Received: 15 December 2020 | Revised: 21 April 2022 | Accepted: 24 May 2022

DOI: 10.1002/jnr.25096

MINIREVIEW

JOURNAL OF Neuroscience Research

The beauty of diversity in cognitive neuroscience: The case of sex-related effects in language production networks

Andrea Marini[1,2]

[1]Department of Language and Literatures, Communication, Education and Society, University of Udine, Udine, Italy

[2]Claudiana - Landesfachhochschule für Gesundheitsberufe, Bolzano, Italy

Correspondence
Andrea Marini, Dipartimento di Lingue e Letterature, Comunicazione, Formazione e Società, University of Udine, Via Margreth, 3, 33100 Udine, Italy.
Email: andrea.marini@uniud.it

Abstract

Over the past few decades, several studies have focused on potential sex-related differences in the trajectories of language development and functioning. From a behavioral point of view, the available literature shows controversial results: differences between males and females in language production tasks may not always be detectable and, even when they are, are potentially biased by sociological and educational confounding factors. The problem regarding potential sex-related differences in language production has also been investigated at the neural level, again with controversial results. The current minireview focuses on studies assessing sex-related differences in the neural networks of language production. After providing a theoretical framework of language production, it is shown that the few available investigations have provided mixed results. The major reasons for discrepant findings are discussed with theoretical and methodological implications for future studies.

KEYWORDS
cognitive neuroscience, gender, language, neural networks, neurolinguistics

1 | INTRODUCTION

Traditional models of cognitive processing in the brain underestimate the role of inter-individual diversity. As highlighted in a recent review, several factors “contribute to individual differences in neural structure, function, and related cognitive performance” (Dotson & Duarte, 2019, p. 181). Among these, socioeconomic status, level of parental education, and phonological working memory are thought to significantly affect language development (Riva et al., 2017; Romeo et al., 2018).

What can we say about sex? Over the past few decades, several studies have focused on potential sex-related differences in the trajectories of language development and functioning. For example, investigations using the MacArthur–Bates Communicative Development Inventories across different languages have shown that girls tend to process their first words and combine them earlier than boys (e.g., Fenson et al., 1994; Eriksson et al., 2012; see Rinaldi et al., 2021 for a recent review). Such differences may persist also in later stages of development (Hyde & Linn, 1988; Voyer & Voyer, 2014) but, as highlighted by a recent critical review, even when present, they are quite small (Wallentin, 2020). When it comes to adults, the available literature shows controversial results. Let us consider the stereotype of female talkativeness. Analyzing conversations from 153 individuals, Liberman (2006) reported that men produced on average fewer words per day ($N = 6073$) than women ($N = 8805$). However, Mehl et al. (2007) failed to find any difference in the average number of words produced daily by 210 women and 186 men (approximately 16,000 words per day). A partial

Edited by Cristina Antonella Ghiani and Sara Bulgheroni. Reviewed by Min Xu and Francesca Bosco.

explanation of such discrepancies may be found in the study by Ardila and Rosselli (1996) who analyzed discourse production in a cohort of 180 Spanish-speaking healthy adults showing that women produced more words than men only among adults aged between 51 and 65 years. On the contrary, younger women and men (aged between 16 and 50 years) produced speech samples with similar amounts of words.

Therefore, age is apparently a critical variable affecting sex-related differences in talkativeness. How about the efficiency of lexical production? In a study by Halpern (1992) women were better than men on tasks of language production and verbal fluency. More recently, Weiss, Kemmler, et al. (2003) assessed potential sex-related differences in cognitive functions (including language) in a cohort of 97 students (51 women). The participants were asked, among other things, to perform a semantic and a phonological fluency task. Women performed better in the semantic condition but were no different than men in the phonological one. Semantic fluency tasks represent an indirect way to assess the extension of a person's mental lexicon (i.e., the number of known words). Tombaugh et al. (1999) failed to find any significant differences between women and men on either semantic or phonological fluency tasks in a large cohort of 1300 individuals. However, their performance was significantly biased by factors such as age (older people may know more words but may also experience slowed and less efficient abilities of lexical selection) and, most of all, level of education (persons with high education typically know more words and perform better on such tasks). Unfortunately, in the study by Weiss, Kemmler, et al. (2003) the two groups were not balanced for age. Furthermore, women had also higher verbal IQs. Altogether, these factors might have biased their results. It appears, then, that the available evidence on sex-related differences in language production may not always be detectable and, even when they are, may be potentially biased by sociological and educational confounding factors. Nonetheless, sex-related differences can be observed in the prevalence of congenital disorders also affecting language development and functioning as shown, for example, by the higher incidence of developmental disorders such as developmental dyslexia, primary language impairment, and autism spectrum disorders in boys (e.g., Baron-Cohen et al., 2005; Chilosi et al., 2021; McCarthy & Arnold, 2011).

The problem regarding potential sex-related differences in language production has also been investigated at the neural level. Indeed, growing evidence suggests that male and female brains might process information with both shared and, at least partially, specific neural networks (e.g., Hill et al., 2014; Xu et al., 2020). For example, in a meta-analysis of studies focusing on sex differences in phonological and visuospatial working memory networks, Hill et al. (2014) showed not only larger activations in limbic and prefrontal areas (e.g., bilateral amygdalae and cingulate gyri) in females and wider activations in the inferior parietal lobe (IPL) and superior parietal lobe (SPL) and the precuneus in males but also shared activations in other regions of the brain (e.g., bilateral middle frontal gyri [MFGs], left cingulate gyrus, left IPL and SPL, and left middle temporal gyrus [MTG]). Nonetheless, the available literature on gender differences in the neural networks underpinning language processing is quite controversial (e.g., Kaiser et al., 2008; Sato, 2020).

Let us consider the long-lasting debate about potential sex-related similarities/differences in lateralization. Under the assumption that linguistic (mostly lexical and grammatical) skills are usually left-lateralized, studies have focused on the possibility that male and female brains have different functional organizations. Already Chrichton-Browne (1879) had suggested that the symmetry between the two hemispheres may be stronger in women than men. In a seminal review on this topic, gathering data from clinical studies of patients with brain lesions, psycholinguistic investigations on healthy participants, as well as anatomical and electrophysiological investigations, McGlone (1980) concluded that male brains may be more asymmetrical than female brains in both linguistic and non-linguistic functions. This apparently suggests that language processing is more left lateralized in men than in women highlighting the possibility of a bilateral organization for female brains (Harris, 1980). More recently, in a voxel-based morphometric analysis of the brains of 465 healthy adults, Good et al. (2001) showed that male brains have increased leftward asymmetry in posterior temporal areas related to language processing.

However, results from several investigations are all but univocal as many did not provide evidence for a difference in lateralization of lexical functions between men and women (e.g., Allendorfer et al., 2012; Garn et al., 2009; Watkins et al., 2001). For example, Watkins et al. (2001) did not report lateralization differences among the sexes in a cohort of 124 participants. The inconsistency of such results has also been highlighted by recent reviews (e.g., Wallentin, 2009) and metanalyses (e.g., Sommer et al., 2008). Analyzing the effect sizes of the neuroimaging studies included in their metanalysis, Sommer et al. (2008) showed that the resulting mean weighted effect size was so weak that the often-reported differences in lateralization may be found only in some linguistic tasks

Significance

Over the past few decades, few functional studies have focused on potential sex-related differences in the neural networks of language production. However, they have provided mixed results. This minireview focuses on the major reasons for discrepant findings: developmental issues, lack of control of critical variables that are known to affect language development and its neural organization (e.g., socio-economical status, bilingualism), different sample sizes, methodological differences affecting task choice, and the lack of a clear theoretical background about the cognitive and neural underpinnings of language production. Finally, this review highlights theoretical and methodological implications for future studies.

and may even be absent at the population level (see also Sommer et al., 2004). Another highly controversial issue concerns the potential volumetric and functional differences between male and female brains in the neural networks processing language. Despite long-dated claims regarding gender differences on language networks, an influential critical review highlighted that the available evidence is not clear enough to account for their inclusion as a large confounding factor in neuroimaging studies of language processing (Wallentin, 2009).

The current paper aims at commenting on the results from neuroimaging studies focusing on language production under the lens of the current knowledge about the cognitive and neural underpinnings of linguistic production. After describing an influential neurocognitive model for language production, the results from functional studies will be discussed to comment on the presence or absence of potential sex-related differences in the neural correlates of language production.

2 | NEUROCOGNITIVE ORGANIZATION OF LANGUAGE

Language is a complex cognitive function (Friederici et al., 2017; Indefrey, 2011). Growing evidence has shown that language is implemented in an extensive neural network with epicenters in cortical and subcortical areas in both hemispheres (e.g., Catani, Dell'Acqua, Bizzi, et al., 2012; Indefrey, 2011; Piervincenzi et al., 2016; Vigneau et al., 2006).

First, the speaker needs to generate a communicative intention and a structure or mental depiction of the contents of what (s)he wants to convey (mental model or story scenario generation) that will serve as a foundation for the development of the story structure (Gernsbacher, 1990). In this preliminary stage of message preparation language interacts with other cognitive abilities such as attention, executive functions, working memory, long-term semantic and episodic declarative memory (e.g., Ferretti et al., 2017; Mozeiko et al., 2011): the abilities to focus the attention to the goal at hand, plan what must be said next, monitor one's own production, and inhibit potentially distracting actions are crucial. Furthermore, the speaker needs to consider the interlocutors' expectations by generating a theory of their mind, and both linguistic (i.e., what has already been said) and extralinguistic (e.g., information about the place and time in which the conversation takes place) context. This preliminary stage of discourse generation requires the recruitment of vast areas in bilateral frontal lobes. Activations in the orbitofrontal cortex (BA 47 and BA 11), anterior cingulate gyrus (ACG, BA 24), and supplementary motor area (SMA, BA 6) as well as in the dorsolateral prefrontal cortices (DLPFCs) have been frequently reported (e.g., Hirschfeld et al., 2008). Of note, lesions to the ACG and SMA are often related to a reduced propension to speak (e.g., Devinsky et al., 1995) suggesting a role of these areas in the generation of the motivation to speak. On the other hand, the activations in bilateral DLPFCs have been implicated in executive functions (Yuan & Raz, 2014). For example, patients with lesions to left (Coelho et al., 2012) and right (Marini, 2012) DLPFC may experience deficits in planning and monitoring the contents of their narratives. In this preliminary stage of message preparation, a key role is also played by the ability to generate a communicative intention. According to Catani and Bambini (2014), this complex ability is likely implemented in epicenters in medial and dorsomedial prefrontal areas involved in mentalizing (Lombardo et al., 2010; Van Overwalle, 2009) and connected to Broca's area through the frontal aslant tract (Catani, Dell'acqua, Vergani, et al., 2012). Of note, this tract of fibers extends to more frontal areas involved in theory of mind generation which is another major component of the initial stages of discourse planning. A role in the integration of higher-order language has also been proposed for the forceps minor of the corpus callosum (e.g., Mamiya et al., 2018; Solso et al., 2016).

Once the story structure has been generated, the speaker needs to organize it in sequences to be converted in propositions and eventually verbalized through processes of conceptual preparation, lexical selection, lexical access, and production (e.g., Indefrey & Levelt, 2000). The stage of conceptual preparation allows for the activation of a target lexical concept (i.e., a concept "for which there is a lexical item in the mental lexicon" Levelt, 2001; page 13,464) that best fits with the communicative intention of the speaker. The activated lexical concept triggers a process of lexical selection where the semantic information contained in the lexical concept is spread to lemmas in the mental lexicon (Roelofs, 1992). A lemma is a complex information containing the grammatical category of the word and all its morphosyntactic valences that are necessary for grammatical encoding (i.e., the generation of the sentence). Neuroimaging studies using reading and lexical generation tasks showed that the activation of the lexical concept and the subsequent stage of lexical selection are related to activations in a network involving the left temporal lobe (i.e., the temporal pole, BA 38; anterior aspects of the inferior temporal gyrus (ITG) and the fusiform gyrus, BA 37), the left IFG (i.e., posterior aspect of Broca's area, BA 44; precentral sulcus, BA 6), and portions of the cerebellum (e.g., De Zubicaray et al., 2006; Indefrey, 2011). In this regard, consolidated neuropsychological evidence (e.g., Damasio et al., 1996) suggests that the left temporal lobe contributes to keep the lexical concept active in memory until the target word has been selected. The left IFG might also contribute to this network thanks to its role in phonological working memory and for its potential implication in the ability to select informative words, that is, words that are linguistically and pragmatically sound in the communicative context (Marini & Urgesi, 2012; Mazzon et al., 2019). As for white matter (WM) tracts crucial for the phase of lexical selection, a critical role is apparently played by the anterior portions of the frontal aslant tract, the inferior fronto-occipital fasciculus, and the anterior thalamic radiations (Corrivetti et al., 2019).

Once the lemma has been activated, its morphosyntactic information likely interacts with a basic recursive combinatorial operation called Merge (Chomsky, 1995) that triggers sentence generation and placement of the selected lemma in the correct position in the sentence. A recent meta-analysis supports the role of a fronto-temporal network in this process (Zaccarella et al., 2017). Within this network, the posterior aspect of left pars opercularis (BA44) and the infero-posterior aspect of the superior temporal gyrus (STG) (BA22) are connected through the long segment of the arcuate fasciculus. Namely the left pars opercularis has been proposed to act as the syntactic merger (e.g., Zaccarella & Friederici, 2015), whereas the pSTS/STG complex maps the morphosyntactic information associated to words to the syntactic structures generated by left pars opercularis (e.g., den Ouden et al., 2012). A role in this phase of grammatical encoding is likely played also by the left caudate nucleus in the basal ganglia that has been found related to the detection of syntactic anomalies (Moro et al., 2001).

The selected lemma spreads its activation to the word's phonological code with a speed which is dependent on the word's frequency (stage of phonological encoding). Growing evidence supports a role for the posterior aspect of the left STG/MTG in phonological code retrieval and of the left IFG in phonological encoding (Indefrey, 2011). Furthermore, recent evidence supports the hypothesis that also the cingulum-cingulate gyrus, which connects the cingulate gyrus with other brain regions, plays a role in phonological processing (e.g., Walton et al., 2018). This phonological information must then be combined into syllables which receive a stress pattern resulting in a phonological word. A process of phonetic encoding will then convert the retrieved phonemes in abstract articulatory representations (i.e., the articulatory score) that will eventually be produced during the stage of articulation. These last two stages of message production are implemented in a wide network involving cortical and subcortical areas: phonetic encoding (SMA and left anterior insula; e.g., Dronkers, 1996; Carreiras et al., 2006); articulation (left precentral gyrus, left thalamus, basal ganglia, and dentate nucleus in the right cerebellar hemisphere; e.g., Peeva et al., 2010; Tettamanti et al., 2005). Of note, growing evidence suggests that these epicenters are interconnected by a wide array of WM pathways with the inclusion of posterior fronto-striatal and frontal aslant tracts, corpus callosum, and the cortico-spinal tract (e.g., Corrivetti et al., 2019).

3 | PUTATIVE SEX-RELATED DIFFERENCES IN THE NEURAL NETWORKS FOR LANGUAGE PRODUCTION

The available literature was searched using PubMed. The search included studies assessing sex differences in language production with neuroimaging techniques. The titles and abstracts of the selected papers were checked and only those papers reporting original research, reviews or metanalyses including healthy children, adolescent, and adults were selected. Studies focusing on patients with developmental disorders, acquired brain injuries, and/or neurodegenerative syndromes were excluded. The results showed that over the past 30 years few investigations have been carried out to directly explore potential sex-related differences in brain activations on linguistic production tasks. Namely, the research yielded 13 original studies (4 focusing on children), two metanalyses and one systematic review. Unfortunately, these studies have mainly assessed such relation focusing on lexical selection skills (i.e., lexical generation tasks) and not giving the possibility to relate potential sex-related differences to specific phases of discourse production.

Buckner et al. (1995) performed two PET experiments on a cohort of university students and workers. In the former, 12 male and 20 female right-handed adult participants who were native English speakers aged between 18 and 35 years performed an *overt verb generation task* where they were asked to read nouns and say aloud the corresponding verbs. In the latter, 12 male and 17 female adult participants (same participants as the former experiment) were administered a *stem completion task* requiring them to read three-letter word stems and then say aloud English words that could complete the sequence. Both tasks required participants to produce words but with an important difference: in the stem completion task the beginning of the word had already been presented with a facilitation in the process of lexical retrieval. In the verb generation task the provided noun activated the corresponding lexical concept that triggered the process of lexical selection and access. Accordingly, both tasks elicited shared activations in the left inferior frontal gyrus (IFG) (BA 44 and 45) that is involved in stages of lexical selection, lemma activation, and phonological code retrieval. Of note, during the verb generation task participants showed further activations in more anterior aspects of the left IFG (BA 10 and 46). Interestingly, even if the activations were similar between males and females in both tasks, in the verb generation task such activations were larger in males. Obviously, the reason for such slight difference is not easily interpretable (also considering the lack of differences in reaction times between male and female participants in this investigation). Furthermore, the available structural evidence about potential sex-related differences in the left IFG are quite controversial (Blanton et al., 2004; Su et al., 2008; Wilke et al., 2007). For example, Su et al. (2008) did not detect any difference in the degree of myelination within the left IFG in a cohort of 8-year-old boys and girls. Nonetheless, in a study involving 200 children, adolescents and young adults aged 5 through 19 years Wilke et al. (2007) found lower gray matter volume in boys in this area, whereas Blanton et al. (2004) found the opposite (i.e., lower gray matter volume) in girls in an investigation with 46 participants aged 6 to 17 years old.

Allendorfer et al. (2012) assessed potential sex differences in *verb generation* during fMRI in 46 right-handed English-speaking healthy adults (26 females) with a mean age of 40 (the age range of the participants was not provided). The participants' linguistic skills were assessed before entering the scanner with tasks assessing, among other things, lexical comprehension, naming, phonological and semantic fluency. Interestingly, the two groups did not differ on any language measure. They were administered two verb generation tasks during the fMRI session. The former was a block-design *covert verb generation* task requiring participants to hear nouns and covertly generate the corresponding verbs. The latter was an event-related verb generation task requiring participants to listen to concrete nouns and then provide one of three possible answers depending on the instructions: (1) Mentally generate the verbs associated with the noun (covert generation); (2) Speak out the related verbs (*overt generation*); and (3) Repeat the heard noun (overt noun repetition). Behaviorally, males and females performed similarly on the overt verb generation task. Furthermore, both groups showed similar language lateralization and broadly similar activation patterns. Nonetheless, a few differences could be found after controlling for performance. Indeed, males showed greater activations in the right MFG and superior frontal gyrus (SFG), right caudate nucleus, and ACG. Furthermore, better performance on verb generation this time correlated with increased right caudate nucleus in basal ganglia and ACG activation in males and with increased right MFG/SFG activation in females, suggesting that males and females might use partially different strategies in language processing but with similar outcomes. Overall, then, this study supports the possibility that performance may be a significant variable to account for when considering potential sex-related differences in the neural correlates of lexical production.

Overt verb generation was assessed also by Yu et al. (2014) on a cohort of 80 children and adolescents aged 4 to 18 years using MEG. The participants were divided in a cohort of 46 girls and 23 boys. Crucially, the two groups did not differ on a measure of language comprehension and one of lexical production. The verb generation task required subjects to generate a verb as quickly as possible after the presentation of a picture stimulus. Sex-related differences were found in the patterns of fronto-temporal lateralization. Namely, male participants showed a lateralized activation in left IFG (BA 44, 45, 47), left DLPFC (BA 9, 46), left IPL (angular and supramarginal gyri, BA 39, 40), and left STG (BA 22, 38, 41, 42). These are temporal and frontal areas implicated in phases of lexical selection, lemma retrieval, and phonological encoding. Interestingly, female participants had a more bilateral pattern of activations spanning to both right and left IFG (BA 44, 45, 47) and DLPFC (BA 9, 46) supporting the long-debated possibility of a more enhanced lateralization of linguistic networks in males. Of note, however, such differences were evident in the younger participants aged 4 to 6 years. This result apparently indicates that boys might have a left-lateralized fronto-temporal network already at the age of 4 years, whereas girls might lateralize such functions later in time. In this regard, however, it should be reminded that this study employed only 80 participants who were split in 5 age groups containing each a female and a male subgroup. As for children aged 4 to 6, the analyses had been performed on barely five males and five girls. This leaves open the possibility of a low generalizability of such analyses to the general population. Indeed, other studies did not find gender-related differences in children or adolescents involved in verb generation tasks employing MEG (e.g., Kadis et al., 2011) or fMRI (e.g., Plante et al., 2006; Wood et al., 2004).

Using a different task to elicit words, Weiss, Siedentopf, et al. (2003) assessed potential sex differences on a *phonological fluency* task in 20 right-handed healthy psychology students (10 males). The task consisted in producing as many words as possible beginning with specific phonemes. The two groups did not differ on this test. Indeed, they all had high performance on it as they had been selected among the most proficient in a greater cohort of 97 individuals (Weiss, Kemmler, et al., 2003). While performing the task, both groups showed similar activations in bilateral prefrontal cortex, cingulate gyrus, and in the right cerebellum. Importantly, the between-group analysis showed a lack of differences between men and women. This apparently suggests that previous reports about sex differences on such tasks may be biased by task performance rather than by gender as also noted by Allendorfer et al. (2012).

More recently, Gauthier et al. (2009) recruited 44 French-speaking university students divided in four groups made of 11 participants each according to their sex (males vs. females) and proficiency level on a verbal fluency task performed before the experiment (high-proficient vs. low-proficient). During the fMRI scanning they were administered a *covert phonological fluency task*. Again, all groups showed similar activations on the neural network typically associated with lexical selection and access (including, e.g., the IFG, the ACG, the cerebellum, and basal ganglia). However, the authors reported also some differences related to sex and performance level. Indeed, men with high proficiency showed more activations than men with lower proficiency in the right precuneus and left DLPFC, whereas men with lower proficiency showed higher activations in the right IFG. With respect to those with high proficiency, women with low proficiency had increased activation in the left ACG. Interestingly, the authors also reported a sex main effect that was independent of performance levels: men had greater activations in the left ITG, cerebellum, ACG and PCG, right SFG, right DLPFC, and lingual gyrus.

A third way to elicit words is *overt picture naming*. In a PET experiment, Grabowski et al. (2003) examined this ability in 62 healthy adults (31 men) balanced for age (mean age 33 years) and educational level (mean 15 years). During scanning, participants were asked to name aloud the stimuli portrayed in a series of color photographs depicting concrete entities (e.g., animals, fruits and vegetables, musical instruments, etc…). Males and females performed similarly on the naming task in terms of both accuracy and latency. However, men showed increased activation in left ITG and left frontal pole, whereas women had higher activations in the right IFG and the right precentral gyrus.

In Garn et al. (2009) 26 adult participants (13 males) aged between 18 and 30 were enrolled in an fMRI *covert picture naming* experiment requiring them to covertly name a series of 30 drawings of nonliving stimuli (i.e., tools) and 30 drawings of living stimuli (i.e., plants). As it was covert, in this picture naming task it was not possible to have an accuracy measure to control for potential differences in performance between men and women. However, women showed greater activations in left fusiform gyrus when naming plants and in the ACG and left posterior MTG when naming tools. In contrast, men showed higher activations in right STG and left posterior MTG while naming plants and in right STG and right MTG when naming tools.

Overall, the studies employing lexical production tasks provided mixed results. Indeed, two metanalyses have supported the idea that in lexical production tasks it is very difficult to derive a coherent picture by the available evidence. In a metanalysis of studies assessing potential gender differences in handedness, asymmetry of the Planum Temporale, and functional lateralization of language, Sommer et al. (2008) considered the results of 12 studies eliciting verbal outputs through word generation tasks such as *verbal fluency* and *verb generation*. These studies included a total of 1075 right-handed children and adults. This metanalysis showed the absence of any sex-related difference in lateralization. This was further confirmed by other eight studies on 510 subjects employing semantic decision tasks where, again, no difference in lateralization was found between male and female participants. More recently, Sato (2020) performed a systematic review and metanalysis of studies aimed at assessing potential sex-related differences in language processing confirming that sex differences in the BOLD signal or cerebral blood flow was highly inconsistent across fMRI and PET studies.

To date only two studies have focused on potential sex-related differences in discourse production (Angelopoulou et al., 2020; Kaiser et al., 2007). Kaiser et al. (2007) explored potential gender-related differences on a *covert narrative production* task with fMRI. Namely, they asked a cohort of 44 bilingual healthy young adults (22 men, 22 women aged 20–36 years) to imagine to be talking to an interlocutor about what they had done the day before. The authors reported several activations mostly left-lateralized and encompassing the IFG, the posterior aspects of STG, premotor and prefrontal areas, SMA, and basal ganglia. Furthermore, they also reported activations in the right cerebellum. Interestingly, women had left lateralized activation in the IFG (BA 44), whereas men showed a more anterior and bilateral pattern (BA 45). However, it should be stressed that in this study the interindividual variation was quite high with 16 participants (nine males; seven females) having bilateral activations and other 16 (seven males; nine females) showing a more left-lateralized pattern of activation. As showed by Weiss, Siedentopf, et al. (2003), such interindividual variation may have been biased by the level of proficiency of the participants. For this reason, Kaiser et al. (2007) commented in their discussion that they had checked for performance levels asking the same participants to produce narrative samples also out of the scanner. Unfortunately, they limited their quantitative analysis of these speech samples to a fluency measure (speech rate, calculated as number of syllables produced per time unit) which provides information only about something their participants were NOT doing in the scanner (i.e., overt speaking). Future studies should extend such behavioral analyses also to other aspects of narrative discourse processing (e.g., production levels, lexical, grammatical, and discourse-level processing; Marini et al., 2011).

More recently, Angelopoulou et al. (2020) assessed narrative skills in a cohort of 57 Greek-speaking healthy adults aged between 19 and 65 years and with varying levels of education (ranging from 9 to 25 years of schooling). They formed a male ($N = 27$) and a female ($N = 30$) group balanced for age and education (but, unfortunately, with a very high age range). Participants were asked to produce samples of narrative discourse about a personal medical event while in the scanner. The speech samples were transcribed and analyzed focusing on a variety of measures. At the behavioral level, women had higher speech rates and produced a higher percentage of verbs, whereas men produced a higher percentage of nouns. The analyses showed that males had increased values in surface areas of the right fusiform gyrus, left STG, left SFG and MFG, and left IFG. Furthermore, males had also increased gray matter volume in left fusiform gyrus extending to the lingual sulcus and right occipital areas and enhanced cortical thickness in other regions of the brain (right ITG and left ITG extending to the left temporal pole). Interestingly, in this investigation the authors explicitly assessed the relation between brain and linguistic variables in the two groups by performing a series of partial correlations accounting for demographic variables. They found a significant association between speech rate and surface area of the left SFG and MFG. Hierarchical regression analyses showed that the surface area of the superior/middle frontal cluster may serve as a significant predictor of speech rate variance, but only in females. As pointed out by the authors in their discussion, such association could result from statistical factors such as the fact that inter-individual variability was greater among women in both speech rates and the cortical surface of the SFG. This enhanced variability may explain why the relation between these two measures was significant only in women. An alternative possibility may be that greater surface area reflects greater computational capacity. Indeed, portions of this cluster (i.e., the MFG) are included in the DLPFC, which is likely involved in the preliminary stages of message preparation, in the ability to generate a communicative intention, and in mentalizing.

4 | CONCLUSIONS

This brief overview about the potential existence of gender-related differences in the neural networks of language production has shown that the available evidence on this topic is quite controversial (e.g., Kaiser et al., 2008; Sato, 2020). On production tasks male and female brains might process linguistic information with both shared and, at least partially, specific neural networks that may reflect the use of different strategies at the individual level rather than at the gender level. Indeed, in a recent metanalysis Sato (2020) showed that the sex-related differences found in neuroimaging studies focusing on language processing are quite heterogeneous failing to find a coherent direction in these results.

This heterogeneity may have several causes (e.g., Ihnen et al., 2009). Indeed, one of the major problems faced by studies focusing on sex-related differences in brain structure and function is the need to control for several potentially confounding variables that might bias their results (Chen et al., 2007). The available evidence on sex-related differences in language production may not always be detectable and, even when they are, may be potentially biased by developmental, environmental, sociological, and educational confounding factors.

Studies involving children, adolescents or adults may report different findings because of developmental issues (see Etchell et al., 2018 for a systematic review on this topic). For example, let us consider the Basal Ganglia. These subcortical nuclei are an epicenter of language-related neural networks implicated in both grammatical and phonetic encoding (in stages of lemma activation and articulation). Even after correcting for global brain volume, studies focusing on these subcortical structures reveal a consistent gender-related difference with females having greater gray matter volumes (e.g., Lange et al., 1997; Sowell et al., 2002; Wilke et al., 2007). These differences are likely related to the expression of sex hormones during development: higher levels of testosterone are associated with decreases in the volume of caudate nucleus (Herting et al., 2014). Furthermore, together with education level, age might also determine sex-related differences in talkativeness (Ardila & Rosselli, 1996) and affect performance on fluency tasks (Tombaugh et al., 1999) that, in turn, might determine a different organization of the corresponding neural networks.

It is therefore crucial that studies focusing on sex-related differences in language production match their participants according to their age and education level. Another problem regards the lack of control of critical variables that are known to affect language development, functioning, and neural organization such as Socio-Economical Status (Romeo et al., 2018) and linguistic exposure (i.e., in bilinguals; Sulpizio et al., 2020). With the exception of Kaiser et al. (2007), the reviewed studies did not mention whether their participants were monolingual or bilingual and what was their personal history of language exposure. As to this regard, accumulating evidence suggests that bilingualism impacts cognitive functions and the neural organization of language (e.g., Tao et al., 2021). It remains unclear, however, if such impact is similar across the two genders. This is an issue worth exploring in future investigations.

The performance of the participants is another significant variable to account for when considering potential sex-related differences in the neural correlates of linguistic production (Allendorfer et al., 2012). An additional bias might depend on different experimental protocols and data processing. As to this regard, even in absence of sex-related differences in brain activations in areas related to semantic processing on a metalinguistic task (semantic judgment), in Xu et al. (2020) a dynamic causal modeling analysis revealed different effects on modulatory connections within the semantic networks (including three major epicenters in this study: left IFG, SPL, and STG) for men and women. In male participants, the analysis showed more inhibitory influence from left IFG to left STG, whereas female participants showed more inhibitory influence from left SPL to left STG. Furthermore, in the same study a network-based statistics analysis showed stronger connections linking distant prefrontal and parietal areas in females, whereas in males stronger connections were shorter and restricted to frontal areas.

Different sample sizes (Wallentin, 2009) and methodological differences affecting task choice (e.g., Harrington & Farias, 2008) represent other major issues. As for sample size, two meta-analyses showed that the available evidence on the potential lateralization of linguistic functions may be biased by the number of participants: smaller samples showed greater bilateral activations in women than in men; larger cohorts apparently did not confirm such effect (Sommer et al., 2004, 2008). Furthermore, studies have often employed different tasks assessing different linguistic functions but collapsing their conclusions in a broad idea of “language” organization in the brain in males and females. Kansaku and Kitazawa (2001) have clearly shown that different tasks may bias the identification of gender differences. For example, discourse-, rather than lexical-, related tasks might lead to the identification of gender differences. Kansaku et al. (2000) assessed with fMRI brain activations using a story listening task. After correcting for a control condition where the same story was played in reverse mode, the authors found a stronger bilateral activation in the STG and MTG for women (whereas men had stronger left-lateralized activation in the same areas) but no effect of sex-related laterality on other areas such as the MTG. Interestingly, similar findings were observed also on a study with English speakers (Phillips et al., 2000) and likely reflected higher levels of linguistic and conceptual integration required for both narrative comprehension and production. This leads to a final consideration regarding the need for more studies focusing on aspects of language processing that have been neglected so far in the literature on this topic. Indeed, the available evidence on language production is mainly restricted to lexical production tasks (i.e., verb generation, semantic or phonological fluency, and picture naming). Even when discourse production was used to elicit language production, the focus of the analyses was restricted to lexical production skills. However, language is not only lexical skills. There is much more than this, including phases of communicative intention generation, discourse planning and monitoring. We simply do not know almost anything about potential sex-related differences in some stages of narrative discourse and message production such as discourse conceptualization. Future investigations are required to further our knowledge also on these critical aspects of language production.

AUTHOR CONTRIBUTIONS

A.M. conceptualized the paper, wrote the original draft, reviewed it according to reviewers’ suggestions and edited the final draft.

ACKNOWLEDGEMENT

Open Access Funding provided by Universita degli Studi di Udine within the CRUI-CARE Agreement.

CONFLICT OF INTEREST

The author has no conflict of interest to declare.

PEER REVIEW

The peer review history for this article is available at https://publons.com/publon/10.1002/jnr.25096.

REFERENCES

Allendorfer, J. B., Lindsell, C. J., Siegel, M., Banks, C. L., Vannest, J., Holland, S. K., & Szaflarski, J. P. (2012). Females and males are highly similar in language performance and cortical activation patterns during verb generation. *Cortex*, *48*, 1218–1233.

Angelopoulou, G., Meier, E. L., Kasselimis, D., Pan, Y., Tsolakopoulos, D., Velonakis, G., Karavasilis, E., Kelekis, N. L., Goutsos, D., Potagas, C., & Kiran, S. (2020). Investigating gray and white matter structural substrates of sex differences in the narrative abilities of healthy adults. *Frontiers in Neuroscience*, *13*, 1424.

Ardila, A., & Rosselli, M. (1996). Spontaneous language production and aging: Sex and educational effects. *International Journal of Neuroscience*, *87*, 71–78.

Baron-Cohen, S., Knickmeyer, R. C., & Belmonte, M. K. (2005). Sex differences in the brain: Implications for explaining autism. *Science*, *310*, 819–823.

Blanton, R. E., Levitt, J. G., Peterson, J. R., Fadale, D., Sporty, M. L., Lee, M., To, D., Mormino, E. C., Thompson, P. M., McCracken, J. T., & Toga, A. W. (2004). Gender differences in the left inferior frontal gyrus in normal children. *Neuroimage*, *22*(2), 626–636.

Buckner, R. L., Raichle, M. E., & Petersen, S. E. (1995). Dissociation of human prefrontal cortical areas across different speech production tasks and gender groups. *Journal of Neurophysiology*, *74*, 2163–2173.

Carreiras, M., Mechelli, A., & Price, C. J. (2006). Effect of word and syllable frequency on activation during lexical decision and reading aloud. *Human Brain Mapping*, *27*, 963–972.

Catani, M., Dell'Acqua, F., Bizzi, A., Forkel, S. J., Williams, S., Simmons, A., Murphy, D. G., & Thiebaut de Schotten, M. T. (2012). Beyond cortical localization in clinico-anatomical correlation. *Cortex*, *48*, 1262–1287.

Catani, M., Dell'acqua, F., Vergani, F., Malik, F., Hodge, H., Roy, P., Valabregue, R., & Thiebaut de Schotten, M. (2012). Short frontal lobe connections of the human brain. *Cortex*, *48*, 273–291.

Catani, M., & Bambini, V. (2014). A model for social communication and language evolution and development (SCALED). *Current Opinion in Neurobiology*, *28*, 165–171.

Chen, X., Sachdev, P. S., Wen, W., & Anstey, K. J. (2007). Sex differences in regional gray matter in healthy individuals aged 44–48 years: A voxel-based morphometric study. *Neuroimage*, *36*(3), 691–699.

Chilosi, A. M., Brovedani, P., Cipriani, P., & Casalini, C. (2021). Sex differences in early language delay and in developmental language disorder. *Journal of Neuroscience Research*, 1–12. https://doi.org/10.1002/jnr.24976

Chomsky, N. (1995). *The minimalist program*. MIT Press.

Chrichton-Browne, J. (1879). On the weight of the brain and its component parts in the insane. *Brain*, *2*(1), 42–67.

Coelho, C., Le, K., Mozeiko, J., Krueger, F., & Grafman, J. (2012). Discourse production following injury to the dorsolateral prefrontal cortex. *Neuropsychologia*, *50*(14), 3564–3572.

Corrivetti, F., Thiebaut de Schotten, M., Poisson, I., Froelich, S., Descoteaux, M., Rheault, F., & Mandonnet, E. (2019). Dissociating motor-speech from lexico-semantic systems in the left frontal lobe: Insight from a series of 17 awake intraoperative mappings in glioma patients. *Brain Structure and Function*, *224*, 1151–1165.

Damasio, H., Grabowski, T. J., Tranel, D., Hichwa, R. D., & Damasio, A. R. (1996). A neural basis for lexical retrieval. *Nature*, *380*(6574), 499–505.

den Ouden, D. B., Saur, D., Mader, W., Schelter, B., Lukic, S., Wali, E., Timmer, J., & Thompson, C. K. (2012). Network modulation during complex syntactic processing. *Neuroimage*, *59*, 815–823.

Devinsky, O., Morrell, M. J., & Vogt, B. A. (1995). Contributions of anterior cingulate cortex to behaviour. *Brain*, *118*, 279–306.

De Zubicaray, G., McMahon, K., Eastburn, M., & Pringle, A. (2006). Top-down influences on lexical selection during spoken word production: A 4T fMRI investigation of refractory effects in picture naming. *Human Brain Mapping*, *27*, 864–873.

Dotson, V. M., & Duarte, A. (2019). The importance of diversity in cognitive neuroscience. *Annals of the New York Academy of Sciences*, *1464*(1), 181–191.

Dronkers, M. F. (1996). A new brain region for coordinating speech articulation. *Nature*, *384*, 159–161.

Eriksson, M., Marschik, P. B., Tulviste, T., Almgren, M., Pereira, M. P., Wehberg, S., Umek, L. M., Gayraud, F., Kovavecic, M., & Gallego, C. (2012). Differences between girls and boys in emerging language skills: Evidence from 10 language communities. *British Journal of Developmental Psychology*, *30*(2), 326–343.

Etchell, A., Adhikari, A., Weinberg, L. S., Choo, A. L., Garnett, E. O., Chow, H. M., & Chang, S. (2018). A systematic literature review of sex differences in childhood language and brain development. *Neuropsychologia*, *114*, 19–31.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thal, D. J., & Pethick, S. J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development*, *59*(5), 1–173.

Ferretti, F., Adornetti, I., Chiera, A., Nicchiarelli, S., Magni, R., Valeri, G., & Marini, A. (2017). Mental time travel and language evolution: A narrative account of the origins of human communication. *Language Sciences.*, *63*, 105–118.

Friederici, A., Chomsky, N., Berwick, R. C., Moro, A., & Bolhuis, J. J. (2017). Language, mind and brain. *Nature Human Behaviour*, *1*, 713–722.

Garn, C. L., Allen, M. D., & Larsen, J. D. (2009). An fMRI study of sex differences in brain activation during object naming. *Cortex*, *45*(5), 610–618.

Gauthier, C. T., Duyme, M., Zanca, M., & Capron, C. (2009). Sex and performance level effects on brain activation during a verbal fluency task: A functional magnetic resonance imaging study. *Cortex*, *45*(2), 164–176.

Gernsbacher, M. A. (1990). *Language comprehension as structure building*. Erlbaum.

Good, C. D., Johnsrude, I., Ashburner, J., Henson, R. N. A., Friston, K. J., & Frackowiak, R. S. (2001). Cerebral asymmetry and the effects of sex and handedness on brain structure: A voxel-based morphometric analysis of 465 normal adult human brains. *Neuroimage*, *14*, 685–700.

Grabowski, T. J., Damasio, H., Eichhorn, G. R., & Tranel, D. (2003). Effects of gender on blood flow correlates of naming concrete entities. *Neuroimage*, *20*(2), 940–954.

Halpern, D. (1992). *Sex differences in cognitive abilities* (2nd ed.). Lawrence Erlbaum.

Harrington, G. S., & Farias, S. T. (2008). Sex differences in language processing: Functional MRI methodological considerations. *Magnetic Resonance Imaging*, *27*, 1221–1228.

Harris, L. J. (1980). Lateralised sex differences: Substrate and significance. *Behavioral and Brain Sciences*, *3*, 236–237.

McGlone, J. (1980). Sex differences in human brain asymmetry: A critical survey. *Behavioral and Brain Sciences*, *3*, 236–237.

Herting, M. M., Gautam, P., Spielberg, J. M., Kan, E., Dahl, R. E., & Sowell, E. R. (2014). The role of testosterone and estradiol in brain volume changes across adolescence: A longitudinal structural MRI study. *Human Brain Mapping*, *35*(11), 5633–5645.

Hill, A. C., Laird, A. R., & Robinson, J. L. (2014). Gender differences in working memory networks: A BrainMap meta-analysis. *Biological Psychology*, *102*, 18–29.

Hirschfeld, G., Jansma, B., Bölte, J., & Zwitserlood, P. (2008). Interference and facilitation in overt speech production investigated with event-related potentials. *Neuroreport*, *19*(12), 1227–1230.

Hyde, J. S., & Linn, M. C. (1988). Gender differences in verbal ability: A meta-analysis. *Psychological Bullettin*, *104*, 53–69.

Ihnen, S. K. Z., Church, J. A., Petersen, S. E., & Schlaggar, B. L. (2009). Lack of generalizability of sex differences in the fMRI BOLD activity associated with language processing in adults. *Neuroimage*, *45*(3), 1020–1032.

Indefrey, P., & Levelt, W. J. M. (2000). The neural correlates of language production. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences* (pp. 845–865). MIT Press.

Indefrey, P. (2011). The spatial and temporal signatures of word production components: A critical update. *Frontiers in Psychology*, *2*, 255.

Kadis, D. S., Pang, E. W., Mills, T., Taylor, M. J., McAndrews, M. P., & Smith, M. L. (2011). Characterizing the normal developmental trajectory of expressive language lateralization using magnetoencephalography. *Journal of the International Neuropsychological Society*, *17*(5), 896–904.

Kaiser, A., Kuenzli, E., Zappatore, D., & Nitsch, C. (2007). On females' lateral and males' bilateral activation during language production: A fMRI study. *International Journal of Psychophysiology*, *63*, 192–198.

Kaiser, A., Haller, S., Schmitz, S., & Nitsch, C. (2008). On sex/gender related similarities and differences in fMRI language research. *Brain Research Reviews*, *61*, 49–59.

Kansaku, K., Yamaura, A., & Kitazawa, S. (2000). Sex differences in lateralization revealed in the posterior language areas. *Cerebral Cortex*, *10*, 866–872.

Kansaku, K., & Kitazawa, S. (2001). Imaging studies in sex differences in the lateralization of language. *Neuroscience Research*, *41*, 333–337.

Lange, N., Giedd, J. N., Castellanos, F. X., Vaituzis, A. C., & Rapoport, J. L. (1997). Variability of human brain structure size: Ages 4–20 years. *Psychiatry Research: Neuroimaging*, *74*(1), 1–12.

Levelt, W. J. M. (2001). Spoken word production: A theory of lexical access. *Proceedings of the National Academiy of Sciences of the United States of America*, *98*(23), 13464–13471.

Liberman, M. (2006). *Sex-linked lexical budgets*. http://itre.cis.upenn.edu/~myl/languagelog/archives/003420.html

Lombardo, M. V., Chakrabarti, B., Bullmore, E. T., Wheelwright, S. J., Sadek, S. A., Suckling, J., & Baron-Cohen, S. (2010). Shared neural circuits for mentalizing about the self and others. *Journal of Cognitive Neuroscience*, *22*, 1623–1635.

Mamiya, P. C., Richards, T. L., & Kuhl, P. K. (2018). Right forceps minor and anterior thalamic radiation predict executive function skills in young bilingual adults. *Frontiers in Psychology*, *9*(9), 118.

Marini, A., Andreetta, S., del Tin, S., & Carlomagno, S. (2011). A multilevel approach to the analysis of narrative language in aphasia. *Aphasiology*, *25*, 1372–1392.

Marini, A., & Urgesi, C. (2012). Please, get to the point! A cortical correlate of linguistic informativeness. *Journal of Cognitive Neuroscience*, *24*(11), 2211–2222.

Marini, A. (2012). Characteristics of narrative discourse processing after damage to the right hemisphere. *Seminars in Speech and Language*, *33*(1), 68–78.

Mazzon, G., Ajčević, M., Cattaruzza, T., Menichelli, A., Guerriero, M., Capitanio, S., Pesavento, V., Dore, F., Sorbi, S., Manganotti, P., & Marini, A. (2019). Connected speech deficit as an early hallmark of CSF-defined Alzheimer's disease and correlation with cerebral hypoperfusion pattern. *Current Alzheimer Research*, *16*, 1–12.

McCarthy, M. M., & Arnold, A. P. (2011). Reframing sexual differentiation of the brain. *Nature Neuroscience*, *14*, 677–683.

Mehl, R., Vazire, S., Ram Rez-Esparza, N., Slatcher, R., & Pennebaker, J. (2007). Are women really more talkative than men? *Science*, *317*, 82.

Moro, A., Tettamanti, M., Perani, D., Donati, C., Cappa, S. F., & Fazio, F. (2001). Syntax and the brain: Disentangling grammar by selective anomalies. *Neuroimage*, *13*(1), 110–118.

Mozeiko, J., Le, K., Coelho, C., Krueger, F., & Grafman, J. (2011). The relationship of story grammar and executive function following TBI. *Aphasiology*, *25*, 826–835.

Peeva, M. G., Guenther, F. H., Tourville, J. A., Nieto-Castanon, A., Anton, J. L., Nazarian, B., & Alario, F. X. (2010). Distinct representations of phonemes, syllables, and suprasyllabic sequences in the speech production network. *Neuroimage*, *50*, 626–638.

Phillips, M. D., Lurito, J. T., Dzemidzic, M., Lowe, M. J., Wang, Y., & Mathews, V. P. (2000). Gender based differences in temporal lobe activation demonstrated using a novel passive listening paradigm. *Neuroimage*, *11*(5), S352.

Piervincenzi, C., Petrilli, A., Marini, A., Caulo, M., Committeri, G., & Sestieri, C. (2016). Multimodal assessment of hemispheric lateralization for language and its relevance for behavior. *Neuroimage*, *142*, 351–370.

Plante, E., Schmithorst, V. J., Holland, S. K., & Byars, A. W. (2006). Sex differences in the activation of language cortex during childhood. *Neuropsychologia*, *44*(7), 1210–1221.

Rinaldi, P., Pasqualetti, P., Volterra, V., & Caselli, M. C. (2021). Gender differences in early stages of language development. Some evidence and possible explanations. *Journal of Neuroscience Research*, 1–11. https://doi.org/10.1002/jnr.24914

Riva, V., Cantiani, C., Dionne, G., Marini, A., Mascheretti, S., Molteni, M., & Marino, C. (2017). Working memory mediates the effects of gestational age at birth on expressive language development in children. *Neuropsychology*, *31*(5), 475–485.

Roelofs, A. (1992). A spreading activation theory of lemma retrieval in speaking. *Cognition*, *42*, 107–142.

Romeo, R. R., Leonard, J. A., Robinson, S. T., West, M. R., Mackey, A. P., Rowe, M. L., & Gabrieli, J. D. E. (2018). Beyond the 30-million-word gap: Children's conversational exposure is associated with language-related brain function. *Psychological Science*, *29*(5), 700–710.

Sato, M. (2020). The neurobiology of sex differences during language processing in healthy adults: A systematic review and meta-analysis. *Neuropsychologia*, *140*, 107404.

Solso, S., Xu, R., Proudfoot, J., Hagler, D. J., Campbell, K., Venkatraman, V., Barnes, C. C., Ahrens-Barbeau, C., Pierce, K., Dale, A., Eyler, L., & Courchesne, E. (2016). Diffusion tensor imaging provides evidence of possible axonal overconnectivity in frontal lobes in autism spectrum disorder toddlers. *Biological Psychiatry*, *79*(8), 676–684.

Sommer, I. E., Aleman, A., Bouma, A., & Kahn, R. S. (2004). Do women really have more bilateral language representation than men? A meta-analysis of functional imaging studies. *Brain*, *127*, 1845–1852.

Sommer, I. E., Aleman, A., Somers, M., Boks, M. P., & Kahn, R. S. (2008). Sex differences in handedness, asymmetry of the planum temporale and functional language lateralization. *Brain Research*, *1206*, 76–88.

Sowell, E. R., Trauner, D. A., Gamst, A., & Jernigan, T. L. (2002). Development of cortical and subcortical brain structures in childhood and adolescence: A structural MRI study. *Developmental Medicine & Child Neurology*, *44*(1), 4–16.

Sulpizio, S., Del Maschio, N., Fedeli, D., & Abutalebi, J. (2020). Bilingual language processing: A meta-analysis of functional neuroimaging studies. *Neuroscience and Biobehavioral Reviews*, *108*, 834–853.

Su, P., Kuan, C. C., Kaga, K., Sano, M., & Mima, K. (2008). Myelination progression in language-correlated regions in brain of normal children determined by quantitative MRI assessment. *International Journal of Pediatric Otorhinolaryngology*, *72*(12), 1751–1763.

Tao, L., Wang, G., Zhu, M., & Cai, Q. (2021). Bilingualism and domain-general cognitive fucntions from a neural perspective: A systematic review. *Neuroscience and BBiobehavioral Reviews*, *125*, 264–295.

Tettamanti, M., Moro, A., Messa, C., Moresco, R. M., Rizzo, G., Carpinelli, A., & Perani, D. (2005). Basal ganglia and language: Phonology modulates dopaminergic release. *Neuroreport*, *16*(4), 397–401.

Tombaugh, T. N., Kozak, J., & Rees, L. (1999). Normative data stratified by age and education for two measures of verbal fluency: FAS and animal naming. *Archives of Clinical Neuropsychology*, *14*(2), 167–177.

Van Overwalle, F. (2009). Social cognition and the brain: A meta-analysis. *Human Brain Mapping*, *30*, 829–858.

Vigneau, M., Beaucousin, V., Hervé, P. Y., Duffau, H., Crivello, F., Houdé, O., Mazoyer, B., & Tzourio-Mazoyer, N. (2006). Meta-analyzing left hemisphere language areas: Phonology, semantics, and sentence processing. *Neuroimage*, *30*, 1414–1432.

Voyer, D., & Voyer, S. D. (2014). Gender differences in scholastic achievement: A meta-analysis. *Psychological Bullettin*, *140*, 1174–1204.

Wallentin, M. (2009). Putative sex differences in verbal abilities and language cortex: A critical review. *Brain and Language*, *108*, 175–183.

Wallentin, M. (2020). Gender differences in language are small but matter for disorders. In R. Lanzenberger, G. S. Kranz, & I. Savic (Eds.), *Handbook of clinical neurology. Sex differences in neuropsychology and psychiatry* (Vol. *175*, pp. 81–102). Elsevier.

Walton, M., Dewey, D., & Lebel, C. (2018). Brain white matter structure and language ability in preschool-aged children. *Brain and Language*, *176*, 19–25.

Watkins, K. E., Paus, T., Lerch, J. P., Zijdenbos, A., Collins, D. L., Neelin, P., Taylor, J., Worsley, K. J., & Evans, A. C. (2001). Structural asymmetries in the human brain: A voxel-based statistical analysis of 142 MRI scans. *Cerebral Cortex*, *11*(9), 868–877.

Weiss, E. M., Kemmler, G., Deisenhammer, E. A., Fleischhacker, W. W., & Delazer, M. (2003). Sex differences in cognitive functions. *Personality and Individual Differences*, *35*(4), 863–875.

Weiss, E., Siedentopf, C., Hofer, A., Deisenhammer, E., Hoptman, M., Kremser, C., Golaszewski, S., Felber, S., Fleischhacker, W., & Delazer, M. (2003). Brain activation pattern during a verbal fluency test in healthy male and female volunteers: A functional magnetic resonance imaging study. *Neuroscience Letters*, *352*, 191–194.

Wilke, M., Krägeloh-Mann, I., & Holland, S. K. (2007). Global and local development of gray and white matter volume in normal children and adolescents. *Experimental Brain Research*, *178*(3), 296–307.

Wood, A. G., Harvey, A. S., Wellard, R. M., Abbott, D. F., Anderson, V., Kean, M., Saling, M. M., & Jackson, G. D. (2004). Language cortex activation in normal children. *Neurology*, *63*(6), 1035–1044.

Xu, M., Liang, X., Ou, J., Li, H., Luo, Y., & Tan, L. H. (2020). Sex differences in functional brain networks of language. *Cerebral Cortex*, *30*, 1528–1537.

Yu, V. Y., MacDonald, M. J., Oh, A., Hua, G. N., De Nil, L. F., & Pang, E. W. (2014). Age-related sex differences in language lateralization: A magnetoencephalography (MEG) study in children. *Developmental Psychology*, *50*(9), 2271–2284.

Yuan, P., & Raz, N. (2014). Prefrontal cortex and executive functions in healthy adults: A meta-analysis of structural neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *42*, 180–192.

Zaccarella, E., & Friederici, A. D. (2015). Merge in the human brain: A sub-region based functional investigation in the left pars opercularis. *Frontiers in Psychology*, *6*, 524.

Zaccarella, E., Schell, M., & Friederici, A. D. (2017). Reviewing the functional basis of the syntactic Merge mechanism for language: A coordinate-based activation likelihood estimation meta-analysis. *Neuroscience and Biobehavioral Reviews*, *80*, 646–656.

How to cite this article: Marini, A. (2022). The beauty of diversity in cognitive neuroscience: The case of sex-related effects in language production networks. *Journal of Neuroscience Research*, *00*, 1–10. https://doi.org/10.1002/jnr.25096