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DEVELOPMENTAL PSYCHOLOGY | RESEARCH ARTICLE

Influence of spatial perception abilities on reading in school-age children

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Abstract: Spatial perception abilities enable individuals to explore a visual field, to detect spatial position and to infer relationships between visual stimuli. Written words and text are conceptualized spatially along a horizontal mental line, but little is known about the way children develop these representations. The exact relationship between visuo-spatial perception and academic achievement has never been directly assessed. Therefore, our aim was to study the developmental trajectory of space perception abilities by assessing perceptual, attentional and memory components, the relationship between these abilities and reading achievement in school-age children. Forty-nine children aged between 6.5 and 11 years old were divided into four age groups and were assessed with visual bisection, visual search and visual memory location tasks. The results showed that the groups of older children, from the age of nine, improved significantly on the bisection and visual search tasks with respect to all visual fields, while the groups of younger children showed more errors in the left visual field (LVF). Performances on these tasks were correlated with reading level and age. Older children with a low reading score showed a LVF bias, similar to the youngest children. These results demonstrate how abnormal space perception might distort space representation and in turn affect reading and learning processes.



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ABOUT THE AUTHOR

For some years now, Sc. Arnaud Saj has studied the perception and the representation of space in patients with right brain lesions, with or without spatial neglect, in studies with and without rehabilitation. He has a high level of expertise in both clinical neuropsychology and research. This work has led to several clinical publications and confirmed that spatial neglect patients suffer from an impaired internal representation of space with an ipsilesional deviation of their egocentric reference. Recently, in the MRI protocol in patients and healthy controls, he explored the neural correlates of attentional deficits and changes after prism therapy.

PUBLIC INTEREST STATEMENT

This is the first study examining the developmental trends of visuo-spatial perception abilities and their relation to reading performances. This study demonstrates the correlation between the age-related improvement of space perception and the development of the left visual field (LVF), allowing the coverage of a larger peripheral visual area. This is reflected by higher accuracy in spatial exploration and visual attention, which are important for spatial organization when processing visual cues. In terms of application, this study shows the importance of specific spatial perception abilities for learning to read. More precisely, it shows the existence of a relation between reading levels and spatial perception processing abilities for the LVF. On a neuronal level, results show a “bias” towards the LVF in young children and in older children with poor reading performances, which could be related to the immaturity of the contralateral fronto-parietal network of the right hemisphere.

Subjects: Behavioral Neuroscience; Developmental Neuroscience; Perceptual Development; Psychological Science

Keywords: spatial perception; neuropsychology; developmental psychology; reading

1. Introduction

Left-to-right asymmetry is common across several cognitive domains (e.g. language, reading and time perception, for a review, see Boroditsky, 2011). It can be observed during performances on visual tasks involving spatial perception and attention abilities. This asymmetry is educationally reinforced in cultures that read and write from left to right. For example, the left-to-right axis forms the basis for systems representing time and numbers. Spatial perception abilities enable the processing of spatial information by exploring stimuli in the visual field, detecting their spatial position and the relationships between them. These visuo-spatial processing abilities are important for the quality of spatial analysis and spatial organization that, in turn, are fundamental to the development of several specific visuo-spatial abilities, such as spatial attention, orientation, memory and spatial imagery (Barisnikov, 2009; Booth & Siegler, 2006; de Hevia, Izard, Coubart, Spelke, & Streri, 2014; Piazza, Fumarola, Chinello, & Melcher, 2011; Smith & Chatterjee, 2008). These abilities constitute spatial cognition, which is essential for the development of spatial representations, allowing the individual to perform complex spatial tasks (e.g. pattern construction and drawing) and to acquire academic skills (e.g. reading, geometry and numerical skills).

When reading, a word is identified via the central visual acuity system; however, the process of reading also involves the recognition of cues in peripheral areas close to the central visual field (CVF). Therefore, the time of fixation on a word (or part of a word) includes an information extraction time necessary for reading, as well as a planning time for the saccade to the next word (Rayner & Pollatsek, 1981). Therefore, the simple task of reading is not only based on visual acuity but also on the perception of the space adjacent to the word. Basic numerical processing abilities also rely on these visuo-spatial processing abilities. Developmental studies have shown that ~10% of school children present visuo-spatial difficulties (e.g. perception, attention and memory) and learning difficulties that cannot be attributed to language development (Atkinson et al., 2003).

The visuo-spatial deficit hypothesis is a potential explanation for reading difficulties. More generally, the acquisition of reading is often reported to be impaired in many developmental disorders characterized by visuo-spatial deficits. A significant alteration in reading abilities (such as developmental dyslexia, see Mumeaux & Ducrot, 2014) has been observed in 5–6% of school-age children (von Aster & Shalev, 2007). Recent studies have demonstrated a causal link between visuo-spatial attention and learning how to read (Franceschini et al., 2013). Furthermore, it has been suggested that the orientation of visual attention is central to emerging reading abilities among children (Facoetti et al., 2010; Hari & Renvall, 2001; Roach & Hogben, 2007; Vidyasagar & Pammer, 2010). However, few studies have explored spatial perception abilities and reading in this population, and the role of basic visuo-spatial processing abilities (attention, orientation and memory) in reading acquisition throughout development needs to be examined.

The main goal of the present study was to examine the relationship between space perception processing abilities and reading skills in school-age children. Based on the literature, we expected performances on spatial perception tasks (visual bisection and visual search) to be associated with reading level but not with visuo-spatial memory. We also expected developmental changes regarding asymmetry in the visuo-spatial perception field (left/right) to be associated with reading performances.

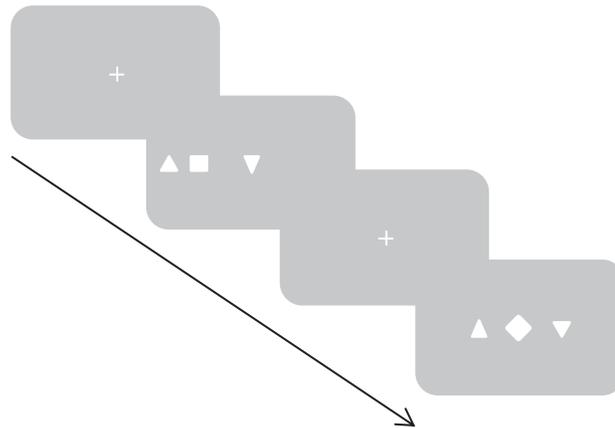
2. Methods

2.1. Participants

A total of 49 children, recruited from the same public elementary monolingual school in Geneva following mainstream education, took part in the study; none of the children repeated their academic year. All children were included in the analyses (24 girls; mean age, $M = 8.69$ years; standard

Figure 2. Example of trial used for the bisection, visual search and spatial memory tasks.

Note: The three tasks were performed in different blocks, each task requiring a similar binary yes/no response.



2.3.2. Task and procedure

Three tasks using the same visual stimuli were presented to the participants. Each task required a similar binary response (indicated by a key-press):

- (1) The bisection task: assessed spatial perception processing; participants were asked to indicate whether the central item was located on the midpoint between the two other items or not (possible responses: yes or no).
- (2) The visual search task: assessed spatial attention processing; participants were asked to indicate whether the single-odd item in the triplet was a square or a diamond (possible responses: square or diamond).
- (3) The visual memory task: assessed memory for spatial location (position); participants were asked to indicate whether or not the three items appeared in the same location as the previous trial (possible responses: same or different). Successive trials were controlled so that the position of items on trial n would correspond to positions on trial $n - 1$ on 50% of all trials (one-back task), irrespective of the actual shape (square, diamond or triangle) of the items

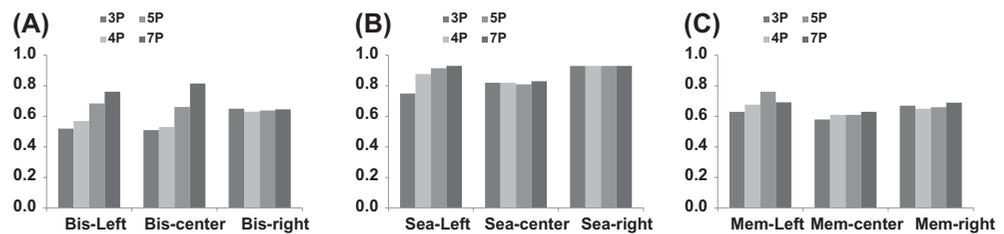
Each task was presented in blocks of 30 trials (10×3 triplet positions on the screen) separated by short rest blocks (fixation point only), and repeated in a different order in two different sessions. This resulted in a total of 30 trials (10-min duration) with stimuli presented in the left visual field (LVF), the right visual field (RVF) or centrally (CVF) for each of the three tasks. All responses were recorded by a keypad for subsequent analyses of the participants' performances. The performances (corrects responses) for the three visual fields for each task were calculated separately.

3. Statistical analyses

Analyses of variance were performed with Statistica software (StatSoft, Maisons-Alfort, France) by considering the mean values of the correct response (CR). We analysed the influence of the factors *group* (3P, 4P, 5P and 7P), *task* (bisection, search and memory) and *visual field* (left, centre and right). In order to see at which age we could observe developmental changes in performances, *post hoc* comparisons were performed with the Newman-Keuls correction. The threshold for statistical significance was set at $p < 0.05$.

Regression and correlation analyses were conducted on individual performance scores for LVF, RVF and CVF for each task in function of the reading level (Swiss scoring system out of six) in order to respond to the hypothesis of asymmetry in visuo-spatial perception through development.

Figure 3. Accuracy (% mean \pm SD) is depicted as a function of the triplet stimulus position in the visual field (left, right and centre) and the group (3P, 4P, 5P and 7P) in the bisection task (A), in the visual search task (B) and the spatial memory task (C).



4. Results

The analysis of the CRs revealed a significant main effect of the factors group ($p < 0.05$), task ($p < 0.05$) and visual field ($p < 0.05$), and a significant interaction between group and visual field ($p < 0.05$). The group–task interaction was not significant ($p = 0.461$) but the group–task–visual field interaction was ($p = 0.045$).

The mean comparison between groups showed that the youngest group made more errors than the oldest group (% mean \pm SD—3P: 67.3 ± 2.5 ; 4P: 73.1 ± 2.2 ; 5P: 77.8 ± 2.2 ; 7P: 81.9 ± 2.2). The 3P group showed a significant difference to the 5P and 7P groups ($p < 0.05$) but not with the 4P group ($p = 0.08$). The 4P group was significantly different to the 7P group ($p < 0.05$) but not to the 5P group ($p = 0.14$). Finally, the 5P group did not show any difference in comparison to the 7P group ($p = 0.21$).

The *post hoc* comparisons for each task showed that the performances of the groups of younger children (3P and 4P) were significantly different compared to the performances of the groups of older children for the bisection and visual search tasks in respect to visual field. For the bisection task (Figure 3(A)) and the visual search task (Figure 3(B)), the group of young children (3P) made more errors than the other groups, particularly in the LVF. The groups did not differ in the memory location task (Figure 3(C)).

We then explored correlations between the difference in performances in LVF, RVF and CVF in each task as well as the scores for each reading level. Significant relationships were found for the LVF and reading level since low reading levels correlated with LVF errors in the bisection ($r = 0.50$, $p = 0.045$) and search tasks ($r = 0.56$, $p = 0.030$). The group of youngest children made more errors in the LVF (Figure 4).

5. Discussion

To our knowledge, this is the first study that has shown the developmental trends of space perception abilities. It is also the first study to report a link between specific space perception biases and reading performances in a child population.

The triplet visuo-spatial perception tasks were used in order to study space perception abilities during development and to assess their possible link with reading capacity. In these tasks, the same stimuli were used to investigate three distinct visuo-spatial processing abilities (perceptual, attentional and memory). In the search task, the group of youngest children showed a significant bias towards the LVF, while no differences in performances were observed between the groups of older children with regard to different visual fields. On the bisection task, the performances of young children showed a bias towards the LVF and CVF. In contrast, on the visual memory task, no differences between groups and visual fields were observed.

Furthermore, the groups' performances on the bisection and visual search tasks correlated with the children's academic grade and their individual reading scores. Increasing reading experience with age seems to improve space perception abilities. This dynamic relationship of mutual influence seems to result in significant improvements with age in space perception and reading abilities.

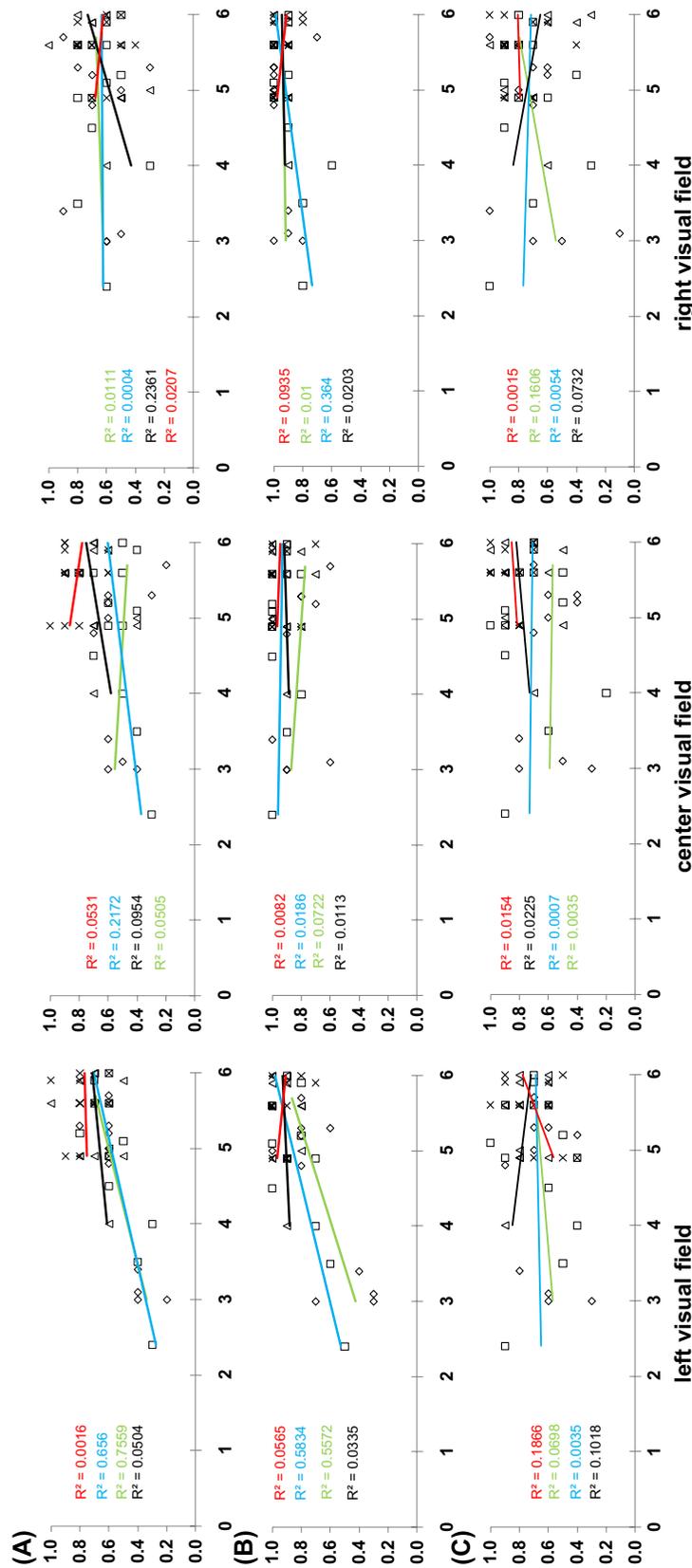


Figure 4. Relation between individual performance scores for LVF, RVF and CVF for each task in function to reading level. (A) Line bisection, (B) Visual search and (C) Visuo-spatial memory task.

Notes: The green line and the diamonds correspond to the 3P group; the blue line and the squares to the 4P group; the black line and the triangles to the 5P group; and the red line and the crosses to the 7P group.

In the first school years, it appears that children present “pseudo-spatial neglect” of the LVF. This bias seems to distort space perception and to disturb correct coding of visuo-spatial information, which affects the process of learning to read and causes increased reading errors. Maturation processes could explain the observed asymmetry for space perception and its developmental changes. In contrast, low reading performances exhibited by some older children could result from a specific deficit in spatial perception abilities. These children showed a bias towards the LVF, similar to the youngest group of children. Furthermore, their low scores for spatial perception and spatial attention were associated with low reading scores.

Correlations between poor attention and a bias towards line bisection have been associated with right hemisphere ineffectiveness (Manly, Cornish, Grant, Dobler, & Hollis, 2005). Developmental studies have also shown that the neuronal system (e.g. fronto-parietal regions) mediating spatial perception processing abilities develops early (Cohen & Cashon, 2001), and that neurological abnormalities in these regions underlie behavioural deficits observed in developmental dyslexia (Waldie & Hausmann, 2010) and dyscalculia (Rotzer et al., 2008).

Several studies have highlighted the role of attention in reading, demonstrating that visual attention skills are one of the most important predictors for reading skills (Bosse, Tainturier, & Valdois, 2007; Franceschini, Gori, Ruffino, Pedrolli, & Facchetti, 2012; Plaza & Cohen, 2007; Valdois, Bosse, & Tainturier, 2004; Valdois, Lassus-Sangosse, & Lobier, 2012). For example, a line bisection test (i.e. marking the centre of a horizontal line with a pencil) demonstrates potential deficits in the orientation of spatial attention in some dyslexic children. Typically, developing readers and adults reading from left to right tend to place their mark of bisection to the left of the true centre of the line (Jewell & McCourt, 2000). Nonetheless, there is no evidence for such a bisection bias in dyslexic children (Sireteanu, Goertz, Bachert, & Wandert, 2005).

With regard to developmental dyslexia, the majority of authors consider language deficits at the level of processing and representing phonological information to be important causal factors, although the precise nature of these deficits is not yet well defined (Castles & Coltheart, 2004; Ramus & Szenkovits, 2008). Simultaneously, there is a growing literature on visuo-spatial deficits being associated with developmental dyslexia (Cohen, Dehaene, Vinckier, Jobert, & Montavont, 2008), including oculomotor deficits (Getman, 1985; Jainta & Kapoula, 2011), visual attention deficits (Bosse et al., 2007; Facchetti, Paganoni, & Lorusso, 2000) and abnormalities in orientation perception (Meerwaldt & Vandongen, 1988; Romani, Ward, & Olson, 1999). Several recent studies have shown that individuals with poorer reading capacities present a deficit in visual search and coding tasks (Franceschini et al., 2012, 2013; Gori & Facchetti, 2015 for review). These authors demonstrated that visuo-spatial attention impaired before reading acquisition could be an explanatory cause of developmental dyslexia. Furthermore, this could be related to the abnormal development of visual magnocellular nerve cells involved in visual guidance control of attention and eye fixation (Stein, 2014). Therefore, difficulties in these abilities could be the consequence of a specific impairment of the magnocellular dorsal stream (Stein, 2014; Vidyasagar & Pammer, 2010 for review), which seems to be involved in learning to read (Ruffino et al., 2010; Stein, 2014; Vidyasagar & Pammer, 2010 for review). Functional imaging studies in children with developmental dyslexia have shown deficiencies in the bilateral temporo-parietal junction areas (Eden & Zeffiro, 1998), with auditory and speech-sound processing for the left part (Gabrieli, 2009). On the other hand, the right temporo-parietal junction is the spatial attention region, responsible for spatial neglect (Corbetta & Shulman, 2011; Mort et al., 2003).

Specific spatial perception biases potentially associated with neglect dyslexia have been largely reported in adult patients with unilateral spatial neglect following (right) brain lesion. Reading errors exhibited by these patients seem to be related to the part of the visual field affected by neglect, usually the left part (for a review, see Vuilleumier & Saj, 2013) of the text and/or words (Friedmann & Nachman-Katz, 2004; Lee et al., 2009). However, it has been shown that neglect developmental dyslexia may be confounded with learning disability (Friedmann & Nachman-Katz, 2004).

Nevertheless, neuropsychological and functional neuroimaging studies on unilateral spatial neglect, dyslexia and dyscalculia (in children and adults) have pointed out the crucial role of the fronto-parietal network for spatial perception, reading and numerical skills (Rotzer et al., 2008, 2009; Saj, Verdon, Vocat, & Vuilleumier, 2012; Sun, Lee, & Kirby, 2010; Verdon, Schwartz, Lovblad, Hauert, & Vuilleumier, 2010).

It is interesting to note that abnormalities in the parietal regions (for a review, see Vuilleumier, 2013) are more often associated with specific learning disabilities such as dyslexia or dyscalculia (Vallar, Burani, & Arduino, 2010). Therefore, in dyslexic patients (children or adults), functional imaging studies have shown reduced activation of the parietal lobe (hyper- or hypo-activated depending on the task), particularly in the left hemisphere (Lobier, Zoubrinetzky, & Valdois, 2012; Peyrin et al., 2012). Since parietal dysfunctioning may underlie dyslexia associated with a reduced visuo-attentional span, some authors propose that such a failure could impede the acquisition of effective word recognition (Peyrin et al., 2012). A decrease in grey matter volume, particularly in the parietal cortex (posterior superior parietal lobule and intraparietal sulcus, respectively) and the frontal cortex was observed in children with dyslexia or dyscalculia (Rotzer et al., 2008, 2009; Sun et al., 2010). Furthermore, several authors have observed alterations in white matter (especially at the upper and lower longitudinal beam) in subjects with dyslexia (Sun et al., 2010) as well as lesions of white matter tracts between different cortical areas present in signs of neglect (Bartolomeo, Thiebaut de Schotten, & Doricchi, 2007) and loss of reading skills.

6. Conclusion

Our results show that spatial perception abilities ameliorate throughout childhood and maintain a dynamic relationship during reading acquisition. The triplet visuo-spatial perception task proved to be a sensitive tool for defining specific space perception processing abilities involved in reading. This task, which is easy to administer, could help with the early detection of such difficulties in neurodevelopmental disorders associated with low academic achievement. This is in accordance with Franceschini et al.'s (2012) longitudinal study, which suggests the predictive value of visual search tasks for future reading acquisition and the early detection of dyslexia. Finally, diffusion tensor magnetic resonance imaging should reveal the structural maturation of white matter in several regions of the frontal and parietal lobes, areas in which white matter maturation is correlated with the development of spatial perception and reading processes. This preliminary study on spatial perception opens a new neuropsychological field on the link between spatial cognition and reading abilities in developmental psychology studies.

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Competing interest

The authors declare no competing interest.

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