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Sex differences in line bisection as a function of hand

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Abstract

If subjects are asked to indicate the midpoint of a horizontal line, they tend to bisect it left of the center, a phenomenon called 'pseudoneglect'. Assuming that this task evokes visuospatial processes, the left bias is generally considered to arise from a right-hemispheric activation. Numerous factors affect pseudoneglect. Although, only few studies have examined the influence of sex in visual line bisection, most of theses studies reported no significant main effect of sex. Possible interactions between sex and other performance factors that are linked to the motor component of this task, e.g. hand use, are rarely examined. We studied the interaction of these two variables using right-handed females and males in a line bisection task. The results clearly indicate that hand use and sex interact, with females showing the left bias to a similar extent with both hands while males show the bias predominantly with the left hand. Moreover, the position of the lines (left, middle and right) significantly affect left bias in visual line bisection and interact with hand use. It is hypothesized that the larger cross-section of the posterior corpus callosum in females enables a stronger interhemispheric connectivity of visuospatial cortical areas resulting in a strong left-sided bias in hand motor cortical areas of both hemispheres. In males, motor cortical activation would accordingly be mainly restricted to the right hemisphere.

Keywords: Pseudoneglect; Gender; Lateralization; Functional cerebral asymmetry; Corpus callosum

1. Introduction

Most studies investigating visual and tactile line bisection have reported that normal right-handed subjects systematically tend to bisect lines and rods left of the center, a phenomenon that is often called 'pseudoneglect' [3]. The leftward bias in visual line bisection described in the literature among normal dextrals has often been linked to stronger activation of the right hemisphere in response to the visuospatial nature of the task [36]. Although, the overall existence of a leftward bisection error for line bisection and similar tasks could be ascertained unambiguously [17], the degree and direction of the deviation seems to depend on different factors. In a comprehensive review and meta-analysis, Jewell and McCourt [17] discussed in detail the significance of these factors and could show that, for example, handedness [5,21,32], scanning direction [6,7], spatial position of lines [21], but see [6], or hand use (e.g. [6,32]) seem to have a more or less stringent influence. Moreover, the authors noted that only few studies have examined sex as a performance factor in visual line bisection tasks. Nine studies examining the influence of sex report no significant effects [4,6,8,13,21,26,27,32,34]. Most of these studies [4,8,26,27,34] investigated visual line bisection only with the preferred hand of the participants. The remaining four studies are very heterogeneous with respect to the age of the participants (subjects of one study had a mean age of 61.6 years [13]), sample size (one study tested only nine males, nine females [6]), properties of the line bisection task (usage of computer and paper pencil versions of the task [21]), or combined usage of both dextral and sinistral subjects [32].

Only two studies showed significant sex-related differences [31,39]. Roig and Cicero [31] found that men's performance indicate a significantly greater left pseudoneglect than women's, whereas Wolfe [39] re-

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ports the contrary. Unfortunately, the first study does not provide sufficient information to estimate effect strengths while the latter study includes no information of the subject's handedness and the hand used. It should be noted that line bisection is not exclusively a visuospatial task but also requires the translation of spatial information into an appropriate motor program. Therefore, it is reasonable to assume that handedness and the hand used can influence the results in line bisection tasks significantly [17] and may also possibly interact with other potential performance factors like sex.

A meta-analysis of Voyer [37] regarding the magnitude of sex differences in functional cerebral asymmetry indicate the presence of significant sex differences in favor of men. This phenomenon is especially documented in the visual modality, regardless of the task used [37]. Although contradictions exist (e.g. [1,18]), many studies in lateralization research demonstrate that the functional cerebral asymmetry of different visuospatial processes is more pronounced in males, while the lateralization pattern tends to be more symmetrical in women (e.g. [10,14,24,30]). Clinical data also support these findings. After localized brain lesions, men tend to display verbal deficits after left hemisphere injuries and visuospatial deficits after right hemisphere damage, while the deficits are less side-specific for women (e.g. [22,23,25]).

The aim of the study is to investigate visual line bisection in dextrals as a function of sex and hand used, and thus to analyze the results of different performance factors and potential interactions between them. We predict these interactions to be key factors for the mechanisms of pseudoneglect.

2. Methods

2.1. Subjects

Thirty-eight subjects, 19 women and 19 men (students in different academic departments) participated in this experiment. The handedness of all subjects were determined with the Edinburgh-Inventory [28]. The asymmetry-index (LQ) provided by this test is calculated as $(R-L/R+L)\times 100$, resulting in values between -100 and $+100$. Positive values indicate dextrality, while sinistrality results in negative values. The mean handedness-score was $+87.4$ (S.D. = 15.1; range from $+47.4$ to $+100$) for women and $+88.2$ (S.D. = 15.8; range from $+47.1$ to $+100$) for men. Nineteen participants (ten men, nine women) showed consistent dextrality (LQ = $+100$) and 19 (nine men, ten women) participants a non-consistent dextrality (LQ < $+100$, range; 88.89–47.4). The reading direction of all subjects was left-to-right. The mean age for women was 27.1 years (S.D. = 6.7, range; 22–49 years) and for men was 27.1 (S.D. = 3.3; range: 23–35 years). Participants who had used any medication affecting the central nervous system during the last 6 months were excluded. All subjects had normal or corrected-to-normal visual acuity and were naive to the study's hypothesis. They were recruited by announcements and were paid for their participation.

2.2. Procedure and materials

The line bisection task contained 17 horizontal black lines of 1 mm width on a white sheet of paper (21×30 cm). The lines ranged from 100 to 260 mm in their length in steps of 20 mm. The mean length was 183.5 mm. They were pseudorandomly positioned so that seven lines appeared in the middle of the sheet, five lines appeared near the left and five lines near the right margin. The sheet was laid in front of the subject's midline. Participants were instructed to bisect all lines into two parts of equal length by marking the subjective midpoint of each line with a fine pencil. All subjects completed the task with each hand in a balanced order. The experimenter covered each line after it was marked to insure that the subjects were not biased by their earlier choices. There were no time restrictions. The deviations to the left or to the right of each line bisection were carefully measured to 0.5 mm accuracy. The percent deviation score for each line was computed as: ((*measured left half* − *true half*)/*true half*) × *100*. This procedure is comparable to other studies [32,33]. We then computed the mean score for all lines, separately for each hand used. Negative values indicate a left bias, whereas positive values indicate a bias toward the right.

To ensure that effects of interest are not mediated by other performance factors in visual line bisection tasks, we include 'line position' (left, centered, and right), 'test order' (experimental start with left or right hand), and 'consistency of handedness' in our analyses.

3. Results

3.1. All line positions

Descriptive statistics are shown in Table 1.

As a first step, we analyzed the degree of the left bias for each hand separately for each sex. Since we expected a significant left-bias in the line bisection task, we used one-tailed one-sample t-tests. Female subjects produced a highly significant left bias in line bisection with their right ($T(18) = -5.50$, $P < 0.0001$) as well as with their left hands ($T(18) = -4.73$, $P < 0.0001$). In contrast, men only showed a highly significant leftward bias using their left hand ($T(18) = -3.80$, $P < 0.001$),

Table 1
Relative and absolute directional deviations (in % and mm) for visual line bisection as a function of gender, hand, and line position[a]

Line position		Males ($N=19$)		Females ($N=19$)		All ($N=38$)	
		Left hand	Right hand	Left hand	Right hand	Left hand	Right hand
Left	%	−2.88 (0.84)	−2.43 (0.71)	−2.82 (0.68)	−3.66 (0.67)	−2.85 (0.53)	−3.05 (0.49)
	mm	−2.24 (0.75)	−1.74 (0.58)	−2.17 (0.55)	−2.96 (0.61)	−2.21 (0.46)	−2.35 (0.43)
Center	%	−2.98 (0.69)	−1.00 (0.65)	−2.22 (0.46)	−2.21 (0.47)	−2.60 (0.42)	−1.61 (0.41)
	mm	−3.00 (0.70)	−1.05 (0.65)	−2.33 (0.47)	−2.26 (0.46)	−2.67 (0.42)	−1.65 (0.40)
Right	%	−1.10 (0.73)	1.31 (0.65)	−1.53 (0.68)	−1.06 (0.66)	−1.32 (0.49)	0.13 (0.50)
	mm	−1.03 (0.67)	0.94 (0.53)	−1.59 (0.55)	−1.23 (0.56)	−1.31 (0.43)	−0.15 (0.42)
All	%	−2.39 (0.63)	−0.74 (0.47)	−2.19 (0.46)	−2.30 (0.42)	−2.30 (0.39)	−1.52 (0.34)
	mm	−2.20 (0.60)	−0.60 (0.45)	−2.06 (0.41)	−2.16 (0.36)	−2.13 (0.36)	−1.38 (0.31)

Negative values indicate a deviation to the left; positive values indicate a deviation to the right.

whereas only a marginally significant left bias was apparent for the right hand ($T(18) = -1.56$, $P = 0.069$) (Fig. 1).

Then the data were analyzed by a $2 \times 2 \times 3$ analysis of variance (MANOVA) with repeated measures with 'sex' as a between-subject and 'hand use' and 'line position' (left, middle, and right) as a within-subject factors. Multivariate tests revealed a significant main effect of 'hand use' ($F(1,36) = 4.66$, $P < 0.05$), indicating a stronger left bias for the left hand compared with the left-bias for the right. The main effect of 'line position' was highly significant ($F(2,35) = 8.71$, $P < 0.001$). The left bias in visual line bisection increased when lines were located on the left. Moreover, 'line position' interacted significantly with 'hand use' ($F(2,35) = 4.86$, $P < 0.05$). Post hoc analysis of this effect revealed that differences between left and right hands decreased as the left bias increased with respect to line position. If the lines were positioned to the left, no significant difference between both hands remained (left lines, $T(37) = -0.37$, ns; center lines, $T(37) = 2.36$, $P = 0.02$; right lines, $T(37) = 3.02$, $P = 0.005$). The main effect of 'sex' did not reach significance ($F(1,36) = 1.17$, ns). However, the interaction between hand use and sex was significant ($F(1,36) = 6.89$, $P < 0.02$). Post hoc paired t-tests revealed a significant difference in leftward bisection between left and right hands in men ($T(18) = 3.31$, $P = 0.004$), whereas no such difference appeared in women ($T(18) = -0.24$, ns). Another post hoc analysis using unpaired t-tests revealed a significant difference in left-bias between males and females when the right hand was used ($T(36) = 2.47$, $P = 0.018$), whereas no sex-difference appeared for the left hand ($T(36) = -0.26$, ns). The alpha adjustments of all multiple test procedures were achieved with the sequentially rejective Bonferroni test [16].

When absolute errors were taken into account, the pattern of significant MANOVA main effects and interactions as well as post hoc tests remained unchanged. Moreover, post hoc analyses including 'test order' and 'consistency of handedness' as between subject variables revealed no significant main effects or any interaction effects on the results presented above.

3.2. Center lines (only)

Even when center lines were analyzed separately, and thus the line position factor was eliminated, the results remain very similar to the results of the whole data set. One-tailed one-sample t-tests revealed that female subjects produced a highly significant left bias in line bisection with their right hands ($T(18) = -4.68$, $P < 0.0001$), as well as with their left hands ($T(18) = -4.79$, $P < 0.0001$). In contrast, men only showed a highly significant leftward bias using the left hand ($T(18) = -4.30$, $P < 0.0001$), whereas only a marginally significant left bias was apparent for the right hand ($T(18) = -1.53$, $P = 0.072$).

Moreover, the 2×2 MANOVA with repeated measures revealed that the main effect of 'hand use' ($F(1,36) = 6.39$, $P < 0.02$), as well as the interaction of 'hand use' and 'sex' ($F(1,36) = 6.31$, $P < 0.02$) were significant, whereas the main effect of 'sex' was not ($F(1,36) = 0.10$, ns). Overall, the left bias was significantly stronger when the left hand was used. Alpha adjusted post hoc t-tests showed the same pattern of results as the whole data set. Male subjects showed a

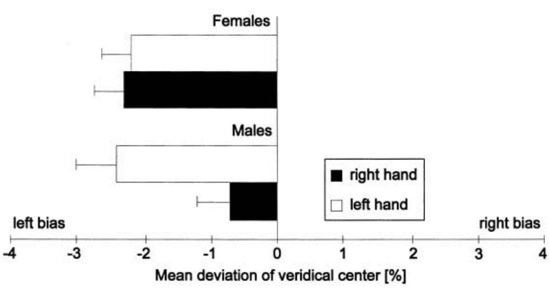

Fig. 1. Mean leftward deviation from the true center in line bisection according to gender and hand used.

highly significant difference in leftward bias between right and left hands ($T(18) = 2.93$, $P < 0.01$), whereas female subjects did not ($T(18) = 0.02$, ns). However, in contrast to the post hoc analyses of the whole data set, there was no sex-related difference in the left bias for the right ($T(18) = 1.50$, ns) or for the left hand ($T(18) = -0.92$, ns). This finding resulted from an overall enhancement of the left bias in males, whereas the left bias in females was slightly reduced, when the data were compared with the whole data set.

The main effects, interactions, and post hoc tests still show the same pattern when absolute errors were taken into account.

4. Discussion

The most important result to be considered is the sex difference in line bisection as a function of the hand used. In contrast to Roig and Cicero [31], and similar to other studies [4,6,8,13,21,26,27,32,34], no overall sex difference but an overall well known leftward bias was found (for review [17]). Moreover, we could confirm that this larger leftward bias is, at least in dextrals, more pronounced when using the left hand compared with the right one (e.g. [6,13,21,32], for review: [17]). Thus, subjects erred to the left with either hand, although this left bias was more pronounced with the left than with the right hand. Altogether these effects resulted in a data pattern with females having an equally strong pseudoneglect with either hand while this was only clearly evident with the left hand in males. Since handedness scores and average age were virtually equal for our female and male sample, these results indicate a sex difference in the neural organization of hand use in line bisection.

The lack of significant interaction between sex and hand use in earlier studies could possibly be due to the fact that most of these studies, which included sex as a between-subject variable and a possible performance factor, investigated visual line bisection only with the preferred hand of the participants. The few remaining studies which included hand use, as well as sex in the design are very heterogeneous with respect to the age of the participants (subjects of one study had a mean age of 61.6 years [13]), sample size (one study tested only nine males and nine females [6]), properties of the task (usage of computer and paper pencil versions of the task [21]), or combined usage of both dextral and sinistral subjects [32].

Scanning strategies have been implicated as a source of directional deviations in visual line bisection [6]. Although, a left-to-right scanning strategy may be 'innate' it is more likely to result from over-learned habits acquired during learning to read [6]. This is strongly supported by Chokron [8], who investigated reading habits on line bisection in French and Israeli subjects. Although we did not control scan direction directly, we have no reason to expect that male and female subjects show a difference in scan direction that could bias the pattern of data in this study. All participants had consistent left-to-right reading habits. However, we can not rule out the possibility that males and females have different scanning strategies. If this would be the case, the sex-dependency of line bisection might have resulted from a gender difference in scanning strategies.

The analyses of the absolute errors show the same results regarding the main effects or interactions for hand use and/or sex. Nevertheless, it should be noted that a dominance for visuospatial processing does not necessarily indicate a more accurate performance of the right hemisphere (and corresponding left hand), but rather can result in more errors under certain conditions. For example, a study investigating hemispheric dominance and gender in the perception of an illusory figure [30] could show that the 'spatially dominant' right hemisphere of males was significantly more deceived than the left in this task. No significant hemispheric difference was observed in females. Overall, the illusion deceived both genders to equal extent. This indicates that gender-related hemispheric differences could result in a different pattern of lateralization instead of simple differences in accuracy.

Similar to other studies, the position of line was another important performance factor in visual line bisection [17]. As in earlier experiments (e.g. [21]), we observed that pseudoneglect was increased when subjects viewed lines presented in the left hemispace and was decreased, when lines were presented in the right. This effect was especially apparent, when the right hand was used. While such hemispatial effects may be explicable in perceptual terms, such that the left hemispace stimuli lead to a greater right hemisphere engagement and hence greater attentional biases to the left [19], purely perceptual factors would not be expected to be altered by hand usage [21]. For this reason, Luh [21] concludes that both motor and perceptual asymmetries may underlie the hemispatial effect.

However, the result of an overall leftward bias in line bisection in dextrals supports the notion of a stronger activation of the right hemisphere in response to the visuospatial nature of the task [36]. This effect seems to be on average more pronounced when using the left hand [6,32] contralateral to the spatially dominant right hemisphere. The sex difference in hand use could then be related to the degree of interhemispheric connectivity in the splenial portion of the posterior corpus callosum through which visual cortical areas communicate. There is evidence that the right and the left hemispheres are anatomically and functionally more connected in females than in males [9,11,15,20,29,35], for review [12] but also see [2]. Although speculation regarding sex differences in callosal size is still a matter of controversy, only very few studies report data in the opposite direction. Functionally more connected hemispheres would imply that in female subjects visuospatial information of the dominant right hemisphere could modulate motor areas of the left as well as of the right hemisphere, resulting in pseudoneglect of similar extent for both hands used. In contrast, in males the effect of an activation of right-hemispheric spatial structures would be more restricted within the ipsilateral hemisphere resulting in a strong leftward bias in line bisection only when the left hand is used. Non-consistent right-handers have a larger overall corpus callosum area. Especially in males, this is pronounced in the anterior half and isthmus of the corpus callosum [38], where motor fibers cross. Since, however, consistency of handedness seems not to be relevant for the results of this study, we are inclined to believe that sex differences, in particular, in the posterior part of the corpus callosum could be relevant in visual line bisection. If this interpretation is valid it would indicate that a specific sex difference in interhemispheric connectivity would constitute the critical variable which produces the interaction between hand use and sex in pseudoneglect.

Regarding the clinical implication for the interpretation of the directional deviations displayed by neglect patients, we are in agreement with Brodie and Pettigrew [6]. 'When visual line bisection is performed by a neglect patient using the left hand it is, therefore, only correct to conclude that neglect is reduced if significant leftward deviations from the objective middle remain present' ([6], page 469).

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