The Developmental Eye Movement Test in French Children

Lionel Moiroud, Anaïs Royo, Maria Pia Bucci

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Lionel Moiroud, OD,[1]* Anaïs Royo, OD,[2] and Maria Pia Bucci, PhD[1]

SIGNIFICANCE: This study reported that the Developmental Eye Movement (DEM) test for French children is similar to the American ones and that all parameters of the DEM test improve up to the age of 10 years.

PURPOSE: The DEM test has been normalized for several different populations of children, but there are no published norms for French children. This study aimed to determine values of the DEM test for French-speaking children.

METHODS: A total of 327 children from 6 to 12 years of age participated in the study. The DEM test was administered as outlined in the manual.

RESULTS: Significant differences were found between the ages, and DEM test scores improved with age until about 10 years. Developmental Eye Movement test scores were similar to those reported in American children.

CONCLUSIONS: Cortical and central structures responsible for oculomotor and attentional capabilities are developing until about 10 years of age, and that could explain the improvement of the DEM test score up to this age. Furthermore, values of the DEM test in French children are similar to the American ones that are currently used as norms by French clinicians.

Author Affiliations:

[1]MoDyCo UMR 7114 CNRS — Université Paris Nanterre, Nanterre, France

[2]Pôle santé Henri Arnaud, Saint-Sulpice-la-Pointe, France

*lionel.moiroud@gmail.com

Richman and Garzia[1] introduced for the first time the Developmental Eye Movement test to explore eventual deficits in saccadic eye movements and visual-verbal automaticity in children. Since 1987, clinicians from several countries have used this test, which has been normalized on 556 English-speaking American schoolchildren from 6 to 13 years of age. During the last decade, several studies used the Developmental Eye Movement test on children from different countries to provide normative data for Cantonese children,[2] Italian children,[3] Chinese children,[4] Spanish children,[5] and Portuguese children.[6] The Developmental Eye Movement test is an easy, practical, and economical tool to assess oculomotor performance in children; in fact, it allows a quantitative measure of oculomotor skills by the reading-aloud of numbers. Indirectly, it measures the efficiency of visual search and eye-movement control in a simulated reading task. In other words, the Developmental Eye Movement test leads to an indirect evaluation of the quality of saccades during a reading task, and it could replace an eye-tracker evaluation, which requires heavier instrumentation and is more expensive. To run the Developmental Eye Movement test is quite simple, it consists of three test cards: two cards (A and B) in which 80 numbers (40 for each test card) are arranged into two vertical columns of 20 numbers and a third card (C) where the same 80 numbers shown on the two previous cards are arranged horizontally in 16 rows of 5 numbers each. According to Richman and Garzia,[1] the two cards A and B allow the evaluation of the child's rapid naming capability by minimizing the oculomotor component (vertical presentation). At the same time, the horizontal arrangement of numbers on the C card necessitates the saccadic eye movements of the child. However, it needs to be noted that other researchers[7] found that the Developmental Eye Movement test was not correlated with saccadic eye movement performance but with reading performance.

Before running the test, the examiner would make a pretest with the child consisting of 10 single numbers separated by equal spacing; this is to verify that the child knows numbers and can read them without any difficulty. Afterward, test cards A, B, and C are presented to the child. The child is asked to read aloud the numbers on them in the right order, and the examiner counts the time taken to read the cards and the errors made.

The examiner measures four scores: the vertical score that is the total time needed to read test cards A and B, the horizontal score that is the time to complete test card C, the number of errors made while reading test card C, and the ratio score (i.e., the ratio between the horizontal and the vertical scores). A high ratio score means that a child has more difficulties in reading numbers horizontally (test card C). Recent research has reported the reliability of the Developmental Eye Movement test in clinical practice.[8]

Clinicians in France usually refer to American norms,[1] to date, because there are no established norms for the use of the Developmental Eye Movement test with children in France. This is surprising when one considers that the differences between education systems in English-speaking and French-speaking countries are well known, not forgetting the differences in the languages.

Our first objective in the present study was to establish quantitative data from the Developmental Eye Movement test used to valuate French children from 6 to 12 years old. Our second objective was to compare these data to the American values.

METHODS

Subjects

The investigation adhered to the principles of the Declaration of Helsinki and was approved by our Institutional Human Experimentation Committee (INSERM CEEI-IRB, n° 16-290). Written consent was obtained from the children's parents and from each child using an age-appropriate assent after an explanation of the experimental procedure.

The directors of five schools in the area surrounding Toulouse were contacted, and two of them gave their approval (one school was public, and the other private). All children attending the two schools were invited to participate in the study, but only children/parents who signed the consent were included.

Children came from different social and ethnic backgrounds, but data on socioeconomic status and racial/ethnic origin were not collected. Therefore, it is unknown how representative the sample is of the general French population.

These schools were not located in the priority education areas (defined as a low socioeconomic area, according to Government criteria, where unemployment is high [≥8%] or where low income is the predominant situation).

All children had at least one ophthalmological evaluation during their schooling.

Inclusion criteria were as follows: normal visual acuity (in each eye 20/25), normal stereopsis (Lang-stereotest AG, Küsnacht, Switzerland). The absence of any binocular vision deficit, such as strabismus or high phoria, was evaluated by the cover test.[9] Exclusion criteria for phoria at distance and near, respectively, were >2 prism diopters exophoria and >6 prism diopters exophoria, or any esophoria. These values were chosen to be within one standard deviation of Morgan's norms.[10] All children had to have adequate number-naming skills determined by the Developmental Eye Movement pretest. A total of 327 children from 6 to 12 years old participated in the study. Fifteen children were excluded from the study (3 children did not understand the test, 5 children failed to finish reading card C, and 7 children had poor visual acuity, strabismus, or phoria values that exceeded Morgan's norms by one standard deviation at distance or near.[10] The characteristics of the children tested are shown in Table 1.

Procedures

The Developmental Eye Movement test was administered in accordance with the recommendations of the manual.[11] Two authors (LM and AR), who are clinicians and experienced examiners, performed the Developmental Eye Movement with children. The limited number of examiners allowed a better reproducibility in the methodology, and the instructions were given to the child. Each child was seated comfortably, and the Developmental Eye Movement test was presented on a table. The examiner used a chronometer, followed the answers, and noted the child's mistakes on the sheet provided for this purpose. After explaining the test, the time was started when the child began to read the numbers and stopped as the last digit was read. Based on other studies and for more precision, we chose to keep two decimal places after the decimal point when timing.

The child was asked to read as quickly as possible test cards A, B, and C without using his fingers. As explained in the manual, the vertical time is the sum of seconds of the time taken to read cards A and B. According to the authors of the Developmental Eye Movement test,[1] the errors made in vertical tests were minimal and could be ignored in the calculation of vertical scores.

The horizontal adjusted time is the time, in seconds, to read card C. Only the addition errors (the child added a number) and the omission errors (the child skipped a number) are counted as indicated by the formula given in the manual: horizontal adjusted time = test C time in seconds × [80/(80 – omission + addition)]. The number of errors includes all errors (omission, addition, substitution, and transposition).

TABLE 1. Demographic data of subjects by age

Age (y)	Female	Male	Total
6	30	31	61
7	29	29	58
8	22	20	42
9	25	26	51
10	20	20	40
11	20	20	40
12	17	18	35
Total	128	132	327

Statistical Analysis

A linear regression model was used in which the dependent variables were those measured at the Developmental Eye Movement test (vertical time, horizontal time, number of errors, and ratio horizontal/vertical), and the predictor variable was the age in years of the children tested. An ANOVA was also performed with groups as intersubject factor and variables of the Developmental Eye Movement test as within-subject factors. To assess the difference between American norms, a one-way ANOVA was used. Bonferroni post hoc comparisons were employed. An independent Student *t* test was used to compare the Developmental Eye Movement values between the French and English-speaking children from different age groups. The effect of a factor is significant when the $P < .05$.

RESULTS

Fig. 1 shows the vertical (A) and horizontal (B) time, the number of errors (C), and the ratio (D) obtained by the Developmental Eye Movement test according to the age (in years) of each child tested and the regression line. All these variables decreased significantly while the age of children increased. The R^2 values were 0.47 ($P < .0001$), 0.56 ($P < .0001$), 0.28 ($P < .0001$), and 0.32 ($P < .0001$), respectively, for vertical time, horizontal adjusted time, the number of errors, and the ratio.

ANOVA confirmed the developmental trend over time for all four variables of the Developmental Eye Movement test.

In Figs. 2A and B, the median with the interquartile range of the vertical time and of the horizontal adjusted time, respectively, is shown for each group of children tested; ANOVA reported a significant group effect ($F_{6, 320} = 50.71$ [$P < .0001$] and $F_{6, 320} = 81.18$ [$P < .0001$] for the vertical time and the horizontal adjusted time, respectively). With the Bonferroni correction, it was seen that the values of vertical time and of the horizontal adjusted

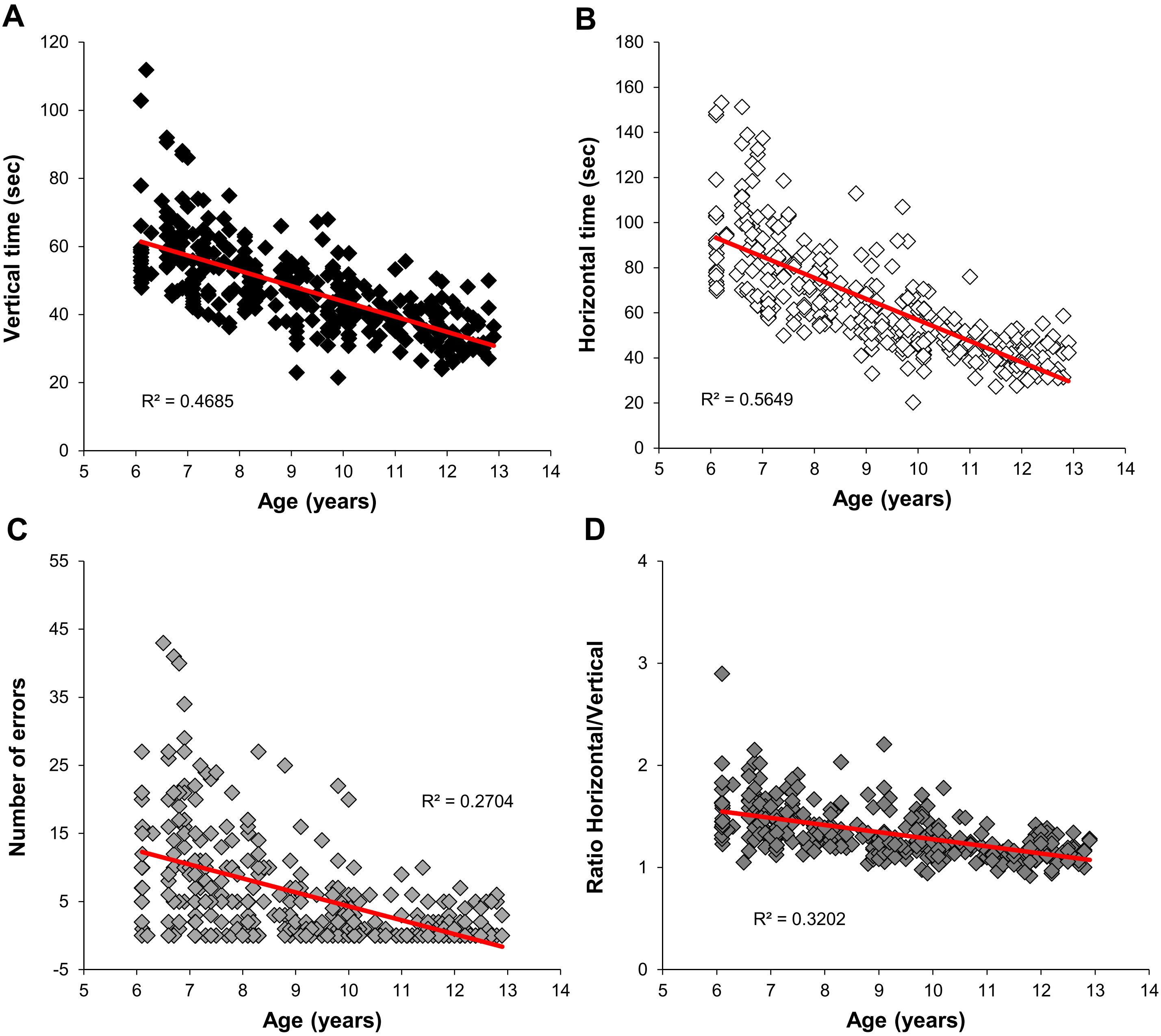

FIGURE 1. Vertical (A) and horizontal (B) time in seconds, number of errors (C), and ratio (D) of the Developmental Eye Movement test subtests for each child examined. Line represents the corresponding regression.

time decreased significantly until the age of 10 years (all $P < .0001$). The values of the vertical time and of the horizontal adjusted time were similar to the group of 10-, 11-, and 12-year-olds.

In Fig. 2C, the box plots of the number of errors made by the different groups of children tested are shown. ANOVA reported a significant group effect ($F_{6,\ 320} = 26.10$, $P < .0001$). The Bonferroni correction reported that the number of errors decreased significantly for each group of children up to 10 years old (all $P < .0001$). The values of the number of errors were similar to each group of the older children (10, 11, and 12 years old).

Finally, the box plot of the ratio of the different groups of children tested is shown in Fig. 2D. ANOVA reported a significant group effect ($F_{6,\ 320} = 27.87$, $P < .0001$). The Bonferroni correction reported that the ratio decreased significantly for each group of children up to 10 years old (all $P < .0001$). The value of the ratio was similar to the older groups of children (10, 11, and 12 years old).

We wanted to explore whether there was a difference between American data[1] (currently used as norms) and our French data from the Developmental Eye Movement subtest (Figs. 3A to D for the different subtests). The independent Student *t* test failed to show any significant difference between French and American data ($t = -0.12$, $P = .9$; $t = -0.11$, $P = .9$; $t = 0.22$, $P = .8$; and $t = -0.17$, $P = .9$, respectively, for the vertical time, horizontal adjusted time, errors, and ratio).

DISCUSSION

The goal of the present study was to collect data from the Developmental Eye Movement test in a sample of French children and to compare these results with those obtained from an American sample. These findings will be discussed individually hereinafter.

Developmental Eye Movement Results Improve with Age of Children

Our results show an improvement in all parameters of the Developmental Eye Movement test up to the age of 10 years and then the stabilization of these results after this age until at least 12 years old. There could be several explanations for this finding.

First, the oculomotor system is still not mature in young children. The cortical and subcortical structures controlling this system (frontal eye field, posterior parietal cortex, supplementary eye field, dorsolateral prefrontal cortex, basal ganglia, thalamus, superior colliculus, and cerebellum) have been the subject of numerous neuroimaging studies that have documented changes during development.[12–15]

Visual acuity, fixation, saccades, binocular coordination, attention, and cognitive factors also improve with age. During reading, older children tend to make fewer fixations per sentence, the duration of fixation decreases, the amplitude of the

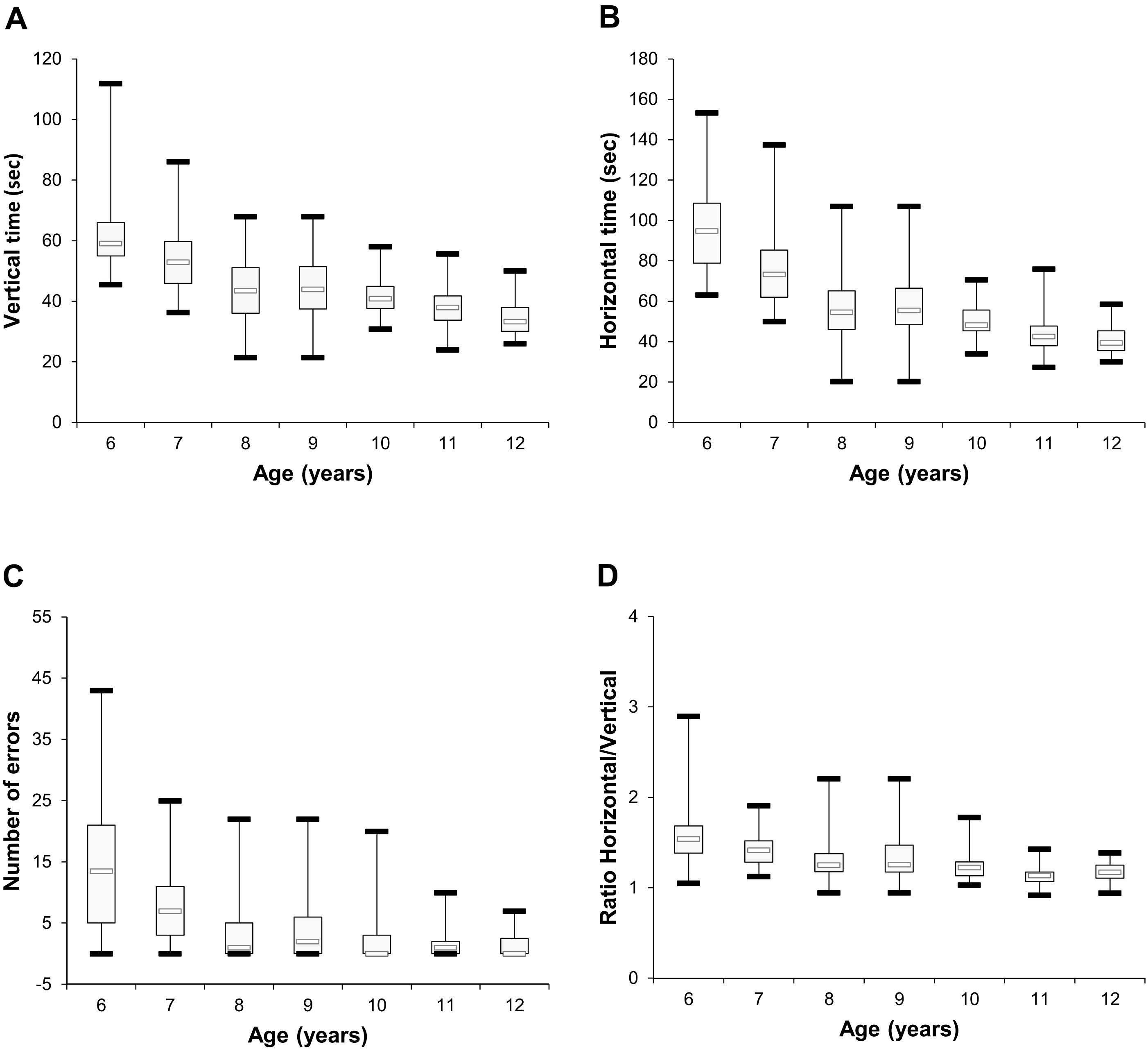

FIGURE 2. Box plot with median and interquartile range of vertical (A) and horizontal (B) time in seconds, number of errors (C), and ratio (D) of the Developmental Eye Movement subtest for each age group.

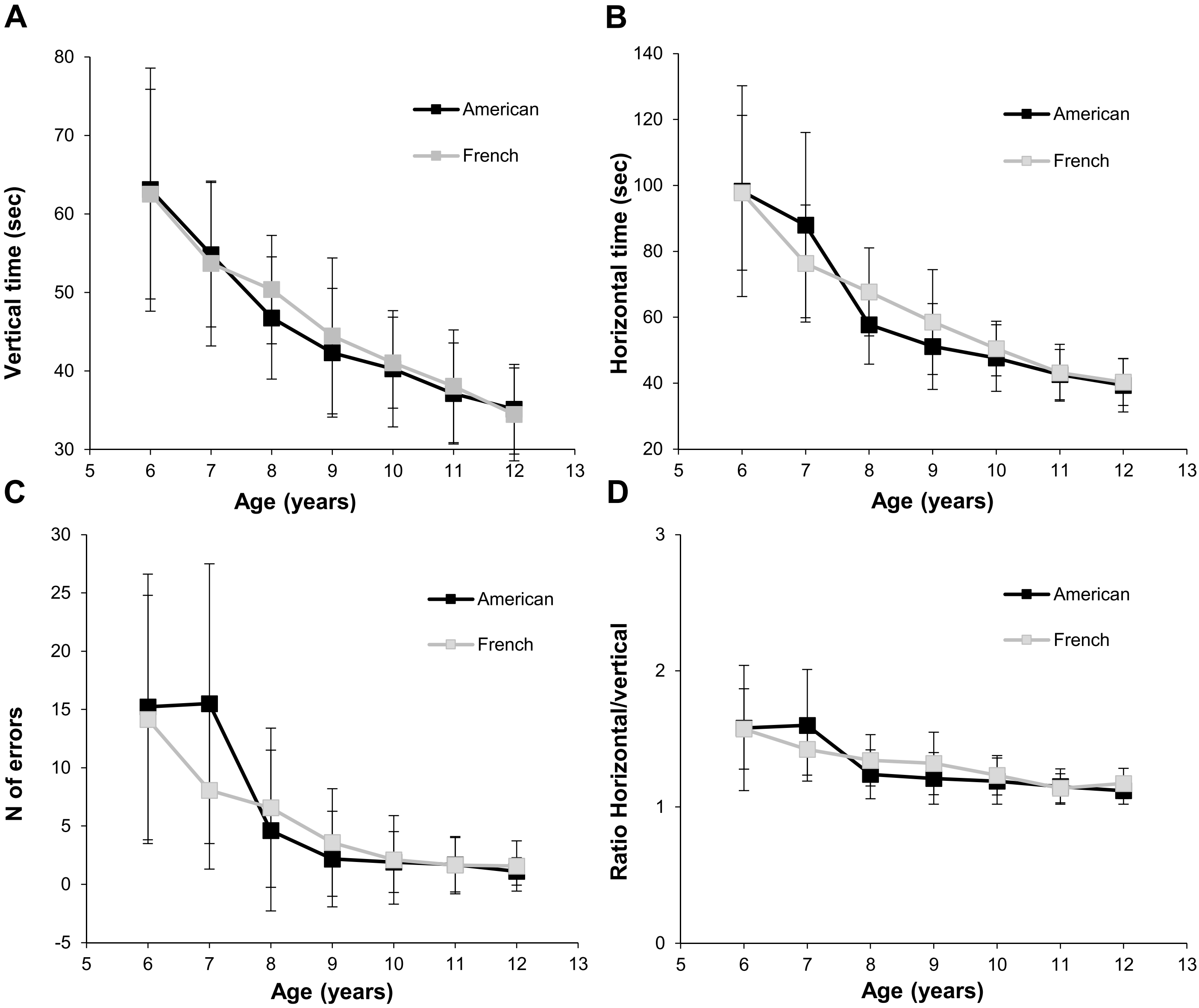

FIGURE 3. Comparison of Developmental Eye Movement subtest (mean and standard deviation of vertical (A) horizontal (B) time in seconds, number of errors (C), and ratio (D) for each age group between American[1] and French subjects.

saccade increases, and the probabilities of regression saccades and refixation decrease.[16–18] All these studies reported that reading capabilities improved with age, but in children from 10 years onward, without reading deficits, such abilities and oculomotor patterns are stabilized and reach the same level of development as adults.

Other factors such as attentional and visuospatial factors that are important for performing the Developmental Eye Movement test are also developing with the age of the child.[19,20]

Similarity between American and French Data

In this study, for the first time, we compared French data with those reported from other American studies as we are using the same norms in France. We did not observe any statistical difference between American norms and French results, suggesting that the present study could be used by clinicians as norms for a French population. Several studies have compared Developmental Eye Movement scores between different types of population to explore an eventual influence of the language and culture on the Developmental Eye Movement test. For instance, first Pang et al.[2] and afterward Xie et al.[4] provided Developmental Eye Movement norms for the Chinese population (for Cantonese and Mandarin languages), and they compared these values to those recorded in other countries (America and Spain). These studies showed that the Developmental Eye Movement score in the subtest depended on language and the educational system; indeed, Chinese children start to learn to read earlier with respect to Western countries (3 to 4 years vs. 5 to 6 years),[21] leading to different values in the scores of the Developmental Eye Movement subtests. In 2012, Facchin et al.[3] developed the Developmental Eye Movement test norms for Italian children, and they reinforced the hypothesis that Developmental Eye Movement values were language and culture dependent. Indeed, comparison with other normative data (Chinese, Japanese, Spanish, Portuguese, and American) highlighted differences between the values obtained. These authors advanced the idea that different statistical methods applied in data comparison and the reliability of the test could also be at the origin of the differences reported between the various studies.

Finally, it is reasonable to question what exactly the Developmental Eye Movement test is measuring given that there is disagreement in the literature.

For instance, some studies failed to find any correlation between the Developmental Eye Movement test performance and saccadic parameters (accuracy, latency, speed),[7] even if these authors established a strong correlation with the reading performance. In contrast, other studies[22,23] have shown that the results of the Developmental Eye Movement test do not correlate with poor saccadic performance or other oculomotor symptoms. We think that the Developmental Eye Movement test is useful for judging the reading performance and speed of visual processing, particularly in children with reading disorders.[24]

Limitations

It should be noted that the socioeconomic status of each family who participated in the study, the race/ethnicity and origin of the child, and demographic information other than age and sex of the participants were not collected.

CONCLUSIONS

These findings demonstrate that the values of the Developmental Eye Movement test in French children are similar to the American ones. French practitioners can use the Developmental Eye Movement test because it stands for their evaluations. Cortical and central structures responsible for oculomotor and attentional capabilities are developing until about 10 years of age, and that could explain the improvement of the Developmental Eye Movement score up to this age.

Depending on the country and language spoken, the Developmental Eye Movement norms may vary, and these differences could be related to the age at which children learn to read and to the culture of each country.

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