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Gender differences in pre-attentive change detection for visual but not auditory stimuli

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HIGHLIGHTS

- We compared pre-attentive processing in males and females across visual and auditory modalities.
- No significant gender differences were observed for auditory MMN (aMMN) amplitude, but visual MMN (vMMN) amplitude was higher in males than females.
- Increment duration vMMN could be a good indicator for pre-attentive processing.

ABSTRACT

Objective: Despite ongoing debate about gender differences in pre-attention processes, little is known about gender effects on change detection for auditory and visual stimuli. We explored gender differences in change detection while processing duration information in auditory and visual modalities.
Method: We investigated pre-attentive processing of duration information using a deviant-standard reverse oddball paradigm (50 ms/150 ms) for auditory and visual mismatch negativity (aMMN and vMMN) in males and females ($n = 21$/group).
Result: In the auditory modality, decrement and increment aMMN were observed at 150–250 ms after the stimulus onset, and there was no significant gender effect on MMN amplitudes in temporal or fronto-central areas. In contrast, in the visual modality, only increment vMMN was observed at 180–260 ms after the onset of stimulus, and it was higher in males than in females.
Conclusion: No gender effect was found in change detection for auditory stimuli, but change detection was facilitated for visual stimuli in males.
Significance: Gender effects should be considered in clinical studies of pre-attention for visual stimuli.

1. Introduction

Pre-attentive detection of change in the environment is fundamental for adapting to a rapidly changing environment and ensuring survival (Nagy et al., 2003). Because mismatch negativity (MMN) can be generated under non-attentional conditions, it has been considered to be an index of pre-attentive sensory memory. Relative to the memory template formed in response to standard auditory stimuli, MMN generated by deviant stimuli is a negative event-related potential (ERP) component that peaks at 100–250 ms and may have altered duration, frequency, and/or more complex properties (e.g., emotional words, syntax) (Naatanen, 2000; Naatanen et al., 2007). Auditory MMN (aMMN) has been widely studied to elucidate the mechanisms and cortical networks

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underlying pre-attentive processing. Indeed, aMMNs include two sub-components: (1) the supra-temporal subcomponent, generated from the bilateral supra-temporal area, which is related to detection of pre-perceptual change, and (2) the frontal subcomponent, produced predominantly from the right frontal area, which is associated with involuntary attention switch caused by input information changes (Alho, 1995; Escera et al., 1998; Naatanen et al., 2007; Rinne et al., 2000).

In addition to the auditory modality, MMN has been observed in the visual modality. Recent studies have demonstrated visual MMN (vMMN) for color (Czigler et al., 2004), motion direction (Pazo-Alvarez et al., 2004), orientation (Astikainen et al., 2008), spatial frequency (Kenemans et al., 2003), shape (Tales et al., 1999), duration (Chen et al., 2010; Qiu et al., 2011), and facial expressions (Chang et al., 2011; Zhao and Li, 2006). vMMN is a negative ERP component measured at the temporo-occipital electrodes with variable latency between 150 and 350 ms after stimulus onset. vMMN represents memory-based detection of deviant visual stimuli. Importantly, a recent study by Berti et al. further supported that vMMN reflected a pre-attentive process of visual deviance detection (Berti, 2011). Moreover, two recent reviews provided indirect evidence for the pre-attentive nature of vMMN (Kimura, 2012; Winkler and Czigler, 2012).

Some evidence suggests that gender differences in incidental learning and visual recognition memory could be due to greater unconscious processing of environmental stimuli in females (McGivern et al., 1998), implying that pre-attentive processing might explain gender differences in cognition. To test this hypothesis, several studies investigated gender effects on aMMN with inconsistent results (Aaltonen et al., 1994; Barrett and Fulfs, 1998; Hansenne et al., 2003; Ikezawa et al., 2008; Kasai et al., 2002; Matsubayashi et al., 2008; Nagy et al., 2003; Schirmer et al., 2005). For example, compared to males, females exhibited larger aMMN in response to changes in intensity of pure tonal stimuli and vocal emotional expressions (Barrett and Fulfs, 1998; Ikezawa et al., 2008; Schirmer et al., 2005), and this effect was stronger in the right hemisphere (Ikezawa et al., 2008). In contrast, one magneto-encephalography (MEG) study showed that males had stronger aMMN in the left hemisphere than females (Matsubayashi et al., 2008). Moreover, some studies reported no gender effects on aMMN amplitude in response to tonal, phonetic, or frequency changes (Aaltonen et al., 1994; Hansenne et al., 2003; Kasai et al., 2002). A possible explanation for these diverse results could be methodological variance among experiments. For example, dichotic listening tasks do not allow control of inattention purity, which is critical to measure MMN. Furthermore, using the traditional oddball paradigm to obtain MMN can create confounds. In this paradigm, aMMNs are derived by subtracting the ERP waveforms elicited by standard stimuli from those of deviant stimuli. Because standard stimuli are presented more frequently, their neuronal processing likely has greater refractory effect than deviant stimuli. Thus, MMN could confound the detection of differences in low-level processing between deviant and standard stimuli. In addition, when deviant and standard stimuli in the same oddball block are compared directly, different physical stimuli can elicit offset responses. This may also lead to errors in estimating the pre-attentive memory comparison-based MMN (Jacobsen and Schroger, 2003). Consequently, our study controlled inattention purity and refractory effects to measure MMN.

To our knowledge, only one study using the traditional oddball paradigm has reported no impact of gender on vMMN (Langrova et al., 2012). However, the human perceptual system relies more on vision than audition to characterize physical objects. The scalar timing model proposed by Gibbon and attention shift hypothesis proposed by Penney suggest that auditory stimuli are often experienced as lasting longer than visual stimuli of equivalent duration, and discrimination is more accurate for auditory than for visual stimuli, implying that auditory stimuli are easier to detect (Gibbon, 1991; Penney et al., 2000; Penney, 2003). Interestingly, Jausovec and Jausovec found that responses under attentional control (e.g., early evoked gamma response, as well as P1 and P3 components), which were larger in females, showed more noticeable gender differences in the visual modality than in the auditory modality (Jausovec and Jausovec, 2009a,b). We hypothesized that gender differences in change detection would be evident in the visual modality, but not in the auditory modality because auditory stimuli are more easily differentiated, thus creating a ceiling effect.

A critical factor in measuring MMN is the difference in refractory response of the neural populations that respond to frequent and infrequent stimuli (Peter et al., 2010). Schroger and Wolff developed an equal-probability sequence protocol that equalizes the state of refractoriness for control and deviant stimuli (Schroger and Wolff, 1996). Specifically, they reported that the equal-probability sequence control condition produced the same result as the deviant-standard reverse oddball modality. Moreover, Evstigneeva and Aleksandrov explained these findings, reporting that deviant stimuli could elicit genuine MMN using the deviant-standard-reverse method with a "safe" presentation probability of 15%, and a presentation probability of 20% can control the refractoriness more effectively than 15% (Evstigneeva and Aleksandrov, 2009). It is worthwhile to note that the deviant-standard-reverse paradigm cannot completely exclude refractoriness due to the different percentages of standard and deviant stimuli, but it can effectively control the refractoriness. Jacobsen and Schorger used this paradigm only for aMMN. We believe that the paradigm also applies to vMMN because the refractory effect likely arises due to different frequencies of stimulation, which should occur in all types of neurons. Because the deviant-standard-reverse paradigm is easier to construct and can effectively control refractoriness, the present study used this paradigm with a greater deviant stimulus presentation probability of 20% to obtain genuine duration aMMN/vMMN, reflecting memory-based mismatch detection.

2. Method

2.1. Participants

Participants included 22 female (25–45 y, mean 32.7 y) and 22 male (24–46 y, mean 31.3 y) Chinese adults. One female and one male were excluded from the analyses because of excessive artifacts in the EEG recording, leaving 21 females and 21 males in the statistical analyses. All participants were right-handed, reported normal auditory and normal or corrected-to-normal vision, had no history of current or past neurological or psychiatric illness, and used no medications known to affect the central nervous system. Informed consent was obtained from each subject, and experimental procedures were approved by the Ethics Committee of the Department of Psychology, Harbin Medical University.

2.2. Stimuli and procedure

All participants were seated in a comfortable chair in front of the center of screen in a darkened, sound-attenuated, and electrically-shielded room. The experiment consisted of two separate tasks with the order counterbalanced across participants.

Task1: Duration vMMN

Subjects were instructed to focus their attention on a black cross in the center of the screen, which was displayed throughout the stimulus blocks. Two solid black squares (1 cm × 1 cm) were