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Research report

Sex differences in language asymmetry are age-dependent and small: A large-scale, consonant–vowel dichotic listening study with behavioral and fMRI data

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ABSTRACT

Men are often believed to have a functionally more asymmetrical brain organization than women, but the empirical evidence for sex differences in lateralization is unclear to date. Over the years we have collected data from a vast number of participants using the same consonant–vowel dichotic listening task, a reliable marker for language lateralization. One dataset comprised behavioral data from 1782 participants (885 females, 125 non-right-handers), who were divided in four age groups (children <10 yrs, adolescents = 10–15 yrs, younger adults = 16–49 yrs, and older adults >50 yrs). In addition, we had behavioral *and* functional imaging (fMRI) data from another 104 younger adults (49 females, aged 18–45 yrs), who completed the same dichotic listening task in a 3T scanner. This database allowed us to comprehensively test whether there is a sex difference in functional language lateralization. Across all participants and in both datasets a right ear advantage (REA) emerged, reflecting left-hemispheric language lateralization. Accordingly, the fMRI data revealed a leftward asymmetry in superior temporal lobe language processing areas. In the $N = 1782$ dataset no main effect of sex but a significant sex by age interaction emerged: the REA increased with age in both sexes but as a result of an earlier onset in females the REA was stronger in female than male adolescents. In turn, male younger adults showed greater asymmetry than female younger adults (accounting for <1% of variance). There were no sex differences in children and older adults. The males in the fMRI dataset ($N = 104$) also had a greater REA than females (accounting for 4% of variance), but no sex difference emerged in the neuroimaging data. Handedness did not affect these findings. Taken together, our findings suggest that sex differences in language lateralization as assessed with dichotic listening exist, but they are (a) not necessarily reflected in fMRI data, (b) age-dependent and (c) relatively small.

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1. Introduction

"Women use their whole brain, men just half of it" (Anitei, 2007). Statements like this can be found in several publications as the idea of a sex difference in brain lateralization has become part of our folklore. Its origin probably lies in a study by Lansdell (1961). He found that lesions of the left temporal lobe disrupted performance on a verbal test only in men, and suggested that women might be less affected by unilateral lesions because they have a more bilateral language organization. Sex differences in lateralization thus do not only have anecdotal value, but might have important practical clinical implications. Moreover, sex differences in lateralization have been suggested to be the reason why, on average, men and women differ on certain cognitive tasks. For example, the female advantage in verbal tasks, such as verbal fluency or verbal memory (Kimura, 2000), is said to be based upon a more bilateral representation of language in women (Levy, 1971). In turn, the male advantage in spatial abilities, such as mental rotation (Voyer et al., 1995), is considered to rely on a more asymmetrical brain organization in men (Levy, 1971).

The actual empirical evidence for a more asymmetrical, male brain, however, is far less convincing than popular beliefs suggest. A vast number of studies, review articles (e.g., McGlone, 1980), or books (e.g., Kimura, 2000) have addressed sex differences in lateralization. The first meta-analyses on this topic reported that the proportion of studies that found a more asymmetrical pattern in females than males was between 6.4% and 14.9% in the auditory (Hiscock et al., 1994), between 7.8% and 12.3% in the visual (Hiscock et al., 1995), and between 5.5% and 13.8% in the tactile modality (Hiscock et al., 1999a). Voyer (1996) was the first to systematically quantify the magnitude of sex difference in functional laterality. Indeed, a significantly stronger functional asymmetry emerged in males in the visual, auditory and tactile modality; however, the sex effect was very small accounting for approximately .1% of variance. A recent update that focused on sex differences in dichotic listening (DL) corroborated Voyer's earlier findings: a significant but small bias favoring males with Cohen's $d = .054$ (Voyer, 2011, i.e., well below .1% explained variance). The studies described so far relied mostly or solely on behavioral data. However, the two meta-analyses of Sommer et al. focused on studies that used neuroimaging techniques to investigate sex differences in language lateralization [structural and functional Magnetic Resonance Imaging (fMRI), Positron Emission Tomography, and transcranial Doppler Sonography]. The structural and functional imaging data did not reveal any significant sex effects (Sommer et al., 2004, 2008). However, some of the studies also collected behavioral data alongside neuroimaging data. Here, a small bias favoring men emerged (Hedge's $g = .30$, i.e., about $d = .30$ and 2% explained variance), but only when consonant–vowel DL tasks were employed (Sommer et al., 2008). Taken together, meta-analyses for functional asymmetries in general, and functional verbal asymmetries in particular, point to a very small but reliable sex effect with a more asymmetrical brain organization in males.

The advantage of meta-analyses is that they provide sufficient statistical power to detect smaller population effects. However, their results might be subject to publication bias, i.e., findings are more likely to be published when they find sex differences as compared to null results. In fact, Sommer et al. (2008) argued that the small, behavioral male advantage in DL they found is the result of a publication bias. In order to reliably test for sex differences in lateralization in a single study large numbers of participants are required since – from the results of the meta-analysis – small population effects can be expected. Over the years, we have collected data from a consonant–vowel DL task, which although collected by different researchers and different laboratories (cf. Hugdahl, 1995), were acquired with the same stimulus material and instructions. The Bergen DL task is a well-documented, reliable procedure to assess speech lateralization, which has been validated through comparisons with amobarbital sodium (Amytal) injections (Hugdahl et al., 1997). The task typically reveals a right ear advantage (REA) for verbal material reflecting a left-hemispheric speech lateralization (for review see e.g., Bryden, 1988). The Bergen DL database comprises purely behavioral data from $N = 1783$ participants – more than three times larger than the largest sample size reported by Voyer's (2011) meta-analysis on DL ($N = 477$, from Hiscock and MacKay, 1985). Furthermore, the Bergen DL database comprises behavioral *and* fMRI data of the same Bergen DL task from an additional 104 right-handed participants. Together, the two datasets combine the strength of a meta-analysis (large statistical power) with the strength of a single study (no publication bias). In addition, the datasets enable us not only to investigate behavioral effects but also their underlying neuronal activity in the same paradigm.

The large sample size also allows for the investigation of inter-individual differences. For example, sex differences in language lateralization as measured with DL have been shown to depend upon age. For instance, adult men yielded an *in*creasing while adult women yielded a *de*creasing REA with age (Cowell and Hugdahl, 2000). This finding is of particular relevance for the claim that women's more bilateral representation of language might protect them against verbal impairments after unilateral lesions. Since unilateral lesions affect older rather than younger adults, one would expect that a sex difference in lateralization should be particularly pronounced in older adults. The results of Cowell and Hugdahl (2000) are in alignment with this hypothesis. In children, an early review came to the conclusion that a REA in DL exists from birth, with boys and girls being similarly lateralized (Hahn, 1987). This is supported by more recent empirical findings (e.g., Westerhausen et al., 2010a). In general, studies interested in age effects tend to be either restricted to children (e.g., Hahn, 1987) or compare children with younger adults (Hugdahl and Andersson, 1986), or compare younger adults with older adults (e.g., Cowell and Hugdahl, 2000; Bracco et al., 2011). The large, purely behavioral sample of the Bergen DL database comprises participants from 5 yrs up to 89 yrs, allowing us to investigate sex differences in verbal asymmetry across an almost complete age range.

In non-right-handers language is more often represented bilaterally or in the right hemisphere than in right-handers (e.g., Knecht et al., 2000). Since the large, purely behavioral