Pseudoneglect and development: Age-related spatial bias in bisection and drawing

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Abstract

The numerous studies on pseudoneglect have generated inconsistent results and disagreement concerning the underlying mechanisms. Most research supports the hypothesis that hemispheric lateralization is the main reason for the persistent leftward bias in spatial tasks. Findings on the influence of reading direction, handedness and participant age are largely contradictory. As a result of brain maturation adults usually perform with significant leftward bias. However, both hemispheric activation and scanning habits exert an influence on space representation, which varies across age groups. Preschoolers, middle school children and adults were tested on the line and word bisection tasks and on house-person-tree drawing tasks. The analysis of their performance produced results consistent with an explanatory account that the direction of the spatial bias shifts leftwards in the course of development.

Keywords: pseudoneglect, line bisection, age differences, house-person-tree drawing task

Introduction

Cognitive processes have their limitations that may lead to distortion in perception or judgment. Different biases arise when cognitive resources are challenged, but are also partially rooted in the cultural context and can be learned implicitly, including our ability to navigate through space and construct adequate spatial representations of the close environment. The temporal and spatial structure of the viewing behavior is independent from the goal of the task and is attributed to the horizontal asymmetries of the visual and attentional systems.

The hemispatial neglect syndrome is a neuropsychological disorder where patients have difficulties processing stimuli from the contralesional hemispace. The condition is generally due to impairment of the ability to direct attention and movement, although it might as well be attributed to the inability to form spatial representations (Bisiach, 1996). Patients with left visuospatial neglect bisect horizontally presented lines to the right of their objective center. In contrast, neurologically normal people usually perform the task with significant leftward bias. This exploratory inclination to look slightly to the left of the center of the presented stimuli is known in the literature as pseudoneglect (Bowers & Heilman, 1980).

Pseudoneglect is typically interpreted in terms of the hemispheric lateralization of the brain and has two complementary components – visual and motor. The visual component incorporates the scanning habits and the attentional and perceptual effects, while the motor component refers to the overdriven movements, like directional hypometria, perceptual motor activation and cueing (Macdonald-Nethercott, Kinnear, & Venneri, 2000). In one of the first studies on pseudoneglect leftward errors were made only in the paper-and-pencil version of the line bisection task and not in the computer version of the task (Luh, 1995). This result supports the contribution of the above mentioned motor factor to the leftward spatial bias. Both hemispheres are engaged in directing attention to the contralateral space, but as the right hemisphere is generally more active during spatial tasks this could lead to subsequent enhanced attendance to the left visual hemispace. This was demonstrated in a cancellation task designed to deliberately activate the left or the right hemisphere (Vingiano, 1991). A more recent fMRI study also showed increased activation in the right intra-parietal sulcus and lateral peristriate cortex during judgment and performance of line bisection tasks (Cicek, Deouell, & Knight, 2009).

In a series of eye-tracking experiments on viewing behavior in exploring complex scenes participants demonstrated a marked initial leftward bias that was independent of the category of the presented images (Ossandon, Onat, & Konig, 2014). It is generally accepted that people tend to scan the visual field in the direction that they read. Opposite reading habits give rise to opposite spatial bias when performing the line bisection task – left-to-right readers bisect the lines to the left of their veridical center, while right-to-left readers deviate to the right (Chokron & Imbert, 1993). In a similar study the line bisection performance of adults, 8-year-olds and preschoolers coming from cultures with opposite reading habits was compared and differences were found in all groups (Chokron & De Agostini, 1995). Usually the developmental shift in the observed bias in line bisection is from right to left, as demonstrated in an experiment with 4-5 and 10-12 years old children (Dellatolas, Coutin, & De Agostini, 1996).

There is evidence that with the maturation of the corpus callosum during puberty, spatial processing shifts from the contralateral to the right hemisphere. Right-handed prepuberty children showed rightward bias in line bisection tasks when using their right hand and a leftward bias with their left hand. The adult and puberty groups bisected the lines to the left with both hands (Hausmann, Waldie, & Corballis, 2003). Another study also showed that learned directionality and movement preferences have little influence on placement of single object on a page. Both

French and Moroccan dextral children manifested similar leftward bias in a draw-a-tree task, supporting the advantage of brain lateralization over learned cultural habits, including reading direction (Picard & Zarhbouch, 2014).

Both neglect and pseudoneglect, despite the difference in the underlying neurological mechanisms, have similar behavioral manifestation and are assessed with the same tasks, such as line and word bisection, drawing or bisecting a simple figure and exploration of complex scenes. Basically, both lines and words are bisected to the left of their objective center by adults, in accordance with the hemispheric activation hypothesis and the reading direction hypothesis. However, the effect is more pronounced in word bisection showing that an additional mechanism might be involved. In a series of experiments with lines and orthographic strings (words, pseudowords, symbols), lines were bisected always to the left, while words yielded a different result depending on their length – short ones (3-4 letters) were bisected with a general right-side bias (Arduino, Previtali, & Girelli, 2010).

As the beginning of the word is more informative than its end, oculomotor behavior shows that attention is usually directed to the left of the word center, while trying to access the mental lexicon in establishing a matching cohort. According to the Attentional scaling hypothesis, proposed by Fischer (1996), orthographic strings are processed differently than other symbolic or pictorial material. Word bisection is biased toward the beginning of the horizontally presented words, depends on their length and the ease of lexical access - Hebrew-American bilinguals showed a greater leftward bias in their second language (English) than native English readers (Fischer, 1996). Both English and Hebrew readers showed greater leftward bias for words and pseudowords than for lines (greatest for low-frequency words), and people with developmental dyslexia deviated more to the left than controls (Gabay, Gabay, Henik, Schiff, & Behrmann, 2015). Interestingly, dyslexic children have been reported to show inversed pseudoneglect in line bisection tasks, shifting their subjective center to the right of the veridical one (Michel, Bidot, Bonnetblanc, & Quercia, 2011).

There are numerous studies on pseudoneglect with inconsistent results as well as disagreement concerning the underlying mechanisms. The goal of the current study was to combine explicit and implicit measures to dissociate the attentional component in spatial processing. We tested three age groups – preschoolers, sixth-graders and adults on line and word bisection tasks and draw-a-house-person-tree tasks. In accordance with previous studies, we used paper-and-pencil tasks and only long and low-frequency words.

As different spatial tasks supposedly tap into different aspects of spatial awareness, we compared performance on active (implicit) and passive (explicit) spatial tasks across three developmental stages with different reading expertise (see Barrett, Kim, Crucian, & Heilman, 2002 for a discussion on the difference of implicit and explicit tasks). Both the hemispheric activation and the directionality hypotheses predict that right-handed preschool children would exhibit a right spatial bias in all tasks, because of the prevalence of the motor component in spatial judgments and their inability to read. Sixth-graders should have mixed results due to already established reading habits but incomplete brain lateralization. Adults were expected to have a strong leftward bias, especially in the word bisection tasks, in accordance with the Attentional scaling hypothesis.

Method

In order to address the research questions above, we carried out an experimental study protocol consisting of a series of five tasks used in previous research on pseudoneglect in three population age groups – preschool children, middle school children, and young adults. The experimental tasks were line bisection, word bisection, and drawing a house, a person, and a tree on a blank sheet of paper in landscape orientation. The dependent variable was the degree of lateral (left or right) spatial bias in participants' performance.

Participants were asked to perform two passive (line and word bisection) and three active spatial tasks (drawing a simple figure). Line bisection is the most widely used and rigid measure for neglect in clinical settings, and for pseudoneglect in neurologically normal people, and is more connected to attention. The word bisection task is thought to activate semantic processing together with the spatial representations. Drawing reflects higher order cognitive functions – instead of passive judgment, it involves the ability to plan and execute a simple task in peripersonal space. We hypothesized that with age the direction of the bias should shift from right to left, and this would be reflected in the performance of the middle school group.

Participants

60 Bulgarian speaking participants (22 men) took part in the study. The preschool group consisted of 19 children (8 boys), with a mean age of 4 years and 4 months (M = 53.37, SD = 3.47, range 49-59, calculated in months). The middle school group consisted of 20 children (4 boys), with a mean age of 148 months (12 years and 3 months), SD =3.65 and range 139-154 months. The adults were 21 (10 men), with a mean age of 28 years, SD = 11.02 and range 18-51 years. All adults gave their written informed consent before the study. Informed written consent for the children was given by their parents.

All participants underwent assessment for handedness, given that some studies report a significant influence of handedness on bisection and drawing tasks (e.g. Jewell & McCourt, 2000; Picard & Zarhbouch, 2014). Only right-handed participants' data were considered further. From the analyses were excluded data from two preschoolers who used predominantly their left hand in the drawing tasks (in accordance with Kastner-Koller, Deimann, and Bruckner, 2007), two participants from the 12-year-old group who self-reported as left-handed; three adult participants who self-reported as ambidextrous but reported predominant use of their left hand on the handedness questionnaire.

Thus, statistical analyses were performed on the data from 17 preschool children (7 boys), 18 middle-schoolers (4 boys) and 18 adults (9 men). The mean age of the adult and middle school groups remained the same, and a t-test showed no significant difference between the age of the recruited and the analyzed groups of preschoolers (p = .890). None of the preschool children had reading or writing habits.

Stimuli

Two types of stimuli were used in the study – five straight horizontal lines and ten words, presented on two separate sheets of paper A4 format, portrait orientation. The lines and the words were printed in advance, while the drawing tasks were executed on blank sheets of paper format A4 with landscape orientation. The lines had a mean length of 10.9 cm (SD = 2.2), and were positioned to the left or to the right side of the sheet, in a way that no two lines was exactly below each other. Only very long and low frequency words were chosen for the task. The mean length of the words in characters was 13.4 (SD = 2.1), or 3.9 cm (SD = 0.7) and their mean objective frequency was 0.19 (SD = 0.23, range 0.00-0.59). Objective frequency data for the Bulgarian words (Simov, Osenova, Kolkovska, Balabanova, & Doikoff, 2004) was converted into frequency score per million and 10-base logarithm of the score was taken with one added to the score per million to avoid the undefined Lg(0). The words had an odd number of characters in order to avoid an overlap between their orthographic and physical center. For the same reason a handwriting script and not block letters, was used. The words were written in *Segoe Script*, bold, font size 13, again on different positions to the left or to the right of the A4 sheet.

Table 1: Means and SDs (in parentheses) of the line and word length in centimeters; word length in number of characters and their objective frequency (Simov et al., 2004)

	Length in cm	Length in characters	Frequency
Words	3.9 (0.7)	13.4 (2.1)	0.19 (0.23)
Lines	10.9 (2.2)		

Procedure

All participants had to perform line and word bisection, and also draw a house, a person and a tree on three separate sheets of paper. The order of the line and word bisection tasks and the drawing tasks was counterbalanced for the adults and the middle-schoolers. Preschoolers performed the tasks in random order. The sheets of paper were placed one by one in front of the participants and taken away after the execution of each task. Participants were asked to cross the middle of the lines and words as fast and as accurately as possible, and to draw a house, a person and a tree, on their own terms. For the 4-year-olds the instructions were more detailed, as the experimenter had to be sure that they understood the task well.

Results

The performance on the active and passive tasks was measured with two different types of indices. For the analyses of the line and word bisection data, a Percent deviation score was calculated as the difference between the left bisected part and the true half, divided by the true half and multiplied by 100 ((left bisected-half)/half*100) (see Fujii, Fukatsu, Yamadori, & Kimura, 1995; Failla, Sheppard, & Bradshaw, 2003).

Also, a novel drawing bias index was developed that took into account both the size of the drawing and its deviation from the center. First, the distance between the two outmost points on the lateral axis of the drawing was divided by two. The distance from this central point C_1 to the outer points was taken as the drawing`s radius R. Each Bias index was calculated as the proportion of the shortest distance (⊥) from C_1 to the sheet's midline C_2 ($\pm\perp C_1C_2$, negative values coded left), and the absolute sum of $\pm\perp C_1C_2$ and R.

$$\textbf{\textit{Drawing Bias Index}} = \frac{\pm\perp C_1C_2}{|\pm C_1C_2 + R|}$$

This calculation yielded values between -1 and +1, with zero for the centrally positioned objects. For both measures negative values indicated left bias and positive values indicated right bias.

Preschool children

The data of 17 four-year old children from the preschool age group were subjected to analyses of Bias for each of the five tasks. Table 2 shows the means, standard deviations, and range of values for Line Bisection and Word Bisection Bias.

Table 2: Means, standard deviations, and range for Deviation Percent Score (Line/Word Bisection) in 4 year olds.

Experimental Task (Bias)	M	SD	Min	Max
Line Bisection	6.88	11.84	-12.83	30.20
Word Bisection	6.05	9.47	-16.20	22.18

Note: Negative values correspond to a Left side preference.

In the Line Bisection Task, children's choices were significantly biased towards the right-hand side of the lines, as seen in the percent deviation score, M = 6.88, SD = 11.84, $t_{(16)}$ = 2.40, p = .03. Children's performance in the Word Bisection Task was similarly biased rightwards, M = 6.05, SD = 9.47, $t_{(16)}$ = 2.63, p = .02.

The drawing placement choices of the preschool children were analyzed in terms of the House bias index, Person bias index, and Tree bias index, respectively.

One-sample t-tests evaluated whether children's drawings were positioned with significant lateral bias. Table 3 shows the means, standard deviations, and range for each drawing task.

Table 3: Means, standard deviations, and range for the drawing tasks bias indices in preschool children.

Experimental Task: Bias Indices	M	SD	Min	Max
Draw a House	.24	.54	-.83	.90
Draw a Person	-.01	.56	-.82	.93
Draw a Tree	.11	.49	-.73	.71

Note: Negative values correspond to a Left side preference.

There was no lateral bias in the Draw-a-house task, $M = .24$, $SD = .54$, $t_{(16)} = 1.79$, $p = .09$, the Draw-a-person Task, $M = -.01$, $SD = .56$, $t_{(16)} = .11$, $p > .1$, or the Draw-a-tree Task, $M = .11$, $SD = .49$, $t_{(16)} = .96$, $p > .1$. In neither of the three object drawing tasks did children's object placements deviate reliably from the sheet's midline.

Middle school children

The data of 18 twelve-year olds from the middle school age group were analyzed for Bias for each of the five tasks. Table 4 shows the means, standard deviations, and range for the Line Bisection and Word Bisection Bias measures.

Table 4: Means, standard deviations, and range for Deviation Percent Score (Line/Word Bisection) in the middle school group.

Experimental Task (Bias)	M	SD	Min	Max
Line Bisection	.22	4.94	-9.69	9.25
Word Bisection	-.97	9.71	-26.09	12.31

Note: Negative values correspond to a Left side preference.

In both bisection tasks, twelve-year olds' choices were not reliably biased to one of the sides, all p's > .1.

The drawing choices of the 12-year olds were analyzed in a similar way to the data of the preschool children. One-sample t-tests yielded a reliable lateral bias for the Person and Tree Bias index measures. Table 5 shows the means, standard deviations, and range for each drawing task.

Table 5: Means, standard deviations, and range for the drawing tasks bias indices in 12-year old children.

Experimental Task: Bias Indices	M	SD	Min	Max
Draw a House	-.06	.17	-.39	.21
Draw a Person	-.40	.14	-.60	-.13
Draw a Tree	-.13	.15	-.41	.15

Note: Negative values correspond to a Left side preference.

The analyses revealed no lateral bias in the Draw-a-house task, $p > .1$, but we found a reliable Left bias in the Draw-a-person and Draw-a-tree tasks, $t_{(17)} = 11.87$, $p < .001$, and $t_{(17)} = 3.59$, $p = .002$, respectively.

Adult group

The data of 18 adult participants were analyzed for Bias. Table 6 shows the means, standard deviations, and range for the Line Bisection and Word Bisection Bias measures.

Table 6: Means, standard deviations, and range for Deviation Percent Score (Line/Word Bisection) in adults.

Experimental Task (Bias)	M	SD	Min	Max
Line Bisection	-1.21	5.49	-13.10	7.25
Word Bisection	-.83	3.21	-8.45	4.78

Note: Negative values correspond to a Left side preference.

In neither task, did adults' performance show any lateral bias, p's > .1.

The drawing choices of the adults were analyzed in terms of the House, Person, and Tree bias indices. Table 7 shows the means, standard deviations, and range for each object drawing task.

Table 7: Means, standard deviations, and range for the Draw-a-House, Draw-a-Person, and Draw-a-Tree indices, in the adult group.

Experimental Task: Bias Indices	M	SD	Min	Max
Draw a House	-.27	.26	-.72	.25
Draw a Person	-.45	.22	-.77	.03
Draw a Tree	-.25	.21	-.58	.13

Note: Negative values correspond to a Left side preference.

In all three object drawing tasks, adults exhibited a reliable Left bias: in the Draw-a-house task, $M = -.27$, $SD = .26$, $t_{(17)} = 4.23$, $p = .001$, in the Draw-a-person Task, $M = -.45$, $SD = .22$, $t_{(17)} = 8.79$, $p < .001$, and in the Draw-a-tree Task, $M = -.25$, $SD = .21$, $t_{(17)} = 5.07$, $p < .001$.

In summary, we found a reliable Right bias in preschool children's performance on the two bisection tasks, and a reliable Left bias in adults' performance on the drawing tasks. Twelve-year olds had no lateral bias on the bisection tasks, and a reliable Left bias on two of the three drawing tasks. In addition, in order to evaluate whether their performance differed from each of the other age groups we analyzed their performance measures in combination with the other groups in separate multiple analyses of variance on the bisection tasks and on the drawing tasks. A MANOVA revealed a significant main effect of age group in line and word bisection ($F(4,98) = 3.75$, $p = .007$; $\eta^2_p = .133$). A post-hoc analysis (Scheffé) revealed that the difference was between the adults and the preschoolers ($p = .016$ for the line bisection task; and $p = .05$ for the word bisection task). No difference was found between the performance of the middle school children and either of the other two groups (Figure 1).

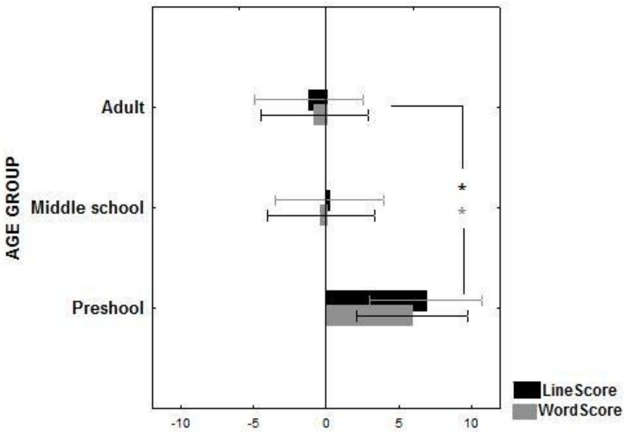

Figure 1. Percent deviation line and word scores as a function of age group. Positive values indicate deviation to the right and negative values indicate deviation to the left. Error bars denote .95 confidence intervals. * $p < .05$.

A MANOVA showed a significant main effect of age group in the drawing tasks ($F(6,96) = 4.73$, $p < .001$; $\eta^2_p = .228$). Post-hoc analysis (Scheffé) revealed that the adults and the preschoolers performed differently in all drawing tasks – in the draw-a-house task ($p = .001$), in the draw-a-tree task ($p = .006$) and in the draw a person task ($p = .003$). Middle school children differed from preschoolers only in the draw-a-person task ($p = .01$). Again, no difference was found between the performance of the middle school children and the adults (Figure 2).

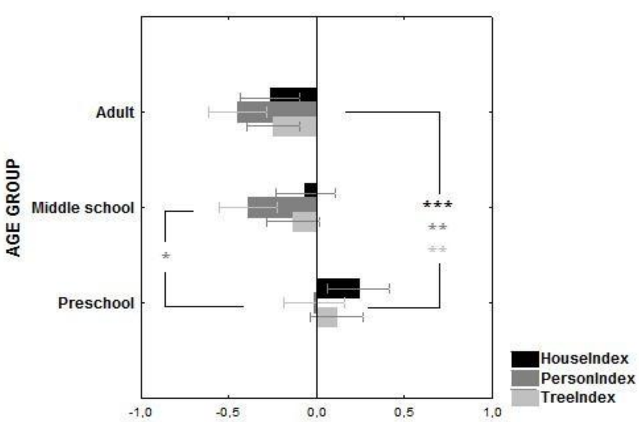

Figure 2. Drawing bias index as a function of age group. Positive values indicate deviation to the right and negative values indicate deviation to the left. Error bars denote .95 confidence intervals. *** $p < .001$; ** $p = <.01$; * $p < .05$.

Discussion

The present study showed spatial bias in different cognitive spatial tasks across three age groups. Interestingly, the direction of the demonstrated bias depended significantly on the nature of the tasks. In the passive tasks (line and word bisection), results showed bias only for the preschool group, and in the active (drawing) tasks - only for the middle school children and the adults. This suggests that implicit and explicit tasks might reflect different types of spatial processing. Furthermore, with development the direction of the bias was indeed shifted from right to left, but also across the tasks. Generally, all participants deviated more to the left in the implicit tasks. One explanation would be that the explicit instruction in the bisection task made participants more attentive, resulting in overdriven movements for the preschoolers because of the pervasive motor component. Another speculation would be that a certain familiarity effect could enhance the ability to form object representations in the peripersonal space, resulting in difference in performance.

Preschoolers exhibited significant rightward bias in the line and word bisection tasks, consistent with reports of previous studies (Dellatolas et al., 1996; Dobler, Manly, Atkinson, Wilson, Ioannou, & Robertson, 2001). As reported by Dellatolas et al. (1996), when four-year-old children use their right hand, a low degree of hemispheric interaction due to callosal immaturity may be the reason which leads to enhanced left hemisphere involvement, shift of attention to the right side and rightwards overestimation.

The 12-year-old middle school children were not reliably biased in the bisection tasks. As reported by Hausmann et al. (2003), there is a robust developmental step to the adult pattern of pseudoneglect between the ages of 10-12 and 13-15. In their study, a group of 10-12 year old children demonstrated a symmetrical neglect for the line bisection task, whereas their eldest group (13-15 year olds) showed a leftwards bias. As proposed by Hausmann et al. (2003), this developmental step can be attributed both to corpus callosum maturation and hormonal change during puberty.

Furthermore, for the adult group, the line and word bisection task showed no significant bias although the overall mean scores indicated a leftward directionality.

In order to assess the leftward bias we used implicit measures of visual-spatial computation as in the person-tree-house drawing task (Barrett et al., 2002). As expected, the adult group demonstrated a leftward bias for all three types of object drawings, similar to the results in the study of Barret et al. (2002). The middle-schoolers` drawings also showed a leftward bias though to a smaller degree. This leftward bias is consistent with previous studies using the draw-a-person task (Heller, 1991) and the draw-a-tree task (Picard & Zarhbouch, 2014) and indicates that at this age the right hemisphere asymmetric activation is evident and reading habits affect spatial attention.

Notably, Barrett et al. (2002) reported that reading habits (left to right or right to left) could not reverse the leftward bias in the house-tree-person drawings of adults. In our study we found that preschoolers exhibited no lateral bias and tended to place their drawings in the middle of the page. Thus, when reading habits are not established and there is no imbalanced left hemispheric activation, children's perceptual right space is not attenuated.

Conclusion

The present study used both implicit and explicit tasks in three age groups with different reading skills. Age had significant effect in all tasks, but results depended on the nature of the tasks. Adults differed from preschoolers in all tasks. Middle school children performed like the adults, and differed from the preschoolers in only one of the implicit tasks. These results are consistent with previous studies stressing the importance of corpus callosum maturation in the the asymmetric activation of the right hemisphere, as well as the importance of the reading habits.

Unlike previous research, we did not find significant spatial bias for the adults and the middle school children in the explicit tasks. One explanation might be the enhanced executive control over motor performance. This would mean that when attention is engaged, pseudoneglect might be attenuated with maturation. However, due to the small sample sizes, not definite conclusion can be made.

Notably, in the present study was used a novel index to assess the spatial bias in the drawings` placement, taking into account not only the deviation of the drawing but its size. That is why it is difficult to compare our results with earlier results. Subsequent studies are planned with 7-8 year old children and illiterate adults in order to examine further the influence of brain maturation and scanning habits on the spatial representation of the immediate surroundings.

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