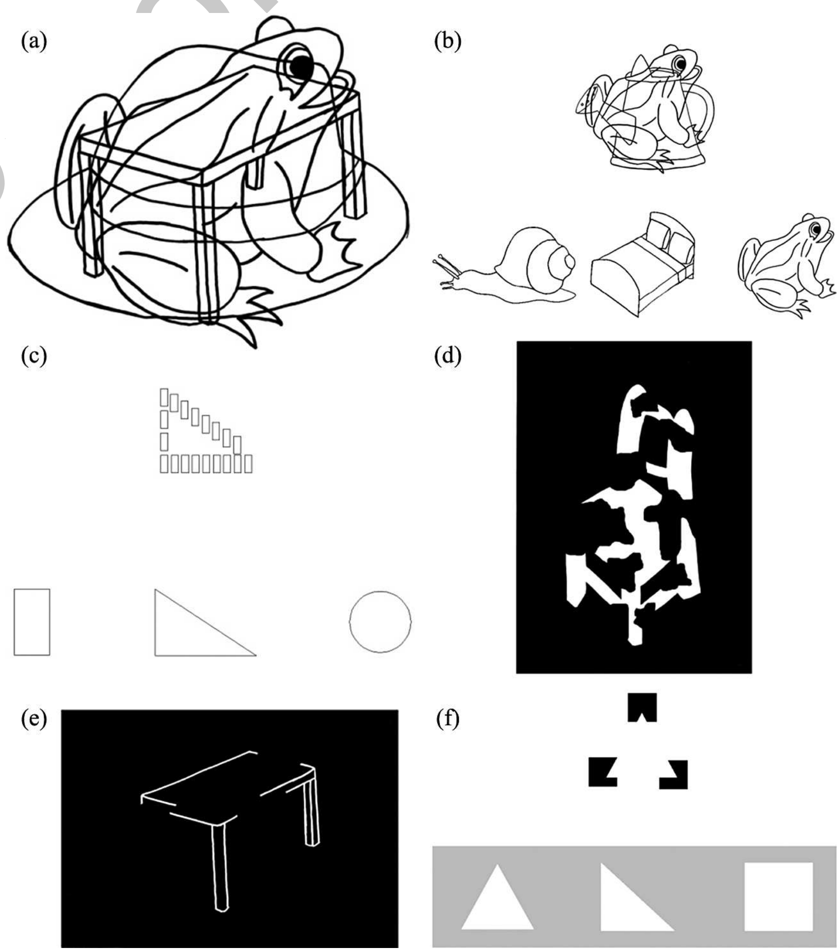


**Figure 3.** Examples of items found in the subtests for the intermediate processing stage. (a) Naming task and (b) Matching task from the overlapping figures subtest, (c) Hierarchical figures subtest, (d) White silhouette task, and (e) Outlined drawing task from the incomplete figures subtest, and (f) White figures subtest.

had to identify among three pictures the one hidden in the overlapping figures (Figure 3b). Each task consisted of 36 items. The naming task began with 12 items with fully overlapping figures, followed by 12 items with a partial overlap, and then 12 items with figures with no overlap but touching outlines. For each overlapping level, children were first presented with two, three, and then four figures, each with four items. In the matching task, all items included fully overlapping figures with eight, twelve, and sixteen items for two, three, and four figures, respectively, presented in a counterbalanced order.

### Hierarchical figures

This subtest, drawing from the study of Navon (1977), assessed the preferential perceptual processing strategy (global or local) used to identify forms. Children were presented with a series of basic shapes (local) arranged to form a geometric figure (global). The subtest was divided into two tasks in which children had to select one of three shapes corresponding to either the overall shape of the stimuli (global identification task, see Figure 3c) or the constitutive elements (e.g., crosses) (local identification task). Local and global identification tasks were administered in a counterbalanced order. Each task consisted of 30 items presented in random order; in half of the items, the local and global features referred to the same shape (e.g., a square made of squares), and in the other half, the local and global features corresponded to different shapes (e.g., a square made of triangles). Figures consisted of simple (rectangle, square, triangle, circle, and ellipse) and complex geometric shapes (diamond, star, cross, and hexagon).

### Incomplete figures

Inspired by Biederman's (1987) work, this subtest assessed the visual closure of objects, that is, the ability to form a coherent global perception based on an object's local features. Children were asked to recognize and name living and non-living objects depicted by a white image on a black background degraded by 50%. Again, this subtest was divided into two 30-item tasks: (a) one task presented white silhouettes (Figure 3d) and (b) the other presented white outline drawings (Figure 3e). These two tasks were administered in a counterbalanced order across participants. The image degradation was either in the middle of the drawing (for the easiest items), at the intersections, or on the prototypical parts. Each task started with 10 items degraded on the prototypical part, followed by the 10 items degraded at the intersections, and then the 10 items with the degradation in the middle.

### White figures

This subtest assessed visual closure abilities on geometrical shapes. Children were presented with 10 simple white geometric figures surrounded by black shapes suggestive of the white figure's edges, as a variation of the Kanisza (1979) figures. This subtest included two tasks administered in the following order: a naming task in which participants had to name the white shape and a matching task in which they had to select one of three shapes that corresponded to the target (Figure 3f).



## Visual perceptual processing: Late analysis

Three subtests inspired from the BORB (Humphreys & Riddoch, 1993) were included to assess late analysis, namely object constancy, object decision, and object completion. These subtests examined the children's ability to form a view-independent perception of the object.

### Object constancy

Object constancy is a matching task designed to assess the visual recognition of objects presented from an unconventional perspective. This subtest was divided into two distinct tasks: one with black outline drawings on a white background (Figure 4a) and the other one with colored drawings. The two tasks were administered in a counterbalanced order across participants. Children were asked to select one of three possibilities that matched the target object presented from a different perspective. Correct answers represented the target object from nine possible perspectives (rotation of 45°, 90°, 135°, 180°, 225°, 270°, and 315° on the horizontal

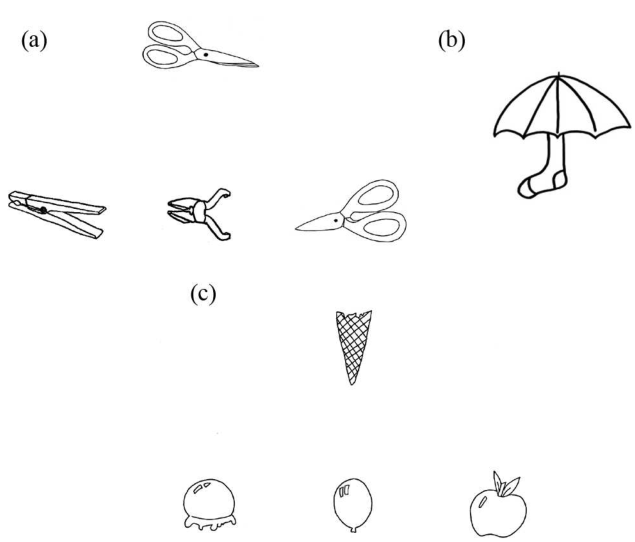

Figure 4. Examples of items found in the subtests for the late processing stage. (a) Object constancy, (b) Object decision, and (c) Object completion.

plane, and two vertical views from above and below). The distractors presented objects with a similar overall shape to the target. For each task, three items were presented for each rotation or view, with a total of 54 items.

### Object decision

Object decision is a subtest designed to evaluate the access to the 3D-structural representation of the object based on known, physical characteristics. Children were presented with a series of black outline drawings presented on a white background and were asked to decide whether the presented object was real or not (Figure 4b). A total of 32 items were presented in random order, with 16 items with living objects (e.g., owl, dog) and 16 with nonliving objects (e.g., trousers, chair). In each category, half of the items were real objects presented from a prototypical perspective, while the other half were nonreal objects created by assembling the parts of real objects.

### Object completion

Object completion is a matching task assessing the ability to access the structural description of the object on the basis of its local parts. Children were presented with parts of an object and had to choose the missing parts of the target object from among three possibilities (Figure 4c). The subtest included 10 items with living objects (e.g., owl, dog) and 10 items with nonliving objects (e.g., trousers, chair) presented in random order, with a total of 20 items. The distractors consisted of parts of real objects presenting a similar global shape to the correct response.

## Visual spatial processing

Visual spatial processing was assessed in a series of three matching tasks, namely location in a box, topology, and evaluation of distances, which were designed to examine how children process spatial relationships.

### Location in a box

Location in a box is a matching task designed to test the ability to determine the position of elements in an overall configuration. It was inspired by the block matching task of the L94 battery (Stiers et al., 2001). This subtest was divided into two distinct tasks: one had a grid within the frame and the other only a frame; both tasks included one, two, or three red squares. The two tasks were administered in a counterbalanced order across participants. Children were asked to select one of three possible frames with red squares located in the same position as the target (Figure 5a). Among the three proposals, one was identical to the target, one presented the red squares in the same arrangement but in another position within the frame (displacement error), and one presented the red squares in a different arrangement with one square displaced to another position within the frame (distortion error). The size of the frame and the number of red squares were manipulated to create items of increasing difficulty presented in the following order: 16-cell frame (four items with one square and four items with two squares), 25-cell frame (10 items with two squares), 36-cell frame (10 items with two squares and 10 items with three), and 49-cell frame (10 items with two squares and 10 items with three), with 58 items per task for a total of 116 items.



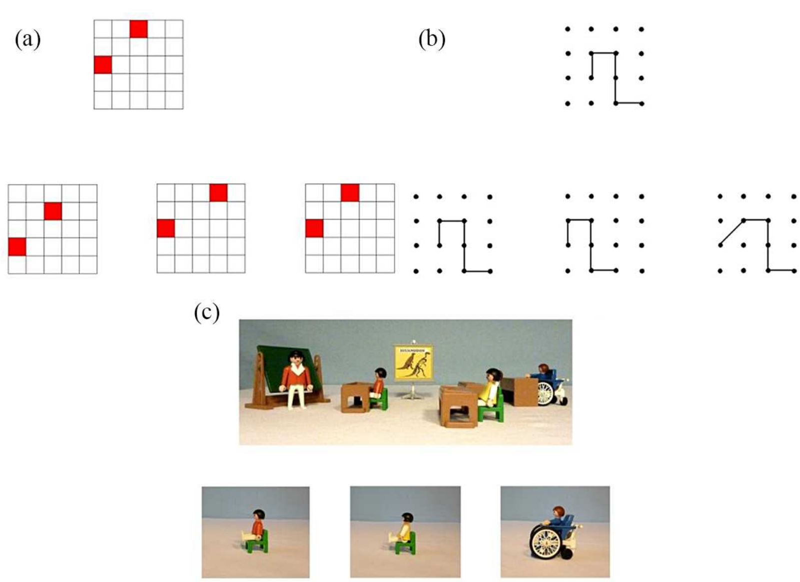


**Figure 5.** Examples of items found in the subtests for visual spatial analysis. (a) Location in a box, (b) Topology, and (c) Evaluation of distances.

### Topology

Inspired by the DTVP II spatial relation test (Hammil, Pearson, & Voress, 1993), this subtest assessed the ability to discriminate topographical relationships between different interrelated elements. Children were presented with a square matrix in a regular arrangement of 9, 12, 16, 25, or 36 black dots. Within this arrangement, some of the dots (3 to 10 dots) were connected to each other by lines that formed a path (Figure 5b). Children were asked to select the same arrangement as the target from among three possibilities (i.e., the same path located in the same position). Among the three proposals, one was identical to the target, one presented the interconnected dots in the same arrangement but in another position within the matrix (displacement error), and one presented the interconnected dots in a different arrangement in which one dot was displaced by one position (distortion error). The size of the matrix and the number of interconnected dots were manipulated to create items of increasing difficulty administered in the following order: 9-dot matrix (four items with three interconnected dots), 12-dot matrix (four items with four interconnected dots), 16-dot matrix (four items with five interconnected dots followed by four items with six interconnected dots), 25-dot matrix (four items with seven interconnected dots followed by four items with eight interconnected dots), and 36-dots matrix (four items with nine interconnected dots followed by four items with ten interconnected dots), for a total of 32 items in the subtest.

### Evaluation of distances

This subtest assessed the judgment of relative distances between elements in the child's environment and in a visual scene. Children were presented with photographs of Playmobil figures (men, women, children, animals, and everyday objects) that depicted a daily life scene (Figure 5c). The subtest was divided into two distinct tasks requiring the child to assess the distance using an egocentric or allocentric cue. These two tasks were administered in a counterbalanced order across participants. In the estimation of egocentric distance, the child had to choose the character closest to him from among three possible answers. In the evaluation of allocentric distance, the child had to identify the closest character to a target object. A distance of 3, 4, 5, 7, and 10 cm separated the characters from one another. The items were presented in an increasing order of difficulty, with items with larger distances being presented first (random presentation within each distance). For each task of the subtest, there were six items per distance, with a total of 60 items.

### Control subtests

Two additional subtests were administered as a control task to measure the children's speed processing and naming abilities.

### Reaction time

The reaction time subtest is a matching task used to measure the general processing speed required to provide a manual motor response using the switches, the matching skills, and to measure visual-attention abilities. These individual motor response latencies were used to control for inter-individual differences in general processing speed in the matching tasks. Children were presented with 24 colored geometric shapes (e.g., circle, arrow, rectangle, and cross) and were asked to select the identical stimuli from among three possibilities. The distractors were highly distinguishable from the targets as they differed in shape, size, and color to minimize perceptual processing. As in the other matching tasks of the battery, stimuli were left in full view with no time limit.

### Picture naming

In the picture-naming task, children were asked to name 45 black outline drawings of objects and animals presented in the battery. This was implemented to ensure that the children knew the names of the pictures used in the different subtests without any additional perceptual processing requirements.

## Procedure

Children were tested individually in a quiet room. The administration of subtests was distributed over three to five sessions of 45 minutes maximum depending on the child's attention. The order of the subtests was counterbalanced across children with the exception of the two control subtests: reaction times was the first subtest administered to allow the children to become familiarized with the equipment, while picture naming was the final subtest. Each subtest started with two practice trials that presented the easiest items to ensure that children understood the instructions and requirements of the task. No feedback was provided during the test. Children answered in an autonomous manner, with the examiner only intervening in the case of technical problems or to recall the instructions if needed.

## Results

All computations were performed using Statistica 13 software (StatSoft France). Accuracy data did not fit a normal distribution; as a result, percentages (P) of correct responses were subjected to a natural logarithm transformation using the formula LN [P/(100–P)]. Despite this transformation, our data did not follow a normal distribution. Accordingly, data were analyzed using non parametric statistics each time when it was appropriate.

First, the selection of the most appropriate tasks is performed by removing any that were considered too easy (ceiling effect analyses) or redundant (correlation analyses). Children were considered to perform at ceilings in tasks where they reached at least 95% of correct responses from the younger age groups. Percentages of correct responses of TD children in the 15 subtests of the battery are presented in Table 4.

Second, internal consistency was examined in each of the 12 remaining subtests using the Cronbach α coefficient to assess subtest reliability of the underlying processes.

Third, the theoretical validity of the battery was examined by exploring the latent factorial structure of the different subtests. It was analyzed using exploratory factor analysis with normal Varimax rotation, which represents the best choice for our type of data because it maximizes the variance on the factors and provides a clear structure of the factor weights. This analysis aimed to determine whether the latent structure reflect the different processing levels of the Humphreys and Riddoch's (1987a) model, and how the different subtests co-vary with the underlying latent factors.

Fourth, correlation analyses were performed to examine a possible correlation between the scores obtained on the Visual Perception subtest of the Beery-VMI (VP; Beery, Buktenica, & Beery, 2010) and the scores obtained on each of our subtests. This VP subtest allows the assessment of visual-perceptual matching abilities, and only requires identifying each item's identical match from a set of similar shapes with limited task motor requirements. Based on factorial analysis, a global score of performances for each of the three factors was computed. Correlation analyses were also performed to determine a possible correlation between the scores obtained on the VP and these global scores.

Lastly, nonparametric Kruskal-Wallis tests (with a significance level of 5%) were separately conducted for each factor on percentages of correct responses to assess the effect of Age (5–6, 7–8, 9–10, 11–12, 13–14). When statistically differences were detected, separate nonparametric Mann-Whitney with Bonferroni adjustments for multiple comparisons (with a significance level of 5%) were performed to determine performances differences between age groups.

### *Task sensitivity*

As depicted in Table 4, results showed the presence of a ceiling effect on the colored drawings task of the object constancy subtest and on some parts of the overlapping



**Table 4.** Descriptive statistics: Mean percentage of correct responses and standard deviation for each subtest according to the five age groups.

| | 5–6 years | | 7–8 years | | 9–10 years | | 11–12 years | | 13–14 years | |
|---|---|---|---|---|---|---|---|---|---|---|
| Visual perceptual processes | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* | *M* | *SD* |
| *Early level* | | | | | | | | | | |
| Length | 47.9 | 10.7 | 48.5 | 11.9 | 49.7 | 12.1 | 53.9 | 16.4 | 56.0 | 12.1 |
| Surface | 57.7 | 13.2 | 62.5 | 11.9 | 65.2 | 10.8 | 68.8 | 9.8 | 65.6 | 11.8 |
| Orientation | 60.5 | 11.5 | 69.2 | 8.2 | 70.4 | 10.9 | 75.4 | 6.5 | 73.8 | 10.7 |
| Position | 70.1 | 10.8 | 76.0 | 13.9 | 80.4 | 10.5 | 84.4 | 7.8 | 83.9 | 6.1 |
| Detection of visual features | 86.8 | 11.8 | 90.2 | 8.4 | 94.7 | 6.2 | **95.8** | 7.3 | **96.3** | 6.9 |
| *Intermediate level* | | | | | | | | | | |
| Overlapping figures naming: Complete | 66.0 | 16.9 | 82.1 | 16.1 | 92.6 | 8.2 | 93.9 | 6.9 | 94.7 | 6.0 |
| Overlapping figures naming: Partial | **97.0** | 5.7 | **99.3** | 4.2 | **99.1** | 3.3 | **99.7** | 1.4 | **100.0** | 0 |
| Overlapping figures naming: Touching | **99.8** | 1.4 | **99.3** | 3.1 | **100.0** | 0 | **99.3** | 2.4 | **99.8** | 1.4 |
| Overlapping figures matching | **96.9** | 4.3 | **98.3** | 2.3 | **98.4** | 3.1 | **99.5** | 1.3 | **98.7** | 2.3 |
| Hierarchical figures | 85.9 | 15.9 | 91.1 | 9.7 | **95.4** | 6.3 | **96.8** | 5.6 | **97.7** | 4.7 |
| Incomplete figures: Silhouettes | 54.0 | 25.2 | 69.1 | 17.0 | 78.7 | 14.1 | 87.2 | 11.9 | 91.0 | 10.1 |
| Incomplete figures: Outline | 89.1 | 10.1 | 94.9 | 6.1 | **96.5** | 4.8 | **98.5** | 2.3 | **98.8** | 2.4 |
| White figures | 78.2 | 16.9 | 91.8 | 11.8 | **96.4** | 6.2 | **98.4** | 4.6 | **98.7** | 2.5 |
| *Late level* | | | | | | | | | | |
| Object constancy: Outline | 87.9 | 7.4 | 89.2 | 7.0 | 93.7 | 5.3 | **95.5** | 5.4 | **95.3** | 3.7 |
| Object constancy: Colored | **96.2** | 5.5 | **95.1** | 9.0 | 93.4 | 14.6 | **96.6** | 8.1 | **95.6** | 11.9 |
| *Visual spatial processes* | | | | | | | | | | |
| Location in a box: Grid | 83.7 | 18.4 | 90.1 | 9.7 | 83.4 | 12.8 | 85.5 | 16.0 | 80.9 | 15.6 |
| Location in a box: No grid | 83.5 | 14.9 | 88.4 | 8.8 | 83.7 | 12.5 | 84.4 | 15.0 | 79.6 | 17.5 |
| Topology | 89.2 | 15.8 | 94.5 | 7.7 | 91.4 | 8.6 | 90.8 | 11.6 | 86.9 | 14.9 |
| Distances: Egocentric | 85.9 | 13.9 | 88.4 | 11.2 | 85.1 | 14.6 | 84.9 | 13.3 | 83.8 | 11.4 |
| Distances: Allocentric | 88.5 | 7.5 | 88.9 | 8.0 | 85.6 | 10.0 | 86.8 | 13.4 | 86.5 | 8.5 |

*Note*. All scores are significantly higher than chance ($ps < .05$), set at 33% because of the three response possibilities in each matching task. Bold numbers represent performances reaching the ceiling level (>95% of correct responses).

figures subtest (i.e., matching task; partially overlapping and touching items of the naming task). The detection of visual features subtest proved to be time-consuming to administer and unattractive for children, as they had difficulty maintaining their attention and completing this task (e.g., they frequently said that it was too long or it was not fun). Subsequently, these different tasks were removed from the battery.

Correlation analyses were used to examine whether some tasks were redundant. These analyses revealed significant positive correlations between the white silhouette drawing and outline drawing tasks in the incomplete figure subtest ($r = 0.52$; $p < .001$) and between the white silhouette drawing task of the incomplete figures subtest and the white figures subtest ($r = .56$; $p < .001$). Indeed, these tasks assessed the same processing (i.e., visual closure). Subsequently, the easiest correlated tasks were systematically removed as they proved to be less discriminating (i.e., outline drawing task of the incomplete figure subtest and the white figure subtest). The more difficult silhouette drawing task of the incomplete figures subtest was retained, as children's performances did not reach the ceiling level. Correlation analysis also revealed significant positive correlations between the location in a box and topology subtests ($r = 0.75$; $p < .001$). As these two subtests assessed the same processing (i.e., spatial localization), the easiest subtest (i.e., topology) was removed.



### Internal consistency

The majority of subtests reached coefficients exceeding .80 (Table 5). These high reliability indexes suggest that the subtests are a reliable measure of the underlying processes with highly correlated items. Slightly lower reliability was observed in the length, surface, and overlapping figures (naming task) subtests, with coefficients ranging between .70 and .80, which are acceptable coefficients of internal consistency. No coefficient could be calculated for the object decision subtest, because it presented a near zero variance. For the object completion subtest, the coefficient of internal consistency reached only .59, which represents a low reliability measure. Such a low coefficient might indicate that the subtest items measure different latent variables, resulting in a lower correlation between items.

**Table 5.** Coefficients of internal consistency (Cronbach alphas) for each subtest.

| Visual perceptual processes | α Cronbach coefficients |
|---|---|
| *Early level* | |
| Length | .73 |
| Surface | .74 |
| Orientation | .80 |
| Position | .85 |
| *Intermediate level* | |
| Overlapping figures naming: Complete | .79 |
| Hierarchical figures | .92 |
| Incomplete figures: Silhouettes | .93 |
| *Late level* | |
| Object constancy: Outline drawings | .82 |
| Object decision | / |
| Object completion | .59 |
| *Visual spatial processes* | |
| Location in a box: Grid | .93 |
| Location in a box: No grid | .92 |
| Distances: Egocentric | .85 |
| Distances: Allocentric | .81 |

### Theoretical validity

Exploratory factor analysis conducted on the remaining 12 subtests with developmental data yielded three factors that explained 56.78% of the model's variance. The output factors did not reflect the structure proposed in Humphreys and Riddoch's model. Q7

As shown in Table 6, the four subtests of early analysis (length, surface, position, and orientation) loaded on Factor 1 (early analysis), which captured 16% of the variance. Factor 2 (intermediate and late analyses) explained 21.62% of the variance and regrouped six subtests, which respectively assess the ability to form a view-dependent and -independent representation of the object, and to access to the structural representation of the object: the three subtests in the intermediate analysis, namely, hierarchical figures, overlapping figures (completely overlapping items of the naming task), and incomplete figures (white silhouette drawing task), and the three subtests in the late analysis, namely

**Table 6.** Factor loadings for exploratory factor analysis of BEVPS subtests.

| | Factor 1 (Early analysis) | Factor 2 (Intermediate and late analyses) | Factor 3 (Spatial analysis) |
|---|---|---|---|
| Length | **.76** | .04 | .03 |
| Surface | **.73** | .30 | .01 |
| Orientation | **.71** | .34 | .00 |
| Position | **.51** | .40 | −.08 |
| Hierarchical figures | −.05 | **.76** | .06 |
| Object constancy: Outline drawings | .17 | **.74** | .03 |
| Overlapping figures naming: Complete | .27 | **.72** | .00 |
| Incomplete figures: Silhouettes | .34 | **.66** | .04 |
| Object completion | .28 | **.54** | −.14 |
| Object decision | .11 | **.50** | .13 |
| Location in a box: Grid | −.08 | −.09 | **.90** |
| Location in a box: No grid | .11 | −.07 | **.87** |
| Distances: Egocentric | .01 | −.02 | **.80** |
| Distances: Allocentric | −.18 | .05 | **.65** |

*Note*. Factor loadings >.50 are in boldface. We applied a normal varimax rotation to raw data to maximize the variance on the factors and obtain a clear structure of the factor weights.

**Table 7.** Coefficients of correlations between the VP subtest of the Beery-VMI and our different subtests and factors.

| Visual perceptual processes | Visual perception subtest Beery-VMI |
|---|---|
| *Early level* | |
| Factor 1 | .52 |
| Length | .32 |
| Surface | .41 |
| Orientation | .46 |
| Position | .40 |
| *Intermediate level* | |
| Factor 2 | .57 |
| Overlapping figures naming: Complete | .45 |
| Hierarchical figures | .37 |
| Incomplete figures: Silhouettes | .46 |
| *Late level* | |
| Object constancy: Outline drawings | .43 |
| Object decision | .21 ns |
| Object completion | .40 |
| *Visual spatial processes* | |
| Factor 3 | −.04 ns |
| Location in a box: Grid | .00 ns |
| Location in a box: No grid | .06 ns |
| Distances: Egocentric | .04 ns |
| Distances: Allocentric | .02 ns |

*Note.* ns means that the coefficient of correlation is not significant at a 95% confidence level.

object constancy (outline drawing task), object completion, and object decision subtests. Finally, the two subtests assessing basic spatial dimensions of visual perception, namely location in a box (with and without grid tasks) and evaluation of distances (egocentric and allocentric tasks), loaded on Factor 3 (spatial analysis), which explains 19.16% of the variance.

## Convergent validity

Table 7 shows the significant positive correlations between the VP and the tasks assessing visual perceptual processing, except for the object decision subtest ($r = .21$, $p > .05$). Subtests assessing basic visual spatial processing did not show any significant correlations with the VP. Table 7 also shows the significant positive correlations between Factor 1 and VP scores ($r = .52$, $p < .05$), and between Factor 2 and VP scores ($r = .57$, $p < .05$), but no significant correlation between Factor 3 and VP scores ($r = -.04$, $p > .05$).

## Developmental trajectories

As shown in Figure 6, nonparametric Kruskal-Wallis tests (with a significance level of 5%) were separately conducted for each factor on percentages of correct responses, and revealed that Factors 1 and 2 showed a significant increase in performance across ages (5–6, 7–8, 9–10, 11–12, 13–14), $H(4) = 37.63$; $p < .001$, and $H(4) = 100.59$; $p < .001$, respectively. Factor 3 did not show any significant increase in performance across age, $H(4) = 6.31$; $p > .05$. More specifically, in Factor 2, the effect of age was computed separately for the subtests loading to intermediate and late levels of analysis, to compare their two developmental curves, and to be sure that no great age discrepancy was present between the construction of view-dependent and -independent object representation, which are clearly separate in adult literature. These two levels showed a significant increase in performance with age, $H(4) = 88.16$; $p < .001$, and $H(4) = 66.53$; $p < .001$, respectively. Factor 1 showed a significant improvement in the performances of children aged between 5–6 and 9–10 years, 11–12 years, 13–14 years ($ps < .001$), and between 7–8 and 11–12 years ($p < .002$), 13–14 years

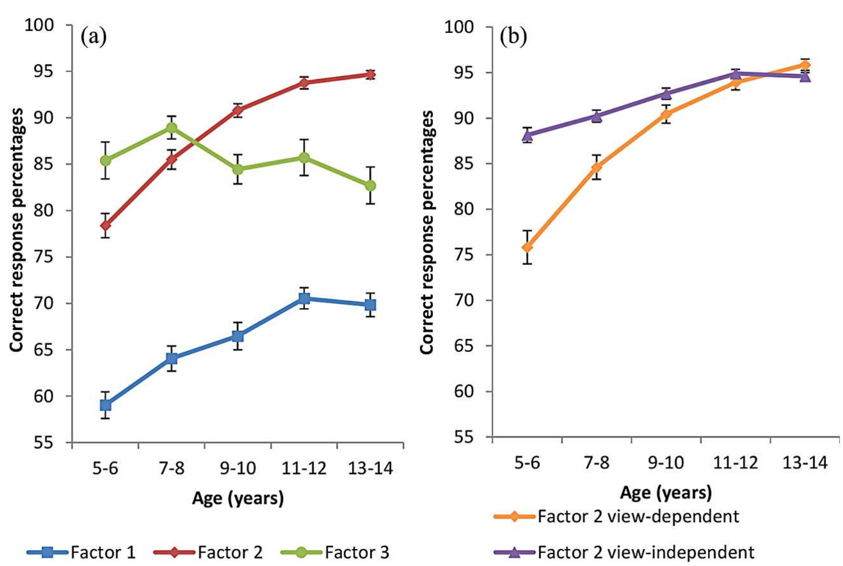


**Figure 6.** Correct response percentages presented by (a) factor and (b) view type in factor 2 *Note.* Error bars represent standard error of the mean.

($p < .006$). Children's performances also vary according to age in Factor 2 (global) for view-dependent object recognition: 5–6 years <7–8 years <9–10 years <11–12 years = 13–14 years ($ps < .001$); as well as view-independent object recognition: 5–6 years = 7–8 years <9–10 years = 11–12 years = 13–14 years ($ps < .001$).

## Discussion

The present study aimed to assess the different processing levels of the presemantic stage of Humphreys and Riddoch's model as well as basic visual spatial abilities in the same sample of TD children. Therefore, 15 subtests were created and administered to 179 children aged between 5 and 14 years 11 months who were divided into five age groups. The most relevant tasks were selected by excluding subtests or tasks with a ceiling effect (over 95% of correct answers) in younger children as well as tasks that were too long or redundant in comparison with other tasks (i.e., assessing the same visual perceptual or spatial process). The final battery of tests therefore includes ten subtests for visual perceptual assessment and two subtests for visual spatial assessment after the elimination of 30% of the total amount of items found in the original battery. Using an exploratory factorial analysis, results showed that the 12 remaining subtests are organized into three latent factors.

Factor 1 accounts for the variance of four subtests (length, surface, orientation, and position), and shows satisfactory to very good coefficients of internal consistency. In accordance with Humphreys and Riddoch's model, these subtests assess the early level of visual perceptual processing, allowing for the analysis of basic shape components and the coding of local and global parts of an object.

Factor 2 accounts for a large part of the variance and includes six subtests. Unlike Humphreys and Riddoch's model, the subtests assessing the intermediate and late levels of visual perception processing were regrouped under the same factor. As expected, this includes three subtests (incomplete figures, overlapping figures, and hierarchical figures) that correspond to the intermediate processing level and relate to the ability to integrate local and global traits into a view-dependent recognition of an object. Unexpectedly, however, this factor also included three subtests (object constancy, object decision, and object completion) corresponding to the late processing levels, which allows an object to be recognized from a view-independent representation through prototypical representations stored in long term memory (Humphreys & Riddoch, 2006; Peissig & Tarr, 2007).

One possible explanation for the division of our visual perceptual subtests into only two latent factors could relate to the nature of the perceptual processing demand. In subtests loading on Factor 1, the child is requested to process a single characteristic of simple shapes and lines that could be performed by processing local (e.g., length) or global (e.g., surface) information about the stimuli. By contrast, the subtests loading on Factor 2 consisted of objects presented in different conditions (e.g., overlapping) and from different viewpoints (e.g., unconventional perspective), which demand the analysis and integration of both local and global information. Thus, we could assume that the subtests loading on Factor 1 involve the visual analysis and coding of basic local details or simple shapes, while the subtests loading on Factor 2 involve integrative and transformative visual perceptual processes that allow the object to be recognized based on view-dependent or -independent representations. This could explain why our results did not distinguish between these different processing levels as in Humphreys and Riddoch's model.

It is worth noting that various studies of visual object recognition in children do not reveal any hierarchical structure between the different visual perceptual processes, questioning both the independence of visual perceptual processing, and the relevance of such an organization in children (Barca, Cappelli, Di Giulio, Staccioli, & Castelli, 2010; Bezrukikh & Terebova, 2009; Bova et al., 2007; Chokron et al., 2010; Stiers et al., 2001). In contrast, our results brought evidences supporting the organization of visual perceptual processes in at least two factors, the first devoted to the analysis of basic features of objects and the second devoted to view-dependent and view-independent representations of objects. Nevertheless, in a developmental perspective, future studies are needed to examine whether the dissociation between intermediate and late visual perceptual processing is an emerging property in older children and whether the different processing levels could be dissociated in children with visual perceptual deficits as reported in clinical and non-clinical adult populations (Humphreys & Riddoch, 1987b, 2006; Riddoch et al., 2008; Rumiati et al., 1994). Finally, all subtests of Factor 2 showed good to very good internal consistency, except the object completion subtest, which presented low reliability, and the object decision subtest, for which this coefficient could not be calculated. This suggested that the items of these two subtests do not correlate with each other and might instead rely on different underlying constructs. In particular, living and nonliving objects were presented in these subtests based on a semantic distinction that is usually made in the literature. In this respect, Merten (2006) found that the recognition of these two categories of items is only moderately correlated in brain-injured patients. This led us to question the relevance of including these items in a single measure, as they might depend on distinct cognitive processes.

As expected, the two subtests assessing visual spatial processing load separately on Factor 3, namely the evaluation of distances (egocentric and allocentric cues) and the location in a box (with and without a grid). These two subtests present good and excellent internal consistency, respectively. Such results indicate that these coefficients provide reliable measures of the underlying processes, including items that were closely related as a group.

Moreover, correlation analyses revealed significant positive correlations between the VP subtest of the Beery-VMI and all tasks assessing visual perceptual processes loading on Factors 1 and 2 (except for the object decision task), but no such correlations between the VP subtest and tasks assessing visual spatial processes loading on Factor 3. Therefore, our visual perceptual tasks seem to effectively assess visual perceptual processing, as does the VP subtest of the Beery-VMI. The absence of any correlation between visual perceptual and spatial tasks, and between visual spatial tasks and the VP, confirms the division of tasks in different processing abilities: on the one hand, visual perceptual processing, and on the other, visual spatial processing. This dissociation between visual perceptual and spatial processes is consistent with the two visual pathways, vision for perception which allows recognition and identification of objects, people and natural scenes and depends on ventral, occipito-temporal pathway. While, vision for action allows visual guidance of actions through analyses of visual spatial information, and visual motor planning, and depends on dorsal, occipito-parietal pathway (Milner & Goodale, 2008).

Regarding the development of visual perceptual and spatial processing abilities, our results showed distinct developmental trajectories between the three factors, each showing specific age-related changes. These results bring further support to the developmental separation of the underlying processing. In Factor 1, children's performances improved significantly until 8 years, similarly to the results of Pisella's et al. (2013) study. These performances slightly improved between the ages of 9 and 14 years, but barely reached a correct response rate of 70%, suggesting that these processes could still develop in later childhood and adolescence. However, the different subtests loading to the early processing stage do not seem to follow the same developmental pathways. Pisella et al. (2013) reported a significant improvement in performances for length and surface judgment tasks until 8 years, but until adulthood for the orientation judgment task. In contrast to this long-term development of a single basic perceptual characteristic (e.g., length, surface, orientation), the literature reported that the discrimination of simple shapes or drawings (processing at least two basic perceptual characteristics at the same time) was already mature by the age of 6 years (Bova et al., 2007; Stiers et al., 2001).

In Factor 2, performances significantly improved from 5–6 years, reaching the ceiling level (over 95% of correct answers) at 11–12 years. However, further analyses showed different developmental pathways in the performances of the intermediate processing stage (view-dependent object recognition) and late processing stage (view-independent object recognition). It would appear that the intermediate stage develops earlier, as our 5- to 6-year-old children responded correctly to 88% of items, compared to 75% of items in the late stage. However, from the age of 9–10 years, both types of processes develop in parallel, reaching 95% of correct answers at the age of 11–12 years. Similarly, Bova et al. (2007) showed a significant improvement in intermediate processing task between the ages of 6 and 11 years. Yet, the author also specified that the performances on some subtests (e.g., recognition of incomplete figures) still improved after the age of 11 years. Our results are in accordance with several studies reporting the early development of late perceptual processing in relation to view-independent object representation (Bezrukikh & Terebova, 2009; Bova et al., 2007; Stiers et al., 2001).

Regarding the subtests of Factor 3, the performances did not improve with age, but already showed an 85% correct response rate by the age of 5–6 years. This could mean that first levels of difficulty of our tasks were too easy, even for younger children, or this could mean that basic visual spatial processes (e.g., spatial location) develop early, as also suggested by Bezrukikh & Terebova (2009). Nevertheless, Pisella's et al. (2013) study suggested the long-term development of visual spatial processes between the ages of 4 and 12 years. Further research should consider separate analysis of the four specific tasks included in Factor 3 in order to provide a more precise developmental trajectory of visual spatial processing abilities.

In summary, our results showed that the various visual perceptual and spatial processes are divided into three factors, two loading to visual perceptual processes and one to visual spatial processes. This repartition fit with the two visual pathways, the ventral pathway for vision-for-perception, and the dorsal pathway for vision-for-action, separating object recognition and

spatial analysis to guide movements. Moreover, in the visual perceptual processes, the distinction between early (basic visual features), and intermediate/late analyses (view-dependent and -independent representations of objects) could also fit with the Feature Integration Theory of Treisman and Gelade (1980). This theory, mainly concerned by visual attentional skills, distinguished the detection of basic visual features and their processing through different integrative processes (e.g., figure-ground segregation and features grouping), but do not allow to distinguish the different processes in each, detection and integration processes, and do not consider late analysis processes such as in the
Q12 Humphreys and Riddoch (1987) model. Our results also showed that these visual perceptual and spatial processes follow separate developmental courses. To the best of our knowledge, no study in children has provided a systematic assessment of the different visual perceptual and spatial processes in the same sample of children. Furthermore, as seen in the introduction (Table 1), the majority of studies use a limited number of tasks, which could also explain the discrepancies in the results between these studies and our own. More studies are needed with a larger population of children for each age group in order to confirm the present results; the division of visual perceptual and spatial processing in three distinct factors, two devoted for visual perceptual processes that progress with age, and one for visual spatial processes which do not progress with age. An important issue to address will be to examine how tasks parameters (i.e., semantic categories, response type), and item difficulty (i.e., number of targets, positions of the items, perceptual threshold for a difference to be perceived) influence children's performances. Future studies should also consider the older children and adult population to provide a more precise developmental trajectory of visual perceptual processing abilities and specify their relation to basic visual spatial processing in terms of object recognition. Finally, the use of the Battery for the Evaluation of Visual Perceptual and Spatial processing (BEVPS) in children and adults with visual perceptual deficits should examine the sensitivity of this battery for the detection of a specific processing deficit, which could open up the perspective for developing an adapted intervention program. As the involvement of praxis, motor, and language functions is strictly limited in this test battery, this new tool could be used to assess visual perceptual deficits in children with neuro-developmental pathologies such as cerebral palsy, associated with cognitive or motor disabilities.

However, at the present time and in the absence of a tests battery available for the specific assessment of the different levels of visual perceptual and spatial processing in children, these processes must therefore be assessed using subtests from different batteries such as the DTVP 2 or the TVPS 3. From a clinical point of view, the distinction between the different processing levels provide relevant information to specify the child profile through qualitative analyses and observations of their performances and the strategies used during the different tasks. In fact, visual perceptual disorders will have a negative effect on other visual cognitive processes requiring prior object recognition. It is therefore necessary to distinguish between the various possible causes of impairments in visual spatial, visual motor and visual constructive tests. Such distinction is essential for implementing individual-based intervention strategies for children.



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