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Sex differences in auditory processing in peripersonal space: an event-related potential study

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Abstract

Further processing of auditory stimuli in free-field is attenuated when participants are in contact with speakers versus not touching them. Studies in the visual domain have found that men and women utilize different strategies for processing spatial information. In the current study, we examined sex-related differences in event-related potentials (ERPs) while men and women performed an auditory discrimination task in peri-personal space when either holding speakers or resting their hands in their laps. We found that males responded more accurately than females to targets in attended locations, and that the sexes exhibited different ERP patterns during task performance. These differences are consistent with existing predictions of female top-down and male bottom-up strategies in spatial processing.

Keywords

Event-related potentials (ERPs); auditory; spatial; proprioceptive; crossmodal; attention; sex differences

INTRODUCTION

Sex differences exist in the performance of spatial tasks as evidenced by behavioral [1, 2], functional magnetic resonance imaging (fMRI) [3–7], and event-related potential (ERP) studies [8, 9]. In studies of mental rotation and manipulation of shapes, enhanced blood-oxygen level dependent (BOLD) activation was observed in the right parietal lobe, precuneus, and lateral occipital cortex for men; while for women, additional areas of activation were observed in parietal, left temporal-occipital, and frontal cortex [4, 5, 7].

These findings do not necessarily indicate large-scale topographical differences in the functional organization of cortical processes. A number of studies suggest that hormones modulate spatial task performance. Increased testosterone levels appear to enhance performance on mental rotation tasks [10, 11], while increased progesterone levels in women during the luteal phase of their menstrual cycle enhance the across-field advantage related to efficient interhemispheric transfer during complex semantic tasks [12]. These findings suggest that differences in hormonal fluctuations may be partially responsible for differences in performance. Frost et al. [13] proposed that previously-observed sex differences in activation and processing patterns may be due to distinctions on a microscopic level, with sex differences in neuronal density, connectivity, and/or synaptic efficiency.

These microscopic differences could be related to genetics, hormones, or even experiential differences between the sexes.

In one study of mental rotation where men and women performed equally well on the task, differing BOLD activation patterns were observed [14]. The fact that different neural networks were recruited to perform the task at equal levels suggests that men and women were applying different strategies. Men show activation in occipital and parietal regions during spatial task performance, which indicates men use a bottom-up “gestalt” strategy [3]. In contrast, women show activation in frontal regions reflecting recruitment of a more top-down reasoning strategy for spatial task performance [3].

Thus, different activation patterns may reflect the initiation of different strategies, and not morphological differences between the sexes. Lamm et al. [8] found differences in the slow cortical ERP potentials between good and poor performers of a visuospatial mental rotation task, independent of sex. Poor performers of both sexes showed more slow potential negativity. These results suggest that neural networks are differentially recruited in relation to participant strategy.

Strategic approaches to spatial task performance can also apparently differ between the sexes. In a classic ERP visuospatial oddball task, men were faster and more accurate and had larger P1 (related to early sensory processing) and P3 (implicated in the updating of short-term memory) amplitudes than women, while women had larger N1 (involved in categorization) amplitudes than men [9]. Apparently, women were employing different strategies than men to perform this task, leading to differences in cortical activation patterns and performance.

Such strategic differences are also observed when participants are required to perform tasks in real space. Gorbet and Sergio [7] found that male participants had greater BOLD activation in the lateral sulci than females when visually guided hand movements were incongruent with eye movements. When hand and eye movements were congruent, activation in spatial processing areas was greater in women. These results suggest that men and women differentially recruit spatial processing areas depending on the nature and difficulty of the task.

Studies of sex differences related to auditory tasks have focused predominantly on language and semantic processing [15]. We were interested in whether sex-related processing differences during *spatial* task performance would be found in the auditory and haptic domains. In a recent ERP study we observed that proprioceptive cues interact with auditory attention such that less extended processing is necessary when subjects touch a sound source [16]. In the current study, we specifically wanted to investigate whether a complex spatial task requiring multisensory integration in a non-visual domain would reveal differences in how the sexes recruit cortical processing resources. We anticipated that in concordance with previous findings from visuospatial studies [3, 5, 6, 9], men’s performance would reflect earlier sensory gating and categorization of the auditory spatial information in keeping with the application of bottom-up gestalt processing and that in contrast women’s performance would reflect later, cognitive top-down processing. Such a finding would suggest that the sex differences observed in previous visuospatial tasks are robust across different sensory modalities and reflect a difference in general strategic approaches between men and women in spatial tasks.

METHODS

Subjects

Twenty subjects (10 women; ages 18–32, $M=21.6$) participated after giving written informed consent; 18 were right-handed (as assessed through self-report). The experiment was approved by the North Dakota State University Institutional Review Board for the protection of human participants in research.

Stimuli and Apparatus

A fast-paced random sequence of pink noise bursts (50 ms, at 76 dB SPL) was delivered by two loudspeakers (left/right, 60 apart, at 60 cm distance). Stimuli were delivered in sequence as per a classic auditory sustained attention oddball paradigm, and not dichotically. Oddball stimuli occurred 5% of the time, with attended “target” stimuli thus occurring 2.5% of the time. Frequent “standard” stimuli occurred 47.5% of the time from each speaker. Stimuli were presented with an inter-stimulus interval of 120–360 ms, with no two targets ever occurring in succession. In the *hold* condition, subjects cupped their hands around the sides of the speakers with their palms in direct contact with the speakers. In the *lap* condition, subjects rested their hands in their laps. The task requirements were identical.

Procedure

We used a central fixation point throughout each block in order to minimize blinks and eye movements. The subjects’ task was to attend to either the left or right speaker and to respond to occasional increased-bandwidth oddballs (i.e., targets) from the attended speaker by pressing a footswitch, and to ignore all stimuli from the other speaker. Subjects completed 12 experimental blocks lasting 3.5 minutes each. The *hand position* occurring first was randomized, and an attend left and an attend right block was run before the next *hand position* was presented. Whether subjects attended left or right first was counterbalanced. *Hand position* conditions were interleaved.

Behavioral data

Percentage of correct target detections (hits) and mean reaction time (RT) were calculated for each combination of attended target *location* (*left*, *right*) and *hand position* (*lap*, *hold*). A response was associated with a preceding target if it occurred 200–800 ms after its onset. Responses outside this window were classified as false alarms. In order to examine potential differences in accuracy and RT between conditions, mixed-measures ANOVAs were run using the within-subject factors of *hand position* (*lap*, *hold*) and target *location* (*left*, *right*), and the between-subjects factor of *sex* (*male*, *female*).

ERP recording

EEG was recorded from 162 scalp sites and the EOG was monitored with a total of six electrodes located at the outer canthi and above and under each eye. Impedances at all electrode sites were kept below 5 kOhms. Automated artifact rejection was performed prior to averaging to discard trials during which an eye movement, a blink, or amplifier blocking occurred. Artifact criteria of $\pm 120 \mu\text{V}$ from -100 to 600 milliseconds of stimulus onset were applied. The remaining trials were averaged per condition, with a baseline of -100 to 0 ms.

ERP data analysis

ANOVAs were carried out comparing mean amplitudes within specified time windows centered to the peak deflections of interest and referenced to the prestimulus baseline. Greenhouse-Geisser corrections were applied as necessary for violations of sphericity. The

following time windows were tested: 60–110 ms (P1 wave), 125–145 ms (N1 wave), 240–280 ms (N2 wave), and 200–450 ms (P3 wave).

For the P1, N1, and N2 time windows, amplitudes were measured at 26 frontocentral sites in three clusters: a left and right cluster of ten electrodes per hemisphere, and a central cluster of six electrodes (left: F1 to F3 down to C1 and C3 in the 10–10 system; right: F2 to F4 down to C2 and C4; center: Fz to Cz). For the P3 time window, amplitudes were measured at 18 parietocentral sites in three clusters: a left, right, and center cluster of six electrodes each (left: P1 to P3 up to CP1; right: P2 and P4 up to CP1; center: CPz down to Pz).

For the P1, N1 and N2 latency ranges mean ERP amplitudes of attended and unattended standard stimuli were subjected to mixed-measures ANOVAs with the within-subject factors *hand position* (*lap*, *hold*), *stimulus location* (*left*, *right*), *attention* (*left*, *right*) and *cluster* (*left*, *right*, *center*), and the between-subjects factor *sex* (*male*, *female*). For the P3 latency range, mean ERP amplitudes of the attended and unattended oddball stimuli were subjected to an ANOVA with the same factors.

RESULTS

Behavioral data

There was a main effect of *sex*: men were far more accurate in detecting attended oddballs than women ($F[1,18]=10.79$, $p<.01$, $h^2=.38$; male $M=93\%$; female $M=84\%$). No other significant differences were observed for RT or accuracy.

ERP data

The P1 wave elicited by standard stimuli had a frontocentral peak latency of 80 ms post-stimulus. It did not differ in amplitude across *hand positions* ($F[1,18]=1.2$, $p>.29$), and was independent of *sex* ($F[1,18]=.64$, $p>.44$). However, there was a significant *attention* $\times$ *location* effect ($F[1,18]=6.37$, $p<.03$, $h^2=.26$), with the mean P1 amplitude appearing to be larger for stimuli emerging from attended locations, replicating a well-established finding in the literature [17].

The next clear deflection observed was the N1 wave (an index of early sensory processing, i.e., feature encoding [18]), with a peak latency of 142 ms. Subjects showed a larger N1 in the *lap* condition than in the *hold* condition ($F[1,18]=5.31$, $p<.04$, $h^2=.23$). Critically, there was also an effect of *sex*: the N1 amplitude was larger for males than females ($F[1,18]=4.81$, $p<.05$, $h^2=.21$). The ANOVA revealed a classic *attention* $\times$ *location* interaction: amplitudes appeared to be larger for attended vs. unattended stimuli. ($F[1,18]=60.36$, $p<.001$, $h^2=.77$). Finally, there was a significant *location* $\times$ *cluster* interaction, with the N1 amplitude appearing to be consistently larger at electrodes contralateral to the stimulated side compared with ipsilateral or central clusters ($F[2,17]=20.1$, $p<.001$, $h^2=.7$).

We observed the N2 deflection at a peak latency of 274 ms. This waveform usually reflects categorization and further processing mechanisms [17, 19, 20, 21, 22]. As with our previous study [16], there was a main effect of *hand position* ($F[1,18]=6.98$, $p<.02$, $h^2=.28$), with amplitudes in the *hold* condition attenuated in comparison to *lap*. Again, there was a main effect of *sex*: women had a larger N2 than men ($F[1,18]=11.61$, $p<.01$, $h^2=.39$). A visual inspection of Figure 1 suggests females also had an extended N2 latency. Again we observed the classic effects, with amplitude apparently larger to stimuli presented at attended locations ($F[1,18]=7.11$, $p<.02$, $h^2=.28$) and also apparently larger at electrodes contralateral to the attended side ($F[2,17]=4.46$, $p<.03$, $h^2=.34$).

The P3 is a waveform elicited by rare stimuli presented in a recurring sequence, and has a parietocentral topography [23]. As seen in Figure 2, there was a significant main effect of *sex*: men showed a larger P3 amplitude to the attended oddballs compared to women ($F[1,18]=4.37$, $p<.05$, $h^2=.2$). We also observed an established *attention x location* effect, with larger P3 amplitudes for oddball stimuli in attended locations ($F[1,18]=23.92$, $p<.001$, $h^2=.57$). Finally, there was a main effect of *cluster*, apparently reflecting larger amplitudes at left electrodes in comparison to right or center electrodes ($F[2,17]=4.14$, $p<.03$, $h^2=.33$).

DISCUSSION

We replicated the finding from our previous study [16] that the N2 amplitude is significantly attenuated when participants are holding the speakers, and extended this result by observing a similar effect on the amplitude of the N1. These findings indicate less effortful processing when participants are touching the speakers because they are aware of the position of their limbs in peri-personal space, as confirmed by previous findings in studies with monkeys [24] and humans [25].

The new findings are ERP differences between the sexes. Male participants had larger N1 and P3 amplitudes, whereas female participants had a larger N2. The larger N1 observed in males suggests that men are implementing spatial processing strategies in early categorization stages of processing; the larger N2 amplitude in women suggests that they utilize later, more effortful cognitive processing strategies when performing this demanding spatial task. Of interest, in a visual inspection of more accurate female performers in comparison to less accurate male performers, we still observed larger N2 amplitudes in women compared to men. Thus males and females appear to demonstrate differential processing regardless of their individual performance. We also observed a larger P3 deflection to attended oddballs in men, which suggests a more rigorous application of short-term memory updating during task performance [23]. This is consistent with our finding that men were on average 9% more accurate. Overall, our findings with auditory stimuli are consistent with previous findings that when performing visuospatial tasks men use a stimulus-driven approach while women utilize cognitive strategies [3, 5, 6, 9, 13, 14].

To our knowledge this is the first study to show ERP differences between the sexes during an auditory spatial task performed in peri-personal space. That men and women utilized different strategies to perform the task in the present study is evident, but it is not clear whether these differences are due to inherent differences occurring on a macroscopic organizational level, or to differences at a more microscopic level such that hormonal or environmental factors have a primary impact on observed sex differences. The present results do suggest, however, that men use bottom-up processing at early, semi-automatic stages while women use later cognitive top-down strategies to perform spatial tasks. These differences in strategic approach appear to be generalizable across sensory modalities.

CONCLUSION

We found evidence that during a non-language auditory spatial task in peri-personal space, men and women adopt different strategies during task performance. Women appear to use a cognitive, top-down approach that requires later, extended processing and the recruitment of frontal neural networks while men appear to use bottom-up gestalt strategies that require earlier recruitment of spatial processing networks.

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References

1. Lewald J. Gender-specific hemispheric asymmetry in auditory space perception. *Cognit Brain Res*. 2004; 19:92–99.
2. Parsons TD, Larson P, Kratz K, Thiebaut M, Bluestein B, Buckwalter JG, et al. Sex differences in mental rotation and spatial rotation in a virtual environment. *Neuropsychologia*. 2004; 42:555–562. [PubMed: 14728927]
3. Hugdahl K, Thomsen T, Ersland L. Sex differences in visuo-spatial processing: An fMRI study of mental rotation. *Neuropsychologia*. 2006; 44:1575–1583. [PubMed: 16678867]
4. Bell EC, Willson MC, Wilman AH, Dave S, Silverstone PH. Males and females differ in brain activation during cognitive tasks. *NeuroImage*. 2006; 30:529–538. [PubMed: 16260156]
5. Boghi A, Rasetti R, Avidano F, Manzone C, Orsi L, D'Agata F, et al. The effect of gender on planning: an fMRI study using the Tower of London Task. *NeuroImage*. 2006; 33:999–1010. [PubMed: 17005420]
6. Butler T, Imperato-McGinley J, Pan H, Voyer D, Cordero J, Zhu Y, et al. Sex differences in mental rotation: Top-down versus bottom-up processing. *NeuroImage*. 2006; 32:445–456. [PubMed: 16714123]
7. Gorbett DJ, Sergio LE. Preliminary sex differences in human cortical BOLD fMRI activity during the preparation of increasingly complex visually guided movements. *Eur J Neurosci*. 2007; 25:1228–1239. [PubMed: 17331218]
8. Lamm C, Bauer H, Vitouch O, Göttschnigg R. Differences in the ability to process a visuo-spatial task are reflected in slow cortical potentials in human subjects. *Neurosci Lett*. 1999; 269:137–140. [PubMed: 10454151]
9. Vaquero E, Cardoso MJ, Vázquez M, Gómez CM. Gender differences in event-related potentials during visual-spatial attention. *Intern J Neuroscience*. 2004; 114:541–557.
10. Neufang S, Specht K, Hausmann M, Güntürkün O, Herpertz-Dahlmann B, Fink GR, et al. Sex differences and the impact of steroid hormones on the developing human brain. *Cercor*. 2008 advance access published. doi: 10.1093.
11. Hausmann M, Slabbekoorn D, Van Goozen SHM, Cohen-Kettenis PT, Güntürkün O. Sex hormones affect spatial abilities during the menstrual cycle. *Behav Neurosci*. 2000; 114:1245–1250. [PubMed: 11142657]
12. Bayer U, Kessler N, Güntürkün O, Hausmann M. Interhemispheric interaction during the menstrual cycle. *Neuropsychologia*. 2008; 46:2415–2422. [PubMed: 18420232]
13. Frost JA, Binder JR, Springer JA, Hammeke TA, Bellgowan PSF, Rao SM, Cox RW. Language processing is strongly left lateralized in both sexes. *Brain*. 1999; 122:199–208. [PubMed: 10071049]
14. Jordan K, Wüstenberg T, Heinze H, Peters M, Jäncke L. Women and men exhibit different cortical activation patterns during mental rotation tasks. *Neuropsychologia*. 2002; 40:2397–2408.
15. Halpern, DF. Sex differences in cognitive abilities. 2. Hillsdale (NJ): Lawrence Erlbaum; 1992.
16. Simon-Dack SL, Teder-Sälejärvi WA. Proprioceptive cues modulate further processing of spatially congruent auditory information. A high-density EEG study. *Brain Res*. 2008; 1220:171–178. [PubMed: 17999923]
17. Näätänen, R. Attention and brain function. Hillsdale: New Jersey; 1992.
18. Näätänen R, Picton T. The N1 wave of the human electric and magnetic response to sound: a review and an analysis of the component structure. *Psychophysiology*. 1987; 24:375–425. [PubMed: 3615753]
19. Teder W, Alho K, Reinikainen K, Näätänen R. Interstimulus interval and the selective attention effect on auditory ERPs: “N1 enhancement” versus processing negativity. *Psychophysiology*. 1993; 30:77–87.

20. Teder W, Näätänen R. Event-related potentials demonstrate a narrow focus of auditory spatial attention. *NeuroReport*. 1994; 5:709. [PubMed: 8199343]
21. Teder-Sälejärvi W, Hillyard SA. The gradient of auditory spatial attention in free-field: An event-related potential, ERP) study. *Percept Psychophys*. 1998; 60:1228–1242. [PubMed: 9821784]
22. Teder-Sälejärvi WA, Hillyard SA, Röder B, Neville H. Spatial attention to central and peripheral auditory stimuli as indexed by event-related potentials, ERPs. *Cognit Brain Res*. 1999; 8:213–227.
23. Picton TW. The P3 wave of the human event-related potential. *J Clin Neurophysiol*. 1992; 9:456–479. [PubMed: 1464675]
24. Graziano MSA, Hu XT, Gross CG. Coding the Locations of Objects in the dark. *Science*. 1997; 277:239–241. [PubMed: 9211852]
25. Dufour A, Touzalin P. Improved visual sensitivity in the perihand space. *Exp Br Res*. 2008 Accepted May 2008. 10.1007/s00221-008-1453-2

Figure 1.

Grand-average ERPs (referenced to average mastoids) to attended standard stimuli over five frontocentral sites approximating the locations of FC1, FC2, FC3, FC4, and FCz in the 10–10 system. Top panel: males versus females, *lap* attend left/right. Bottom panel: males versus females, *hold* attend left/right.

Figure 2.
Grand-average ERPs to attended oddball stimuli (sites identical to Fig. 1). Top panel: males versus females, *lap* attend left/right. Bottom panel: males versus females, *hold* attend left/right.