Research report

Sex differences in left–right confusion depend on hemispheric asymmetry

Marco Hirnstein[a],, Sebastian Ocklenburg[b], Daniel Schneider[b] and Markus Hausmann[a]*

[a]*Department of Psychology, University of Durham, Durham, UK*
[b]*Biopsychology, Institute of Cognitive Neuroscience, Ruhr-University Bochum, Bochum, Germany*

ABSTRACT

Numerous studies have reported that women believe they are more susceptible to left–right confusion than men. Indeed, some studies have also found sex differences in behavioural tasks. It has been suggested that women have more difficulties with left–right discrimination, because they are less lateralised than men and a lower degree of lateralisation might lead to more left–right confusion (LRC). However, those studies reporting more left–right confusion for women have been criticised because the tasks that have been used involved mental rotation, a spatial ability in which men typically excel. In the present study, 34 right-handed women and 31 right-handed men completed two behavioural left–right discrimination tasks, in which mental rotation was either experimentally controlled for or was not needed. To measure the degree of hemispheric asymmetry participants also completed a dichotic listening test. Although women were not less lateralised than men, both tasks consistently revealed that women were more susceptible to left–right confusion than men. However, only women with a significant right ear advantage in the dichotic listening test had more difficulties in LRC tasks than men. There was no sex difference in less lateralised participants. This finding suggests that the impact of functional verbal asymmetries on LRC is mediated by sex.

Crown Copyright © 2008 Published by Elsevier Srl. All rights reserved.

1. Introduction

Discriminating left from right is a useful and sometimes crucial (e.g., driving) ability in human everyday life which is acquired through different stages in childhood. For instance, children at 7 years of age are able to correctly discriminate their own left and right body parts but even at 11 years of age only about 50% of the children are able to apply the word left and right to other persons correctly (Dellatolas et al., 1998; Rigal, 1994). According to Benton (1968) an adult level of left–right orientation is normally attained at 12 years of age.

However, there are still inter-individual differences in the performance of left–right discrimination in adults, particularly between males and females.

Previous research unequivocally suggests that women believe their performance is inferior to that of men when discriminating left from right. In an early study by Wolf (1973), physicians and their spouses were asked whether they have difficulties in quickly identifying left versus right. Only 8.8% of the males but 17.5% of the females answered they get confused "frequently" or "all the time". Since then, many other self-evaluation studies have revealed that women rate

themselves more susceptible to left–right confusion (LRC) than men (Hannay et al., 1990; Harris and Gitterman, 1978; Jaspers-Feyer and Peters, 2005; Jordan et al., 2006; Snyder, 1991; Teng and Lee, 1982; Williams et al., 1993). Williams et al. (1993) found a relationship between self-ratings in LRC and social desirability for women but not for men, suggesting that sex differences in self-ratings might simply reflect a gender stereotype. Accordingly, this study failed to show any sex differences in a behavioural LRC task (see also Hannay et al., 1983, 1990).

Whether sex differences in self-rating actually reflect sex differences in performance remain controversial. One of the first experimental studies that investigated behavioural performance was carried out by Bakan and Putnam (1974). Their participants, 400 undergraduate students, accomplished the Laterality Discrimination Test (Culver, 1969), in which they were asked to label pictures of human body parts as left or right. In fact, females had higher error rates than males (for more recent studies see Ofte, 2002; Ofte and Hugdahl, 2002). Similarly, Snyder (1991) found that men responded faster in the Right–Left Orientation Test (Benton et al., 1983) in which participants had to manually localise lateral body parts in response to the examiner's commands (e.g., ''Touch your right ear with your right hand.''). Moreover, reaction times in these tasks were moderately correlated with self-evaluated left–right confusability, indicating that self-evaluation possesses at least some behavioural validity.

However, as Jordan et al. (2006) pointed out, those behavioural studies that found sex differences in LRC might be confounded by sex differences in mental rotation. Mental rotation refers to the ability to rotate mental representations of two- and three-dimensional objects and is known to be one of the most sex-sensitive cognitive abilities, with men outperforming women by about one standard deviation (Linn and Petersen, 1985; Masters and Sanders, 1993; Peters et al., 1995; Voyer et al., 1995). Indeed, mental rotation has often been involved in LRC tasks. For example, Ofte and Hugdahl (Ofte, 2002; Ofte and Hugdahl, 2002) presented their participants with human stick figures which were either viewed from the front or back with arms outstretched or crossed. Participants were then asked to mark with a pen either the right or left hand. In other studies (Snyder, 1991; Bukan and Putnam, 1974), participants were asked to label photographs of body parts depicted from different viewing positions or label body parts of people sitting opposite them as left or right (Culver, 1969; Benton, 1959). In all those tasks participants have to abandon an egocentric point of view and take another person's perspective – a cognitive manipulation which involves a certain degree of mental rotation. Hence, the observed sex differences in LRC might be superimposed on mental rotation and it is crucial, therefore, to control mental rotation in left–right discrimination when evaluating sex differences.

The first attempt to take mental rotation into account during LRC was made by Jordan et al. (2006). In this study, participants had to indicate via a button press whether a bunch of pencils presented on photographs was to the left or right of an iced-tea can. No sex difference in accuracy or reaction time emerged. Due to the simplicity of this task, the authors carried out a second experiment, in which women and men had to navigate through a virtual reality maze, while making several left–right decisions. Here, a significant sex difference was found, with men navigating faster through the maze than women. Since the latter task was significantly related to mental rotation performance, the authors concluded that sex differences in LRC do not emerge in simple tasks, but in difficult tasks when mental rotation is involved.

However, we hypothesise that hemispheric asymmetries are another factor of crucial importance for potential sex differences in LRC. First of all, there is evidence showing that LRC depends particularly on the left hemisphere. For example, Sholl and Egeth (1981) have demonstrated that LRC is based on verbal labelling, i.e., participants do not mix up left and right, but have difficulties with labelling the directions correctly as 'left' or 'right'. Since labelling is a verbal process, it probably involves the language dominant left hemisphere. Moreover, patients suffering from Gerstmann's syndrome, a neurological disorder characterised by four major symptoms, agraphia, acalculia, finger agnosia and LRC, (Gold et al., 1995; Gerstmann, 1940) have lesions in the angular gyrus or supramarginal gyrus of the left hemisphere. Further empirical evidence for a specific involvement of the left hemisphere comes from a study of Hannay et al. (1983) who measured regional cerebral blood flow during the Laterality Discrimination Test for men and women separately. Activations in bilateral occipital and left parietal areas were found for both sexes. In men, however, better performance in left–right discrimination was associated with less activation in the left occipital lobe. These findings suggest that if LRC and hemispheric asymmetries are linked, sex differences in hemispheric asymmetries might also underlie sex differences in LRC. In fact, women are generally considered as being less lateralised than men (e.g., Hausmann and Güntürkün, 1999; McGlone, 1980).

Corballis and Beale (1976, 1970) argued that a perfectly bilaterally symmetrical organism could not respond differentially to a stimulus and its mirror-image. Conversely, a lateralised brain serves as a prerequisite for left–right discrimination. This could imply that stronger lateralisation might be associated with less LRC. Following this rationale, women should be more susceptible to LRC, because they are less lateralised than men. However, the empirical evidence for this notion is rather sparse possibly because those studies that found more LRC in women are confounded by mental rotation as indicated above. Other researchers have tried to test Corballis and Beale's notion by comparing right- with left-handers (the latter are also said to be less lateralised). The results have been contradictory. While Silverman et al. (1966) found that left- and mixed-handers performed more poorly on left–right discrimination tasks than right-handers (see also Hannay et al., 1990; Harris and Gitterman, 1978), other studies failed to find significant effects of handedness (Bakan and Putnam, 1974; Maki et al., 1979; Snyder, 1991).

One explanation for this inconsistency might be inappropriate measurement of hemispheric asymmetry, or that measurement was lacking altogether. Instead of measuring the degree of hemispheric asymmetry directly, it was simply assumed that women/left-handers are less lateralised than men/right-handers (e.g., Bakan and Putnam, 1974). Also, as pointed out above, LRC might depend on verbal labelling. It is thus reasonable to assume that hemispheric asymmetries in

language are particularly relevant for LRC. Although handedness is related to language lateralisation, it is more appropriate to measure the degree of language lateralisation more directly, for example by using a dichotic listening task.

The purpose of the present study is twofold: firstly, this study investigates whether sex differences in LRC do exist, if mental rotation is controlled for. Secondly, we want to examine whether reduced lateralisation (in language) is associated with an increase in LRC (Corballis and Beale, 1976, 1970) and whether potential sex differences in LRC are based on reduced lateralisation in women. In contrast to previous studies and due to the importance of language lateralisation, a dichotic listening test was used to determine the degree of lateralisation. In addition, the present study addresses whether self-ratings in LRC are related to performance in those LRC tasks used here.

2. Methods

2.1. Participants

Overall, 65 neurologically healthy women ($N = 34$) and men ($N = 31$) participated in the present study. Students from different faculties of the Ruhr-University Bochum were tested, with the vast majority being psychology undergraduates. The mean age for women was 24.12 years (SD = 6.57) and 25.65 years (SD = 4.30) for men. All participants were right-handed, as determined by the Edinburgh Handedness Inventory (EHI; Oldfield, 1971). The laterality index provided by this test is calculated by $LQ = [(R - L)/(R + L)] \times 100$, resulting in values between -100 and $+100$. Positive values indicate a preference for the right hand, while negative values indicate left-handedness. Women had a mean LQ of 89.14 (SD = 15.47, range: 50–100), while the mean LQ for men was 90.11 (SD = 12.54, range: 62.5–100). There was no sex difference in LQ [$t(63) = .28$, $p = .78$].

2.2. Procedure

Participants started the experiment with two behavioural experiments, the 'Left–right commands task' and the 'Pointing-hands task', in a counterbalanced order. Subsequently, they completed a dichotic listening test, the EHI and a left–right self-rating questionnaire. Performing the behavioural tasks first prevented possible stereotype activation effects of the self-rating questionnaire.

2.3. Dichotic listening

The degree of language lateralisation was assessed by the Fused Rhymed Words Test (FRWT) of Hättig and Beier, 2000, a German adaptation of a dichotic listening test developed by Wexler and Halwes (1983). In previous studies, the FRWT achieved a concordance rate of 86% with the sodium amytal Wada tests and a test–retest reliability of .65 to .87 (Hättig and Beier, 2000). The test consists of 10 pairs of rhyming words which differ only in the initial letter. When presented dichotically, paired words fuse into a single percept. After each trial, participants were asked to indicate the word they had heard. The test starts with 40 unilateral practice trials, followed by four blocks of 40 trials, resulting in a total of 160 trials. In line with Hättig and Beier, 2000, the number of items correctly reported with the left (LOP) and right ear (ROP) were used to calculate the degree of asymmetry (λ) as $\lambda = \ln(\text{ROP}/\text{LOP})$, with values ranging from -4.38 to $+4.38$. Negative values indicate a left ear advantage (LEA), that is, a presumed right-hemispheric advantage for language, while positive values indicate a right ear advantage (REA), a left-hemispheric advantage for language. A value of 0 indicates no ear/hemisphere advantage. As expected, 57 out of 65 participants had a right ear/left-hemispheric language advantage. To investigate the relationship between verbal hemispheric asymmetry and LRC, we checked for each individual via Chi-square tests (see Wexler et al., 1981) whether the LEA or REA (i.e., the relative difference between LOP and ROP) was actually significant. Of 65 participants, 37 (19 women, 18 men) showed a significant REA, four a significant LEA (two women, two men) and 24 (13 women, 11 men) no significant ear advantage. Due to the small number of LEA participants, these participants were excluded from subsequent analyses. Of those remaining 61 participants, women had a mean λ of 1.64 (SD = 1.19, range -1.1–3.99) and men a mean λ of 1.49 (SD = 1.23, range $-.81$–3.99). There was no sex difference in λ [$t(59) = .49$, $p = .63$].

2.4. Behavioural LRC tests

2.4.1. Left–right commands task

2.4.1.1. METHOD. While in many previous behavioural LRC experiments, participants typically responded to visually presented stimuli, in everyday situations people often respond to verbal instructions, such as ''Turn left'' or ''Please, give me the book to your right'', etc. In the Right–Left Orientation Test (Benton et al., 1983), participants followed verbal commands, but as pointed out above, the results of this test might be confounded by mental rotation. The 'Left–right commands' task thus involved following verbal instructions, but did not require mental rotation.

Participants were sitting upright on a chair with their hands on their knees (starting position). All participants were recorded with a video camera. The verbal instructions consisted of 60 verbal commands, 20 simple, 20 complex and 20 neutral commands in a pseudorandomised order. Verbal commands were presented via loudspeakers (approximately 2 m away from the participants). In the simple condition, participants were asked to move one part of their body, e.g., ''Lift your right foot'' or ''Lift your left arm''. To increase the probability of LRC, participants were confronted with more complex verbal commands which included two left/right commands at the same time, such as ''Touch your right ear with your left hand'' or ''Lift your right hand and your left foot''. In the control condition, participants were asked to e.g., ''Raise both arms'' or ''Fold your hands''. To increase the probability of LRC, a time limit of 2 sec was set for each command. Thus after 2 sec the next command started. Participants were asked to follow the commands and, after the appropriate response, to return to their starting position. Only if participants followed the command correctly,

e.g., ''Lift your right foot'', but mixed up left and right, i.e., they lifted the left instead of the correct right foot, was this considered as LRC. LRC error percentage scores were calculated for both simple and complex commands.

2.4.1.2. RESULTS. The per cent error rates in the simple and complex conditions for men and women with and without a significant right ear advantage on the dichotic listening task are shown in Table 1.

A mixed $2 \times 2 \times 2$ ANOVA with difficulty (simple, complex) as a repeated measures factor and sex (males, females) and lateralisation group (significant REA, no ear advantage) as between-participant factors was computed. Throughout, effect sizes are given as the proportion of variance accounted for (partial η^2) and p-levels for post hoc t-tests were adjusted using Bonferroni correction. Overall, women made more errors than men (main effect sex: $F(1,57) = 11.26$, $p = .001$, $\eta^2 = .17$) and since there was no sex by difficulty interaction [$F(1,57) = 1.00$, $p = .32$, $\eta^2 = .02$], this was true for the simple [$t(31) = 3.22$, $p = .003$] and the complex condition [$t(59) = 2.89$, $p = .005$]. However, lateralisation group interacted with sex and difficulty [$F(1,57) = 4.88$, $p = .031$, $\eta^2 = .08$]. As can be seen in Table 1, men and women with no ear advantage performed about equally well in the complex condition [$t(22) = .40$, $p = .70$], whereas the performance of women with significant REA was significantly worse than that of men with significant REA [$t(31.13) = 3.31$, $p = .002$]. In the simple condition, no sex difference emerged (all $t < 2.51$, ns). Finally, participants showed, as expected, more LRC in the complex than in the simple condition, as indicated by a main effect of difficulty [$F(1,57) = 22.71$, $p < .001$, $\eta^2 = .29$].

2.4.2. Pointing-hands task

2.4.2.1. METHOD. For the 'Pointing-hands task', stimuli were adapted from Brandt and Mackavey (1981). The stimulus set consists of photographs of left and right hands taken in eight different orientations (Fig. 1).

In the first condition, all hands pointed either upwards or downwards and participants were instructed to label them as ''up'' or ''down''. This condition (''up/down-pointing'') served as a control condition. In the second condition, all hands pointed towards the left or right. Accordingly, the participants had to label them as pointing towards the ''left'' or ''right'' (''left/right-pointing''). The left–right-pointing condition requires no mental rotation. In the third condition, hand stimuli were presented in the same orientation as in condition
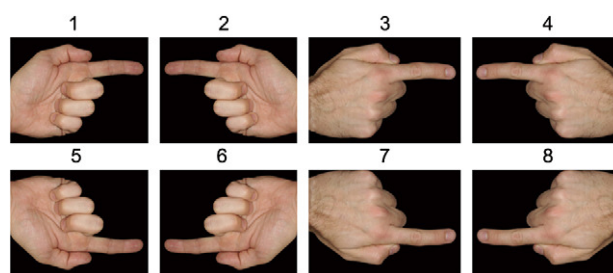

Fig. 1 – Stimuli of the 'Pointing-hands task'. Note that hands (1) and (2) are in rather familiar (not-rotated) orientations whereas hands (3) – (8) are in rather unfamiliar (rotated) orientations.

two, but now participants had to identify whether they saw a left or right hand, regardless of its pointing direction (''left/right-hand''). As can be seen from Fig. 1, hand stimuli (3) to (8) need to be mentally rotated because they are presented in unusual orientations (rotated hands). In contrast, hand stimuli (1) and (2) are shown in more familiar orientations, and thus mental rotation was assumed to be less essential (not-rotated hands). If sex differences in LRC result from mental rotation, they should only emerge in condition three and particularly for the rotated hands. However, sex differences should be minimal for not-rotated hands.

The participants completed all three conditions in a randomised order. The stimuli were presented separately for 2 sec on a PC screen. Each stimulus was presented 10 times in a pseudorandomised order, resulting in 80 trials for each condition. During each trial, participants were asked to indicate verbally the pointing direction, i.e., ''up/down'' (up/down-pointing condition), ''left/right'' (left/right-pointing condition) or whether a left or right hand was presented (left/right-hand condition). To increase the probability of LRC, a response was only considered to be correct if it was made within 2 sec. Error rates (in percent) were used as the dependent variable.

2.4.2.2. RESULTS. The results on the pointing-hands task are shown in Table 2.

Two participants had to be excluded because their responses were not recorded due to technical problems. The data from the remaining 30 women and 29 men were analysed with a mixed $3 \times 2 \times 2$ ANOVA with condition (up/down-pointing, left/right-pointing, left/right-hand) as repeated measures and sex and lateralisation group (significant REA, no ear advantage) as between-participants factors. As in the 'Left–right commands task', women committed more errors than men (main effect sex: $F(1,55) = 9.86$, $p = .003$, $\eta^2 = .15$). Also, all participants made more errors in the left/right-hand than in the up/down-pointing or left/right-pointing condition (main effect condition: $F(2,110) = 108.74$, $p < .001$, $\eta^2 = .66$). A significant interaction between sex and condition [$F(2,110) = 9.07$, $p < .001$, $\eta^2 = .14$] further revealed that women showed LRC particularly in the difficult left/right-hand condition [$t(57) = 3.47$, $p = .001$], whereas no sex difference emerged for up/down-pointing [$t(59) = .81$, $p = .42$] or left/right-pointing [$t(59) = 1.62$, $p = .11$]. Moreover, sex interacted significantly with lateralisation group [$F(1,55) = 8.37$, $p = .005$,

Table 1 – Mean error rate in % (SE in brackets) for women and men of different ear advantages across the simple and complex condition in the 'Left–right commands task'			
Error rate in %		Simple condition	Complex condition
Women	REA	1.58 (.56)	7.90 (1.16)
	No ear advantage	2.31 (.67)	3.85 (1.40)
Men	REA	0	1.94 (1.19)
	No ear advantage	0	3.18 (1.52)

Table 2 – Mean error rate in % (SE in brackets) for women and men of different ear advantages across all conditions in the 'Pointing-hands task'						
Error rate in %		Up/down-pointing	Left/right-pointing	Left/right-hand		
				Total	Rotated hands	Not-rotated hands
Women	REA	.22 (.13)	.44 (.18)	30.37 (3.28)	35.39 (3.99)	15.29 (2.57)
	No ear advantage	.29 (.14)	.58 (.20)	18.56 (3.76)	21.54 (4.56)	9.62 (3.72)
Men	REA	.14 (.12)	.28 (.17)	8.61 (3.19)	10.28 (3.88)	3.61 (2.50)
	No ear advantage	.11 (.16)	.11 (.22)	18.30 (4.08)	22.27 (4.96)	6.36 (3.20)

$\eta^2 = .13$]. Whereas men and women with no ear advantage did not differ in LRC [$t(22) = .14$, $p = .89$], women with significant REA were clearly outperformed by men with significant REA [$t(26.69) = 4.27$, $p < .001$]. Moreover the three-way interaction between sex, lateralisation group and condition was significant [$F(2,110) = 9.17$, $p < .001$, $\eta^2 = .14$]. Women with significant REA were particularly outperformed by men with significant REA in the more difficult left/right-hand condition [$t(26.96) = 4.66$, $p < .0001$]. Men and women with significant REA did not differ in up/down- and left/right-pointing conditions (all $t < .66$, ns). Men and women without a significant REA did not differ in any condition (all $t < 1.43$, ns).

To further investigate whether women only made more LRC errors in the left/right-hand condition because of mental rotation, a separate $2 \times 2 \times 2$ ANOVA with stimulus set (rotated, not-rotated hands) as a repeated measures factor and sex and lateralisation group as between-participants factors (Table 2).was computed. As expected, the analysis revealed strong main effects of stimulus set [$F(1,55) = 41.32$, $p < .0001$, $\eta^2 = .43$] and sex [$F(1,55) = 10.72$, $p = .002$, $\eta^2 = .16$], indicating higher error rates for the rotated-hands stimuli and women, respectively. However, stimulus set did not interact with sex [$F(1,55) = 1.24$, $p = .27$, $\eta^2 = .02$], i.e., women showed more LRC for both rotated hands [women: mean = 29.39% ± SE = 3.43; men: 14.83 ± 2.94%; $t(57) = 3.21$, $p = .002$] and not-rotated hands [women: 12.83 ± 2.36%; men: 4.66 ± 1.42%; $t(47.78) = 2.97$, $p = .005$]. Again, there was no sex difference in LRC in participants with no ear advantage [$t(22) = .23$, $p = .81$], but men with significant REA clearly outperformed women with significant REA [$t(24.78) = 5.44$, $p < .001$], as indicated by a sex by lateralisation group interaction [$F(1,55) = 8.15$, $p = .006$, $\eta^2 = .13$]. Finally, there was a three-way interaction between sex, lateralisation group and stimulus set [$F(1,55) = 4.21$, $p = .045$, $\eta^2 = .07$]. Although men with significant REA outperformed women with significant REA with both rotated hands [$t(27.05) = 4.36$, $p < .001$] and not-rotated hands [$t(23.61) = 3.58$, $p = .002$], the sex difference was particularly pronounced in the rotated hands (women had a higher error rate of 25 percentage points, compared to 12 percentage points in the not-rotated hands, see Table 2). Again, there was no sex difference between men and women without a significant REA in either rotated or not-rotated hands ($t < .65$, ns).

2.4.3. Left–right self-rating questionnaire

2.4.3.1. METHOD. We adopted the LRC self-rating questionnaire from Jordan et al. (2006). The questionnaire consists of eight items. The first four items were derived from Hannay et al. (1990) and the last four items from Jaspers-Feyer and Peters, 2005 (2005; see also Jordan et al., 2006). For each item participants had to indicate on a five-point scale whether they had ''no problems at all'' (''1'') or ''severe'' problems (''5''). According to Jordan et al. (2006) the first four items specifically deal with left–right judgements (LRC-items, e.g., ''Do you know left from right?''), whereas the other four items are more generalised directional questions (DIR-items, e.g., ''Do you consider yourself to have a good sense of direction?''). Means of LRC- and DIR- items were calculated for 59 participants (30 women, 29 men). Two participants had to be discarded from analyses because they did not answer all questions.

2.4.3.2. RESULTS. The results of the self-rating questionnaire are shown in Table 3.

A mixed $2 \times 2 \times 2$ ANOVA with between-participants factors sex and lateralisation group (significant REA, no ear advantage) and question type (LRC, DIR) as repeated measures was calculated. Participants rated themselves more prone to LRC with situations described in DIR questions than those described in LRC questions (main effect question type: $F(1,55) = 20.97$; $p < .001$, $\eta^2 = .28$). Although self-ratings were rather low for both sexes (see Table 3), women judged themselves less capable in differentiating left from right than men, indicated by a significant main effect of sex [$F(1,55) = 11.17$; $p = .001$, $\eta^2 = .17$]. No further effect approached significance (all $F(1,55) \leq 1.98$; $p \geq .17$, $\eta^2 \leq .04$).

2.4.4. Relationship of LRC, asymmetry and LRC self-rating

The previous analyses have suggested that verbal hemispheric asymmetries affect left–right performances of men and women. We thus wanted to investigate the relationship between LRC and lateralisation more thoroughly; specifically whether there is a linear relationship as implied by Corballis and Beale (1976, 1970). Also, we were interested in whether

Table 3 – Mean LRC and DIR self-ratings (SE in brackets) on a five-point scale (1 = ''no problems at all'', 5 = ''severe problems'') for women and men of different ear advantages			
Mean		LRC questions	DIR questions
Women	REA	1.79 (.15)	2.51 (.17)
	No ear advantage	1.961 (.19)	2.48 (.20)
Men	REA	1.42 (.15)	1.78 (.17)
	No ear advantage	1.64 (.19)	1.93 (.21)

LRC self-ratings can predict LRC performance for both sexes. Therefore, multiple linear regressions were carried out, separately for men and women, with LRC performance in the 'Left–right commands' (separately for simple and complex condition) and the 'Pointing-hands task' (separately for rotated and not-rotated hands stimuli of the left/right-hand condition) as the dependent variable and asymmetry (λ for dichotic listening, LQ for hand preference) and self-rating (LRC and DIR questions) as predictors. For males, no multiple regression was calculated for the simple 'Left–right commands task', since none of the men made any mistakes. For all other LRC performances, no significant model was found (all $F_{(4,28)} \leq 2.60$, $p \geq .06$). For women, multiple regressions revealed a significant model for the complex 'Left–right commands task' [$F_{(4,29)} = 4.66$, $p = .006$] accounting for 43% of variance. Only LRC questions contributed significantly to the regression ($\beta = .58$, $p = .003$), i.e., the more females rated themselves being prone to LRC, the higher was their error rate. Also, a significant model for not-rotated hands in the 'Pointing-hands task' emerged [$F_{(4,27)} = 4.45$, $p = .008$], which accounted for 44% of variance. The model was mainly based on DIR questions ($\beta = .37$, $p = .038$) and LRC questions ($\beta = .44$, $p = .029$). Again, women who rated themselves more prone to LRC indeed revealed higher error rates.

3. Discussion

The aim of the present study was to investigate the influence of hemispheric asymmetry on sex differences in LRC. Males and females completed two behavioural LRC tasks and a dichotic listening test. Specifically, we intended to answer the following two main questions: (a) Do sex differences appear in LRC tasks which do not require mental rotation? (b) Is LRC performance related to language lateralisation? In addition, we were interested in whether (c) sex differences in LRC self-rating reflect sex difference in LRC performance.

3.1. Do sex differences appear in tasks which do not require mental rotation?

Both the 'Left–right commands' and the 'Pointing-hands task' revealed robust sex differences accounting for up to 17% of variance (note that effect sizes higher than 14% are considered as large effects (Cohen, 1988). Women clearly made more errors than men, a finding which is in alignment with previous studies (Bakan and Putnam, 1974; Ofte, 2002; Ofte and Hugdahl, 2002; Snyder, 1991). However, those previous studies have been criticised by Jordan et al. (2006), because the reported sex differences in LRC might have been confounded by sex differences in mental rotation. In the present study, however, a profound sex difference was found in the 'Left–right commands task', in which no mental rotation was required. None of the 29 men committed any left–right errors in the simple condition. Also, although in the 'Pointing-hands task' the degree of mental rotation varied (rotated versus not-rotated hands), sex differences in LRC remained stable. These findings clearly suggest, for the first time, that sex differences

in LRC exist independently of sex differences in mental rotation.

3.2. Is LRC performance related to language lateralisation?

It has been suggested that a lower degree of lateralisation is associated with more LRC (Corballis and Beale, 1976, 1970). As a result, women, who are assumed to be less lateralised than men, should also be more susceptible to LRC. Indirect support for a link between LRC and hemispheric asymmetry comes from Manga and Ballesteros (1987) who applied a lateralised reaction time task to participants who reported themselves to be highly or less susceptible to LRC. The participants had to decide whether a 'T' presented to the left or right visual field was tilted $45°$ to the left or right. Participants who rated themselves less susceptible to LRC responded faster when the stimuli were presented in the right than in the left visual field. Participants who rated themselves highly susceptible to LRC did not show any reaction time difference between visual fields. Based on these findings, the authors concluded that participants who are more susceptible to LRC are also less lateralised. However, the present study has demonstrated (see Section 3.3) that LRC self-ratings are not necessarily a good predictor for actual performance in laboratory-based LRC tasks (see also Jordan et al., 2006).

The present study also challenges the assumption that a reduced lateralisation is associated with more LRC (Corballis and Beale, 1976, 1970) and that women are more susceptible to LRC than men because they are less lateralised. Although the present study revealed no sex difference in dichotic listening (or handedness), men and women differed in their susceptibility to LRC. Nevertheless, the presence of an REA in dichotic listening was linked to a sex difference in LRC, supporting the notion that language lateralisation is relevant for LRC. Although the relationship between language lateralisation and LRC is not linear, women with a significant REA were more highly susceptible to LRC than men with a significant REA, whereas no sex differences in LRC emerged for less lateralised participants (no ear advantage).

Voyer and Ingram (2005) have shown that the right ear/left hemisphere advantage in fused dichotic listening as used in the present study can be a result of a consistent attentional bias. This attentional bias, however, has been suggested to be partly a result of a larger activation of the language dominant left hemisphere, leading to a greater attentional bias towards the right ear (Voyer and Ingram, 2005; Voyer, 2003). Thus, we cannot rule out that hemispheric asymmetries in attention might have additionally affected LRC.

The lack of sex difference in dichotic listening might be explained by the hormonal status in women during testing which was not controlled for and which was not the focus of the present study. Previous studies have shown that the degree of lateralisation can fluctuate during the menstrual cycle (e.g., Hausmann, 2005; Hausmann et al., 2002; Hausmann and Güntürkün, 2000; Holländer et al., 2005; Sanders and Wenmoth, 1998). Future studies might address the question of whether LRC is affected by natural fluctuations in sex hormone levels.

Although women who are strongly lateralised in dichotic listening revealed LRC in the 'Pointing-hands task',

particularly when stimuli were rotated, and less LRC if they were not rotated, this does not explain why they are also more prone to LRC than men in the complex 'Left–right commands task' where no mental rotation was needed. This suggests that deficits in mental rotation are not exclusively responsible for LRC in strongly lateralised women.

The question why the influence of verbal (and maybe attentional) lateralisation on LRC differs according to sex remains unanswered. However, the present data indicate that men and women with a similar degree of language lateralisation do not necessarily perform equally well in LRC. Possibly, men and women apply different cognitive strategies to solve left–right discrimination problems. Which specific cognitive strategy they employ or whether a specific strategy is superior or not might be partly influenced by the way cognitive skills are organised (and lateralised) in the brain.

Time restrictions in LRC tasks in the present study might have increased the likelihood of LRC in women. Studies that have employed similar tasks but had no time restriction have failed to find sex differences (Teng and Lee, 1982; Snyder, 1991). Time restrictions may increase the probability of LRC since it impedes use of cognitive strategies such as "I know I'm right-handed, so the hand I use for writing indicates right" (McMonnies, 1996). Therefore, sex differences in LRC in the present study might have emerged because women lack the time to apply those strategies adequately. However, the reason why time restrictions should especially affect women with significant REA (and not men with significant REA) remains unclear.

3.3. Do sex differences in LRC self-rating reflect sex difference in LRC performance?

In accordance with previous studies women rated themselves as being more prone to LRC than did men (Jordan et al., 2006; Williams et al., 1993; Hannay et al., 1990; Teng and Lee, 1982; Harris and Gitterman, 1978; Wolf, 1973). This effect thus seems to have remained stable for the last 35 years (from 1973 until now). Moreover, a sex difference emerged in the relationship between self-rating and actual performance: while in women self-rating questions were significantly related to performance, this was not the case for men, that is, only women rated their left–right discrimination abilities with any degree of accuracy. Interestingly, this result is in alignment with Jordan et al. (2006), who reported a weak correlation between self-ratings and a behavioural LRC task for women, but not for men. Although self-ratings were already relatively low for all participants, they were even lower for men, indicating that men hardly reported having any problems with LRC at all. Possibly, men are just less likely to admit that they have problems with LRC, maybe because this is not in accordance with the stereotype of men being superior in spatial abilities.

One should bear in mind, however, that even though self-ratings had some predictive value, at least in women, they only marginally translate into behavioural sex differences in LRC. Sex differences in LRC should therefore be investigated directly via behavioural tasks instead of self-reports.

3.4. Limitation to egocentric bodily stimuli

Apart from the fact that previous studies investigating sex differences in LRC might have been confounded by mental rotation, some of these studies used bodily stimuli while others used non-corporeal objects or navigation. This could have further contributed to inconsistencies between studies focusing on sex differences in LRC, because mental rotation of bodily stimuli activates different brain networks than mental rotation of objects (Blanke et al., 2005; Zacks et al., 1999). In the present study, only egocentric bodily stimuli were used in the 'Pointing-hands task' (mental rotation needed) and in the 'Left–right commands task' (mental rotation not needed). According to Seurinck et al. (2004) there is no sex difference in brain activation when hands need to be rotated. So, it is unlikely that sex differences in LRC in the 'Pointing-hands task' results from sex-specific brain activations. However, it might be interesting to investigate whether similar results can be obtained for non-corporeal objects or extrapersonal/allocentric space.

3.5. Handedness and LRC

To investigate potential relationships between lateralisation and LRC the present study compared men with women, because women are thought to be less lateralised (e.g., Hausmann and Güntürkün, 1999; McGlone, 1980). Conversely, other researchers have compared right- with left- and mixed-handers, because left- and mixed-handers are thought to be less lateralised (Hellige, 1993). The decision to compare men with women was partly driven by the very inconsistent findings regarding handedness and LRC. Silverman et al. (1966) and Hannay et al. (1990) found left-handers to be more affected by LRC than right-handers, while Jordan et al. (2006) and Bakan and Putnam (1974) found no differences. Snyder (1991) even found no difference in accuracy but reported that left-handers responded faster to left–right decisions than right-handers. These contradictory results might have emerged because LRC was based only on self-reports instead of experimental studies (Jordan et al., 2006; Hannay et al., 1990). The present study has demonstrated that in addition to simply comparing supposedly more and less lateralised participants (such as left- or right-handers), it is important directly to measure the degree of (language) lateralisation. However, it would be interesting to compare left- with right-handers, if behavioural LRC tasks are used and hemispheric asymmetries are assessed experimentally.

4. Conclusion

In sum, the present study suggests that behavioural sex differences in LRC do exist. Women are more susceptible to LRC than men, even if mental rotation is experimentally controlled for. This sex difference in LRC may be mediated by hemispheric asymmetries for verbal material. Women with significant REA had more difficulties with left–right discrimination than men, whereas women without an ear advantage made roughly the same number of left–right errors as men.

Hence, in contrast to the literature, our data suggest that whether a high degree of lateralisation relates to reduced LRC depends on the participant's sex.

REFERENCES

Bakan P and Putnam W. Right–left discrimination and brain lateralization. *Archives of Neurology*, 30: 334–335, 1974.

Benton AL. Right–left discrimination. *Pediatric Clinics of North America*, 15: 747–759, 1968.

Benton AL, Hamsher K, Varney NR, and Speen O. *Contributions to Neuropsychological Assessment*. New York: Oxford University Press, 1983.

Blanke O, Mohr C, Michel CM, Pascual-Leone A, Brugger P, Seeck M, et al. Linking out-of-body experience and self processing to mental own-body imagery at the temporoparietal junction. *The Journal of Neuroscience*, 25: 550–557, 2005.

Brandt J and MacKavey W. Left–right confusion and the perception of bilateral symmetry. *The International Journal of Neuroscience*, 12: 87–94, 1981.

Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. 2nd ed. Hillsdale, NJ: Lawrence Erlbaum Associates, 1988.

Corballis MC and Beale IL. Bilateral symmetry and behavior. *Psychological Review*, 77: 451–464, 1970.

Corballis MC and Beale IL. *The Psychology of Left and Right*. Hillsdale: Erlbaum, 1976.

Culver CM. Test of right–left discrimination. *Perceptual and Motor Skills*, 29: 863–867, 1969.

Dellatolas G, Viguier D, Deloche G, and De Agostini M. Right–left orientation and significance of systematic reversal in children. *Cortex*, 34: 659–679, 1998.

Gerstmann J. Syndrome of finger agnosia, disorientation for right and left, agraphia, acalculia. *Archives of Neurology and Psychiatry*, 44: 398–408, 1940.

Gold M, Adair JC, Jacobs DH, and Heilman KM. Right–left confusion in Gerstmann's syndrome: a model of body centered spatial orientation. *Cortex*, 31: 267–283, 1995.

Hannay HJ, Ciaccia PJ, Kerr JW, and Barett D. Self-report of right–left confusion in college men and women. *Perceptual and Motor Skills*, 70: 451–457, 1990.

Hannay HJ, Leli DA, Falgout JC, Katholi CR, and Halsey Jr JH. rCBF for middle-aged males and females during right–left discrimination. *Cortex*, 19: 465–574, 1983.

Harris LJ and Gitterman SR. University professors' self-descriptions of left–right confusability: sex and handedness differences. *Perceptual and Motor Skills*, 47: 819–823, 1978.

Hättig H and Beier M. FRWT: Ein dichotischer Hörtest für Klinik und Forschung. *Zeitschrift für Neuropsychologie*, 11: 233–245, 2000.

Hausmann M. Hemispheric asymmetry in spatial attention across the menstrual cycle. *Neuropsychologia*, 43: 1559–1567, 2005.

Hausmann M, Becker C, Gather U, and Güntürkün O. Functional cerebral asymmetries during the menstrual cycle: a cross-sectional and longitudinal analysis. *Neuropsychologia*, 40: 808–816, 2002.

Hausmann M and Güntürkün O. Steroid fluctuations modify functional cerebral asymmetries: the hypothesis of progesterone-mediated interhemispheric decoupling. *Neuropsychologia*, 38: 1362–1374, 2000.

Hausmann M and Güntürkün O. Sex differences in functional cerebral asymmetries in a repeated measures design. *Brain and Cognition*, 41: 263–275, 1999.

Hellige JB. *Hemispheric Asymmetry. What's Right and What's Left*. Cambridge: Harvard University Press, 1993.

Holländer A, Hausmann M, Hamm JP, and Corballis MC. Sex hormonal modulation of hemispheric asymmetries in the attentional blink. *Journal of the International Neuropsychological Society*, 11: 263–272, 2005.

Jaspers-Feyer F and Peters M. Hand preference, magical thinking and left–right confusion. *Laterality*, 10: 183–191, 2005.

Jordan K, Wüstenberg T, Jaspers-Feyer F, Fellbrich A, and Peters M. Sex differences in left/right confusion. *Cortex*, 42: 69–78, 2006.

Linn MC and Petersen AC. Emergence and characterization of sex differences in spatial ability: a meta-analysis. *Child Development*, 56: 1479–1498, 1985.

Manga D and Ballesteros S. Visual hemispheric asymmetry and right–left confusion. *Perceptual and Motor Skills*, 64: 915–921, 1987.

Maki RH, Grandy CA, and Hauge G. Why is telling right from left more difficult than telling above from below? *Journal of Experimental Psychology*, 5: 52–67, 1979.

Masters MS and Sanders B. Is the gender difference in mental rotation disappearing? *Behavior Genetics*, 23: 337–341, 1993.

McGlone J. Sex differences in human-brain asymmetry – a critical survey. *Behavioral and Brain Sciences*, 3: 215–227, 1980.

McMonnies CW. Left/right confusion. Part one – The general problem. *Australian Journal of Learning Disabilities*, 1: 15–18, 1996.

Ofte SH. Right–left discrimination: effects on handedness and educational background. *Scandinavian Journal of Psychology*, 43: 213–219, 2002.

Ofte SH and Hugdahl K. Right–left discrimination in male and female, young and old subjects. *Journal of Clinical and Experimental Neuropsychology*, 24: 82–92, 2002.

Oldfield RC. The assessment and analysis of handedness: the Edinburgh Inventory. *Neuropsychologia*, 9: 97–113, 1971.

Peters M, Laeng B, Latham K, Jackson M, Zaiyouna R, and Richardson C. A redrawn Vandenberg and Kruse Mental Rotations Test: different versions and factors that affect performance. *Brain and Cognition*, 28: 39–58, 1995.

Rigal R. Right–left orientation: development of correct use of right and left terms. *Perceptual and Motor Skills*, 79: 1259–1278, 1994.

Sanders G and Wenmoth D. Verbal and music dichotic listening tasks reveal variations in functional cerebral asymmetry across the menstrual cycle that are phase and task dependent. *Neuropsychologia*, 36: 869–874, 1998.

Seurinck R, Vingerhoets G, de Lange FP, and Achten E. Does egocentric mental rotation elicit sex differences? *Neuroimage*, 23: 1440–1449, 2004.

Sholl MJ and Egeth HE. Right–left confusion in the adult: a verbal labelling effect. *Memory and Cognition*, 9: 339–350, 1981.

Silverman AJ, Adevai G, and McGough WE. Some relationships between handedness and perception. *Journal of Psychosomatic Research*, 10: 151–158, 1966.

Snyder TJ. Self-rated right–left confusability and objectively measured right–left discrimination. *Developmental Neuropsychology*, 7: 219–230, 1991.

Teng EL and Lee AL. Right–left-discrimination: no sex difference among normals on the Hands Test and the Route Test. *Perceptual and Motor Skills*, 55: 299–302, 1982.

Williams RJ, Standen K, and Ricciardelli LA. Sex differences in self-reported right–left confusion by adults: a role for social desirability? *Social Behavior and Personality*, 21: 327–332, 1993.

Voyer D and Ingram J. Attention, reliability, and validity of perceptual asymmetries in the fused dichotic words test. *Laterality*, 10: 545–561, 2005.

Voyer D. Reliability and magnitude of perceptual asymmetries in a dichotic word recognition task. *Neuropsychology*, 37: 393–401, 2003.

Voyer D, Voyer S, and Bryden MP. Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, 117: 250–270, 1995.

Wexler BE and Halwes T. Increasing the power of dichotic methods: the fused rhymed words test. *Neuropsychologia*, 21: 59–66, 1983.

Wexler BE, Halwes T, and Heninger GR. Use of a statistical significance criterion in drawing inferences about hemispheric dominance for language function from dichotic-listening data. *Brain and Language*, 13: 13–18, 1981.

Wolf SM. Difficulties in right–left discrimination in a normal population. *Archives of Neurology*, 29: 128–129, 1973.

Zacks J, Rypma B, Gabrieli JDE, Tversky B, and Glover GH. Imagined transformations of bodies: an fMRI investigation. *Neuropsychologia*, 37: 1029–1040, 1999.