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Developmental Changes in Visual Line Bisection in Women Throughout Adulthood

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It has been suggested that some hemispheric asymmetries change in a systematic way from young adulthood to older age. However, little is known whether these changes are due to differential aging of a single hemisphere or based on age-related alterations of interhemispheric interactions. A sample of 281 right-handed neurologically healthy participants (151 women), ranging from age 20 to 79, was investigated with a line-bisection task. Previous studies indicate the midpoint estimation shows a consistent left-ward bias from the veridical center, which is accentuated when the left hand is used to bisect lines. These findings support the view of a right hemispheric superiority in spatial attention. This study revealed this pattern to be stable in men throughout adulthood. However, women from 50 to 69 years of age showed a reduced leftward bias and a reduced hand effect compared to men and younger women. The results suggest that developmental changes in hemispheric asymmetry of spatial attention are more pronounced in women and support the view that neuromorphological changes during adulthood differ between sexes.

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When neurologically normal right-handed individuals bisect horizontal lines and rods, midpoint estimations deviate slightly to the left of the veridical center (e.g., Bowers & Heilmann, 1980; Bradshaw, Nettleton, Wilson, & Bradshaw, 1987; Corballis, 1995; Hausmann, 2005; Hausmann, Ergun, Yazgan, & Güntürkün, 2002; Hausmann, Waldie, & Corballis, 2003; McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001; Scarisbrick, Tweedy, & Kuslansky, 1987; see Jewell & McCourt, 2000, for a review), a phenomenon that is often called *pseudoneglect* (Bowers & Heilman, 1980). Kinsbourne (1970) suggested that attentional biases arise as a result of an asymmetric activation of the cerebral hemispheres. A preponderant task-dependent activation of one hemisphere biases attention to the contralateral side. According to Kinsbourne's model, a consistent tendency to shift the transsection slightly toward the left end of the lines indicates a task-dependent activation that predominantly involves the right hemisphere (RH), due to the visuospatial character of the line-bisection task. Similarly, subsequent explanations for this consistent leftward bisection bias focus on RH superiority in spatial attention. Specifically, it has been assumed that the left hemisphere (LH) only directs attention to the contralateral right hemispace, whereas the RH can direct attention to both sides of space (Heilman & Valenstein, 1979; Heilmann & Van Den Abell, 1980; Mesulam, 1981). Thus, the asymmetry in allocation of attention (i.e., pseudoneglect) can be described as an underrepresentation of the left hemispace or an overrepresentation of the right hemispace.

The RH superiority in spatial attention is supported by clinical studies showing that patients with lesions to the right parietal lobe, or as recent studies suggest, to the right superior temporal cortex (Karnath, Ferber, & Himmelbach, 2001), show a lack of awareness of stimuli, objects, persons, or events in left hemispace. Consequently, patients with *left hemineglect* deviate to the right of the objective middle when bisecting horizontal lines.

Although pseudoneglect in neurological normal participants is a fairly robust phenomenon (with an effect size of approximately 1.25), the magnitude of the bias is influenced by a wide range of performance factors (see Jewell & McCourt, 2000, for a review). The majority of studies focus on factors related to the stimulus or the experimental condition (e.g., directional scanning, lateralized cues, line length, spatial location, etc.), whereas factors of individual variation are frequently neglected. One of the most relevant factors when investigating individual differences is age of the participants. Understanding age-related changes in the brain mechanisms that underlie visuospatial attention is of both theoretical and practical interest, because most patients with neglect syndrome are beyond their fifth decade of life. Surprisingly, however, most studies of pseudoneglect recruit university students (Jewell & McCourt, 2000) and only a few studies have investigated line bisection in older individuals. One of these studies found that older participants, ranging in age from 61 to 82 years (mean age = 70.1 years), erred significantly toward the right (left hemineglect), whereas a younger age group (age range = 21–40 years, mean age = 30.4 years) and a middle age group (age range = 42–60 years, mean age = 50 years) did not shift significantly from the veridical center (Fujii, Fukatsu, Yamadori, & Kimura, 1995). Although not statistically significant, all age groups showed a trend towards larger rightward errors with increasing age, which is in line with the rightward bisection bias found in another study (Stam & Bakker, 1990) involving an older group of participants (mean age of 58 years).

The left hemineglect in older participants is in agreement with the differential aging hypothesis (Goldstein & Shelly, 1981), which states that aging involves greater loss of RH function compared with LH function, or that the RH ages more rapidly than the LH (e.g., Ellis & Oscar-Berman, 1989). This view is based on the finding that differential age-related impairments also apply to patients with RH injuries, which is characteristically associated with more prominent visuospatial impairments rather than verbal impairments.

A recent study (Failla, Sheppard, & Bradshaw, 2003) investigated line bisection in 107 neurological normal right-handed participants, ranging in age from 5 to 70 years. The youngest group comprised 5- to 7-year-old children and the oldest group comprised 60- to 70-year-old adults. Two additional groups (10–12 years and 20–30 years) were also tested. The two extreme groups (youngest and eldest) both showed a rightward bias with the right hand and a left bias with the left hand. This phenomenon is known as *symmetrical neglect* and has been previously shown in neurological normal children (Bradshaw et al., 1987; Dellatolas, Coutin, & De Agostini, 1996; Dobler, Manly, Atkinson, Wilson, Ioannou, & Robertson, 2001; Hausmann, Waldie, et al., 2003; Roeltgen & Roeltgen, 1989). Symmetrical neglect in children has been attributed to callosal immaturity (Bradshaw et al., 1987; Dobler et al., 2001; Hausmann, Waldie, et al., 2003; Roeltgen & Roeltgen, 1989). Based on their overall findings, Failla et al. (2003) hypothesized that differences between age groups in line bisection reflect a combination of functional changes of the RH and the corpus callosum.

The two intermediate age groups tested by Failla et al. (2003) showed a strong left bias (right pseudoneglect) with the left hand and a nonsignificant left bias with the right hand, which is the most common pattern of results (e.g., Brodie & Pettigrew, 1996; Hausmann et al., 2002; Hausmann, Corballis, & Fabri, 2003; Hausmann, Waldie, et al., 2003; Luh, 1995; Scarisbrick et al., 1987; see Jewell & McCourt, 2000, for a review). This hand-use difference has been interpreted within the framework of the activation-orientation hypothesis (Halligan & Marshall, 1989; Kinsbourne, 1970; McCourt, Freeman, Tahmahkera-Stevens, & Chaussee, 2001; Reuter-Lorenz & Posner, 1990). Because each hand is controlled primarily by the contralateral hemisphere, the activation-orientation hypothesis states that utilization of the left and right hand when bisecting horizontal lines causes a generalized activation of the contralateral RH and LH cerebral cortex, respectively. This activation then produces a greater degree of orientation toward the left or right hemispace (McCourt et al., 2001). A stronger left bias with the left hand supports the idea of RH superiority in visuospatial attention and suggests that the contralaterality of hand-use control is superimposed on an underlying hemispheric asymmetry in spatial attention (McCourt et al., 2001). Thus, left-hand use tends to exacerbate hemispheric asymmetry and increases the leftward bias compared to right-hand use; conversely, right-hand use would tend to equilibrate hemispheric arousal, resulting in a reduction of the leftward bias (Jewell & McCourt, 2000). However, the finding that right pseudoneglect persists when the right hand is used to bisect lines indicates an interhemispheric communication between the RH, which dominates visuospatial attention, and the LH, which mainly controls the right-hand response (Failla et al., 2003; Hausmann et al., 2002; Hausmann, Corballis, et al., 2003; Hausmann, Waldie, et al., 2003). According to the activation-orientation hypothesis (Halligan & Marshall, 1989; Kinsbourne, 1970; McCourt et al., 2001; Reuter-Lorenz & Posner, 1990), one might suggest that use of the right hand produces less interhemispheric spreading activation from LH motor areas to the RH relative to the intrahemispheric spreading activation produced by use of the left hand. Thus, line bisection with the right hand probably involves the corpus callosum.

Support for the importance of the corpus callosum in line bisection is shown in studies investigating patients with callosal infarction (Corballis, 1995; Kashiwagi, Kashiwagi, Nishikawa, Tanabe, & Okuda, 1990) and split brain participants (Hausmann, Corballis, et al., 2003; Heilman, Bowers, & Walson, 1984). These individuals show significant deviation to the right of the veridical middle, particularly when the right hand is used, compared to neurotypical controls. Moreover, there is evidence that the hand-use effect differs between men and women with a mean age of 27.1 years, ranging from 22 to 49 years (Hausmann et al., 2002), which has been replicated in adult participants of similar age in a follow-up study (Hausmann, Waldie, et al., 2003). Men showed a leftward bias, which was especially pronounced when the left hand was used compared to when the right hand was used. In contrast, women showed no difference in bias related to hand use. This sex difference in hand use has been interpreted in terms of sex-dimorphic differences in interhemispheric connectivity (Hausmann et al., 2002; Hausmann, Waldie, et al., 2003). Although still a topic of debate, a number of studies have found sex differences in size or shape of the corpus callosum that suggest larger interhemispheric connectivity in women than men (for a review, see Driesen & Raz, 1995; but see also Bishop & Wahlsten, 1997). According to the activation-orientation hypothesis (Halligan & Marshall, 1989; Kinsbourne, 1970; McCourt et al., 2001; Reuter-Lorenz & Posner, 1990), increased cortico-cortical connectivity in women would predict a similar RH activation regardless of hand use. However, it is still unclear whether right pseudoneglect and/or the hand-use difference remain stable over adulthood, or if there are developmental changes associated with either of these effects.

Using an extended sample size of 281 (151 women) neurological normal participants, ranging between 20 to 77 years of age, this study intends to determine age- and sex-related changes in line bisection as a function of hand use. Besides the clinical relevance—most patients with left hemineglect are in or beyond their fifth decade of life (Jewell & McCourt, 2000)—this procedure may help to elucidate any developmental changes in hemispheric asymmetry and callosal function related to spatial attention throughout adulthood.

MATERIALS AND METHODS

Participants

We investigated 281 neurological normal right-handed participants (151 women, 130 men) of different professions. The mean age of the participants was 47.46 years ($SD = 15.47$), ranging from 20 to 79 years. The group was divided into six age decade groups of 20 to 29, 30 to 39, 40 to 49, 50 to 59, 60 to 69, and 70 to 79 years. The handedness of all participants was determined with the Edinburgh Handedness Inventory (Oldfield, 1971). The laterality quotient (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, negative values indicate sinistrality. The mean age and LQ for men and women in the different age groups are shown in the Table 1.

The reading direction of all participants was left to right. Those who had used any medication affecting the central nervous system during the last 6 months were excluded. All participants reported being free of any neurological or attention concerns or cognitive dysfunctions. All participants had normal or corrected-to-normal vision and were naive to the study's hypotheses.

Procedures and Materials

The visual line-bisection task is commonly used to verify hemispatial neglect and investigate hemispheric asymmetries in spatial attention in neurological healthy participants. The line-bisection task used here was identical to that of previous studies (e.g., Hausmann et al., 2002; Hausmann, Corballis, et al., 2003; Hausmann, Waldie, et al., 2003) and should not be confused with line or interval bisection in vision research to determine hyperacuity thresholds (e.g., Klein &Levi, 1985; Levi & Klein, 1983). It comprised 17 horizontal black lines of 1 mm (.14° of visual angle) width on a white sheet of paper (29.5 × 21 cm, standard page DinA4). The lines ranged from 100 to 260 mm in their length (in steps of 20 mm) subtending 14.25° and 36.00° of visual angle, respectively. The mean length was 183.5 mm (25.84° of visual angle). Degrees of visual angle correspond to the approximate viewing distance of 40 cm. They were pseudorandomly positioned so that 7 lines appeared in the middle of the sheet, 5 lines appeared near the right margin, and 5 appeared near the left margin. The lateralized lines were 13 mm away from the margin. The line lengths for the 7 centered lines were 12 cm (1), 18 cm

TABLE 1
Sample Size, Laterality Quotient (LQ), and Mean Age for the Different Age Groups Separated for Men, Women, and All Participants

	Ages						
Variable	*20–29*	*30–39*	*40–49*	*50–59*	*60–69*	*70–79*	*All*
Women							
n	23	25	29	37	21	16	151
LQ (*SD*)	87.4 (13.50)	92.4 (14.70)	95.5 (11.10)	95.9 (10.50)	99.5 (1.50)	100 (0.00)	94.91 (11.28)
Age (*SD*)	23.39 (2.29)	34.56 (2.25)	44.20 (2.56)	54.02 (2.89)	63.61 (2.47)	73.50 (1.86)	47.64 (15.62)
Men							
n	22	24	18	36	17	13	130
LQ (*SD*)	98.1 (5.00)	99.3 (2.20)	98.3 (4.80)	96.2 (8.40)	99.4 (2.40)	99.2 (2.70)	98.15 (5.53)
Age (*SD*)	24.81 (2.97)	34.79 (2.35)	44.61 (2.52)	53.83 (2.77)	62.76 (2.79)	73.46 (2.63)	47.26 (15.35)
All							
n	45	49	47	73	38	29	281
LQ (*SD*)	92.71 (11.50)	95.81 (11.14)	96.56 (9.27)	96.09 (9.51)	99.47 (1.94)	99.65 (1.85)	96.41 (9.21)
Age (*SD*)	24.08 (2.71)	34.67 (2.28)	44.36 (2.53)	53.93 (2.81)	63.23 (2.62)	73.48 (2.19)	47.46 (15.47)

Note. LQ is calculated as $[(R - L)/(R + L)] \times 100$, resulting in values between –100 and +100.

(2), 22 cm (2), and 24 (2); (*M* = 20 cm) and the line lengths for the five left and five right lateralized lines were 10 cm, 14 cm, 16 cm, 20 cm, and 26 cm (*M* = 17.2 cm). The sheet was laid in front of the participant's body midline under normal room lighting conditions. 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 participants completed the task with one hand and then repeated it with the other. Order of first hand use was counterbalanced over participants. The experimenter covered each line after it was marked, to ensure that the participants were not biased by their previous choices. There were no time restrictions. The deviations from the true midpoint were carefully measured to 0.5 mm accuracy. The percentage of deviations for each line was computed as [(measured left half – true half) / true half] × 100. This procedure is comparable with that used in other studies (Scarisbrick, et al., 1987; Shuren, Wertman, & Heilman, 1994) and takes individual line length into account. The mean score for all lines was computed separately for each hand used and for all lines. Negative values indicate a leftward bias and positive values indicate a rightward bias. For all tests, a significance level of 5% (two-tailed) was used. The significance of all multiple post hoc tests was adjusted using Bonferroni-Holm correction (Holm, 1979).

RESULTS

The mean deviation scores from actual midpoint were subjected to a mixed factor analysis of variance (ANOVA) with Age group (6) and Sex (2) as between-subject factors, and Hand use (2) and Line position (3; left, center, right) as within-subject factors. The significant intercept effect indicated an overall leftward bias of –.81 ± .16, $F(1, 269) = 24.83$, $p < .001$. The overall leftward bias was not affected by Age group, $F(5, 269) = 1.42$, $p = .22$. Neither the main effect of sex, $F(1, 269) = 2.42$, $p = .12$., nor the interaction between Age group and Sex was significant, $F(5, 269) = .51$, $p = .77$. As expected, ANOVA revealed a strong effect of Hand use, $F(1, 269) = 79.53$, $p < .001$. A strong left bias was found for the left hand, –1.89 ± .17, but not for the right hand, .28 ± .22. There was a significant interaction between hand use and age, $F(5, 269) = 4.21$, $p = .001$. Finally, the three-way interaction between hand use, age, and sex reached significance, $F(5, 269) = 2.81$, $p = .017$.

To explore this three-way interaction, each sex was analyzed separately. The interaction between Age group and Hand use remained significant in women, $F(1, 145) = 6.18$, $p < .001$, but this interaction was not significant in men, $F(1, 124) = .54$, $p = .74$. This suggests there are age-related changes in women that influence the hand-use difference that are absent in men. Alpha-adjusted post hoc analyses revealed a hand-use difference in women for the first three decades (ages 20 – 29: –2.26 ± .72, $p = .005$, ages 30 – 39: –3.25 ± .79, $p < .001$, ages 40 – 49: –1.97 ± .58, $p = .002$), which disappeared in their 50s and 60s (ages 50 – 59: –.09 ± .31, *ns,* ages

60 – 69: –.10 ± .64, *ns*), and re-emerged in the oldest group (ages 70 – 79: –5.14 ± 1.08, $p < .001$). These age-related changes in the female group were not limited to one hand but were present in both the left, $F(1, 145) = 3.27$, $p = .008$, and the right hand $F(1, 145) = 2.53$, $p = .032$, although they seem to be slightly stronger when the left hand was used.

One-sample *t* tests (alpha-adjusted for multiple testing) were conducted separately for each age group and hand-use condition, to determine whether or not the mean percentage deviation scores differed significantly from zero. When using the left hand, male performance deviated significantly to the left of the veridical center, whereas it did not deviate from the true center when using the right hand. In women, when using the left hand, the leftward bias is absent in the age group of 50 to 59 years. All other female age groups showed a significant left bias. Similar to men, no significant deviations from the veridical center were observed when women used their right hand to bisect lines, although a trend for a rightward bias appeared in the oldest group (1.84 ± .98, $p = .08$). The results are shown in Figure 1.

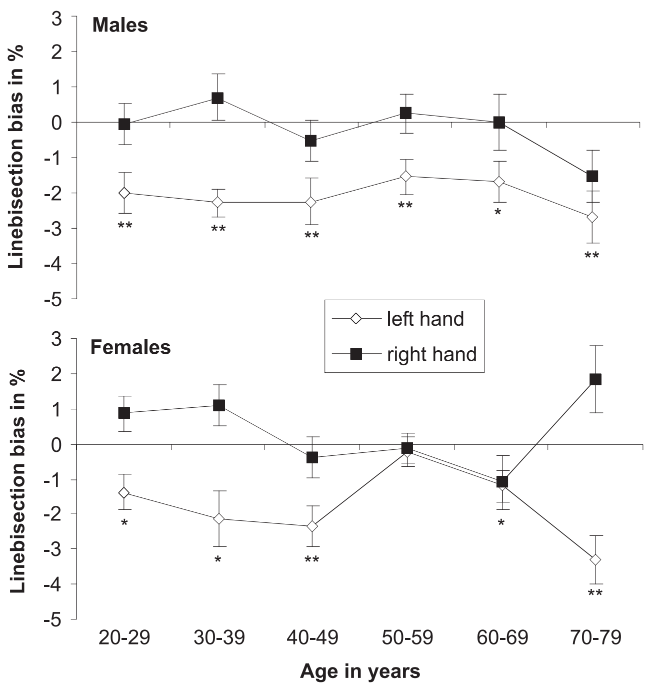

FIGURE 1 Means and standard errors of the line-bisection bias (%) for the left and right hand across age groups, separated for men (top) and women (bottom). Negative values indicate a leftward bias, positive values indicate a rightward bias. Asterisks indicate significant deviations from the veridical center as a function of hand use and age group (*$p < .05$; **$p < .001$). Only the left-hand bias reached significant leftward deviations.

The main effect of line position was significant, $F(2, 538) = 25.20$, $p < .001$. Post hoc analyses revealed that the leftward bias for the lines located near the left margin, –1.42 ± .19, and in the center, –1.17 ± .25, differed significantly from that of right-located lines, .17 ± .18, both p's < .001. The difference in the left bias between the center and left-located lines was not significant ($p = .66$). The interaction between Hand use and Line position was also significant, $F(2, 538) = 7.34$, $p = .001$. When using the left hand, a leftward bias was found in all line positions (left: –2.18 ± .23, center: –2.19 ± .21, right: –1.32 ± .22). In the right-hand condition, however, the direction of the bias was affected by line position (left: –.66 ± .25, center: –.16 ± .43, right: 1.66 ± .22). No other main effect or interaction reached the level of statistical significance, all F's < 1.83, *ns*.

It has recently been shown that the hand-use difference in line bisection fluctuates across the menstrual cycle (Hausmann, 2005). This might explain why some studies obtain sex differences in hand use (Hausmann et al., 2002; Hausmann, Waldie, et al., 2003) and others do not (this study). However, this also suggests a larger variability in the data of younger women, in particular, when cycle phases of those participating women are not controlled. To investigate whether female participants showed a larger variability in line bisection compared to men, a Mann–Whitney test of male and female standard deviations in all 36 conditions (2 hands × 3 line positions × 6 age groups) was calculated. The analysis revealed a nonsignificant tendency for larger standard deviations in the female group compared to men, $Z = -1.52$, $p = .064$, one-tailed. This difference was significance when only the three youngest age groups (20s, 30s, and 40s) were included in the analysis, $Z = -1.84$, $p = .033$, one-tailed. The standard deviations of women were virtually identical to that of men for the three oldest groups, $Z = -.13$, $p = .913$.

DISCUSSION

The overall left bias in line bisection that is typically observed in neurological normal individuals was also found in this study and was particularly pronounced when the left hand was used. This is in agreement with many other studies (e.g., Brodie & Pettigrew, 1996; Hausmann et al., 2002; Hausmann, Corballis, et al., 2003; Hausmann, Waldie, et al., 2003; Luh, 1995; Scarisbrick et al., 1987; see Jewell & McCourt, 2000, for a review) and is consistent with the activation-orientation hypothesis (Halligan & Marshall, 1989; Kinsbourne, 1970; McCourt et al., 2001; Reuter-Lorenz & Posner, 1990). Moreover, the robust overall leftward bias (right pseudoneglect) did not change across adulthood, which is in contrast to previous studies showing an overall rightward bias in older adults (Fujii et al., 1995; Stam & Bakker, 1990). In agreement to Failla et al. (2003), it was the hand-use difference that changed from early to late adulthood. In this study, however, the hand-contingent age effect was driven by the female group. Women showed the characteristic hand-use difference from the second to the fourth decade of age, whereas no hand-use difference appeared in their 50s and 60s, followed by a left bias with the left hand and a (nonsignificant) right bias with the right hand (symmetrical neglect) in their 70s. Men of all age groups showed a robust hand-use difference, that is, a leftward bias (right pseudoneglect) only when using the left hand. A tendency toward symmetrical neglect in later adulthood was previously shown (Failla et al., 2003). Unfortunately, Failla et al. (2003) did not analyze men and women separately, thus it is impossible to determine if their nonsignificant trend was a result of combining the sexes.

The current results are only partly in line with the differential aging hypothesis (Goldstein & Shelly, 1981), which states that RH is more susceptible to age-related degeneration. Although this might contribute to the age-related changes of the left-hand bias, which was slightly stronger than the changes in the right-hand bias, a differential functional decline of the RH relative to the LH predicts a shift toward the right (left hemineglect) or at least a reduced left bias for both hands. However, a reduced left bias with the left hand appeared only in women in their 50s. All other age groups showed a significant leftward bias when the left hand was used. It is unlikely that the re-emerged hand-contingent age effect in older women resulted from a reversed degeneration. It is more likely that it reflects a combination of two different functional changes. As suggested by Failla et al. (2003), there is a functional decline of the RH and the functional integrity of the corpus callosum with increasing age.

Neuroanatomical support for the differential aging hypothesis (Goldstein & Shelly, 1981) comes from magnetic resonance imaging (MRI) studies, showing an age-related RH shrinkage of the striatum (Gunning-Dixon, Head, McQuain, Acker, & Raz, 1998), which has a role in the integration of psychomotor behaviors, involving motor functions and attention allocation (Ring & Serra-Mestres, 2002). Little is known about the effect of sex on age-related changes in brain structures. There is, however, some evidence that neuromorphological changes occur in one sex faster (and earlier) than in the other. For example, age-related shrinkage in the parieto-occipital and temporal region is more apparent in men than in women (Cowell, Allen, Zalatimo, & Denenberg, 1992), which suggests that men (rather than women) are more likely to show age-related differences in line bisection. However, the same study revealed asymmetries in temporo-parietal and frontal regions not to be affected by aging in either sex (Cowell et al., 1992). Coffey et al. (1998) found that the effects of age on the frontal lobe are more pronounced in men and concluded this to be consistent with a decrease of the width of anterior callosal regions at an earlier age in men than in women (Cowell et al., 1992). However, this study found developmental changes in line bisection exclusively in women.

As noted earlier, the importance of the corpus callosum in line bisection has been demonstrated in patients with callosal infarction (Corballis, 1995; Kashiwagi et al., 1990) and in split brain participants (Hausmann et al., 2003; Heilman et al., 1984). If interhemispheric transfer is not possible or inefficient, the hemisphere controlling the responding hand seems to be responsible for the direction of the attentional bias (Failla et al., 2003), which results in a left bias with the left hand and a right bias with the right hand. This phenomenon, known as symmetrical neglect, is shown in children before puberty (Bradshaw et al., 1987; Dellatolas et al., 1996; Dobler et al., 2001; Failla et al., 2003; Hausmann, Waldie, et al., 2003; Roeltgen & Roeltgen, 1989). Although the number of callosal fibers reaches its maximum in utero (LaMantia & Rakic, 1984), quantitative MRI has shown that the total midsaggital callosal area increases in size up to the age of 20 years, particularly in the regions of the midbody and splenium (Giedd et al., 1996; Pujol, Vendrell, Junque, Marti-Vilata, & Capdevila, 1993), most likely through myelogenesis of fibers (Salamy, 1978). Consequently, the symmetrical neglect in older adults has been attributed to a callosal degeneration with aging (Failla et al., 2003).

In support of this hypothesis, a number of MRI studies showed an age-related decrease of total callosal size or its subareas (Driesen & Raz, 1995; Doraiswamy et al., 1991; Dubb, Gur, Avanti, & Gee, 2003; Takeda et al., 2003; Weis, Kimbacher, Wenger, & Neuhold, 1993). However, the corpus callosum in adults seems to be relatively immune to age-related shrinkage between the third to seventh decade of life (Biegon et al., 1994; Cowell et al., 1992; Johnson, Farnworth, Pinkston, Bigler, & Blatter, 1994; Pfefferbaum, Lim, Desmond, & Sullivan, 1996; Sullivan, Rosenbloom, Desmond, & Pfefferbaum, 2001). Moreover, evidence exists that age-related changes in the morphology of the corpus callosum differ between men and women (Dubb et al., 2003; Suganthy, Raghuram, Antonisamy, Vettivel, Madhavi, & Koshi, 2003). For example, Cowell et al. (1992) obtained MRIs from 146 participants, ranging between 2 to 79 years, and found relatively little change with age throughout the callosal body, isthmus, and anterior splenium once maximum was reached. However, women did not attain maximum size/width in subareas of the corpus callosum until the fifth decade of life, whereas men had already peaked and declined considerable by this age. This is about the same age when developmental changes in line bisection occurred in women of this study. Another MRI study (Dubb et al., 2003) of 94 men and 95 women with an age range of 18 to 84 years revealed that the female splenia tend to expand more with age, whereas the male genu tended to contract. The majority of these neurodevelopmental changes in adult callosa occurred after the third decade of life. Dubb et al. (2003) suggested that “it would be reasonable to posit hormonal differences as the underlying cause” and hypothesize “that estrogen exerts a positive effect on the callosum or testosterone exerts a negative effect” (p. 518).

Although sex hormone levels were not controlled in this study, it was recently shown that the hand-use difference fluctuates across the menstrual cycle (Hausmann, 2005). The hand-use difference was significantly reduced when estradiol levels were high. Women in their menses (low estradiol levels) showed a strong hand-use difference that was virtually identical to that of men. Such hormonal effects might explain sex differences in line bisection as a function of hand use in younger and middle-aged adults (Hausmann et al., 2002; Hausmann, Waldie, et al.,

2003) and the lack of sex differences in younger participants in this study, depending on the cycle phase in which younger women were tested. This is supported by the larger variability of the data for younger women (20s, 30s, and 40s) found in this study. Although it is unlikely that the reduced hand-use difference in women, ranging from 50 to 59 years, arises from activating effects of gonadal hormones, it might be possible that age-related changes in the morphology of the corpus callosum are due to hormonal changes following menopause (organizing hormone effects). In fact, there is support from animal literature suggesting that sex hormones affect callosal structure during adulthood in female rats (Fitch & Denenberg, 1998; Mack, Fitch, Cowell, Schrott, & Denenberg, 1993; Nunez & Juraska, 1998).

In accordance with other studies (e.g., Hausmann et al., 2002; Hausmann, Waldie, et al., 2003; Luh , 1995; Milner, Brechmann, & Pagliarini, 1992; see Jewell & McCourt, 2000, for review), a strong effect of line position was found. The left bias was increased when participants viewed lines located on the left, whereas it was reduced when lines were located on the right. Although such hemispatial effects may be explicable in perceptual terms, such that the left hemispace stimuli lead to a greater RH activation, and thus to a greater leftward bias (Kinsbourne, 1970), purely perceptual factors would not predict this effect to be related to hand use (Luh, 1995). The strongest left bias appeared when the left hand bisected lines in the ipsilateral left hemispace. The left bias was reduced when the left hand bisected lines in the contralateral right hemispace. Correspondingly, a right bias was found when the right hand bisected lines in the ipsilateral right hemispace, which was strongly reduced (slightly shifted to the left) in the contralateral left hemispace. These findings suggest that the space relative to the body midline in which action is performed exerts significant influence on the allocation of attention (Dobler et al., 2001).

In an earlier study, Hausmann, Güntürkün, and Corballis (2003) found that on a figural comparison task (also involving predominantly RH capacities), there was a RH asymmetry that was reduced with age in men, but increased in women. This pattern of results seems to be exactly opposite from that of this study. In this earlier study, however, women of the older group ranged between 55 to 74 years (mean age = 63.8 years). If women in their 50s, 60s, and 70s were grouped together (age range = 50 to 76 years, mean age = 60.95 years), a significant difference between the right-hand bias (–.01 ± .38) and the left-hand bias (–1.18 ± .32) appears in our study. This finding suggests that the large RH asymmetry in the study of Hausmann, Güntürkün, et al. (2003) might be similarly driven by women in their 70s. Although figural comparison and line bisection differ in various aspects, and thus should be compared with caution, the results highlight the need for larger sample sizes and smaller age-range categories when investigating age-related effects on brain functions and behavior.

In combination with neuroanatomical findings, the results of this study suggest that sex- and age-related changes in line bisection may be the result of two distinct processes. The first process refers to sex- and age-related changes in RH, as stated by the differential aging hypothesis (Goldstein & Shelly, 1981). The second process refers to sex- and age-related changes in the functional integrity of the corpus callosum. Although both age-related processes are assumed to interact with each other, its appearance and behavioral relevance in line bisection might differ across age; that is, age-related changes of transcallosal transfer might occur later or more gradual compared to RH degeneration.

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