



Tactile rod bisection: Hemispheric activation and sex differences

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Abstract—Blindfolded subjects estimated with either hand the center of rods positioned in either left or right hemispace. In one condition, they also performed a concurrent verbal task. Bias and variability of bisection settings were the dependent variables. Bisections performed in left hemispace were biased to the left of true center, more so when the left hand was used. In contrast, bisections performed in right hemispace were biased rightward, more so when the right hand was used. There were no significant differences in variability of bisections in any condition. Interactions of hand with hemispace in which the task was performed differed for the two sexes. Moreover, the secondary verbal task had no effect on either measure. We conclude that of several factors that may underlie bisection biases, attention was the most relevant. Copyright © 1996 Elsevier Science Ltd.

Key Words: spatial attention; hemispheric specialization; bisection.

Introduction

Judging the center of horizontally oriented linear stimuli, either in the visual or tactile modality, is a task that has been used widely to explore lateralization of perceptual and attentional factors in normal subjects [1, 3–13, 27, 29, 30, 33, 36–38]. Several of these studies have shown that normal subjects tend to judge the center of a visually inspected line or of a rod felt tactually to be to the left of the physical center [1, 3, 5–8, 22, 25, 29]. Moreover, the same effect occurs when subjects bisected the gap between two points [4]. Left-sided bias has been reported most consistently when subjects bisect stimuli presented frontally and centered on their body [1, 3–8, 11, 12, 22, 29, 36–38]. The left-sided bias increases when bisections are performed with the left hand [6, 11, 12, 22, 29, 38] or by left-handers with either hand [38]. However, there have been some failures to replicate the left-sided bias in the midline condition [9, 30]. The results of studies in which the stimulus extends mainly into or is confined entirely in one hemispace have been less consistent [3, 6, 12, 22, 29, 30, 32, 33, 37]. However, there seems to be a tendency for bisections to shift leftward when performed in left hemispace and with the left hand compared to all the other hemispace/hand conditions [12, 22, 29, 32, 39].

The authors of the above studies have offered several different interpretations of the processes responsible for biases of normal subjects in bisection tasks. They can be divided into three main classes:

1. **Perceptual hypothesis.** According to this interpretation, the right hemisphere (RH) has better visuo-spatial processing abilities than the left hemisphere (LH); in particular, in spatial tasks where metric information is relevant [20]. As a result, stimuli in contralateral (left) hemispace are perceived with higher resolution [i.e. smaller JNDs (just noticeable differences)] than are stimuli in ipsilateral (right) hemispace. Therefore, the left extent of linear stimuli whose centers are aligned with the midline body axis would have greater perceptual salience than would their right extent; consequently, the judged center of the line will be misplaced to the left of the true center. This hypothesis can account for left-sided biases when the true center of stimuli is aligned with the midline body axis without positing additional mechanisms (e.g. attention). Since, according to this view, stimuli in left hemispace are perceived with higher resolution than those in right hemispace, the perceptual hypothesis predicts that variances of bisection errors would be greater in right than in left hemispace. Furthermore, bisection settings with the left hand, due to its direct anatomical connections to the RH, would show higher spatial resolution than would settings with the right

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hand, an effect that also should be reflected in the variance of bisection settings.

2. Attentional ('Pseudoneglect') hypothesis. It has been suggested that bisections errors of normal subjects are due to an 'attentional amputation' of the right extremity [3, 33]. Bowers and Heilman [3] referred to this bias as 'pseudoneglect', although it is on a smaller scale and in the direction opposite to that of bisection errors of right brain-damaged patients with left neglect. The abnormal displacement of the center by patients has been interpreted by some investigators as an imbalance between opposing lateralized attentional mechanisms [17]. Similarly, in normal subjects, an attentional imbalance between the two cerebral hemispheres is assumed to account for biases in tasks such as line bisection that appear to depend heavily on lateralized cerebral mechanisms [18, 19]. In such tasks, when one hemisphere is more engaged than the other, attention will shift contralaterally, according to this view. Since spatial tasks in which metric information is relevant seem to depend more on the RH's than the LH's function, attention will shift to the left of stimuli, at the cost of decreased attention to their right side [20, 29]. However, since the attentional hypothesis, unlike the perceptual hypothesis, assumes that RH's activation does not increase the perceptual salience of stimuli in left hemispace, it would not predict differences between variances of bisection settings in the two hemispace conditions.

There are other possible differences between the contributions of perceptual and attentional factors to bisection biases. The perceptual factor is constrained by stable and enduring specializations in hemispheric functions as well as by direct anatomical connections between each hemisphere and the contralateral hand. Attentional factors, by contrast, are affected by lateralized cues (e.g. see [30, 35]). Lateralized cueing effects on bisection performance might result also from the hand used to perform the task or the intention to move it to one side, as well as from placing stimuli in one hemispace [33]. Thus, the attentional hypothesis would be confirmed if bisections shift laterally when hemispace and hand factors are manipulated, but variances of the bisection settings do not change.

3. Scan-track hypothesis. Halligan *et al.* [11] and Marshall and Halligan [27] proposed an interpretation of line bisection that uses a psychophysical approach and stresses the motor/kinesthetic aspects of the task. These authors point out how the preferred direction of ocular scanning or the spatio-motor cueing imposed by the use of a hand (which may determine the 'internal' direction of scanning) may result in biases in line bisection. More specifically, they suggest that an attentional 'searchlight' in spatial register with overt eye movements scans a linear stimulus, starting at one end of it and stopping when the scan enters a psychophysical indifference zone within which different

spatial locations are smaller than the JND. Since subjects who start scanning from the (preferred) left end of the line would enter the indifference zone from the left side, their bisections would tend to be biased to the left side of true center. A test of this hypothesis would require control of the direction of scanning. This can be done easily in the tactual modality, in which the direction of the hand movement can be controlled, and (if subjects are blindfolded) in which settings are not likely to be influenced by ocular scanning.

In the present study, we examined the relative contribution of perceptual, attentional and scanning factors in a tactile bisection task performed in left and right hemispace. We made the following predictions:

1. According to the perceptual hypothesis, bisection settings of rods located in left hemispace will show decreased variability relative to bisections performed while the rods are in right hemispace. According to the attentional hypothesis, only the size of the biases, and not variances of settings, will be affected by the position of the rods in hemispace. Additionally, the attentional hypothesis predicts that the direction of the bias will be dependent on which side of space the focus of attention is directed during the task. Therefore, we predict that task-dependent RH's activation will push attention to the left, whereas lateralized cueing (e.g. use of one hand, placing stimuli in one hemispace) will pull attention towards the side of the cue.
2. By the perceptual hypothesis, performance with the left hand would be more accurate (i.e. show smaller variances of settings) than performance with the right hand, because the left hand has direct neuroanatomical connections with the RH.
3. If the anticipated biases in bisections described above are still present when scanning is equal in both directions across trials, the scan-track hypothesis would be invalidated, at least for tasks involving manual scanning.

In addition to the above predictions, we examined in the present study the role played by sex of the subject as a factor in performance of rod bisection. There are reports of sex differences in degree of hemispheric lateralization in spatial/attentional tasks [2, 16, 21, 22]. If male brains are more lateralized in attentional/spatial functions than those of females, males would be expected to show greater effects of hemispatial manipulation, both with regard to average biases of bisection settings and their variances.

We were interested also in the effect of performing a secondary verbal task on tactile rod bisection. If, as expected, such a task selectively engages and activates the LH, then one might expect an increase in the variance of bisection settings, relative to performance without the secondary task, because the verbal task may interfere with the right hand's sensory/motor exploration of the rod [28]. As a verbal task would be expected to activate

the LH, it is possible that it would produce a rightward shift in the allocation of attention and, hence, a rightward shift in bisection settings.

We used a variant of the original Bowers and Heilman's [3] rod bisection task in order to test the hypotheses described above. In our study, blindfolded subjects of both sexes were instructed to align a marker to the center of a wooden rod located in left or right hemispace, using either the left or the right hand. They were instructed to scan the rods fully in both directions before making their judgment.

Method

Subjects

Sixteen right-handed (by self-report) students at L'Università La Sapienza (Rome, Italy). One-half of the subjects were males and the other one-half were females.

Apparatus

Six wooden rods, 1 cm in diameter, of the following lengths, were used: 20, 24, 28, 30, 35 and 40 cm. A thin line was drawn in the center of the rods in order to permit the experimenter to measure accurately the subjects' settings. The rods were presented on a wooden board with a groove (1 cm long and 0.5 cm deep) in its center and parallel to its long side. A metal pointer was attached to the center of the board and pointed towards the rods, which were inserted in the groove.

Procedure

Subjects were blindfolded and instructed to sit upright in front of a table where the board was located. One of the six rods, chosen according to a predetermined sequence, was placed in the groove with one of its extremities aligned to the metal pointer. The position of the rod (left or right of the pointer) changed randomly from trial to trial. The experimenter guided the hand of the subject to the pointer's position, where scanning of the rod began.

Subjects were requested explicitly to follow this sequence of actions: (1) run the index/middle finger of one hand along the whole extent of the rod from one extremity to the other, back and forth, several times, to get a 'feel' of the length; (2) take a first estimate of the midpoint by sliding the rod in the groove so as to align the estimated center to the metal pointer; (3) repeat the procedure of running the finger from one extremity to the other and make adjustments until they were confident that the center of the rod aligned to the pointer.

Subjects were reminded to scan the rod from one extremity to the other in both directions after each adjustment in order to perform a final 'check' of the setting. There were no time constraints in performing this sequence of actions. The experimenter, who sat at the opposite side of the table, measured each setting to the nearest mm.

After 12 consecutive trials performed with one hand, the subjects were instructed to use the other hand in performing the task. One-half of the subjects in each sex group started the session with the left hand and the other half with the right hand. For 24 consecutive trials, the board was placed in either left or right hemispace by aligning the center of the board (i.e. the

metal pointer) to the left or right shoulder of the subject. The hemispace conditions were counterbalanced in ABBA order (left first for one-half of the subjects in each sex group and right first for the other one-half). Two subjects in each of these groups of four subjects were tested with the single-task condition first and the other two with the dual-task condition (i.e. a verbal concurrent task while judging the center of the rod) first. The two tasks were alternated. In this manner, for instance, a subject starting with the left hemispace condition and the single task would, after 24 trials, switch to the right hemispace and the dual task, next continue doing the single task in the right hemispace, and conclude with the dual task in the left hemispace condition.

Secondary task

During the dual-task condition, all subjects performed aloud a backward counting task, starting from a three-digit number which changed randomly from trial to trial. Subjects were asked to concentrate mainly on the primary task (i.e. bisecting) and to carry out both tasks simultaneously and without interruptions. Occasionally, the experimenter, who monitored the subjects, would remind them to perform in the desired manner. Errors in counting backwards were ignored by the experimenter. Subjects always began counting before starting the primary task. Only a few subjects commented on the difficulty of doing two unusual things at the same time, but only during the initial trials of the first block. The whole experiment took approximately 1.5 hr.

Scoring

Deviations were converted to signed percentage scores (positive if bisections were to the right, negative if to the left) by subtracting the true half-length of the rod from the measured distance of each setting from the left extremity of the rod, and then dividing this value by the true half-length and multiplying the quotient by 100. Percentage signed deviations from the true physical midpoint were analyzed as measures of bias in bisections. In addition, the standard deviations of the bias scores in each hand/hemispace/task condition (across order) were calculated and analyzed separately as measures of variability of judgments.

Results

Two repeated-measure ANOVAs were performed, one on the bias scores and one on the variability of judgments, with sex as between-subjects factor, and task, hemispace, hand and rod length as within-subjects factors. *Post-hoc* comparisons were performed with the Newman-Keuls' test when interactions were significant. In addition, *t*-tests were used to compare averaged bias scores for each hemispace by hand against zero (i.e. the real midpoint value).

Bias

The ANOVA revealed a main effect of hemispace [$F(1,14) = 47.93$, $P < 0.0002$]. Subjects bisected to the left of the true center when the rods were in left hemispace

(mean = -3.04% ; S.E. = 0.26) and to the right of the true center when rods were in right hemisphere (mean = 2.20% ; S.E. = 0.25).

The main effect of the hand factor was also significant [$F(1/14) = 8.25$, $P < 0.01$]. Subjects bisected with the left hand to the left of the true center (mean = -1.38% ; S.E. = 0.26) and with the right hand to the right of true center (mean = 0.54% ; S.E. = 0.30).

The interaction of hemisphere and hand was significant [$F(1/14) = 8.85$, $P < 0.01$]. Both hands were biased ipsilaterally to the hemisphere in which the task was performed. (In left hemisphere: for the left hand, mean = -3.50% , S.D. = 0.33 ; for the right hand: mean = -2.89% , S.D. = 0.39 . In right hemisphere: for the left hand, mean = 0.75% , S.D. = 0.35 ; for the right hand: mean = 3.66% , S.D. = 0.32 .) Additionally, the ipsilateral hand appeared more biased than the hand crossing the body midline. However, when the right hand bisected in contralateral (i.e. left) hemisphere, its bias did not differ significantly (as shown by a *post-hoc* test) from that of the left hand in this same hemisphere. All other bisections in each hemisphere/hand condition differed significantly from each other according to *post-hoc* tests. Comparisons with *t*-tests against zero showed that there was a significant bias in all conditions, except for the left hand in right hemisphere.

The main effect of sex approached significance [$F(1/14) = 3.40$, $P < 0.08$]. However, this factor interacted significantly both with hemisphere and hand factors [$F(1/14) = 8.11$, $P < 0.001$]. As shown in Fig. 1: (a) males' bisections with their right hand in left hemisphere (mean = -3.42% , S.D. = 0.48) showed more leftward shifts compared to the bisections of females (mean = -2.37% , S.D. = 0.53); (b) males' bisections in right hemisphere with either hand (left hand: mean = -0.52% , S.D. = 0.43 ; right hand: mean = 3.26% , S.D. = 0.48) were less biased to the right than those of the females (left hand: mean = 2.01% , S.D. = 0.51 ; right hand: mean = 4.06% , S.D. = 0.48). A *post-hoc* test revealed that all bisections in each sex/hemisphere/hand condition differed significantly from each other, with the following exceptions: (1) in left hemisphere, bisections of males with either hand and of females with the left hand; and (2) in right hemisphere, bisections of females with either hand and that of males with the right hand. Comparisons with *t*-tests of bisections against zero in each sex/hemisphere/hand condition showed that all bisections were biased significantly, except for males' performance with the left hand in right hemisphere.

Rod length interacted significantly with task [$F(5/70) = 3.66$, $P < 0.006$] and with hemisphere [$F(5/70) = 2.73$, $P < 0.02$]. *Post-hoc* comparisons showed that the first interaction arose because subjects tended to bisect the 20 cm (smallest) rod to the right of the true center in the dual-task condition, in contrast to their bisections of all the other lengths in both task conditions, which were biased to the left. The rod length by hemisphere interaction arose because of increasing biases (left-

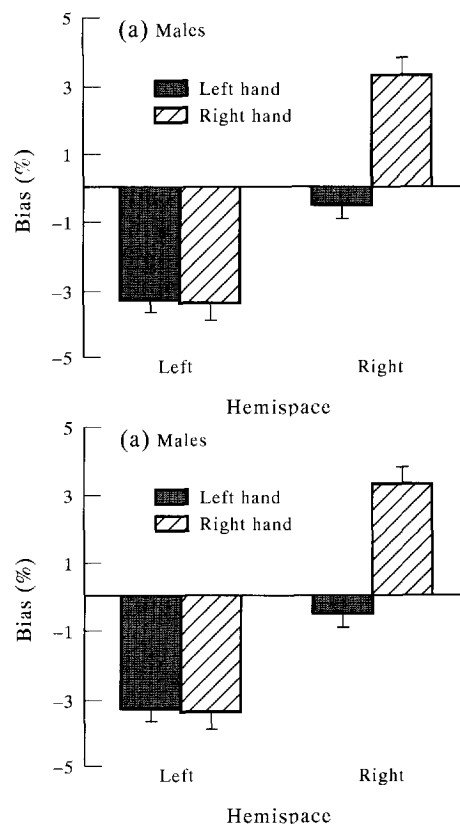


Fig. 1. Mean and S.E.M. of percent biases of males (A) and females (B) in bisecting rods in left and right hemisphere with the left and right hands. Positive values indicate biases to the right of the true center; negative values indicate leftward biases.

ward in left hemisphere and rightward in right hemisphere) with increasing rod length.

None of the other factors or interactions was significant or approached significance.

Variability of judgments

The main effect of sex was significant [$F(1,14) = 11.30$, $P < 0.005$]. Males' bisections were less variable (mean = 3.35 , S.E. = 0.17) than those of females (mean = 4.34 ; S.E. = 0.21). No other factors were significant for this measure.

Discussion

The findings can be summarized briefly as follows. Hemisphere and hand had a similar effect on the bias of bisections: there was a significant shift towards the side ipsilateral to the hand and the hemisphere where bisections were performed. These effects were shown by both males and females. However, in left hemisphere, males bisected significantly more to the left with their right hand than the females did; and, in right hemisphere, males with either hand appeared less biased toward the right than the females with either hand (although the difference was

statistically reliable only for the left hand). All of these systematic shifts occurred without concurrent changes in the variance of the bisections. Finally, the backwards counting task did not produce any appreciable effect on either bisection biases or variance.

These findings support the conclusion that the location in space of stimuli affects the bias in tactually judging their half-lengths and that tactile performance depends on which hand carries out the bisections. This hand effect may be due either to activation of the contralateral hemisphere by tactile and possibly muscle and joint stimulation of the hand used; or it may be due to a motor bias that causes the hand to overshoot the target in a centrifugal direction ipsilateral to the hand. A finding favoring the motor bias hypothesis is the observation [25] that subjects using a mouse to place the bisection mark of a line on a computer screen (a procedure that greatly reduces the range of hand movements), showed a reduced leftward bias compared to their performance on a paper and pencil visual bisection task.

Additionally, this study replicated the effect reported in several studies (e.g. [6, 22]) of a stronger leftward bias in left hemisphere and with the left hand. However, we showed also that the leftward bias in bisection can reverse to a right-sided bias when bisections are performed in right hemisphere, especially so when the right hand is used.

In the previous literature on bisection tasks, three major accounts of the normal subjects' bisection performance have been offered. (1) Perceptual hypothesis [6]: bisections are shifted to the left because the perceptual salience of space regions is greater on the left side of the horizontal coordinate; (2) attentional hypothesis (e.g. [3]): bisections are shifted to the left because the right side of the stimuli is not fully attended (the right side is 'neglected'); (3) scan-track hypothesis (e.g. [27]): objects are usually scanned from left to right, causing the attentional 'searchlight' to enter from the left a psychophysical indifference zone in which different locations are not discriminable and, consequently, to undershoot the true center to the left of the zone.

With regard to the prediction of the perceptual hypothesis that greater salience of stimuli in one side of space would be reflected in a smaller dispersion of the errors compared to the less salient region of space, our measure of variability (i.e. the variance of the bisections) failed to show any specific perceptual advantage of one spatial location over the other. This finding contradicts previous researchers' hypotheses that left hemisphere is more salient than right hemisphere because left hemisphere is processed by the perceptually more competent RH [3, 5]. Hemispheric differences in perceptual salience, if they exist, do not seem to play a significant role in bisection tasks. However, it may be relevant to this issue that Julesz and colleagues' [14] investigation of depth perception with random-dot stereograms displays did not find left and right hemispaces anisotropy for spatial resolution.

Whereas our findings are not consistent with the perceptual hypothesis, they support clearly the attentional

hypothesis, in particular with regard to the effects of both hemisphere and hands in shifting the bias of the bisections. Hemisphere and hand influenced the estimation of the rods' center in a consistent way: left hand and/or left hemisphere shifted the bias leftward and right hand and/or right hemisphere shifted the bias rightward.

The significant interaction of hemisphere and hand seems to suggest that the effects of these two factors were not additive. The two hands were biased equally in left hemisphere but their biases were different in right hemisphere. However, the significant interaction of these two factors with sex would suggest that the equal bias in left hemisphere is accounted by the males' performance in this condition. Therefore, we suggest the following account of the hemisphere and hand interaction: (1) the spatial/metric nature of the bisection task would be expected to increase the RH's activation [23]. Such right hemispheric activation would cause a leftward shift of attention/intention [19], and consequently of bisections, that is independent from the biases due to hemisphere and hand factors. If males are more lateralized than females for spatial functions, then unilateral cerebral activation would be expected to be stronger for males than females. This interpretation overall is consistent with our finding that males show in most conditions a stronger leftward bias or less strong rightward bias than that shown by the females. (2) In the condition in which all the above named factors contribute simultaneously to a leftward shift, i.e. when males bisect in left hemisphere with the left hand, the leftward bias easily could reach a ceiling or threshold at which biases are eventually detected or not tolerated by the perceptual system. As a consequence, males' errors may not appear more biased to the left than those of the females in this condition.

The effects we found are consistent with the findings of other visual line bisection [29] and tactile bisection studies [22], according to which a leftward bias seen in left hemisphere reverses direction in right hemisphere. Similarly, Reuter-Lorenz and colleagues [33] found that right-bisected lines presented in the right hemisphere were judged as center bisections whereas left-bisected lines were judged as center-bisected lines when presented in the left hemisphere. However, we failed to replicate the findings of Bowers and Heilman [3], who reported a strong bias to the left in the right hemisphere condition (i.e. opposite to that described here) and a right bias, significantly only for the right hand, in left hemisphere (also counter to the left shift observed in our study). Findings consistent with those reported by Bowers and Heilman were reported by Nichelli and colleagues [30] in a visual line bisection study. Hatta and Yamamoto [12] did not find significant effects of either hemisphere or hand, although their results were in the same direction as those of Bowers and Heilman. The reasons for inconsistencies among these studies may lie in differences in experimental procedures, stimuli, subject population, or other factors. In our study, we may have implicitly introduced cues that can attract attention to one side of space

(e.g. the metal pointer around which the subject slides the rods may have acted as a salient lateral cue drawing attention to its side). Reuter-Lorenz *et al.*'s study [33] confirmed their hypothesis that a lateralized line (even when tachistoscopically presented) can shift attention laterally.

Males and females differed in their performance in the rod bisection task, both in directional errors and accuracy. Females were more variable, as showed by their larger standard deviations of errors compared to males. Males showed a more asymmetric dispersion of errors compared to females. Because of this difference between the two measures, it would be incorrect to claim that one sex is better at spatial tasks than the other. Some authors (e.g. Kimura [15]) have argued that when a function is more lateralized (i.e. more focal), the speed and resolution of processing increase. For this reason, the more lateralized males might be less variable than females in the overall task, but at the same time show stronger lateral biases as a result of a more strongly lateralized mechanism.

The secondary task of counting backwards had no effect on the primary task of bisecting rods in either measure of bias or variability of bisections. We conclude, therefore, that counting backwards engages brain areas that are too distant functionally (e.g. in different hemispheres) from those engaged by the spatial metrics evaluation and the manual performance to have a measurable effect on the latter. Alternatively, the degree of difficulty of the primary or secondary task may have played a role. Kinsbourne and Hiscock [19] proposed that if the secondary task is too easy there is no interference or activation of the orienting mechanisms. In conclusion, we cannot rule out the possibility that secondary tasks that are verbal in nature but with different levels of difficulty would affect performance in our bisection task. In Vingiano's study [40], normal subjects showed biases in a 'spatial' version but not in a 'verbal' version of a visual cancellation task.

Finally, in our bisection task, manual scanning preference [27] could not strongly influence performance, for subjects were blindfolded and explicitly instructed to scan the stimulus in a controlled manner. Hence, the contribution of other factors, like hemispace or hemispheric specialization for metric evaluations, would be expected to be revealed more clearly. We did observe biasing effects in spite of controlling tactual scanning, a finding which supports the idea that attentional shifts are sufficient to cause biases seen in bisection tasks. Nevertheless, it is possible that our procedures failed to control for 'internal' scanning (or even ocular scanning under the eye-patches). It is in the nature of purely tactual estimations that the representation of a stimulus must be reconstructed from consecutive sensations. In the visual modality, in contrast, the whole stimulus can stimulate simultaneously the retinal receptors. It is then possible that the image reconstructed from separate tactual evaluations is also scanned — in the final stages in which the metric judg-

ment is made — according to the directional preferences of the attentional system. However, this interpretation needs to accommodate the fact that in our study, a substantial number of subjects showed biases in opposing directions in different hemispace conditions.

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