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Mismatch negativity and psychophysical detection of rising and falling intensity sounds

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ABSTRACT

Human subjects demonstrate a perceptual priority for rising level sounds compared with falling level sounds. The aim of the present study was to investigate whether or not the perceptual preference for rising intensity can be found in the preattentive processing indexed by mismatch negativity (MMN). Reversed oddball stimulation was used to produce MMNs and to test the behavioral discrimination of rising, falling and constant level sounds. Three types of stimuli served as standards or deviants in different blocks: constant level sounds and two kinds of rising/falling sounds with gradual or stepwise change of intensity. The MMN amplitudes were calculated by subtracting ERPs to identical stimuli presented as standard in one block and deviant in another block. Both rising and falling level deviants elicited MMNs which peaked after 250 ms and did not overlap with N1 waves. MMN was elicited by level changes even when the deviants were not discriminated behaviorally. Most importantly, we found dissociation between earlier and later stages of auditory processing: the MMN responses to the level changes were mostly affected by the direction of deviance (increment or decrement) in the sequence, whereas behavioral performance depended on the direction of the level change within the stimuli (rising or falling).

1. Introduction

Changes in sound level, along with spectral content, can produce changes in the apparent distance to a source (Coleman, 1963, 1968; Strybel & Perrot, 1984). Signals with rising or falling sound level are generally perceived as approaching or receding sound sources (Bronkhorst & Houtgast, 1999; Zahorik, 2005). The salience of rising sound level produced by approaching sources in natural environments has been supported by a number of behavioral studies which suggested high-priority processing for approaching sounds in human and non-human primates. The subjects overestimated increasing compared to decreasing sound levels (Ghazanfar, Neuhoff, & Logothetis, 2002; Neuhoff, 1998; Stecker & Hafter, 2000) and underestimated the time to contact approaching sound sources (Rosenblum, Carello, & Pastore, 1987; Schiff & Oldak, 1990). Similar asymmetry in the discrimination of intensity increments and decrements was found in an oddball experiment (Rinne, Särkkä, Degerman, Schröger, & Alho, 2006).

The perceptual bias for approaching sound objects seems to be reflected in the pattern of neural activity (Bach et al., 2008; Hall & Moore, 2003; Lu, Liang, & Wang, 2001). Generally, converging experimental evidence suggests that brain activations due to spatial auditory processing are centered in the posterior superior temporal gyrus and planum temporale (for a review, see Alho, Rinne, Herron, & Woods, 2014). Furthermore, only the right-hemispheric auditory cortex has shown significant differences in the loci for spatial processing in passive and active listening conditions: the median locus of spatial attention-related modulations have been found in the superior temporal sulcus, significantly inferior to the median locus for passive spatial processing. The fMRI study of Seifritz et al. (2002) demonstrated that rising and falling sound levels activated the right temporal plane more than constant level sounds. Rising compared to falling levels activated a widely distributed network of activity subserving auditory spatial perception and attention. A more recent fMRI study reported activity of the right amygdala and left temporal areas in response to rising compared to falling sound level (Bach et al., 2008).

Previous electrophysiological studies of auditory processing of dynamic acoustical information accumulated an ample body of data concerning cortical evoked responses elicited by changes of sound level. Two components of event-related potentials (ERPs) are thought to reflect the first stage of passive (preattentive) auditory processing: 1) the N1 wave elicited by an onset and simple change detection process (for a review, see Näätänen & Picton, 1987) 2) the mismatch negativity (MMN) elicited by a sensory memory-based deviance detection process (for a review, see Näätänen, Paavilainen, Rinne, & Alho, 2007). The N1 component reflects differential activation of neural elements sensitive to various stimulus features, and the MMN indexes the process of

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comparison of incoming stimuli to representations generated on the basis of temporal regularities extracted from the auditory input (e.g., Horváth, Winkler, & Bendixen, 2008). According to a more general interpretation of MMN response, the ultimate function of the MMN-generating process is to adjust neuronal models underlying detection of auditory objects by initiating changes in those particular models whose predictions were mismatched by the acoustic input (Winkler, 2007).

An important dissimilarity between the N1 and MMN components is that N1 amplitude diminishes when the stimulus intensity is decreased (Beagley & Knight, 1967; Picton, Goodman, & Bryce, 1970; Rapin, Schimmel, Tourk, Krasnegor, & Pollack, 1966), whereas MMN is elicited by both sound level increases and decreases, its magnitude following the magnitude of level changes irrespective of the direction of change (Näätänen, 1992). An MMN can be elicited by either an increment or decrement in certain acoustical dimension (e.g., intensity or frequency). If the deviant stimulus has higher intensity or frequency than the standard, the MMN generated is called an increment MMN. In the opposite direction of deviance (if the deviant has lower intensity or frequency than the standard), the MMN generated is called a decrement MMN. The effect of the direction of deviance was described for duration MMN (Colin et al., 2009; Okazaki, Kanoh, Takaura, Tsukada, & Oka, 2006; Peter, McArthur, & Thompson, 2010; Takegata, Tervaniemi, Alku, Ylinen, & Näätänen, 2008), for frequency MMN (Jacobsen & Schröger, 2001; Karanasiou et al., 2011; Peter et al., 2010) and for sound velocity MMN (Shestopalova, Petropavlovskaia, Vaitulevich, & Nikitin, 2015). These authors shared the view that increment MMNs were larger in magnitude than decrement MMNs. However, a few studies comparing the MMNs produced by increments and decrements of intensity still have not come to a definite conclusion. Some studies have reported no differences between increment and decrement intensity MMNs (Altmann et al., 2013; Näätänen, 1992), while Rinne et al. (2006) have found that decrement MMN was higher and peaked later. A comprehensive study of Jacobsen, Horenkamp, and Schröger (2003) designed in order to separate memory-comparison-related effects of intensity from refractoriness-related ones has revealed that sound level increments elicited MMNs which were higher than decrement MMNs but could hardly be separable from the N1 wave, whereas decrement MMNs were free from this contamination due to their longer latency. This discrepancy between the properties of increment and decrement MMNs is not typical for MMNs elicited by cues apart from intensity (e.g., by frequency or duration). It should be also noted that most of the above mentioned MMN studies employed constant level stimuli as standards and deviants. The only MMN experiment which used smooth intensity changes has not found any differences in MMN amplitudes and latencies for rising and falling intensity (Altmann et al., 2013).

The effect of deviance direction can be easily modeled by the reversal of the functional roles of the stimuli within the oddball sequence. The influence of standard-deviant reversals on preattentive processing of various sound features was explored in a number of studies using a reversed oddball paradigm (e.g., Jacobsen & Schröger, 2003; Peter et al., 2010). When the roles of standards and deviants are reversed, an increment sequence turns into a decrement one, and vice versa. Hence, the change of the context within which a rising/falling level sound appears (i.e., the change of the sequence structure) makes it possible to obtain the same direction of deviance (for instance, increment) using opposite directions of sound level change: the sequences containing rising intensity deviants in the context of constant standards or constant deviants in the context of falling level standards both represent the increment configurations. So, the reversed oddball stimulation can be used to separate the effect of the deviance direction from the effect of the direction of sound level change.

Our working hypothesis about the differences between direction of level change (rising or falling) and direction of deviance (increment or decrement sequence) can be exemplified by an increment sequence containing rising deviants among constant standards and two possible opposite configurations. The perceptual priority for rising intensity predicts that behavioral performance would be better 1) for rising deviants among constant standards as compared to falling deviants among constant standards 2) for constant deviants among rising standards as compared to constant deviants among falling standards. If the same bias can be found in MMN responses, the sequences containing rising stimuli would produce higher MMNs (compared to the sequences with falling ones), no matter what the functional role of a rising level stimulus will be, standard or deviant. Then the MMN amplitude elicited by rising deviants among constant standards would be in similar proportions to the MMNs elicited in the two opposite configurations as described above for the behavioral performance. On the contrary, if the MMN-generating mechanisms are related to more general sequence properties aside from rising or falling stimulus level, the proportions between MMN responses would not parallel the psychophysical data.

The question addressed by the present study is whether or not the perceptual preference for rising intensity can be found in the preattentive processing indexed by MMN. The data accumulated by now suggest that behavioral deviance detection may be at least partially governed by the processes underlying MMN generation, and the MMN mechanism may serve as an “alarm signal” which can initiate an attentional switch to a deviant event and exert influences observable at the behavioral level (Paavilainen, 2013; Winkler, 2007). According to another assumption, rising sound level may serve as an intrinsic, unconditioned warning cue which may enhance activation of early preattentive processes related to stimulus detection (Bach et al., 2008). We expected therefore to find a priority for the processing of rising intensity in the behavioral and electrophysiological measures.

In the current experiment we have used the reversed oddball stimulation to produce the MMNs and to test the behavioral discrimination of rising, falling and constant level sounds. During psychophysical measurements, our subjects were required to detect the deviant sounds in the oddball sequences similar to those used to elicit the MMNs. We expected that rise and fall of signal intensity should exert significant effect on the behavioral responses. The speed of the level change was varied using two temporal patterns of rising and falling intensity (gradual and stepwise change). In regard to our earlier MMN study which employed gradual and stepwise change within the stimuli (Shestopalova et al., 2015), we anticipated that the stepwise change of intensity would elicit higher MMNs relative to gradual one, and that both increment and decrement intensity MMNs would be easily separable from the N1 wave. Thus, we contrasted the effects of the level change direction within the stimuli and of the deviance direction in the sequence (i.e., of the configuration reversal) on the MMN amplitude and latency.

2. Methods

2.1. Participants

Nine paid volunteers (1 male, 8 females, aged 27.3 ± 5.8 years, mean ± SD, all right-handed) participated in the experiments. All subjects had normal hearing (self-reported) and no history of neurological or otological disease. Research protocols were approved by the Ethical Committee (IRB) of St.-Petersburg State University (N02-79). Written informed consent from the subjects was obtained prior to the study.

2.2. Apparatus and stimuli

The subjects were seated in a sound-attenuated and electrically shielded chamber and were diotically presented with blocks of auditory stimuli. Each subject participated in a complete experimental cycle consisting of electrophysiological and psychophysical parts. At the beginning of each experimental session the hearing thresholds of the listener’s left and right ear were measured by a simplified staircase procedure, using noise bursts of the same bandwidth as in the main