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Relationship Between Eye Preference and Binocular Rivalry, and Between Eye-Hand Preference and Reading Ability in Children

ABSTRACT: *One goal of the experiment presented here was to check, in children, the relationship between eye preference when sighting at different angles and eye dominance in binocular rivalry. In addition, since it is sometimes argued that a crossed pattern of eye-hand preference might put children at risk of difficulties in learning to read, we evaluated the relationship between this pattern and reading achievement in first and sixth graders. Results showed that a majority of children are right-eyed for monosighting, and that intrinsic preference and spatial factor influence the choice of eye. As many children were right- or left-eye dominant, and eye dominance was not related to eye preference. We found no relationship between eye-hand preference and reading proficiency, thus not confirming that a crossed pattern of eye-hand preference might put children at risk of difficulties in learning to read. Consistent handers were more advanced in reading than inconsistent handers. © 2008 Wiley Periodicals, Inc.* Dev Psychobiol 50: 789–798, 2008.

Keywords: *laterality; eyedness; rivaling stimuli; handedness; reading proficiency*

INTRODUCTION

When forced to look straight ahead with one eye through a telescope, or through a hole in a piece of cardboard, most people almost always use the same eye, referred to as the *preferred eye*. Although some authors refer to this eye as the ‘‘dominant’’ eye for sighting, we will restrict the term ‘‘dominance’’ to the following phenomenon: when looking at two rivaling stimuli through a stereoscope, people declare alternately seeing one or the other stimulus, but report slightly more often the image arriving to one eye, the eye we will refer to as *dominant*. Adult studies have shown that the preferred eye is not necessarily the same as the dominant eye. A first goal of the experiment presented here was to check, in children, the relationship between eye preference and eye dominance. Furthermore, some argue that a crossed pattern of eye-hand preference in children might put them at risk of difficulties in learning to read. The second goal of this study was thus to evaluate the relationship between the pattern of eye-hand preference and school achievement in elementary school.

Eye preference is one of the many sensorimotor asymmetries seen in all bilateral anatomical pairs such as hands, feet, ears, nostrils, and between the two sides of unitary organs like the mouth (McManus, 2002). The interest in eyedness can be traced back to the end of the 16th century: one of the main tests for eye preference, the near-far alignment test, was first described by Giovanni Battista della Porta in *De Refractione* (1593, in Wade, 1998). It consists in aligning one finger with a far-away target (thus aligning one eye with the target and ignoring visual input from the other eye). Other tests can be used to evaluate eye preference: peeking at a faraway image through a telescope or a rolled sheet of paper,

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looking at a faraway image through the hole of a sheet of paper and slowly bringing the paper toward one eye, or looking through the neck of a bottle, for instance. Depending on the test, the choice of one eye is either conscious or unconscious, but this does not seem to influence the choice. The preferred eye is not consistently related to visual acuity (Ehrenstein, Arnold-Schulz-Gahmen, & Jaschinski, 2005; Hebben, Benjamins, & Milberg, 1981; Pointer, 2001). Test-retest stability for eye preference is good (Porac & Coren, 1976; Piran, Bigler, & Cohen, 1982; see Osburn & Klingsporn, 1998, for a different view), however lower than hand stability for writing (Dodrill & Thoreson, 1993). The eye preference studies report a frequency around 65% of right-eyed, 32% of left-eyed, and 3% of inconsistent in eye preference in adults (Porac & Coren 1976; Reiss & Reiss, 1997; Reiss, 1997b). Gender does not affect eye preference as it does for hand preference (Coren, 1993; Saudino & McManus, 1998), and genetic factors seem to play some role (Annett, 1999; Brackenridge, 1982), but to a lesser extent than for handedness (Coren & Porac, 1980). Eye preference correlates with handedness (McManus, Porac, Bryden, & Boucher, 1999), and eye-hand preference correlation is lower than foot-hand preference correlation (Dargent-Pare, De Agostini, Mesbah, & Dellatolas, 1992; Porac, 1997). Most of the eye preference results were obtained with the eyes pointed straight ahead. As it is the case for the non-preferred hand, frequently used when the object to be grasped is on the same side (Leconte & Fagard, 2004), the eye chosen for sighting is influenced by spatial factors: if the target to be looked at is on the side of the non-preferred eye, then individuals tend to use the ipsilateral eye more than the preferred one (Khan & Crawford, 2001).

Like hand preference, eye preference emerges during infancy. Eye preference develops slightly later than handedness. The stability in eye preference tends to increase between 3 and 6 years, and at 6 years, 90% of children have developed some eye preference (Dellatolas, Curt, Dargent-Pare, & De Agostini, 1998; Ozturk et al., 1999). Consistency between hand and eye preferences was found in 68% of preschool-age children, stable across age groups 3–6 years (Mahone, Wodka, & Hiemenz, 2006). This proportion is similar to that found in adults (McManus et al., 1999; Porac & Coren, 1976).

The *dominant* eye is the eye for which a stimulus is predominantly reported when two rivaling stimuli are presented through a stereoscope (Mapp, Ono, & Barbeito, 2003). Binocular rivalry refers to the alternating perceptual states that occur when the images seen by the two eyes are too different to be fused into a single percept (Miller et al., 2000). Eye dominance is a much less consistent individual trait than eye preference. It depends on stimulus variables such as size of the stimulus, temporal properties of the competing stimuli, and on the feature on which bears the rivalry—form versus color, for instance (see Mapp et al., 2003, for a review).

To our knowledge, very few eye dominance studies involving children have been performed. One longitudinal study showed that infants develop a preference for a fusible pattern (vertical stripes presented to each eye) over a rivaling one (vertical stripes presented to one eye, horizontal stripes to the other) at about 12 weeks of age, at the same time as they develop stereopsis (Gwiazda, Bauer, & Held, 1989).

What is the relationship between the preferred eye and the dominant eye? The answer is complicated by the fact that, while eye preference is usually found to be a consistent trait, dominance observed in rivalry studies is more variable within individuals. Many adult studies have shown that eye dominance measured by one criterion does not correlate well with eye preference during monocular sighting (Ehrenstein et al., 2005; see Mapp et al., 2003, for a review). To our knowledge, this question has never been studied in children. One goal of the study presented here was to evaluate the relationship between eye preference and ocular dominance tested on a rivalry paradigm in children. No study so far has looked at the relationship between eye preference, handedness and ocular dominance in children.

The second goal of this study was to investigate whether there is any relationship between the pattern of eye-hand preference and reading proficiency. Dissociation between eyedness and handedness has sometimes been interpreted as a sign of neuropsychological impairment, especially related to reading difficulties. Several older studies suggested some degree of relationship between crossed eye-hand dominance and reading disabilities (Porter, Shafer, & Monroe, 1946). For instance, in a sub-population of 303 subjects ranging from 5 to 75 years, Rengstorff found that among individuals with crossed eye-hand preference, a significantly smaller proportion considered themselves as fast readers than among individuals with uncrossed eye-hand preference (Rengstorff, 1967). The same author found a similar relationship between type of eye-hand preference (crossed vs. uncrossed) and reading comprehension in another sub-population of 78 participants. Left-eyedness alone, regardless of handedness, has sometimes been found to be associated with poor perceptual-motor performance (Flick, 1966). Since these early studies, very little research has been devoted to confirm (or disconfirm) such relationship between reading ability and eye-hand pattern of preference. One recent study showed that crossed hand-eye preference seems to be "a benign characteristic" in relation to tasks requiring attention to both sides of the midline (Mahone et al., 2006). But it can still be heard, from some school teachers in France or in the UK (Beaton, personal communication) at least, that children with discordant eye-hand preference are at risk of difficulties in learning to read. Therefore, the second goal of the study was to check whether the pattern of ocular-manual asymmetry is related to reading achievement in children.

METHODS

Participants

Forty-two students took part in this study. Three of the children used their left hand for writing (7%) whereas the remaining 39 used their right hand (92.8%). The students were from a regular public school in the center of Paris, 18 first graders (10 girls and 8 boys, mean age = 6 years; age range = 6.1–6.11 years), and 24 fifth graders (11 girls and 13 boys, mean age = 10.4 years; age range = 10–11 years). Prior parental consent was required before testing. In order to have a representative sample of children, all children whose parents agreed were included in the study, independently of sex or handedness for writing.

Procedure

The participants were evaluated for eye preference (direction and degree), eye dominance, visual acuity, hand preference (direction and degree), and reading achievement.

Evaluation of Eye Preference

Direction of *eye preference* was first evaluated using two items. The first item consisted in looking at a picture on the wall through a hole in the middle of a sheet of paper, and then slowly bringing the sheet of paper close to the eye. The second item consisted in looking at the same picture through a plastic tube (‘‘telescope’’). For both evaluations the picture was in front of the child. The children were classified as right-eyed (right eye chosen for both items), left-eyed (left eye chosen for both items), or indeterminate (a different eye chosen for each item or hesitation between both eyes).

Degree of *eye preference* was tested by looking at the preferred eye when the angle of sighting changes. It has been argued sometimes that the notion of a preferred eye is jeopardized by the fact that the eye used for sighting varies depending on horizontal target angle, the preferred eye not being used beyond 15° off-center (Khan & Crawford, 2001), apparently due to the larger image size in the ipsilateral than in the contralateral eye (Banks, Ghose, & Hillis, 2004). We thus decided to test the children's sighting eye when looking through a ‘‘telescope’’ at a target situated at five locations on a semi-circular panel. Two series of five targets were used: letters (A, E, I, O, U), or colors (blue, yellow, white, orange, and green). The targets were small circles of 1.5 cm diameter. They were located on the panel around the child, one in front of him (0°), two to the left (−10° and −20°), and two to the right (+10° and +20°). The children were seated in front of the panel, at about 57 cm, and the plastic tube to be used for sighting at the target was replaced between the middle target and the child after each trial. The child was required to place his chin on a chin-holder specially made for the occasion. He was told that he would have to grasp the ‘‘telescope’’ every time after the experimenter named one of the targets, to look at this target through the telescope without moving the head, and then to replace the telescope back at its location. No instruction was given for the hand to be used for grasping the telescope. For each of the two series, each target was named once, in a pseudo-random order since we decided to alternate each time between the two sides. We noted the hand used to grasp the telescope and the eye used for sighting. When the child changed or hesitated between the two eyes, we coded ‘‘indeterminate’’. We made the hypothesis that the participants would tend to use their ipsilateral eye to look at the targets, but to do more so on the side of the preferred eye as tested for sighting straight ahead than on the side of the non-preferred eye.

Evaluation of Eye Dominance

Eye dominance was evaluated by presenting the children with a pair of rivaling stimuli shown on the screen of a laptop computer, through a portable stereoscope. The two stimuli were 2° large diamond-shaped grids, with black and white stripes at 45° to the left or to the right, with a spatial frequency of four cycles per degree and 100% contrast, presented five degrees from each other (see Fig. 1). To facilitate the fusion of the two half images, each half image was surrounded by an alternation of small dots and rectangles. After 1 min, the left and right half images were switched (so that the left stimulus became the right one and vice versa) without the participants being aware of the switch. The pair was presented for 2 min in all. The children were required to sit on the chair, and place their chin on the chin-holder, so that they could see through the stereoscope fixed above the chin-holder. They were instructed not to move during the test. Two computer mice were placed on the table, at hand's height, one on each side. The apparatus was adjustable to fit the child's height. The children were told to push the button of the mouse on his left with his left hand, when seeing more or exclusively the stimulus with the stripes leftward, and to push the button of the mouse on his right with his right hand when seeing more or exclusively the stimulus with the stripes rightward. To ensure that the children understood the instructions, prior to testing we had the children practice with three other pairs of rivaling stimuli

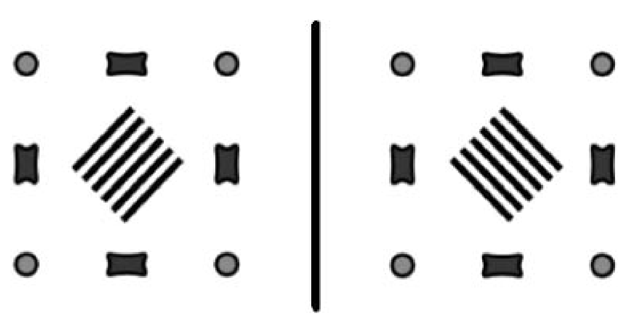

FIGURE 1 Rivaling stimuli used to evaluate ocular dominance.

of the same size, but of different content. After this practice we started the test itself. We used "e-prime" software to present the stimuli and to collect the responses through the mice. We counted the left and right responses. The time of perception of one stimulus is given by summing the time difference between the onset of the corresponding response and the onset of the following response, corresponding to the other stimulus. We calculated the percentage of total time during which the stimulus presented to each eye was reported. This was made separately for the leftward and the rightward stripes, before calculating the mean for each eye. The dominant eye is the one for which the percentage is higher. In our 2005 paper, we argued that the initial percept was more strongly biased than the overall phase dominance (Mamassian & Goutcher, 2005). We thus decided to look also at the initial percept (at time 0).

Evaluation of Reading Achievement

Reading age was assessed with the *Alouette* standardized reading test (Lefavrais, 1965). The Alouette test provides a reading level from 5.11 to above 14.3 years of reading age. The children have to read aloud a 265-word text as quickly and accurately as possible. The text includes rare words, words with similar pronunciation (e.g. "annie-amie"/"ani-ami"), as well as words with contextual graphemes (e.g., "gai-geai"). It also attempts to use foils for set phrases ("au clair de lune" instead of the usual "au clair de la lune") or expected words (e.g., "cordeau," meaning "gardener's line", after "moineau," meaning "sparrow," instead of the expected "corbeau," meaning "crow"). Errors and reading time are recorded while the child is reading. The child is stopped after 3 min. The reading level is obtained either from the reading time (when less than 3 min) or from the number of words read in 3 min, with points deducted for each error in both cases. This reading level is then transformed into a standardized reading age (in months).

Additional Evaluations (Visual Acuity and Hand Preference)

To check the independence of visual preference and ocular dominance vis-à-vis of *visual acuity*, we evaluated the later with the Snellen scale. The children were asked to stand at six meters in front of the Snellen poster, required to hide one eye behind a small cardboard patch they held in their hand, and to read the letter shown by the experimenter with a long stick. The child's visual acuity corresponds to the line with the smallest letters he is able to read (from 10 to 200). A score of 20/20 represents the normal acuity for this test. If the child reads down to the line with the smallest letters, his score is 20/10. If he reads only the top line with the largest letters, he receives the minimum score of 20/200. Scores between 20/20 and 20/10 represent acuity equal or better than the mean population.

To evaluate the direction and degree of handedness, we asked the child to perform or pretend to perform 15 actions (e.g., brushing the hair or throwing a ball). All these items were drawn from standard questionnaires for lateral preferences (Coren, 1993; Corey, Hurley, & Foundas, 2001; Oldfield, 1971; Steenhuis & Bryden, 1989). For each question, the participants had the choice between three answers: "left," "right," or "either left or right." A laterality index (LI) was calculated for hand preference, using the classic formula: [(number of right − number of left)/(number of right + number of left + number of "either hand")] × 100.

RESULTS

Visual Acuity

Visual acuity could be tested on 41 children only, one child being unable to read. All children had normal vision. Most of them had an equal visual acuity with both eyes ($N = 26$), while four children were slightly better with their left eye and eleven children were better with their right eye.

Eye Preference Evaluated by Sighting Straight Ahead

A majority of children used their right eye for sighting in front of them (57.1%), and only two children (4.8%) showed a different preference for the two items. Most right-handed children showed right-eye preference (61.5%), and all three left-handed children showed left-eye preference. A chi-square test showed no age-related difference with respect to this variable (χ^2 $(2) = 1.8$; $p = .40$; see Tab. 1). We found no correlation between the preferred eye and the eye with better visual acuity.

Degree of Eye Preference (Varying Angle of Sighting)

We scored 1 each time the participants used their right eye for sighting, 0 when it was the left eye, and .5 when it was

Table 1. Relative Frequency of Children as a Function of Eye Preference (Hole and Telescope Tests) and Age

	Left-Hand Writers ($N = 3$)			Right-Hand Writers ($N = 39$)		
	Left-Eye Preference (%)	Indeterminate (%)	Right-Eye Preference (%)	Left-Eye Preference (%)	Indeterminate (%)	Right-Eye Preference (%)
First graders	100	0	0	37.5	0	62.5
Fifth graders	100	0	0	30.4	8.7	60.9

indeterminate. For each of the two stimuli (letter and color) and for the five trials, the degree of eye preference could vary between 0 (always the left eye) and 5 (always the right eye). To check whether the kind of stimulus mattered for the eye chosen for sighting, we calculated the correlation between the two conditions. The correlation was highly significant (.96). Thus, we decided to pool the two stimuli so that the degree of eye preference could vary between 0 and 10.

The mean score for eye preference was 6.08, which means that globally the right eye was used more often than the left. There was no significant difference between age groups. We also checked whether this score differed depending on the preferred eye as previously evaluated by sighting straight ahead only. The mean score was 8.12, 7.7, and 2.8 for the right-eyed, indeterminate, and left-eyed children, respectively. An ANOVA on this variable as a function of eye preference indicated that this difference is significant (F (2, 39) = 14.8, $p < .0001$). A LSD post-hoc test indicated that the significance was due to the difference between right-eyed and left-eyed children ($p < .05$).

We calculated an age (×2) × location (×5, repeated measures) ANOVA to see whether the degree of eye preference varied with the location of the target, and whether this was the same for both age groups. For each target the degree of eye preference could vary between 0 (left eye for both stimuli) and 2 (right eye for both stimuli). There was no significant effect for age but a significant effect for target location (F (4,160) = 13.5, $p < .0001$). The children used their right eye more often when the stimulus was in the right visual field than when it was in the left visual field (see Tab. 2). A post-hoc LSD test indicated that the difference is significant between the two leftward locations and the three other locations (center and rightward). In addition, the difference between the center location and the far right location (+20°) is significant. We found no age × location interaction.

We hypothesized that the participants would tend to choose their ipsilateral eye to look at the targets, but to a greater extent on the side of their preferred eye than on the side of their non-preferred eye (as tested for sighting straight ahead). We scored 1 each time the participants used their preferred eye, 0 when it was the non-preferred eye, and .5 when it was indeterminate. For each location,

Table 2. Frequency of Right Eye Choice as a Function of Target Location (max = 2)

	Left −20°	−10°	0°	+10°	+20° Right
All participants	.97	.96	1.3	1.5	1.6
First graders	.81	.91	1.06	1.37	1.44
Fifth graders	1.13	1.02	1.63	1.56	1.73

the score could vary between 0 (when the non-preferred eye was used for both the letter and the color) and 2 (when the preferred eye was used for both stimuli). As can be seen in Figure 2, right-eyed and left-eyed participants more often chose their preferred eye when it was ipsilateral to the target location than when it was contralateral. An ANOVA on the score of preferred-eye use as a function of target location showed that this was significant for right-eyed (F (4,92) = 6.7, $p < .001$), and for left-eyed participants (F (4,60) = 6.1, $p < .001$). An ANOVA on the score of preferred-eye use with eye preference as dependent variable (×2, right eye or left-eye) and with target location as an independent variable with repeated measures, showed no effect for eye preference and no effect for target location but a significant eye preference by target location interaction (F (4,152) = 12.5, $p < .0000$).

Does the use of the ipsilateral eye, even when it is not the preferred one, reflect a tendency to use the ipsilateral hand? In other words, when the children shifted to the ipsilateral non-preferred eye, was it because they first grasped the telescope with the ipsilateral hand? There is a known tendency to use the ipsilateral hand to point to or to grasp laterally presented targets (Leconte & Fagard, 2004). To evaluate whether or not eye choice for sighting reflected hand choice for grasping, we first looked at the relationship between eye and hand used when the target was presented in the center, for both stimuli. As one can see on Table 3, most of the time when the participants used their left eye to look at the target in the center, they first grasped the telescope with their right hand.

We then checked whether the increase in the choice of the left eye as the targets were presented further to the left side solely reflected the increase in ipsilateral hand use. First, we checked whether the frequency of right hand use varied with the location of the target, and whether this was the same for both age groups (we pooled both stimuli as we did for the eye, after checking the correlation between hand choice for both stimuli; $r = .86$, $p < .05$). For each

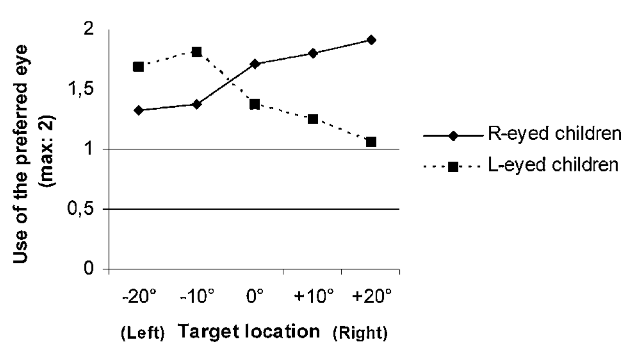

FIGURE 2 Use of the preferred eye (estimated at a straight ahead test) as a function of target location and participant's eye preference.

Table 3. Relative Frequency of Eye-Hand Strategies When the Target was at the Center (Total Differs from 100% Because of Indeterminate Hand or Eye Use)

	Letter		Color	
	Left Eye (%)	Right Eye (%)	Left Eye (%)	Right Eye (%)
Left hand	14.3	0	9.5	2.4
Right hand	19	59.5	21.4	59.5

target location, the score of hand preference could vary between 0 (left hand for both stimuli) and 2 (right hand for both stimuli). An age (×2) × location (×5, repeated measures) ANOVA on the mean score for hand choice showed no significant effect for age and for stimulus, but a significant effect for target location (F (4,160) = 3.5, $p < .01$). A post-hoc LSD test indicated that the difference was significant between the −10° leftward location (hand-use score = 1.6) and three other locations: the center location and the two locations to the right, for which the hand-use score was the same, namely 1.8 (hand-use score for the far left location = 1.7). None of the interactions were significant. Thus, as for the eye chosen for sighting, the target location influenced the hand chosen for grasping the telescope, with less right-hand grasping to the left than to the right. Secondly, we looked at the relationship between the hand chosen to grasp the telescope and the eye chosen to look for laterally presented targets. As one can see on Table 4, the large majority of the left-eyed strategies were preceded with a right-handed grasp: at the two leftward locations, the ratio between right-handed and the left-handed grasps among the left-eyed occurrences varied between 1.1:1 and 3.4:1, depending on the stimulus and the location. Thus, even though the children were more likely to grasp the telescope with their left hand when the stimulus to be looked at was on the left than when it was on the right (and vice versa), this did not wholly account for the increase in the use of the left eye for leftward presentations, and in the use of the right eye for rightward presentations: indeed, the frequency of left-eyed choice increased even when the right hand was used to grasp the telescope.

Eye Dominance

Although children of both age groups were evaluated for eye dominance, only the results of the fifth grade will be reported because the first graders had extreme difficulty with this test. Not moving the head was extremely difficult for them, they had trouble saying when they shifted from seeing one stimulus to the other, they tried some improper strategies (such as blinking one eye) despite the instructions not to, etc. The task was easy enough for the fifth graders. Out of the 24 right-handed fifth graders, one refused to do the task, three saw only one stimulus and never reported rivalry, one did not report rivalry for one of the two patterns, and there was a problem with the apparatus for two. Thus, the results presented here are from 17 children.

It should be kept in mind that the two stimuli were rightward and leftward stripes, and that after 1 min, the left and right stimuli were switched (so that the stimulus presented in the right eye was presented to the left eye and vice versa) without the participants being aware of it. The pair was presented for 2 min in all. One can see on Figure 3 that the percentage of time for which the rightward stimulus was reported (stimulus with the stripes to the right) exceeded 50% whatever the eye it was presented to (we represent only the rightward stimulus on Fig. 3 since the leftward is its complement in terms of percentage of time). Thus, independently of the eye of presentation, there was a preference for the rightward stripes (mean looking time, averaged for right and left eye: 54%) over the leftward stripes (mean looking time, averaged for right and left eye: 46%). A t-test for matched sample, calculated on the mean looking time, showed that this difference is significant (t (16) = 3.2 $p < .01$). We then analyzed whether stimuli seen in one eye had been more reported as compared to the other. The mean looking time, averaged for both stimuli, was 49.9% (SD: 3.8) for the right eye and 50.1% (SD: 3.8) for the left eye. A t-test for matched sample, calculated between the mean looking time for each eye, showed that this difference was not significant ($p = .30$). The mean absolute difference between the two eyes (absolute difference between percentage of time of reporting the stimulus presented in the right eye and

Table 4. Relative Frequency of Eye-Hand Strategies (LE, Left Eye; RE, Right Eye; LH, Left Hand; RH, Right Hand) as a Function of the Target Location (Letter and Color) (Total May Differ from 100% Because of Indeterminate Hand or Eye Use)

	Letter				Color			
	LE–LH (%)	LE–RH (%)	RE–LH (%)	RE–RH (%)	LE–LH (%)	LE–RH (%)	RE–LH (%)	RE–RH (%)
−20°	26.2	28.6	2.4	42.8	11.9	40.5	0	45.2
−10°	16.7	35.7	4.8	38.1	23.8	30.9	2.4	40.5
+10°	11.9	16.7	0	69	11.9	19	0	64.3
+20°	9.5	14.3	0	76.2	7.1	14.3	4.8	71.4

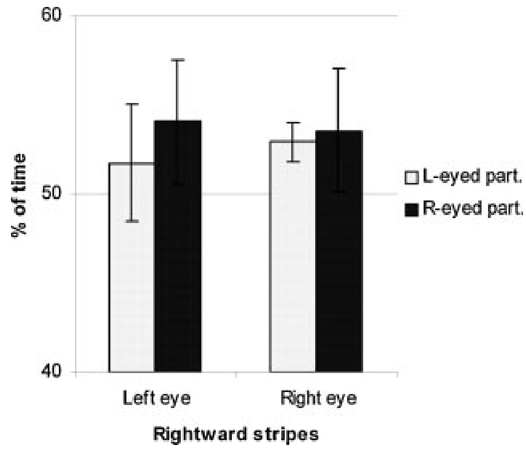

FIGURE 3 Percentage of time when the rightward stripes were reported as a function of eye of presentation and eye preference.

percentage of time of reporting the stimulus presented in the left eye) was 5.2%. Finally, we checked whether there was a difference in the first stimulus reported: the stimulus reported first was slightly more often the stimulus presented in the right eye (56.2%) than the stimulus presented in the left eye (47.3%). However, the difference was not significant ($p = .28$).

To check for individual consistency between eye preference and eye dominance, we first categorized the participants according to their dominant eye. Three children reported about the same time for each eye (mean difference: .000 ms, SD: .001); seven children reported the stimulus presented to the right eye more (mean difference: .07 ms, SD: .07); and seven children reported the stimulus presented to the left eye more (mean difference: −.06 ms, SD: .04). A chi-square test on eye dominance as a function of eye preference showed no relationship between the two classifications. The lack of relationship between eye preference and eye dominance in this study can also be observed in Figure 3: there it can be seen that the children with a left-eye preference did not report the rightward stimulus more when it was presented to the left than to the right eye, and that the children with a right-eye preference even tended to report the rightward stimulus less when it was presented to their preferred right eye than to the left eye. In addition, the eye to which the first reported stimulus was projected was unrelated to eye preference.

Reading Achievement and Pattern of Eye-Hand Preference and Dominance

Unsurprisingly, the score obtained at the *Alouette* test differed significantly between the two age groups (mean reading age: 83.2 and 137.5 months for the first graders and the fifth graders, respectively; $F\ (1.39) = 72.3$, $p < .000$). We calculated a new variable from the difference for each child between his reading score and the mean score expected for his age. Eleven out of the 18 first graders (61.1%) and 15 out of the 24 fifth graders (62.5%) were at or above the reading score expected according to their age. This reading level fits with what can be expected from students attending a regular public school downtown Paris. There was no significant difference between the two age groups for this variable. We then checked whether this difference varied according to the eye-hand pattern of laterality (crossed vs. uncrossed), for each age group separately and then for the whole group. Remember that 64.3% of the children were uncrossed for eye-hand preference (right-handed and right-eyed, or left-handed and left-eyed), whereas 30.9% showed a crossed pattern (right-handed and left-eyed or vice versa; 4.8% of the children did not show eye preference). There was a tendency for the children with crossed laterality pattern to be better than those with uncrossed laterality pattern (stronger among fifth graders than among first graders; see Tab. 5), but the difference was not significant ($p = .54$). In addition, the only child unable to read in first grade was a right-handed-right-eyed child. Finally, the results were the same when the right-handed and right-eyed children were considered separately from the left-handed and left-eyed children. When the same analyses were applied to the dominant eye (which could be done for the fifth graders only), the results were similar: there was no relationship between the dominant eye and reading proficiency.

Note that when degree of handedness alone was considered, using the laterality index (LI), we observed that the more consistently handed children were more advanced in reading than the less consistently handed children (see Fig. 4). This held for both age groups. An ANOVA on the LI as a function of reading achievement indicated that the effect of handedness consistency on reading level was significant ($F\ (1.40) = 4.4$, $p < .05$).

Table 5. Advance in Reading (Reading Age—Age) as a Function of Eye-Hand Pattern of Laterality (Crossed vs. Uncrossed) and Grade

	Advance in reading (in months; (SD))	
Pattern of eye-hand preferences	Uncrossed	Crossed
First graders	3.6 (11.9)	5.2 (6.1)
Fifth graders	4.7 (22.2)	21.3 (30)
All	4.2 (18.2)	13.8 (7.4)

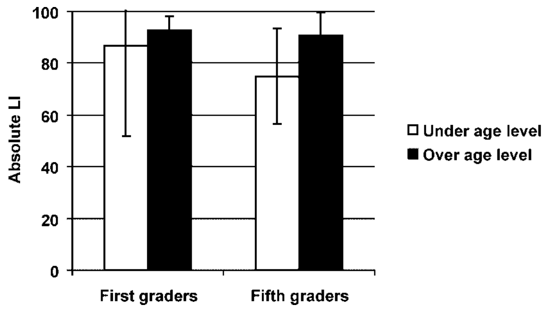

FIGURE 4 Absolute; laterality index (LI) as a function of reading level of the children (over vs. below their age level).

DISCUSSION

Eye Preference

A first goal of the study presented here was to check, in children, the relationship between eye preference and eye dominance. We observed that 33.3% of right-handed children and all three left-handed children chose their left eye for sighting. This was independent of the difference in visual acuity between the two eyes. When tested for degree of eye preference, at various angles of sighting, the children showed some tendency to use the ipsilateral eye for monocular sighting directed toward one side: both right-eyed and left-eyed subjects tended to use their left eye to look at the leftward stimulus more than at the rightward one (and vice versa for the right eye). However, this tendency did not mask eye preference: right-eyed children globally used their right eye more and left-eyed children used their left eye more. Thus, as for hand preference, several factors play a role in eye choice for monocular sighting: spatial alignment is one of them, intrinsic preference is another one. There was no age-related difference in eye preference.

Our study did not show any influence of the category of stimulus on the choice. In contrast with the studies devoted to the influence of the object to be taken on hand choice (see for instance, Almerigi, Carbary, & Harris, 2002), there is no study, to our knowledge, on the variation of eye choice as a function of the category of stimulus. Given the known left-lateralization for processing linguistic stimuli, we could have expected more right eye choice for the letters than for the colors. This was not the case.

These results show (1) that the choice of the sighting eye does not change as a function of stimulus characteristics and thus is not due to a cognitive decision; (2) that this choice varies with the angle of target location; and (3) that the tendency to use the ipsilateral eye is not solely due to a change in hand use for holding the sighting device. The difference in stimulus size in the ipsilateral and contralateral eye might explain part of the ipsilateral eye use (Banks et al., 2004). Those results are in line with Khan and Crawford's study (2001), but they also point to the stability of eye preference in varying spatial constraints.

Eye Dominance

Eye dominance was evaluated by asking the children to look at rivaling stimuli through a stereoscope. We observed an effect of the stimulus, with the rightward stripes being reported significantly more often that the leftward stripes. This effect could be due to the responding hand, at least in right-handers who represent the majority, since the children were told to push the button of the mouse on their right with their right hand when seeing more or exclusively the stimulus with the rightward stripes, and to push the button of the mouse on the left with their left hand when seeing more or exclusively the stimulus with the leftward stripes. We choose to do so in order to facilitate learning the instructions. Nevertheless, by comparing the two presentations (rightward stripes presented to the right eye and rightward stripes presented to the left eye) we could check whether the children reported the rightward stripes more or less depending on the eye the stimulus was presented to. Moreover, the left-handers more often reported rightward stripes. Fourteen out of the 17 children who could be tested for eye dominance showed a dominance of one eye. However, there was the same number of right-eye dominant and of left-eye dominant children. In addition, left-eye dominant and right-eye dominant children were about equally distributed among right-eye preference and left-eye preference children: thus, there seems to be no relationship between the preferred eye chosen for sighting and the dominant eye when looking at rivaling stimuli in children, at least in our procedure. These results are in accordance with adult studies showing that eye dominance does not correlate well with eye preference during monocular sighting (Ehrenstein et al., 2005; Mapp et al., 2003). Since when they report one stimulus, people are not conscious of eye-of-origin information, eye dominance probably reflects a very different process, lower level, than eye preference. We might have found different results if we had varied the contrasts of one stimulus against the other: using such a procedure, Handa et al. (2004) found a relationship between eye preference and eye dominance. Our results might also suggest that eye dominance is less clear in children than in adults.

Origin and Function of Ocular Asymmetries

Where does eye preference come from? Some suggest that the preferred eye is determined by nothing more than the constraint of the sighting task that only one eye be used and the ease or the habit of using a particular eye to perform the task (Mapp et al., 2003). It is not known whether very young children have a preferred eye, but when 3-year-old are tested with the "telescope," they first put it in between the two eyes (Cyclops effect, Barbeito, 1983). However, some authors suggest a genetic factor in eyedness (Zoccolotti, 1978; Reiss, 1997b; but see Saudino & McManus, 1998, and Dellatolas, de Agostini, Jallon, & Poncet, 1988, for a different view).

The question of whether the preferred eye has a special role for visual or oculomotor processes is not clear either. In some visual tasks, such as target detection, performance is better with the preferred than with the non-preferred eye (Schneor & Hochstein, 2005). In addition, imaging studies reveal larger area bilateral activation for preferred eye, as compared with non-preferred eye stimulation (Rombouts, Barkhof, Sprenger, Valk, & Scheltens, 1996). But little is known about the role of the preferred eye for processing information, and what difference, if any, it makes whether the preferred eye is the left or the right one. The second goal of this study was to evaluate the relationship between the pattern of eye-hand preference and dominance and reading achievement in elementary school. It has been sometimes argued that a crossed pattern of eye-hand preference in children might put them at risk of difficulties in learning to read. In this study, we found no relationship between the pattern of eye-hand preference (crossed vs. uncrossed) and reading proficiency, in first grade and in fifth grade. Similarly, we found no relationship between the pattern of eye-hand dominance (crossed vs. uncrossed) and reading proficiency, in fifth grade. These results differ from an old study showing, mostly in adults, that lower reading speed and comprehension have some relationship with crossed eye-hand preference (Rengstorff, 1967). It is not impossible that some relationship exists in adults more than in children. However, our results are in agreement with another previous developmental study showing no relationship between the pattern of eye-hand preference (crossed vs. uncrossed) and reading readiness as evaluated with the metropolitan Reading Readiness Test in children (Stephens, Cunningham, & Stigler, 1967). These results do not confirm the idea that a crossed pattern of eye-hand preference might put children at risk of difficulties in learning to read. Neither do they support the idea that eye-hand preference inconsistency should be considered as an indirect indicator of undeveloped cerebral lateralization. Some studies suggest that eye preference is related to hemispheric specialization for visual attention (see for instance, Roth, Lora, & Heilman, 2002); here we did not find any relationship between eye preference, independently of hand preference, and reading proficiency.

In our study however, we observed that consistent right- and left-handers were significantly more advanced in reading than less consistent handers. These results are in accordance with previous studies showing that consistency of hand preference can be associated with cognitive advantage in young children (Gottfried & Bathurst, 1983; Michel, 1988; Kotwica, Ferre, & Michel, 2008). It might be interesting to confirm, on more children, whether degree of handedness is more related to reading achievement than its direction, or that eyedness related or not to handedness. If it is confirmed, then it would support the idea that handedness inconsistency could be an indicator of undeveloped cerebral lateralization in children.

REFERENCES

Almerigi, J. B., Carbary, T. J., & Harris, L. J. (2002). Most adults show opposite-side biases in the imagined holding of infants and objects. Brain and Cognition, 48(2–3), 258–263.

Annett, M. (1999). Eye dominance in families predicted by the right shift theory. Laterality, 4(2), 167–172.

Banks, M. S., Ghose, T., & Hillis, J. M. (2004). Relative image size, not eye position, determines eye dominance switches. Vision Research, 44(3), 229–234.

Barbeito, R. (1983). Sighting from the cyclopean eye: The cyclops effect in preschool children. Perception & Psychophysics, 33(6), 561–564.

Brackenridge, C. J. (1982). The contribution of genetic factors to ocular dominance. Behavior Genetics, 12, 319–325.

Coren, S. (1993). The lateral preference inventory for measurement of handedness, footedness, eyedness, and earedness: Norms for young adults. Bulletin of the Psychonomic Society, 31(1), 1–3.

Coren, S., & Porac, C. (1980). Family patterns in four dimensions of lateral preference. Behavior Genetics, 10(4), 333–348.

Corey, D. M., Hurley, M. M., & Foundas, A. L. (2001). Right and left handedness defined: A multivariate approach using hand preference and hand performance measures. Neuropsychiatry, Neuropsychology, and Behavioral Neurology, 14(3), 144–152.

Dargent-Pare, C., De Agostini, M., Mesbah, M., & Dellatolas, G. (1992). Foot and eye preferences in adults: Relationship with handedness, sex and age. Cortex, 28(3), 343–351.

Dellatolas, G., Curt, F., Dargent-Pare, C., & De Agostini, M. (1998). Eye dominance in children: A longitudinal study. Behavior Genetics, 28(3), 187–195.

Dellatolas, G., de Agostini, M., Jallon, P., & Poncet, M. (1988). Mesure de la preference manuelle par autoquestionnaire dans la population francaise adulte. Measurement of manual preference by self-administered questionnaire in the adult French population. Revue de Psychologie Appliquée, 38(2), 117–135.

Dodrill, C. B., & Thoreson, N. S. (1993). Reliability of the lateral dominance examination. Journal of Clinical and Experimental Neuropsychology, 15(2), 183–190.

Ehrenstein, W. H., Arnold-Schulz-Gahmen, B. E., & Jaschinski, W. (2005). Eye preference within the context of binocular functions. Graefes Archives Clinical Experimental Ophthalmology, 243(9), 926–932.

Flick, G. L. (1966). Sinistrality revisited: A perceptual-motor approach. Child Development, 37, 612–622.

Gottfried, A. W., & Bathurst, K. (1983). Hand preference across time is related to intelligence in young girls, not boys. Science, 221(4615), 1074–1076.

Gwiazda, J., Bauer, J., & Held, R. (1989). Binocular function in human infants: Correlation of stereoptic and fusion-rivalry discriminations. Journal of Pediatric Ophthalmology & Strabismus, 26(3), 128–132.

Handa, T., Mukuno, K., Uozato, H., Niida, T., Shoji, N., & Shimizu, K. (2004). Effects of dominant and nondominant eyes in binocular rivalry. Optometry and Vision Science, 81(5), 377–383.

Hebben, N., Benjamins, D., & Milberg, W. P. (1981). The relationship among handedness, sighting dominance, and acuity dominance in elementary school children. Cortex, 17(3), 441–446.

Khan, A. Z., & Crawford, J. D. (2001). Ocular dominance reverses as a function of horizontal gaze angle. Vision Research, 41(14), 1743–1748.

Kotwica, K., Ferre, C., & Michel, G. (2008). Relation of stable hand-use preferences to the development of skill for managing multiple objects from 7- to 13-months of age. Developmental Psychobiology, 50(5), 519–529.

Leconte, P., & Fagard, J. (2004). Influence of object spatial location and task complexity on children's use of their preferred hand depending on their handedness consistency. Developmental Psychobiology, 45(2), 51–58.

Lefavrais, P. (1965). Description, définition et mesure de la dyslexie. Revue de Psychologie Appliquée, 15(1), 33–44.

Mahone, E. M., Wodka, E. L., & Hiemenz, J. R. (2006). Hand and eye preference and their association with task approach by preschoolers. Perceptual and Motor Skills, 102(3), 691–702.

Mamassian, P., & Goutcher, R. (2005). Temporal dynamics in bistable perception. Journal of Vision, 5, 361–375.

Mapp, A. P., Ono, H., & Barbeito, R. (2003). What does the dominant eye dominate? A brief and somewhat contentious review. Perception & Psychophysics, 65(2), 310–317.

McManus, C. (2002). Right hand, left hand: The origins of asymmetry in brains, bodies, atoms and cultures. London: Weindenfeld & Nicolson.

McManus, I. C., Porac, C., Bryden, M. P., & Boucher, R. (1999). Eye-dominance, writing hand, and throwing hand. Laterality, 4(2), 173–192.

Michel, G. F. (1988). A Neuropsychological perspective on infant sensorimotor development. In: C. Rovee-Collier, & P. Lipsitt (Eds.), Advances in infancy research (Vol. 5, pp. 1–35). Norwood, NJ: Ablex.

Miller, S. M., Liu, G. B., Ngo, T. T., Hooper, G., Riek, S., Carson, R. G., & Pettigrew, J. D. (2000). Interhemispheric switching mediates perceptual rivalry. Current Biology, 10(7), 383–392.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. Neuropsychologia, 9, 97–113.

Osburn, D. M., & Klingsporn, M. J. (1998). Consistency of performance on eyedness tasks. British Journal of Psychology, 89, 27–37.

Ozturk, C., Durmazlar, N., Ural, B., Karaagaoglu, E., Yalaz, K., & Anlar, B. (1999). Hand and eye preference in normal preschool children. Clinical Pediatrics (Phila), 38(11), 677–680.

Piran, N., Bigler, E. D., & Cohen, D. (1982). Motoric laterality and eye dominance suggest unique pattern of cerebral organization in schizophrenia. Archives of General Psychiatry, 39(9), 1006–1010.

Pointer, J. S. (2001). Sighting dominance, handedness and visual acuity preference: Three mutually exclusive modalities? Ophthalmic and Physiological Optics, 21(2), 117–126.

Porac, C. (1997). Eye preference patterns among left-handed adults. Laterality (Hemispheric Specialisation in Animals and Humans: A Special Issue), 2(3/4), 305–316.

Porac, C., & Coren, S. (1976). The dominant eye. Psychological Bulletin, 83, 880–897.

Porter, R. B., Shafer, H., & Monroe, E. (1946). Research in reading during the war years. Review of Educational Research, 16, 102–115.

Reiss, M. (1997a). Laterality of writing hand in East German samples. Perceptual and Motor Skills, 84(2), 474.

Reiss, M. R. (1997b). Ocular dominance: Some family data. Laterality, 2(1), 7–16.

Reiss, M., & Reiss, G. (1997). Lateral preferences in a German population. Perceptual and Motor Skills, 85(2), 569–574.

Rengstorff, R. H. (1967). The types and incidence of hand-eye preference and its relationship with certain reading abilities. American Journal of Optometry and Archives of American Academy of Optometry, 44(4), 233–238.

Rombouts, S. A., Barkhof, F., Sprenger, M., Valk, J., & Scheltens, P. (1996). The functional basis of ocular dominance: Functional MRI (fMRI) findings. Neuroscience Letters, 221(1), 1–4.

Roth, H. L., Lora, A. N., & Heilman, K. M. (2002). Effects of monocular viewing and eye dominance on spatial attention. Brain 125(Pt 9), 2023–2035.

Saudino, K., & McManus, I. C. (1998). Handedness, footedness, eyedness and earedness in the Colorado Adoption Project. British Journal of Developmental Psychology, 16(2), 167–174.

Schneor, E., & Hochstein, S. (2005). Effects of eye dominance in visual perception. International Congress Series, 1282, 719–723.

Steenhuis, R. E., & Bryden, M. P. (1989). Different dimensions of hand preference that relate to skilled and unskilled activities. Cortex, 25, 289–304.

Stephens, W. E., Cunningham, E. S., & Stigler, B. J. (1967). Reading readiness and eye hand preference patterns in first grade children. Exceptional Children, 33(7), 481–488.

Wade, N. J. (1998). Early studies of eye dominances. Laterality, 3(2), 97–108.

Zoccolotti, P. (1978). Inheritance of ocular dominance. Behavior Genetics, 8(4), 377–379.