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The Development of Visual Object Recognition in School-Age Children

Stefania M. Bova, Elisa Fazzi, and Alessia Giovenzana
Department of Child Neurology and Psychiatry
IRCCS C. Mondino Institute of Neurology
University of Pavia, Italy

Cristina Montomoli
Department of Health Sciences
University of Pavia, Italy

Sabrina G. Signorini, Marina Zoppello, and Giovanni Lanzi
Department of Child Neurology and Psychiatry
IRCCS C. Mondino Institute of Neurology
University of Pavia, Italy

This study documents the age-dependent development of visual object recognition abilities in 115 children age 6 to 11 years, using a battery of neuropsychological tests based on Marr's model (Efron test, Warrington's Figure-Ground Test, Street Completion Test, Poppelreuter-Ghent Test, a selection of stimuli from the Birmingham Object Recognition Battery, a series of color photographs of objects presented from unusual perspectives or illuminated in unusual ways). The results suggest a maturation of complex visual perceptual abilities, possibly related to the development of the cerebral processes involved in object recognition, and could be the starting point for future investigations of these skills in impaired populations.

The development of higher brain functions in childhood is an intriguing and fascinating area of neuropsychology. Many studies have documented the development of higher cognitive functions during childhood and adolescence, and even

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Correspondence should be addressed to Stefania M. Bova, Department of Child Neurology and Psychiatry, IRCCS C. Mondino Institute of Neurology, Via Ferrata 6, 27100 Pavia, Italy. E-mail: stefania.bova@mondino.it

into adulthood, and tried to relate this development to brain maturation processes (Kolb & Fantie, 1997). As regards the visual abilities, the capacity to detect and discriminate simple shapes, subtended by the primary visual cortex (Kandell, Schwartz, & Jessel, 1994; Kovacs, 2000), develops in the very first years of life (Atkinson, 2000; Chiron et al., 1997), even though in more complex shape perception tests, such as the contour integration task, performance has been seen to improve progressively into adolescence (Kovacs, 2000). The development of higher visual abilities occurs later, during childhood and even adolescence, as has been demonstrated by the study of complex visual functions such as visuospatial and visuomotor skills (Akshoomoff & Stiles, 1995; Beery, 1967; Braddik, Atkinson, & Wattam-Bell, 2003; Frostig, Lefever, & Whittlesey, 1961) and of face recognition processes (Carey, Diamond, & Woods, 1980). On the other hand, relatively little attention has, until recently, been paid to the normal development of visual object recognition processes in children (Gathers, Bhatt, Corbly, Farley, & Joseph, 2004; Rentschler, Juttner, Osman, Muller, & Caelli, 2004; van den Hout et al., 2000).

Even though visual object recognition disorders are quite unusual in childhood (Ahmed & Dutton, 1996; Ariel & Sadeh, 1996; Eriksson, Kylliainen, Hirvonen, Nieminen, & Koivikko, 2003; Young & Ellis, 1989), particularly if we think of the forms of visual agnosia from acquired lesions of the occipitotemporal visual system described in adults (Riddoch & Humphreys, 2003), a ventral stream dysfunction has recently been documented in developmental disorders of perception and of visuocognitive functions, and in some cases a visual object agnosia has been reported (Dutton, 2003; Good, Jan, Burden, Skoczenski, & Candy, 2001; Houliston, Taguri, Dutton, Hajivassiliou, & Young, 1999; Stiers et al., 2001). These disorders may stem from a genetic condition (Atkinson et al., 2003; Galaburda & Duchaine, 2003), or may be the expression of congenital brain injury involving the visual systems and giving rise to the clinical picture of cerebral visual impairment (Dutton, 2003; Fazzi et al., 2004; Good et al., 2001; Houliston et al., 1999; Lanzi et al.,1998), the most frequent cause of visual deficit in children in developed countries. However, existing adultomorphic models may not always be suitable for describing impairment of visual recognition in children, who could show different and age-specific neuropsychological pictures (Atkinson, 2000; Dutton, 2003; Galaburda & Duchaine, 2003; Sabbadini, 2000). Moreover, there exist relatively few age-specific neuropsychological tests that investigate these functions.

The definition of clinical protocols for the assessment of visual object recognition skills and the study of their normal development in childhood is the starting point for the study of object recognition defects in impaired populations.

We set out to study the development of object recognition abilities in a sample of normal children, using a protocol of widely accepted and child-suitable object recognition tasks.

METHOD

Participants

A sample of 115 pupils was selected from a primary school in northern Italy. The children ranged in age from 6 years to 11 years 5 months. No child enrolled in the study had major ophthalmological or neurological disorders. Children with refractive errors used their normal prescription lenses.

Procedure

The tests are described in detail in the Appendix, and Figures 1, 2, and 3 show a selection of the items. The test protocol was structured on the basis of Marr's model (1982). Although this cognitive model derives from observation of adults with acquired lesional pathologies, we nevertheless considered it a good starting point, given that it still constitutes the point of reference for the nosographic framing of agnosic disorders, and is still used as a model for computational and functional brain imaging studies (Farah, 2000; Kosslyn et al., 1994). The final battery of tasks was made up of stimuli that had either been carefully selected or newly developed for a school-age population.

In accordance with Marr's model, the tests were grouped as follows (Denes & Pizzamiglio, 1996).

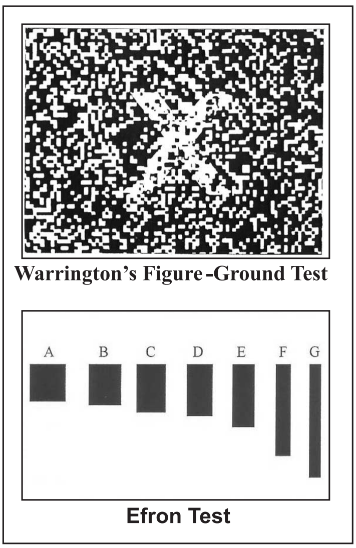

FIGURE 1 Tests assessing the pre-categorical stage of visual processing.

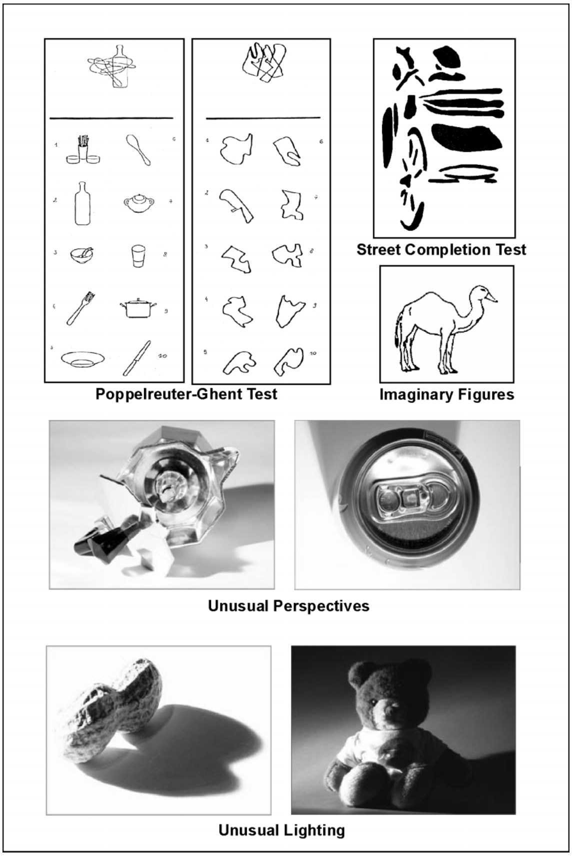

FIGURE 2 Examples of items from the tests assessing perceptual categorization. Stimuli used on Unusual Perspectives and Unusual Lighting were colored versions.

Pre-categorical stage. "Elementary" visual-perceptual ability (discrimination and detection of simple geometrical shapes) was assessed using the Efron Test and Warrington's Figure-Ground Test. These tests are widely used in clinical practice, especially in the study of patients with occipital lobe lesions. Several authors (Warrington & James, 1988) regard successful performance of these tasks as a prerequisite for a diagnosis of apperceptive agnosia; inability to perform them could be due to a deficit of visual acuity.

Perceptual categorization. Perceptual categorization, that is, the ability to recognize the structural identity of an object even when its projection on the retina is altered (object constancy) (Denes & Pizzamiglio, 1996), was assessed using:

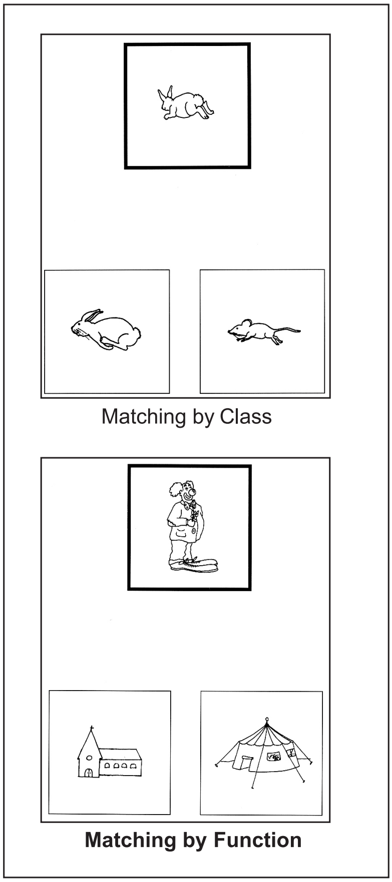

FIGURE 3 Examples of items from the tests assessing semantic categorization.

- The Street Completion Test (SCT; Street, 1931) to assess the ability to integrate incomplete stimuli into a single perceptual configuration (gestalt perception).
- The Poppelreuter-Ghent Test (PGT; Della Sala, Laiacona, Spinnler, & Trivelli, 1995) to test the ability to pick out images superimposed on one another.
- Color photographs of objects viewed from unusual perspectives (UP) and presented under unusual lighting conditions (UL). Warrington and James were the first to use "unusual" views (in their case, black-and-white photographs) of objects, "usual" corresponding to "how the object would usually be drawn." Photographs and drawings of unusually presented objects are now widely used in clinical practice (Farah, 2000; Stiers, De Cock & Vandenbussche, 1999) and in functional brain imaging research (Grill-Spector, Kourtzi, & Kanwisher,

> 2001; James, Culham, Humphrey, Milner, & Goodale, 2003; Kosslyn et al., 1994). Not considering black-and-white photographs and drawings entirely suitable for children, we chose instead to create a new test series made up of color photographs. We decided to use photographs instead of drawings because photographs reproduce more accurately the three-dimensionality of objects, and we preferred color photographs to black-and-white ones because we thought that color photographs would be more appealing to the target population (i.e., children). To decide which objects to photograph, we consulted a dictionary of frequent use (Marconi, Ott, Pesenti, Ratti, & Tavella, 1994) and selected objects (words) from among those that recur most frequently in the vocabulary (reading and writing) of school children. This choice was based on our view that reading and writing frequency are likely to equate with visual frequency and that familiarity with an object's name is associated with familiarity with its physical appearance and with the capacity to recognize it when it is presented visually. Indeed, studies of cross-modal transfer abilities document the presence of these abilities from a very early age, and many naming tasks, designed to evaluate vocabulary, require subjects to name pictures. To be sure that children were familiar with the objects included in the UP and UL series, at the end of the assessment session we asked them to name a usual-view photo of the objects they had not been able to recognize in the unusual view. All children correctly named the usual-view photos.

Constancy of internal representation of objects. Constancy of internal representation of objects was assessed using a series of "imaginary figures" (IF), that is, fanciful images each made up of traits derived from two different objects. These figures were selected from the "Object Decision" test of the Birmingham Object Recognition Battery (Riddoch & Humphreys,1993). The items deemed suitable for inclusion in this protocol were selected from among those defined as "easy" by the authors, and again on the basis of subjective criteria of familiarity and appeal to children. In this task, children must give a reality-based judgment of the images, which they can do only if they are in possession of a correct internal representation of the two objects making up the figure.

Semantic categorization. The capacity to recognize semantic and functional attributes of the stimulus was assessed using two matching tasks in which the children were required to match pairs of drawings by class (MC) and by function (MF). Selection of the items, from those included in the Birmingham Object Recognition Battery (Riddoch & Humphreys, 1993), was again based on subjective criteria of suitability for children (familiarity and appeal).

Before administering the test protocol, we obtained, from the parents of each child, written informed consent to their child's participation in the study. We then examined the children individually, away from the rest of the class. No time limit was set on any of the tests included in the battery and we always encouraged the children to give an answer, even when they found the task difficult or were reluctant to form a hypothesis. The order in which we presented the items was randomized differently in each of the tests; within each age group, we presented the same items in three different sequences so as to eliminate possible effects of semantic association of stimuli.

As we expected, this protocol is easy and rapid to administer (30–40 sec); the stimuli arouse the interest of the children, and this helps to hold their attention, guaranteeing a good level of compliance. Even though statistical analysis showed that some tasks were more informative than others, we nevertheless decided not to eliminate the less informative ones from the protocol, at least in this preliminary phase of the study. After all, the tasks potentially redundant in normal children could prove useful in the study of impaired populations, and our preliminary data on children with cerebral visual impairment seem to support this hypothesis (Bova, Fazzi, Giovenzana, Signorini, & Lanzi, 2003, 2004).

RESULTS

All the children obtained the maximum score both on the Warrington Figure-Ground Test and the Efron Test (ceiling effect). Consequently, performances on these two tests were not included in the statistical analysis. Stata statistical software was used for the analysis (Intercooled Stata, 2003).

In a preliminary phase of the study, we compared the results obtained by two examiners (SMB, AG) in the same sample of children in order to assess the reliability of the newly created tests (UP and UL). The inter-examiner reliability coefficient was .94 for UL and .98 for UP, considered "excellent" by Fleiss (1985).

The next step was to demonstrate the development of object recognition abilities during the selected period of development. A regression analysis was used to assess the relation between age and test performance, using the percentage of correct answers (*n* of correct answers / *n* of items) as the dependent variable and age as a continuous independent variable.

The results demonstrated a significant, age-dependent improvement in visual object recognition skills between the ages of 6 and 11 years. Linear regression analyses showed a significant effect of age on all test performances, except for MC. MC and MF showed a uniform distribution of test performances by age. Figure 4 shows the scatter plot of test performances (SCT, PGT, UP, UL, IF, MC, and MF) versus age, the equation of the regression line and the statistical significance of the regression coefficient.

Descriptive statistics were performed to obtain reference data for comparison with impaired populations. Descriptive statistics (mean values; standard deviations; and 5th, 50th, and 95th percentiles) were calculated for the percentages of

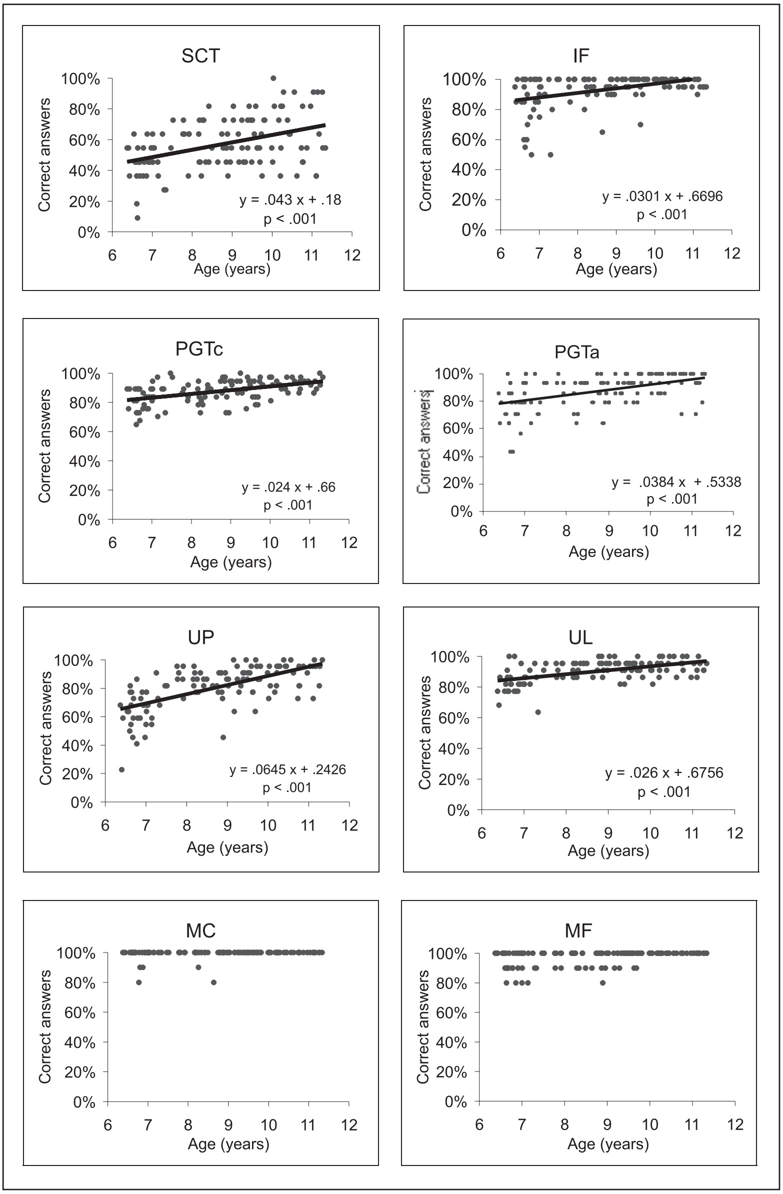

FIGURE 4 Relation between age and test performance (correct answers expressed as a percentage of total answers), equation of the regression line, and statistical significance of the regression coefficient for each test. *Note.* SCT = Street Completion Test; PGTc = Poppelreuter-Ghent Test, overlapping concrete figures; PGTa = Poppelreuter-Ghent Test, overlapping abstract figures; UP = unusual perspectives; UL = unusual lighting; IF = imaginary figures; MC = matching by class; MF = matching by function.

correct answers, omissions and incorrect answers in five age groups: 6 years to 6 years 11 months (22 subjects), 7 years to 7 years 11 months (18 subjects), 8 years to 8 years 11 months (22 subjects), 9 years to 9 years 11 months (25 subjects), 10 years to 11 years 5 months (28 subjects). Table 1 gives the mean values and standard deviations, whereas Table 2 gives the 5th, 50th, and 95th percentiles. Figure 5 shows the boxplots for SCT, PGT, UP, UL tests.

TABLE 1
Descriptive Statistics: Mean Values and Standard Deviations of the Percentages of Correct Answers, Incorrect Answers, and Omissions in the Different Age Groups

	Group 1[a]		Group 2[b]		Group 3[c]		Group 4[d]		Group 5[e]	
Variable	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
SCT										
CA	45.1	11.4	52.2	11.6	55.4	10.6	60.0	11.9	65.3	19.1
IA	39.2	18.3	35.9	16.0	32.6	14.5	29.8	12.7	24.0	16.6
OM	16.5	12.7	11.1	12.3	11.6	12.3	8.7	10.3	9.7	11.6
PGTc										
CA	80.9	8.7	86.7	9.1	84.9	8.6	89.2	6.4	91.8	4.7
IA	12.6	5.7	7.6	4.8	7.9	4.6	6.8	5.5	5.4	3.7
OM	6.7	5.2	5.3	4.8	5.6	4.8	2.9	4.5	2.4	2.4
PGTa										
CA	75.3	15.1	87.7	10.6	85.1	10.8	90.9	7.8	93.4	8.7
IA	17.8	12.2	7.1	9.1	5.8	9.2	5.1	4.8	5.9	8.0
OM	6.8	7.1	5.1	5.9	9.1	6.7	4.0	5.9	0.8	2.2
UP										
CA	62.7	15.8	76.1	15.4	84.1	10.1	88.4	11.1	91.4	11.1
IA	26.9	13.7	17.7	10.2	13.6	9.2	10.4	9.2	8.1	7.7
OM	10.7	8.8	6.3	5.6	3.3	4.0	2.5	2.9	2.1	3.8
UL										
CA	84.1	7.9	88.9	10.2	94.9	5.1	95.2	6.5	94.9	5.7
IA	15.3	8.1	11.6	5.7	7.0	4.1	6.4	4.3	6.5	5.1
OM	1.9	3.0	1.0	3.3	0.4	1.3	0.5	1.5	0.0	0.0
IF										
CA	86.3	16.1	92.8	12.7	94.9	8.0	98.0	6.4	99.6	1.9
MC										
CA	98.2	5.0	100.0	0.0	98.6	4.7	100.0	0.0	100.0	0.0
MF										
CA	94.5	6.7	94.9	7.1	96.4	5.8	98.4	3.7	100.0	0.0

Note. CA = correct answers; IA = incorrect answers; OM = omissions; SCT = Street Completion Test; PGTc = Poppelreuter-Ghent Test, overlapping concrete figures; PGTa = Poppelreuter-Ghent Test, overlapping abstract figures; UP = unusual perspectives; UL = unusual lighting; IF = imaginary figures; MC = matching by class; MF = matching by function.

[a]*n* = 22, age: 6 years to 6 years, 11 months; [b]*n* = 18, age: 7 years to 7 years, 11 months; [c]*n* = 22, age: 8 years to 8 years, 11 months; [d]*n* = 25, age: 9 year to 6 years, 11 months; [e]*n* = 28, age: 10 years to 11 years, 5 months.

TABLE 2
Descriptive Statistics: 5th, 50th, and 95th Percentiles of the Percentages of Correct Answers, Incorrect Answers, and Omissions in the Different Age Groups

	Group 1[a]			*Group 2*[b]			*Group 3*[c]			*Group 4*[d]			*Group 5*[e]		
Variable	*5th*	*50th*	*95th*	*5th*	*50th*	*95th*	*5th*	*50th*	*95th*	*5th*	*50th*	*95th*	*5th*	*50th*	*95th*
SCT															
CA	18.2	45.5	63.6	27.3	54.5	72.7	36.4	54.5	72.7	45.5	63.6	81.8	36.4	63.6	90.9
IA	18.2	36.4	72.7	9.1	36.4	63.6	18.2	31.8	54.5	9.1	27.3	45.5	0.0	18.2	54.6
OM	0.0	9.1	36.4	0.0	9.1	45.5	0.0	9.1	36.4	0.0	9.1	18.2	0.0	9.1	36.4
PGTc															
CA	67.6	81.1	89.2	70.3	87.8	100.0	73.0	87.8	97.3	78.4	91.9	97.3	86.5	91.9	97.3
IA	5.4	12.2	24.3	0.0	8.1	18.9	2.7	6.8	13.5	0.0	5.4	16.2	0.0	5.4	10.8
OM	0.0	6.7	13.5	0.0	5.4	18.9	0.0	5.4	13.5	0.0	0.0	10.8	0.0	2.7	5.4
PGTa															
CA	42.9	78.6	92.9	64.3	92.9	100.0	64.3	85.7	100.0	78.6	92.9	100.0	71.4	96.4	100.0
IA	0.0	17.8	35.7	0.0	3.6	28.6	0.0	0.0	21.4	0.0	7.1	14.3	0.0	0.0	21.4
OM	0.0	7.1	21.4	0.0	7.1	21.4	0.0	7.1	21.4	0.0	0.0	14.3	0.0	0.0	7.1

UP															
CA	40.9	63.6	81.8	54.5	75.0	95.5	72.7	86.4	90.9	63.6	86.4	100.0	72.7	95.4	100.0
IA	13.6	25.0	50.0	0.0	18.2	36.4	4.5	13.6	22.7	0.0	9.1	31.8	0.0	4.5	27.3
OM	0.0	9.0	27.3	0.0	4.5	13.6	0.0	2.3	9.1	0.0	0.0	9.1	0.0	0.0	9.1
UL															
CA	77.3	81.8	100.0	63.6	86.4	95.5	86.4	93.2	100.0	82.8	95.5	100.0	86.4	95.5	100.0
IA	0.0	18.2	22.7	4.5	13.6	22.7	0.0	4.5	13.6	0.0	4.5	13.6	0.0	4.5	13.6
OM	0.0	0.0	9.1	0.0	0.0	13.6	0.0	0.0	4.5	0.0	0.0	4.5	0.0	0.0	0.0
IF															
CA	55.0	85.0	100.0	50.0	95.0	100.0	80.0	95.0	100.0	90.0	100.0	100.0	95.0	100.0	100.0
MC															
CA	90.0	100.0	100.0	100.0	100.0	100.0	90.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
MF															
CA	80.0	100.0	100.0	80.0	100.0	100.0	90.0	100.0	100.0	90.0	100.0	100.0	100.0	100.0	100.0

Note. CA = correct answers; IA = incorrect answers; OM = omissions; SCT = Street Completion Test; PGTc = Poppelreuter-Ghent Test, overlapping concrete figures; PGTa = Poppelreuter-Ghent Test, overlapping abstract figures; UP = unusual perspectives; UL = unusual lighting; IF = imaginary figures; MC = matching by class; MF = matching by function.

[a]$n = 22$, age: 6 years to 6 years, 11 months; [b]$n = 18$, age: 7 years to 7 years, 11 months; [c]$n = 22$, age: 8 years to 8 years, 11 months; [d]$n = 25$, age: 9 years to 6 years, 11 months; [e]$n = 28$, age: 10 years to 11 years, 5 months.

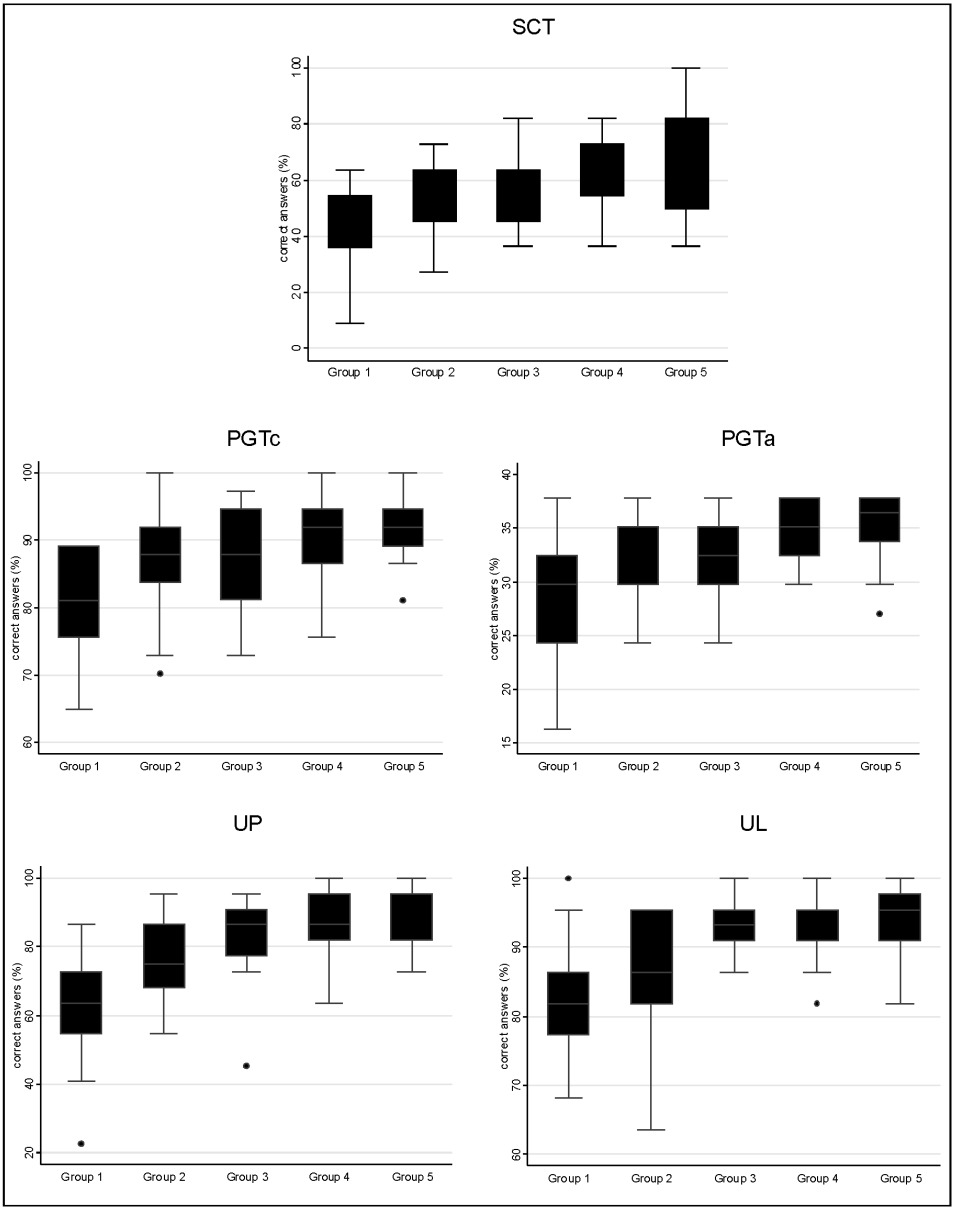

FIGURE 5 Boxplots for SCT, PGT, UP, UL tests. *Note.* SCT = Street Completion Test; PGTc = Poppelreuter-Ghent Test, overlapping concrete figures; PGTa = Poppelreuter-Ghent Test, overlapping abstract figures; UP = unusual perspectives; UL = unusual lighting.

Another step was to verify whether similar cognitive functions underlie performance on the different tests and whether the grouping of the tasks according to Marr's model was justified in and suitable for the study of object recognition abilities in childhood. To address this issue, correlation analysis and factor analysis were performed.

Intercorrelations among the tests were investigated using Pearson's correlation coefficient. Table 3 shows the results of the correlation analysis. Significant correlation coefficients were shown by most test performances. Performances on the SCT; the PGT; and the UP, UL, and IF tests showed significant correlation coefficients. No correlation emerged between MC versus the SCT and the PGT (concrete figures) or between the MC and MF tests. The intercorrelation values were not higher within the groupings—perceptual categorization tests (SCT, PGT, UP, UL and IF) and semantic categorization tests (MC and MF)—than across them.

Furthermore, a factor analysis was carried out to check whether the different tests really tapped different stages of processing. Principal component analysis was conducted and the eigenvalues were used to determine the number of factors to be extracted. An orthogonal rotation (varimax) was carried out to facilitate interpretation of the factors.

Two factors emerged from the factor analysis (a) UP and UL and (b) PGT (concrete figures) and PGT (abstract figures). Together these factors explain 98% of the overall variance, without highlighting the different Marr stages.

In short, the correlation analysis findings showed that similar cognitive functions underlie the solving of the different tasks, but did not highlight test grouping according to Marr's model. This result is confirmed by the factor analysis that suggested that the recognition of rotated (UP), partially lit (UL), and overlapping (PGT) objects are the most sensitive tasks (among those included in our battery)

TABLE 3
Analysis of Correlations Between Test Performances

Variable	*SCT*	*PGTc*	*PGTa*	*UP*	*UL*	*IF*	*MC*	*MF*
SCT	—							
PGTc	.4047**	—						
PGTa	.3761**	.6375**	—					
UP	.4668**	.4184**	.5018**	—				
UL	.3570**	.3556**	.3909**	.6163**	—			
IF	.3838**	.5040**	.4600**	.4901**	.3628**	—		
MC	.0665	.1717	.1879*	.1958*	.1876*	.3296**	—	
MF	.3437**	.3177**	.2766*	.4571**	.2653*	.4765*	.1058	—

Note. SCT = Street Completion Test; PGTc = Poppelreuter-Ghent Test, overlapping concrete figures; PGTa = Poppelreuter-Ghent Test, overlapping abstract figures; UP = unusual perspectives; UL = unusual lighting; IF = imaginary figures; MC = matching by class; MF = matching by function.

$^*p < .05$. $^{**}p < .001$.

for the study of visual-object-recognition skills and seemed to provide justification for the use, in this protocol, of a factor structure other than Marr's.

The final part of the study focused on incorrect answers. The analysis was conducted on the SCT and the UP test. Analyzing the incorrect answers produced on these tests, we were able to pick out specific types. In one type, which we defined "contour-related," the shape and contour of the figures was highlighted (children gave answers like "black marks," "stars," "leaves," and "butterflies" in the SCT, and "circle," "round," and "tube," on the UP). Another type, which we defined "configural attempts," were elaborate and fanciful false recognitions centered on the relationship between the internal parts of the image, and these could be seen as attempts to integrate the details into a perceptual configuration (e.g., "fountain," "bicycle," "man holding something," and "woman near a door" on the SCT, and "wheel going around," "an eye watching me" [a tin can seen from above], "wine glass" [a light bulb], and "basin" [a mocha coffee pot] on the UP). Other incorrect answers, not identifiable as either of the above types, were not further considered. We calculated the relative frequency of the various types of incorrect answer (*n* of each type of incorrect answer / *n* of incorrect answers) in two age bands, 6–8 and 9–11 years. Contour-related errors were significantly more frequent among the younger children than among the older ones (SCT: $z = 4.43$, $p < .0001$; UP: $z = 3.01$, $p < .001$), whereas configural attempts were significantly more frequent among the older than among the younger children (SCT: $z = -4.87$, $p < .0001$; UP: $z = -5.7$, $p < .0001$). Figure 6 summarizes these results.

A final observation can be made with regard to the UP and the UL tests. In these tests, children were presented with the usual representations of objects they had not previously been able to recognize in the unusual mode. At this point, some

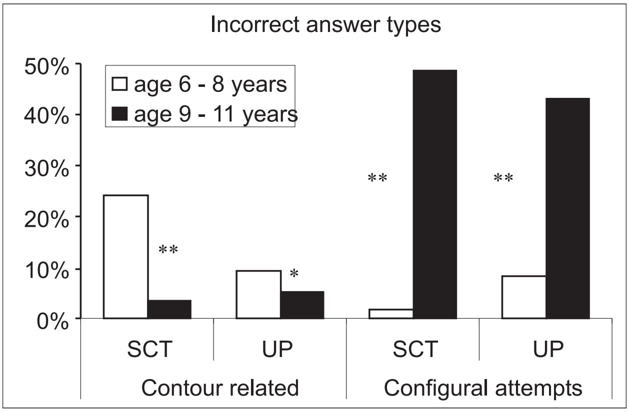

FIGURE 6 Distribution of incorrect answer types by age. *Note.* Each type is expressed as a percentage of total errors. *Note.* * $p < .001$; ** $p < .0001$. SCT = Street Completion Test, UP = unusual perspectives.

children would suddenly recall and name them ("So the one you showed me before was a … as well!") whereas others would go no further than naming correctly the object presented; these latter children did not give any indication that they remembered the image previously presented and, furthermore, were still unable to recognize the unusual image of the stimulus when it was presented to them again after they had seen the usual one. We calculated the percentages of children, in the age bands 6–8 years and 9–11 years, who were suddenly able to recall the objects. The comparison between the younger and older age bands documented that this ability to recall the image is significantly more frequent among the older than among the younger children: $\chi^2(4) = 319.19$, $p < .0001$.

DISCUSSION

This paper presents the data obtained in a sample of healthy school children who underwent a comprehensive battery of neuropsychological tests for the assessment of visual object recognition based on Marr's model of the visuocognitive processes.

The results document an age-dependent development of visual object recognition abilities during childhood. The development of these skills was not found to match the processing stages set out in Marr's theory. Our statistical analysis did not support the grouping of the tests according to this theory, casting some doubt on the clinical usefulness of extending this paradigm to paediatric populations.

As expected and as confirmed by the normal results obtained on the Warrington Figure-Ground and Efron Tests in the whole sample, visual abilities subtended by the primary visual cortex, like simple shape discrimination, are already mature at the age of 6 years.

Higher visual abilities develop later in childhood as documented by the significant relationship between age and performance on our protocol of visual tests. We documented an age-dependent improvement in performances between the ages of 6 and 11 years, even though the performance trend on some of the tasks (like recognition of degraded images in the SCT) seemed to indicate that these maturation processes also continue at later ages.

Our observations are confirmed by the literature. Other studies provide evidence of developing visual recognition skills during childhood, with regard to the human face (Carey & Diamond 1994; Gathers et al., 2004), animals (Davidoff & Roberson, 2002), and objects (Gathers et al., 2004; Rentschler et al., 2004). Functional imaging and neurophysiological studies confirm neuropsychological observations documenting the progressive organization and maturation of the ventral processing stream, the functional pathway in the primate brain that supports visual recognition (Gathers et al., 2004; Gunn et al., 2002; Kovacs, 2000).

The most specific and sensitive tasks for the study of normal development of visual object recognition seem to be those requiring the recognition of objects or figures presented to the visual system in unconventional and hard-to-decode ways, for example, rotated (UP), partially lit (UL), and overlapping (PGT). The UP and UL tests proved to be highly workable, thanks both to their high reproducibility and to the high level of compliance demonstrated by the children. Indeed, tasks of this kind have been selected for the study of the development of higher visual abilities (Gathers et al., 2004; Rentschler et al., 2004).

The age-dependent improvement in performance on the SCT, a well-recognized test for the assessment of gestalt capacity, bears witness to the progressive emergence and maturation of gestalt perception. Analysis of the incorrect answers on the SCT and UP also confirms this maturation. When presented with a figure that they cannot recognize, 6–8 year old children tend to produce an answer that is based on the shape and contour of the image, whereas children aged 9–11 years attempt to integrate the internal parts of the image into a perceptual configuration sometimes producing elaborate and fanciful false recognitions. This behavior suggests that older children rely more on their gestalt strategies for image processing and is coherent with other studies of recognition development, which postulate a developmental trend from the processing of details to the processing of the whole configuration (Carey & Diamond, 1994; Davidoff & Roberson, 2002; Gathers et al., 2004, Rentschler et al., 2004).

In addition, we formed the impression that development of recognition processes is accompanied not only by a progressive extension of the memory store of images and internal representations, but also by a rendering of this store increasingly consciously accessible.

This impression was based on the emergence of a clear reaction, particularly in the older children, when performing the UP and UL tasks. These children, when presented with the usual representation of an object they had not previously been able to recognize in the unusual mode, suddenly recalled and named it. It thus seems that presentation of an object photographed in a conventional manner activates, or places at the subject's disposal, a memory store of images of that object, and that the "trigger" mechanism that gives the subject access to this memory store is present only in older children.

The capacity to identify functional and semantic attributes of the stimuli seems to develop relatively autonomously. Indeed, correlations of the MC and MF tests with age, with each other, and with the other tests included in the protocol, were weak, and performances of these tests in our children seemed to start to plateau from as early as 7 years of age. Moreover, the rare errors made by the younger children appeared to be attributable more to unfamiliarity with the object itself than to a problem related to the mode of presentation used. It is thus probable that other factors, first and foremost cognitive-experiential, contribute to the development of those complex cognitive functions that are in part correlated with visual mechanisms, but in part independent of them.

In conclusion, we have endeavored to document the maturation of visual recognition skills in childhood, and in school-age children in particular. Our observations confirm the progressive improvement of these abilities in children 6–11 years of age. This improvement is possibly related to multiple aspects of brain maturation, such as the organization and development of the ventral processing stream, the improvement of gestalt perception, and the development of a better and more efficient capacity to retrieve object representations from the memory store. Neuroimaging studies would provide data that may shed further light on this issue. Our work could be the starting point for extending the study of these visual functions to impaired populations.

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APPENDIX

Assessment of Precategorical Stage

Efron Test. The subject is required to distinguish between pairs of simple geometrical shapes (one square and one rectangle), which differ from one another in the length of the sides, but which have the same area. Black figures are used on a white (5 × 5 cm) background. The subject has to say whether the pairs of figures from A to G (A vs. A, A vs. B, …, A vs. G) are the same or different.

Warrington's Figure-Ground. The test requires the subject to identify (although not necessarily to name) a geometrical figure set against a fragmented (black and white patterned) background. There are two items to be identified: X and O.

Assessment of Perceptual Categorization

Street Completion Test—SCT. The subject is required to recognize a degraded (fragmented) image. The subject is shown, one after the other, 11 figures in black and white that represent, with increasing ambiguity, real objects. The response is considered correct not only when the subject correctly identifies the object, but also when the answer is sufficiently close to the correct one or expressed in an indirect way that nevertheless indicates that the child has correctly identified the object.

List of stimuli:

1. boat
2. face
3. dog
4. aeroplane
5. car
6. child
7. carriage
8. dancers
9. soldier
10. knight
11. tennis player

Poppelreuter-Ghent Test—PGT. In this test, the subject is required to identify overlapping drawings. The test comprises 13 items (+ one example), of which 9 are drawings of real objects (Concrete Figures, PGTc), and 4 are drawings of abstract shapes (Abstract Figures, PGTa). The subject is shown the stimulus, a set of overlapping drawings of real objects or abstract shapes positioned at the top of the page. The subject is required to identify and indicate which, from among a series of 10 images listed here, are present in the overlapping part. The answer can be given orally, or by pointing to the figures.

List of stimuli:

1. items of furniture (example)
2. containers
3. things used at school
4. cooking utensils
5. little figures of people
6. musical instruments
7. fruit
8. garments

9. animals
10. work tools
11.–14. abstract figures

Unusual Perspectives/Unusual Lighting—UP/UL. These two tests have been developed from scratch. Both are made up of 22 color photographs of objects (22 images of objects photographed from unusual perspectives and 22 images of objects presented under unusual lighting conditions) and by color photographs of the same objects presented in a conventional manner. The latter were to be used, should the child be unable to identify the object, in order to assess his capacity to recognize the stimulus when all its peculiar characteristics are shown. The subject is asked to identify the object; because this is not a naming test, descriptions of the objects or indications regarding their use (e.g., *paintbrush* stimulus = the thing you use for painting) are accepted. The subject is deemed not to have recognized the object (to have recognized it falsely) both when the answer given is clearly wrong (e.g., *shoe* stimulus = bag) and when the answer given is functionally or structurally related to the stimulus (e.g., *paintbrush* stimulus = broom, *cup* stimulus = beaker/glass).

Unusual Perspectives—list of stimuli:

1. coffee pot
2. mobile phone
3. key
4. computer
5. scissors
6. fork
7. light bulb
8. can
9. walnut
10. spectacles
11. pen
12. paintbrush
13. saucepan
14. pepper
15. plate
16. shoe
17. broom
18. chair
19. brush
20. cup
21. telephone
22. television

Unusual Lighting—list of stimuli:

1. garlic
2. peanut
3. banana
4. coffee pot
5. candle
6. chocolate
7. spoon
8. toothpaste
9. dice
10. flower
11. book
12. walnut
13. hazelnut
14. watch
15. teddy bear
16. bread
17. pepper
18. plate
19. broom
20. chair
21. cup
22. grapes

Imaginary Figures—IF. This test requires subjects to give a reality-based judgment. For this test we used 20 of the 128 items that make up the Birmingham Object Recognition Battery. In particular, we chose items from those defined as "easy" in the original battery, and also took care to select those that seemed most suitable for and appealing to children. Of the 20 stimuli selected, 10 are drawings of real objects and 10 are imaginary figures. The latter are fanciful figures, drawings of animals or objects, some of whose traits are replaced with traits belonging to another animal or object in such a way as to create imaginary figures—for example, a camel with a goose's head. The subject is required to indicate whether or not the drawing shown represents an animal or object that really exists.

List of stimuli:

1. cow
2. camel–duck
3. kangaroo–snake
4. goat

5. monkey–rabbit
6. screw
7. seal
8. screwdriver–scissors
9. rhino
10. seahorse–duck
11. fox–horse
12. lion–rabbit
13. kangaroo
14. monkey
15. scissors–screw
16. snake–kangaroo
17. rabbit
18. seahorse
19. tiger
20. mouse–zebra

Assessment of Semantic Categorization

Matching by Class/Matching by Function—MC/MF. These two tests require subjects to identify the semantic and functional characteristics of presented stimuli. They are based on the Birmingham Object Recognition Battery, and use 20 of the 64 items making up the original test. Again, the items selected are all rated as "easy" in the original test, and are all considered suitable for and appealing to children.

In 10 of the 20 selected items, the subject is required to match objects belonging to the same class, and in the other 10 to match objects that are functionally related but that belong to different classes. Each item is made up of three different pictures, the target picture, situated at the top of the page, and two pictures situated at the bottom of the page, one that matches the target, and the other that serves as a distractor. The subject is required to match the target picture with one of the two pictures at the bottom of the page.

Matching by Class—list of stimuli:

1. tiger—tiger, bear
2. arrow—arrow, fountain pen
3. rabbit—rabbit, mouse
4. piano—piano, train
5. car—car, toy train
6. dog—dog, goat
7. daffodil—flower, leaf
8. foot—foot, hand

9. house (bungalow)—house, desk
10. squirrel—squirrel, monkey

Matching by Function—list of stimuli:

1. arrow—nail, screw
2. stamp—envelope, book
3. web—spider, ant
4. train—rail, road
5. tie—shirt, trousers
6. saw—wood, chain
7. bone—dog, cat
8. sock—shoe, hat
9. pyramids—camel, bear
10. clown—circus tent, church