Brain & Language 108 (2009) 175–183

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Putative sex differences in verbal abilities and language cortex: A critical review

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ARTICLE INFO

Article history:
Accepted 18 July 2008
Available online 21 August 2008

Keywords:
Sex differences
Language
Brain structure
Brain function

ABSTRACT

This review brings together evidence from a diverse field of methods for investigating sex differences in language processing. Differences are found in certain language-related deficits, such as stuttering, dyslexia, autism and schizophrenia. Common to these is that language problems may follow from, rather than cause the deficit. Large studies have been conducted on sex differences in verbal abilities within the normal population, and a careful reading of the results suggests that differences in language proficiency do not exist. Early differences in language acquisition show a slight advantage for girls, but this gradually disappears. A difference in language lateralization of brain structure and function in adults has also been suggested, perhaps following size differences in the corpus callosum. Neither of these claims is substantiated by evidence. In addition, overall results from studies on regional grey matter distribution using voxel-based morphometry, indicate no consistent differences between males and females in language-related cortical regions. Language function in Wada tests, aphasia, and in normal ageing also fails to show sex differentiation.

1. Introduction

Sex is interesting, and the mass media and the general public are captivated by findings of differences between men and women. The book *Men Are From Mars, Women Are From Venus*, by John Gray (1992), which argued for large psychological differences between the sexes, has been translated into more than 40 languages and has sold over 30 million copies (http://www.marsvenus.com).

When cognitive neuroscientists are approached by the mass media, it is often with questions related to sex differences.

Textbooks routinely cite sex differences in language competence, usually regarding verbal fluency, as established fact (e.g. Kolb & Whishaw, 2001, p. 558; Mildner, 2008, p. 41; Pinker, 2007, pp. 85–86). Unfortunately, it is often difficult to see where these findings come from; this is not only the case in textbooks, but can also be found in research papers on the topic. For instance, in a study on sex differences (Weiss, Kemmler, Deisenhammer, Fleischhacker, & Delazer, 2003), one can find the following statement, without any data or references to back the claim:

> Women tend to be better than men in rapidly identifying matching items, a skill called perceptual speed. Common linguistic skills, in which females have been found to be superior, are verbal fluency, speech articulation, grammatical skills, and use of more complex and longer sentences.

Similar statements are found in all of the above citations.

A large number of studies reporting sex differences in brain structure and function underlying language processes have also been published (e.g. Shaywitz et al., 1995). The article by Shaywitz and colleagues, suggesting differences in language lateralization, has been cited more than 500 times, indicating the impact that these types of results have on the scientific community, not to mention the broader public opinion.

Most neuroimaging studies, however, do not distinguish between males and females. But if sex differences are real, they may possibly confound results from language studies obtained using neuroimaging techniques such as PET and fMRI. If so, measures must be taken to address the problem.

This review presents a broad overview of the multiple existing approaches to the investigation of sex differences in language performance and in the underlying brain structure and processing as well as in language-related disorders. An enormous number of such papers exist (e.g. Burman, Bitan, & Booth, 2008; Clements et al., 2006; Frost et al., 1999; Grabowski, Damasio, Eichhorn, & Tranel, 2003; Haut & Barch, 2006; Jaeger et al., 1998; Kaiser, Kuenzli, Zappatore, & Nitsch, 2007; Kansaku, Yamaura, & Kitazawa, 2000; Knecht et al., 2000; Plante, Schmithorst, Holland, & Byars, 2006; Schirmer, Zysset, Kotz, & Yves von Cramon, 2004; Shaywitz et al., 1995; Springer et al., 1999; van der Kallen et al., 1998; Weiss et al., 2003 to name but a few). It is not possible to cover all here and at

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doi:10.1016/j.bandl.2008.07.001

the same time present studies from many fields. This review therefore relies primarily on results either from meta-analyses or from studies with a large number of participants ($n > 100$) when they exist.

1.1. Possible evolutionary origins

Before we look at the evidence it is interesting to ask why anyone thinks that there could be differences between the language systems for males and females at all. Two theories exist that include this hypothesis.

The "hunter-gatherer"-hypothesis (e.g. see Kolb & Whishaw, 2001; Mildner, 2008) states that putative sex differences in cognitive abilities arose from a division of labour between the sexes in prehistoric humans. Men were predominantly hunters, whereas women were predominantly gatherers. According to this line of thinking, males explored larger territories during hunting than females would do during gathering, which in turn made males develop better skills for navigation, whereas the females left behind in social groups would have benefited more from developing fine-tuned tools for social interaction, one of which is language. This theory therefore predicts that women are better at language than men.

Another possible evolutionary origin of cognitive sex differences has been suggested by Miller (2000). According to this theory, language may have evolved at least partly for purposes of sexual display. This means that language ability is used in sexual selection as a fitness-indicator. Individuals displaying a large capacity for language are considered fitter by potential partners compared to less eloquent individuals. According to this theory, language is the human equivalent of peacock feathers. Due to the special dynamics of sexual selection there are great differences between the feathers of a male peacock and those of a female. Sexual selection dynamics require that males, at great costs, try to display fitness, e.g. by walking around dressed in dangerously visible colours, while females have the power to decide which male to mate with and must therefore be good detectors of fitness. Evoking such a theory about human language therefore predicts great differences between male and female language capabilities. Only fit males will have the means and the time to develop and produce inciting language. The prediction is thus that males will be better at producing language and will try at great costs to exhibit this, while females, on the other hand, are better at understanding language in order to distinguish good talkers from bad talkers (Miller, 2000). Anecdotal evidence for this theory includes the observation that acclaimed writers are still predominantly male, whereas women are known to buy and read more books than men (e.g. Halpern, 2000).

When applied to language, however, both of these theories suffer from fact that this unique part of human behaviour per definition leaves very little room for cross-species comparison. This makes the theories very difficult to falsify or even investigate scientifically (Gannon, 2002). They are, nevertheless, part of the background for most of the research conducted on sex differences in language and therefore deserve to be mentioned.

2. Sex differences in the normal population

2.1. Verbal fluency

The task perhaps most cited as yielding sex differences is the verbal fluency task (e.g. Kolb & Whishaw, 2001; Mildner, 2008; Pinker, 2007; Sommer, Aleman, Bouma, & Kahn, 2004). The verbal fluency task is usually conducted in two parts, a "lexical" and a "categorical". In both conditions, subjects are asked to come up with as many words in a minute as possible. In the lexical conditions the words have to start with a particular letter, like F, A or S, and in the categorical condition subjects have to name as many objects from a specific category as possible in one minute. Usually, the category is animals.

As an example, Weiss et al. (2003) examined 97 college students (51 women, 46 men) and found women to have a significant advantage in the lexical condition ($p < .02$), but no significant difference was seen in the categorical task ($p < .08$). Unfortunately these groups were not balanced on other important demographic measures, such as age ($p < .002$), and men were found on another test to have a significantly higher verbal IQ ($p < .004$). The results on the verbal fluency task, therefore, are not only weak, but also very difficult to interpret given these confounds in the data. Nonetheless, these findings are summarized in the following way in the abstract of the article: "In general, we found, that women tend to perform at a higher level than men on most verbal tests".

Tombaugh and colleagues, on the other hand, measured word fluency in 1300 individuals (Tombaugh, Kozak, & Rees, 1999). They set up booths at shopping centres, social organizations and places of employment. In this very large sample they found absolutely no differences between men and women. In the lexical condition, men on average came up with 37 words whereas women came up with 37.8 words. In the categorical condition, men named 17.4 animals whereas women named 16.5 animals. Neither of these differences was statistically significant. Performance on both tests, on the other hand, showed great, and greatly significant, dependence on age and educational level.

In summary, Sex is not a significant predictor of performance on the verbal fluency task, when using a large sample size, appropriately controlled for confounds such as age and education.

2.2. Overall performance

Hyde and Linn (1988) conducted a meta-analysis on 165 American language studies of both children and adults, including tests of vocabulary, analogies, anagrams, reading comprehension, speaking or other verbal communication, essay writing, Scholastic Aptitude Test (SAT)-Verbal, and general verbal ability tests such as the American College Testing Program Examination-Verbal. Forty-four (27%) of the studies had found females to perform significantly better than males, 109 (66%) found no significant sex difference, and 12 (7%) found males performing significantly better than females. Overall, this led to a slight female advantage, but when effect-size from the different studies was weighted by number of subjects, the effect was reversed, due to the largest study (including more than 900,000 subjects) finding a small male advantage. The authors conclude that: "Our meta-analysis provides strong evidence that the magnitude of the sex difference in verbal ability is currently so small that it can effectively be considered to be zero" (Hyde & Linn, 1988, p. 64). Interestingly, a significant effect of first-author gender was found in the 165 studies. Studies where the first author was a woman were significantly more likely to report a female language advantage than studies where the first author was a man (though both effects were close to zero).

2.3. Language acquisition

2.3.1. First language acquisition

The most frequently used tests for early language development are the MacArthur–Bates Communicative Development Inventories (Fenson et al., 1994). Fenson et al. (1994) studied 1803 and Feldman et al. (2000) 2156 sociodemographically diverse 1- and 2-year-old American children. The children were assessed by their mothers using a checklist questionnaire paradigm. Significant effects of gender were found in both 1- and 2-year olds on both vocabulary comprehension and vocabulary production. Girls scored significantly higher than boys, however, differences were very small, accounting for 1–2% of the variance. These findings, however, have been replicated in other languages, e.g. Swedish (Berglund, Eriksson, & Westerlund, 2005) in a study of 1019 18-month-old children and Danish (Bleses et al., 2008), in a study of 6112 8–36 months old children. These results thus seem quite robust, even though the small effect size makes an interpretation less than clear. Significant early effects of sex have also been found in studies combining the parental-report procedure with other, experimenter controlled, methods (e.g. Bornstein, Hahn, & Haynes, 2004). However, it is worth noting that in their study of 3291- to 6-year-old children, Bornstein and colleagues found that the female advantage disappears during the sixth year. This may reconcile the consistent findings of an early sex effect and later null-results.

These findings are consistent with an explanation that early language-acquisition differences are part of a general, non-specific developmental difference between the sexes which is also measurable in non-verbal domains (Galsworthy, Dionne, Dale, & Plomin, 2000).

The higher prevalence of autism in boys may also explain at least some part of the difference (see section on developmental disorders below). During the early years the normal sample will also include a small proportion of non-diagnosed autistic children, but as the children grow older these children will become diagnosed and therefore no longer add to the sex difference in the normal sample. The extent to which this can explain developmental language differences has not yet been investigated.

2.3.2. Verbal learning

Kramer, Delis, and Daniel (1988) tested 68 males and 68 females, matched for age and education, on the California Verbal Learning Test (CVLT) in which subjects recall word lists at various delays. Females consistently outperformed males on this task. Significant differences were also found in the way males and females approached the list-learning task. Females showed significantly higher levels of semantic clustering, an indication that they were more likely than males to actively organize the list on the basis of its semantic properties. In contrast, males were more likely than females to cluster the items serially, i.e. they tended to recall the words in the same order in which they were presented. These results suggest that females on this task use more active, efficient modes of organization during initial learning.

In a later study Kramer and colleagues (Kramer, Kaplan, Delis, O'Donnell, & Prifitera, 1997) conducted the same test on children. 401 males and 410 females between the ages of 5 and 16 years were administered the California Verbal Learning Test-Children's Version. Sex differences were again found at all age levels. Girls performed better than boys on all of the recall trials. No Sex $\times$ Age Group interaction was seen, indicating that sex differences in verbal learning and memory were found in children across a wide range of ages. The authors point out that the superior verbal learning performance and semantic organization seen in females occurs even though the males actually scored significantly higher on a measure of vocabulary. This indicates that the sex differences in verbal learning cannot be attributed to sex differences in overall verbal ability. Instead, females were again more likely than males to use a verbally mediated semantic clustering strategy, which for this task seems to be efficient.

The conclusion from this is that the observed differences seem not to be due to a difference in language function per se, but rather to a difference in learning strategy for the particular task. Whether this difference persists across other types of tasks is beyond the scope of the present paper.

2.4. Lateralized behaviour

The claim that women are less lateralized than men can be traced back to Harris (1978) and McGlone (1980) . In an influential review McGlone concluded that "Verbal asymmetries suggesting left hemisphere dominance appear to be more common and more marked in male than in female adult right-handers". This, however, was controversial from the beginning (e.g. Fairweather, 1982). More recently, Boles (2005) conducted a large study on tasks that consistently show a lateralized behaviour. Among these tasks were two language tasks: One task ($n = 446$; 123 females; 323 males) in which subjects recalled one-syllable words, which were presented in pairs in a dichotic listening paradigm. Both sexes exhibited a significant bias towards input from the right ear, projecting primarily to the left cerebral hemisphere. No significant difference in this bias between the sexes was observed. In the other task, subjects ($n = 536$; 149 females 387 males) saw a number-word (e.g. ONE) in each visual field, with a central arrowhead indicating the word to be recognized. Differences in response time were measured. Again, subjects were faster when the word to be processed was in the right visual field, but no significant difference between the sexes was observed ($p > .05$).

Another method for behaviourally measuring level of lateralization is by use of a dual task paradigm in which subjects concurrently perform a verbal and a manual task (e.g. Bowers, Heilman, Satz, & Altman, 1978). Subjects perform worse on both tasks together compared to on their own, due to increased cognitive load, but an interaction has been observed between attenuation of performance and the hand used for the manual task. Interference between tasks is greater when right-handed subjects used their right hand than when they used their left hand. This is thought to be caused by left lateralized speech processing interfering more with left lateralized manual processes (right hand movement) than with a right lateralized manual task (left hand). Again, a sex difference has been reported with males being more left lateralized than females (e.g. Elliott, Weeks, Lindley, & Jones, 1986). Further, a meta-analysis looking at 36 studies revealed a small ($d = 0.1$; $z = 2.54$) but significant difference between sexes (Medland, Geffen, & McFarland, 2002), but upon conducting a "fail safe analysis" (Rosenthal, 1979) the authors states that "this significant result may be due to the exclusive sampling of published results" (Medland et al., 2002, p. 1236). Interestingly, the largest study in the meta-analysis ($n = 1036$) found no significant effects of sex (Ashton & McFarland, 1991).

2.5. Lateralized brain function: evidence from neuroimaging studies

A number of functional imaging studies have reported a more bilateral pattern of activity during language processing in women compared to men (e.g. Kansaku et al., 2000; Phillips, Lowe, Lurito, Dzemidzic, & Mathews, 2001; Shaywitz et al., 1995).

However, when Sommer, Aleman, Somers, Boks, and Kahn (2004, 2008) conducted a meta-analysis on 26 studies (including more than 2100 subjects) they found no significant effect of sex on language lateralization in functional studies, neither in children nor in adults. There was no significant difference in this pattern between word production tasks (i.e. verbal fluency and verb generation) and language comprehension tasks (semantic decision). It is also noteworthy, that studies with a smaller number of subjects were more likely to report sex differences than studies with more subjects. Studies that reported sex differences had 31 subjects on average whereas studies reporting no differences had 76 subjects on average (Sommer et al., 2004). A great challenge for group comparisons in neuroimaging studies, especially with small groups, is to balance subjects on a number of non-specific nuisance variables that are known to influence the imaging signal to a very large degree but which may not influence behaviour. These include to name but a few: respiration, cardiac pulsation, movement (Lund, Madsen, Sidaros, Luo, & Nichols, 2006; Lund, Norgaard, Rostrup, Rowe, & Paulson, 2005) and caffeine intake (Mulderink, Gitelman, Mesulam, & Parrish, 2002). Caffeine alone may boost the fMRI signal by more than 30% (Mulderink et al., 2002) which makes it a highly probable cause of false positives with small sample sizes. Without very rigorous control of these variables group comparisons become very difficult to interpret. Nevertheless, it has been suggested (Kansaku & Kitazawa, 2001; Kitazawa & Kansaku, 2005) that differences in lateralization persist if one restricts the search to complex story comprehension. But this view remains controversial (Sommer, Aleman, & Kahn, 2005).

3. Language-related sex differences in brain structure

3.1. Whole brain results

Though not linked to language it is worth mentioning that a sex difference in overall brain size of around 8.0% (approx. 100 ml) favouring males is well established in the literature (Chen, Sachdev, Wen, & Anstey, 2007; Good et al., 2001; Kruggel, 2006). Males also have a greater global grey matter volume (Chen et al., 2007; Good et al., 2001; Kruggel, 2006; Lemaitre et al., 2005) and 16% more neurons (Pakkenberg & Gundersen, 1997). The significance of this, however, is not clear.

3.2. Regional grey matter differences

Voxel-based morphometry (VBM) is a method for in-vivo investigation of brain structure using magnetic resonance imaging (Ashburner & Friston, 2007). Individual brains are normalized to a standard brain in terms of gross anatomical features (e.g. size), and statistical analysis is then conducted on a more fine-grained level. Two very large VBM studies looked for overall structural differences between the sexes (Chen et al., 2007; Good et al., 2001). Good et al. studied 465 normal adult subjects (200 female; 265 male; ages 17–79) and Chen et al studied 411 subjects (227 female; 184 male; aged 44–48). Both studies found a variety of sex-related differences in brain structure, including regions normally thought to underlie language processes, e.g. inferior frontal (Broca, 1861) and posterior temporal cortex (Wernicke, 1874). Surprisingly, however, the only overlap in grey matter volume differences between these two large studies seems to be that women have more grey matter in the anterior cingulate region. This replicates the results of an older smaller study (Paus et al., 1996) with 105 young right-handed volunteers (42 female and 63 male). In this study significant sex differences were also found in the volume of the cingulate sulcus (female > male) and the Paracingulate sulcus (male > female). One possibility for the inconsistencies in language regions might be that the two studies incorporate quite different age groups, and that regional grey matter volume changes over a person's lifetime, with an interaction between sex and age. However, this is not plausible, since at least one of the studies claim to find no interaction between sex and age for grey matter volume (Chen et al., 2007). Another possibility is that sex-related differences in grey matter volume, if they exist, are subtle, and that VBM as a method may not yet be mature enough for robustly detecting such subtleties (e.g. see Bookstein, 2001), not to mention even more subtle language-related differences across sexes. It is noteworthy, however, that the cingulate region consistently found to differentiate between the sexes in the literature most often is associated with "mind reading" or "mentalizing" capacities (Amodio & Frith, 2006; Frith & Frith, 2006). It is this same capacity which is thought to be lacking in autism (Frith, 2001) (see section on developmental disorders).

3.3. Size of the corpus callosum

The two cerebral hemispheres are connected through the corpus callosum, a dense fibre bundle. The corpus callosum allows for information transfer between the two halves of the cortex, and when it is cut surgically as a treatment for intractable epileptic seizures, the result is a "split brain" where one hemisphere does not have access to important information from the other (Gazzaniga & Sperry, 1967).

Sex differences in size and shape of corpus callosum are often cited as a mere fact (e.g. Cahill, 2006), and it is closely linked to hypotheses about differences in language lateralization across the sexes (Harris, 1978, see above; McGlone, 1980). If the cerebral hemispheres are better "connected" in women, through a larger corpus callosum, then this allows for more interhemispheric communication during language processing and thus potentially less lateralization.

The history behind this conception is long (see Bishop & Wahlsten, 1997), but in recent time it can be traced to the study of de Lacoste-Utamsing and Holloway (1982) who claimed to have found a sex difference in the callosal structures of nine male and five female brains preserved in formalin. The difference was not in overall size, which was almost identical (men: 704 mm^2; women: 708 mm^2), but related to the shape of the splenium, defined as the posterior fifth of the callosum. The splenium, it was argued, was more "bulbous" in women.

This report sparked of a number of other studies. One example is Allen, Richey, Chai, and Gorski (1991), who investigated sagittal MRI-slices of 122 age-matched adults and 24 age-matched children. Half of these were male and half female. The overall area of the corpus callosum was slightly greater in men than in women. This difference, however, was not statistically significant. Instead, a sex difference in callosal shape was reported. Again females were found to have a more bulbous part in the splenial part of the corpus callosum, while males had a more elongated part in the same position. But this did not mean that the size of the structure in itself was different, and since an elongated shape can reasonably be assumed to hold just as many fibres as a bulbous counterpart, this type of shape difference is badly "formed" as an argument for larger interhemispheric connectivity.

Another measurement of the human corpus callosum using magnetic resonance images of 37 living subjects also failed to find overall sex differences in the callosum (Byne, Bleier, & Houston, 1988). Rather, the authors report that the most striking finding was the large variation in callosal size and shape among individuals, regardless of age or sex. This, again points towards the possibility of "discovering" spurious differences when using small sample sizes.

Finally, Bishop and Wahlsten (1997) went through 49 studies on the subject. Sixteen studies examined brains post-mortem with histological techniques, and 33 used magnetic resonance imaging (MRI) to visualize the midsagittal region of living brains. From this comprehensive work the conclusion was clear. Even when correcting for the relative cortical size difference between the sexes no reliable sex difference could be established.

In other words, the alleged sex-related corpus callosum size difference is a myth.

3.4. Cortical asymmetries

Sex differences in language-related lateralization may also arise from differences in structural cortical asymmetry.

3.4.1. Grey matter volume

When looking at cortical grey matter volume asymmetry, Good et al. (2001) found widespread leftwards asymmetry ($n = 465$) common to both sexes and a significant interaction of sex with asymmetry in posterior temporal language regions, with males having increased leftward asymmetry. Gur et al. (1999) also found a greater, non-localised, leftwards asymmetry in men ($n = 80$), but this was primarily based on their finding of no overall asymmetry in women. Others (Watkins et al., 2001) have failed to find asymmetry differences ($n = 124$), and one small study ($n = 24$) even found a larger female leftwards asymmetry in the planum temporale (Knaus, Bollich, Corey, Lemen, & Foundas, 2004). A possible sex difference in grey matter volume asymmetry across the cortex or in posterior temporal cortex in particular therefore does not seem to be outspoken. A recent meta-analysis reached the same conclusion (Sommer et al., 2008).

3.4.2. Cortical thickness

Luders et al.(2006) studied hemispheric differences in grey matter thickness across the lateral and medial cortices in 60 healthy volunteers using VBM and investigated effects of sex. Results suggested global and regionally specific differences between the two hemispheres, with generally thicker cortex in the left hemisphere, most pronounced in motor cortex, middle frontal, anterior temporal and superior parietal lobes. Asymmetry profiles were similar in both sexes, and even though hemispheric differences appeared slightly more pronounced in males compared with females, these differences were not statistically significant.

In summary: Consistent evidence pointing toward a difference in cortical asymmetry between men and women does not presently exist.

4. Sex in language dysfunction

4.1. Sex and language in developmental disorders

Often-cited language-related developmental disorders that affect the sexes differently include: stuttering (Halpern, 2000), dyslexia (Halpern, 2000; Mildner, 2008), autism (Frith, 2001) and schizophrenia (Crow, 2000).

4.1.1. Stuttering

Stuttering is a readily identifiable disorder of speech characterized by frequent interruptions or blocks in the smooth transition from the production of one sound to the production of the subsequent sound. Developmental stuttering is predominantly a male problem. There are three to four times more male than female stutterers (Halpern, 2000), vertically transmitted in a manner that suggests a genetic component (Dworzynski, Remington, Rijsdijk, Howell, & Plomin, 2007; Kidd, Heimbuch, & Records, 1981), e.g. pair-wise concordance for stuttering has been found to be higher in identical male twins than in fraternal same-sex twins (Dworzynski et al., 2007; Howie, 1981). At present, the neuronal basis of persistent developmental stuttering is unknown, but it is known that stuttering is also usually accompanied by an increase in abnormal non-linguistic facial movements (Conture & Kelly, 1991; Mulligan, Anderson, Jones, Williams, & Donaldson, 2003). The basal ganglia-thalamocortical motor circuits through the putamen have been suggested to play a key role in stuttering (Alm, 2004), based partly on the fact that acquired stuttering is predominately a consequence of lesions in this circuit, whereas primary speech and language regions (Boca's area, the temporal planum, insula or Wernicke's area) are not affected (Ludlow & Loucks, 2003). Rather than being a core language deficiency, stuttering should therefore possibly be considered as belonging to a broader category of movement disorder analogous to deficits such as Parkinson's disease that also has an increased male incidence rate (Mayeux et al., 1995; Van Den Eeden et al., 2003).

4.1.2. Dyslexia

The distribution of dyslexics also shows differences between males and females, with a sex ratio ranging from 1.6:1 to 4.5:1 depending on the criterion used for dyslexia (Miles, Haslum, & Wheeler, 1998). But as it is unclear whether reading can be considered a natural language capacity, and since many dyslexics have normal verbal language abilities, I will refrain from discussing it further in this context. It is mentioned here in order to try to provide an unbiased overview of the field of language-related sex differences.

4.1.3. Autism

Another syndrome with a pronounced skewed sex distribution and possibly linked to language function is autism. The male to female ratio is approximately 3 to 1 (Frith, 2001), and a key diagnostic feature of autism is a pronounced language deficiency. Muteness, language delay, echoing of speech, and idiosyncratic use of language are typical features. Indeed, one theory of autism claims that it is caused by an "extreme male brain" (Baron-Cohen, Knickmeyer, & Belmonte, 2005), indicating that the cognitive deficits observed in autists may come from domains in which men generally perform worse than women. However, rather than arising from a deficit in core language competence, a "theory of mind" deficiency may be able to explain some of the language abnormalities seen in autistic children (Frith, 2001; Happé, 1998), and may help to explain why some people with autism actually gain a very high language proficiency (Frith, 2001).

4.1.4. Schizophrenia

A tight evolutionary coupling—related to sexual selection (see above)—between language and schizophrenia has been suggested (Crow, 2000). And there are indeed marked symptomatic sex differences. Males have earlier age of onset even though lifespan incidence rates are similar. Male patients exhibit more negative symptoms, such as social withdrawal, blunted affect, poverty of speech and lack of motivation whereas female patients have a greater preponderance of affective symptoms, such as dysphoria, depression and impulsivity (Leung & Chue, 2000). Again, sex differences in language competence have been reported (DeLisi, 2001; Walder et al., 2006) However, a meta-analysis (Heinrichs & Zakzanis, 1998) on 204 studies including 22 different neurocognitive variables found that schizophrenic patients were impaired across all cognitive domains, including linguistic tasks. Impairments across sexes were not directly compared, but the analyses included a variable for gender distribution across individual studies. This variable was found not to influence results in any of the analyses. Given the widespread types of deficits it is not clear why language should be considered a defining feature of schizophrenia, and sex does not seem to alter this picture in any manifest way. However, decreases in language lateralization have been suggested as an integral part of the symptomatology (e.g. see Sommer, Ramsey, Kahn, Aleman, & Bouma, 2001 for a meta-analysis), but in the one small study published on lateralization differences (comparing 12 female and 12 male patients) none were found (Sommer, Ramsey, Mandl, & Kahn, 2003).

To sum up: Sex differences are found in certain language-related developmental deficits such as stuttering and dyslexia, and also in autism and schizophrenia, in which a language deficit usually is a major symptom. The causes of these deficits are to a large degree unknown. However, common to them all is that the language problem seems to follow from other deficits, rather than the other way around.

4.2. Acquired language disorders

4.2.1. Epilepsy and tumours: evidence from Wada tests

The Wada test (Wada & Rasmussen, 1960/2007) is used to investigate lateralization of cognitive function in patients. It is conducted while the patient is awake. An anaesthesia (usually sodium amobarbital) is injected into one of the internal carotid arteries at a time, thus affecting only one cortical hemisphere. It was first developed to study the spread of epileptic discharges across the hemispheres of the brain. But during this work, Wada observed that patients became aphasic when the language-dominant hemisphere was affected. During the Wada test, patients undergo neuropsychological testing while partly anaesthetised to evaluate cognitive effects. During one injection, typically affecting the left hemisphere, the patient will have impaired speech or be completely unable to express or understand language. The Wada test is usually performed before surgery to remove seizure centres in severe epilepsy or before resurrection of tumours.

Strauss, Wada, and Goldwater (1992) reported results from submitting epileptic patients to the Wada test and found no sex difference in the overall incidence of atypical (right, bilateral) speech patterns. 15 out of 39 male patients and 16 out of 55 female patients were not strictly left lateralized. This does not constitute a statistically significant difference. Helmstaedter, Brosch, Kurthen, and Elger (2004), Helmstaedter, Kurthen, Linke, and Elger (1997) replicated these null-findings twice. In the first study, 22 out of 85 male and 24 out of 82 female patients had atypical cerebral language dominance and in the second study 32 out of 94 males and 35 out of 75 females ($p > .05$ in both cases) were not strictly left-hemisphere dominant. Rather, non-left dominance was found to correlate strongly with age of onset of epilepsy (Helmstaedter et al., 2004).

Needless to say, neither of these results supports hypotheses of sex differences in language lateralization.

4.2.2. Aphasia in unilateral stroke

With a differential language lateralization in women and men one would also expect to find a sex difference in aphasic syndromes as effects of unilateral stroke. Stroke is the clinical designation for a fast-developing loss of brain function due to the interruption of blood supply to all or parts of the brain. This is most often caused by either a blood clot or a haemorrhage.

A sex difference has been suggested in relation to language impairment and recovery rate after stroke, with females outperforming males (Halpern, 2000; Kimura, 1983; McGlone, 1980), e.g. Kimura (1983) studied incidence of aphasia in 143 male and 73 female right-handed patients with unilateral lesions of the left cerebral hemisphere. Aphasia was found to be more frequent in males than in females.

But other stroke studies have failed to replicate these sex differences (Basso, 1992; Pedersen, Jørgensen, Nakayama, Raaschou, & Olsen, 1995; Pedersen, Vinter, & Olsen, 2004). More than 1000 patients were included in the Copenhagen aphasia study (Pedersen et al., 1995, 2004), and initial severity of aphasia was the only clinically relevant predictor of aphasia outcome. Sex, handedness, and side of stroke lesion were not independent outcome predictors, and the influence of age was minimal.

4.2.3. Language decline in normal ageing

If language abilities are different between the sexes, then this should possibly also be reflected in differences in patterns of language decline during normal ageing. Meinz and Salthouse (1998) conducted a meta-analysis on the data from 25 studies (including 5201 participants) to investigate possible sex differences in the patterns of age-related decline in cognitive abilities. No significant main effect of sex was found on verbal tasks, and no interaction between age and sex was identified.

4.3. Hormonal influences on language

A source of sexual differentiation may be the organizational influence of gonadal hormones, such as testosterone, progesterone and oestrogen (Hines, 2002). Both organizational and fluctuating effects on language have been suggested to exist (Becker et al., 2005).

4.3.1. Organizational effects: testosterone

Organizational influences typically occur early in life, usually during critical periods of development, and they are permanent. Evidence from genetic syndromes and cases where women have been prescribed hormones during pregnancy indicate that differentiation of the human internal and external genitalia follows processes consistent with such a model of hormonal influence. High levels of testicular hormones promote masculine-typical development, whereas, in the absence of these hormones, feminine structures appear.

A primary source of information on the cognitive consequences of early hormonal perturbations has come from cases of genital ambiguity, some of which are known to involve hormonal abnormalities of prenatal onset. One such example involves female individuals exposed to high levels of male hormones (androgens) prenatally because of congenital adrenal hyperplasia (CAH). Levels of male hormones in female foetuses with CAH are in the range of normal males, and girls with the disorder are typically born with a degree of genital virilization (i.e. masculinization). A number of studies (see Hines, 2002, for a review) have looked at verbal measures in patients with CAH, including verbal fluency tests, and found no differences in CAH subjects compared to relative controls.

4.3.2. Fluctuating effects: progesterone and estradiol

Hypotheses about a causal link between language lateralization in women and fluctuating levels of progesterone and/or estradiol have been put forward (Bayer, Kessler, Gunturkun, & Hausmann, 2008; Fernandez et al., 2003; Hausmann, Becker, Gather, & Gunturkun, 2002; Hausmann & Gunturkun, 2000). Progesterone and estradiol are both gonadal steroids that vary systematically during the female menstrual cycle. It is assumed that cycle-dependent increases in hormone concentrations during the luteal phase leads "via a decrease of transcallosal neuronal activation, to hemispheric decoupling, which then results in lesser functional asymmetries" (Hausmann & Gunturkun, 2000), i.e. to less language lateralization. Females are, in other words, thought to be more like males during menses than during the luteal phase, i.e. have greater language lateralization. This could potentially explain at least some of the lacking consistency in results from between-sex studies. It is at present, however, not clear how and why this cycling effect would occur, and a direct correlation between steroid-levels and performance on language lateralization tasks has not consistently been found when investigated (Bayer et al., 2008; Hausmann et al., 2002). Further, these results have primarily been obtained by a single group (Bayer et al., 2008; Hausmann & Gunturkun, 2000; Hausmann et al., 2002) using small subject groups ($n = 12–19$) and no meta-analyses exist. Others ($n = 30$) have claimed that the difference arises between premenstrual and postmenstrual weeks (Alexander, Altemus, Petersonm, & Wexler, 2002) rather than mid-cycle and menstrual week, and critical attempts to replicate these findings by researchers with larger subject groups ($n = 55$) have so far not been successful (Compton, Costello, & Diepold, 2004).

Attempts to correlate changes in neural processes underlying language with hormone fluctuations during the menstrual cycle have also been made (Fernandez et al., 2003). Though exiting, the endeavour has at least one serious inherent problem when studied with fMRI. During the menstrual cycle a decline in vascular hematocrit levels has been observed (Hirshoren et al., 2002). Baseline hematocrit is known to influence the blood oxygen level dependent (BOLD) signal measured with fMRI, regardless of neural activation (Gustard, Williams, Hall, Pickard, & Carpenter, 2003). It therefore becomes extremely difficult to effectively disentangle signal changes related to neural activation from changes related to blood composition.

At present the evidence therefore does not convincingly suggest that the distribution of sex hormones plays a major role in development of language proficiency or in processes related to lateralization.

5. Discussion

Certain language-related deficits exhibit clear sex differences, such as stuttering, dyslexia, and autism. But it is unclear whether these deficiencies are really caused by a problem in the systems for language processing, or whether the language deficit is a by-product of something else.

A small but consistent female advantage is found in early language development. But this seems to disappear during childhood. In adults, sex differences in verbal abilities, and in brain structure and function related to language processing are not readily identified. If they exist, they are not easily picked up with the research methods used today. This does not, of course, preclude that sex differences in language exist. Differences might be found if a more detailed and sophisticated level of linguistic analysis than currently used were taken into account (e.g. Jaeger et al., 1998; Kitazawa & Kansaku, 2005). However, this would have to be related to a similarly sophisticated theory of how and why sex differences in language processing might arise at all and/or in any sub-domain of language in particular. At present no such convincing link exists. This review has not included sociolinguistic features of the putative gender divide, but in the event that significant differences were found, cultural explanations would of course also have to be taken into account. Further, it is important to stress that most language-processes are highly complex, and thus there may be more than one cognitive strategy for solving many language-related tasks, e.g. as seen in the verbal learning paradigm (Kramer, Kaplan, Delis, O'Donnell, & Prifitera, 1997; Kramer et al., 1988). Sex differences may exist in the choice of strategy for certain tasks along with other socio-demographic variables, such as age, level of education and previous exposure. Often, however, such a strategy-related bias can only be investigated if one allows for phenomenological "reports" of how subjects actually solved the task (Jack & Roepstorff, 2002). The validity of such an approach, however, is not uncontroversial.

Many of the studies that do find significant differences do so with *p*-values that balance on the edge of significance, pointing towards the so-called "desk-drawer-problem" or "publication bias" (Easterbrook, Berlin, Gopalan, & Matthews, 1991; Halpern, 2000) that studies are only reported if they are significant, and nobody therefore knows the number of studies with null-findings. This general problem is probably even stronger for research on sex differences, since sex is easily measured and often routinely analyzed. Because statistical decision rules result in a certain percentage of false positive results (5% with alpha set at 0.05), there is a high probability that spurious results of sex differences will be published (Hines, 2002). In order to counter this bias it might actually be advantageous for papers to include analyses of sex differences, explicitly with the aim to exclude the possibility of a significant within-study effect of sex. This way, a more realistic picture of sex-related language differences might emerge in the literature. Further, if one really wishes to investigate sex differences it is of utmost importance to do so with studies that are designed for this, i.e. that attempt to replicate results in multiple independent studies (e.g. Haut & Barch, 2006) and/or have ample sample sizes for test–retest reliability evaluation using split-sample analyses.

Interestingly, one very large meta-study found a significant effect of author gender (Hyde & Linn, 1988). This indicates that researchers bring their own preconceptions, or gender stereotypes, with them in their interpretation of data. It must therefore not go unmentioned that the author of the present review is a he, and that this may have biased his reading of the literature. Nevertheless, the overall conclusion is that sex should not be considered a large confounding factor in neuroimaging studies of language processing.

Acknowledgments

This work was supported by The Faculty of Humanities at the University of Aarhus, by The Danish Research Council for Culture and Communication and by The Danish National Research Foundation's grant to Center of Functionally Integrative Neuroscience. The author wishes to thank Lone Frank from Weekend-avisen for inspiring and provoking the making of this paper. Also thanks to Torben Ellegaard Lund, Chris Frith, Dorthe Bleses, Ethan Weed, Kristian Tylén, and Andreas Roepstorff for help and comments.

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