



# Differences in Pre-Attentive Processes of Sound Intensity Change Between High- and Low-Sensation Seekers

## A Mismatch Negativity Study

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**Abstract:** High-sensation seekers are prone to search for changing stimuli. Pre-attentive processes reveal the earliest cortical change detection in response to external stimulus changes. This study recorded the mismatch negativity (MMN) to intensity increments and decrements in a repetitive tone in high- and low-sensation seekers. It was found that the MMN amplitude for intensity-decrement deviants was larger in high- than low-sensation seekers. However, with regard to deviant-increment stimulation, the difference between the two groups was not significant. Consequently, the sensitivity of high-sensitivity seekers to pre-attentively detect a decrease in sound intensity is higher than that of low-sensation seekers.

**Keywords:** sensation seeking, sound intensity, pre-attentive detection, mismatch negativity (MMN)

Sensation seeking (SS) as a personality trait has drawn the attention of many researchers for its association with several youth behavioral problems. For example, previous research has shown that SS and impulsive control served as significant predictors of delinquency (Peach & Gaultney, 2013). The highest rates of delinquency were associated with high SS, high peer deviance, and low levels of parental monitoring (Mann, Kretsch, Tackett, Harden, & Tucker-Drob, 2015). Rahmani and Lavasani (2011) revealed a significant positive relation between Internet dependency with overall seeking and its subscales of disinhibition and boredom susceptibility. LaBrie, Kenney, Napper, and Miller (2014) found that SS can predict drinking behavior. Social disinhibition, as an aspect of SS, also mediated the relationship between engagement in other risk behavior and alcohol use (Wilkinson et al., 2011). Moreover, high levels of SS were associated with increased risk for both alcohol and cannabis dependence (Kaynak et al., 2013).

The construct of SS was first proposed by Zuckerman (1971), who defined it as a need to seek changing, novel, and complex stimulus and experiences; his definition indicated that seeking a changing stimulus is one of the primary characteristics of high-sensation seekers. However, the reason why high-sensation seekers are prone to seek changing stimulus remains unclear. Zuckerman (1994) proposed a model with three basic hypotheses: SS is a product of the evolutionary past; an abundant genetic evidence should be available for SS; and physical evidence can be found in the cognitive neural processes associated with SS. The first hypothesis has not been tested by objective experiments yet. The second hypothesis has got support from some behavioral genetic studies, which showed that the genetic effects on SS are ranging from 34% to 69%, accounting for a large part of the variance (Eysenck, 1983; Fulker, Eysenck, & Zuckerman, 1980; Hur & Bouchard, 1997; Koopmans, Boomsma, Heath, & van Doornen, 1995).

The third hypothesis has got plenty of evidences from experimental studies.

Earlier studies focused on the differences in evoked potentials between high SS and low SS to investigate the physical mechanism of SS. It has been found that the evoked potential, including N1, P1, or N1/P1, to the same auditory and visual stimuli was larger for high SS compared to low SS (Buchsbaum & Stevens, 1971; Mullins & Lukas, 1987; Von Knorring & Perris, 1981) and this difference increased as the intensity of the stimuli became larger (Zuckerman, Murtaugh, & Siegel, 1974; Zuckerman, Simons, & Como, 1988). Based on these results, some researchers posited that high SS seemed to be augmenters of cortical evoked potentials and low SS tended to be reducers (Brabander, Boone, Gerits, & Witteloostuijn, 1995; Lukas, 1987; Zuckerman, 1984, 1990) according to the “augmenting-reducing” theory of Buchsbaum and Silverman (1968). The “augmenting-reducing” theory divided subjects into “augmenters” and “reducers” according to their sensitivity of evoked potentials to stimulus intensity. The evoked potentials of the former became larger as the stimulus intensity increased whereas those of the latter became smaller (Buchsbaum, 1976). A later study by Brocke, Beauducel, and Tasche (1999) used three experimental paradigms: the continuous performance task (CPT), delayed reaction time task (DRTT), and the augmenting-reducing paradigm, to connect SS trait to behavior and physiology measures. They found a positive correlation between SS (Thrill and Adventure Seeking, TAS subdivision) and the N1/P2 slope and a positive relationship between false alarms on the DRTT and Sensation Seeking Scalp (Form V) (SSS-V) total score, which also strongly supported the explanation of SS according to augmenting-reducing theory.

In addition, studies on the neurochemical bases of SS also supported the idea that SS trait has physical bases. Previous research has identified a relatively strong relationship between polymorphisms at dopamine D4 receptor loci and individual differences in self-reported novelty-seeking personality (Munafò, Yalcin, Willis-Owen, & Flint, 2008). Evidence from genetic and PET (Positron Emission Computed Tomography) radioligand displacement studies suggests that individuals higher in SS personality may exhibit both higher endogenous dopamine (DA) level and greater dopaminergic responses to cues of upcoming reward in striatal regions (Derringer et al., 2010; Gjedde et al., 2010; O’Sullivan et al., 2011; Riccardi et al., 2006; Zuckerman, 1985). Higher sensation-seekers have been reported to show lower platelet levels and carry lower activity isoforms of monoamine oxidase (MAO), an enzyme responsible for the breakdown of DA (Carrasco, Sáiz-Ruiz, Díaz-Marsá, César, & López-Ibor, 1999; Verdejo-García et al., 2013; Zuckerman, 1985). Recently, Norbury, Kurth-Nelson,

Winston, Roiser, and Husain (2015) found greater effects of a silent D2 receptor antagonist haloperidol in behaviorally defined higher sensation-seekers, suggesting a greater effect of disrupting signaling by endogenous ligand in these individuals.

In sum, most ERP (event-related potential) studies investigating the physical mechanism of SS have focused on N1 in the auditory channel, which reflected the arousal magnitude of voluntary attention. Although the N1 response indexes the sensitivity to stimulus onset, usually growing in amplitude with increased stimulus intensity (for a review, see Näätänen & Picton 1987), it cannot reflect the sensitivity of SS trait to automatic detection of stimulus change, which can be achieved by another ERP component: mismatch negativity (MMN). MMN reflects sensitivity to automatic detection of change in any repetitive aspect of auditory stimulation (Näätänen, Gaillard, & Mäntysalo, 1978; for a review, see Näätänen, Paavilainen, Rinne, & Alho, 2007) and is usually considered as a marker for pre-attentive change detection (Grimm, Roeber, Trujillo-Barreto, & Schröger, 2006; Näätänen & Michie, 1979; Näätänen, Pakarinen, Rinne, & Takegata, 2004). In addition, studies on the neural chemical mechanism of MMN have found that MMN was related to MAO and NMDA (N-methyl-D-aspartate) receptors (Harms, 2015; Smith, Fisher, Blier, Illivitsky, & Knott, 2015), which were also related to SS as reviewed before. This fact suggested that there should be potential relationship between SS and MMN from the perspective of neural chemical mechanism. Therefore, the present study aims at determining pre-attentive processing in audition, by using the traditional oddball paradigm, in high- and low-sensation seekers. We assumed that the MMN of high-sensation seekers is larger in amplitude than that of low-sensation seekers.

## Methods

### Participants

A total of 245 undergraduates (71 males and 174 females) were tested with a sensation-seeking questionnaire list (SS-IV Chinese Version; Zhang & Chen, 1990). On the basis of the SS-IV scores, 20 participants (14 females, 19.4 years old on average) were randomly selected as the high-sensation seeking (HSS) group from the upper limit 27% of the total group and 20 (13 females, 19.6 years old on average) as the low sensation seeking (LSS) group from the lower limit 27% of the total group. The mean scores were  $25.46 \pm 6.79$  and  $8.26 \pm 2.19$  for the HSS and LSS groups, respectively ( $t = 6.27$ ;  $p < .01$ ). All participants were right handed, presented normal hearing, and had no history

of psychiatric or neurological disorders. The participants signed a consent form and were paid for participation. This study was approved by the Institutional Ethical Committee of the Department of Psychology of the Central China Normal University.

## Stimuli and Experimental Program

A 1,000 Hz, 70 dB, frequent (75%) tone was used as the standard stimulus. The infrequent stimuli included six deviant tones with the same pitch (1,000 Hz) but different intensities (49, 56, 63, 77, 84, and 91 dB;  $p \approx 4.2\%$  for each deviant). We used Neuroscan Company's professional sound production instrument (Stim Audio System P/N 1105) to produce and check sound stimuli, and used its supporting software Stim2 and its hardware to present the stimuli. The deviant intensities relative to that of the standard stimulus were  $-30\%$ ,  $-20\%$ ,  $-10\%$ ,  $+10\%$ ,  $+20\%$ , and  $+30\%$ , respectively. All stimuli were binaurally presented for 50 ms. A total of 2,700 standard stimuli and 900 deviants (150 for each deviant tone) were presented. The SOA was jittered randomly from 400 ms to 500 ms. After the first 15 standard stimuli were presented, standard and deviant stimuli were delivered in a pseudorandom order to ensure that at least two standard stimuli were presented between each pair of deviant stimuli.

During the experiments, the subjects were asked to watch a self-selected silent film (with no subtitles) and ignore the sound from the headphones.

## ERP Recording

The electroencephalogram (EEG) was continuously recorded (band pass = 0.05 Hz to 100 Hz (0.05–30 Hz filtered in offline analysis); sampling rate = 1,000 Hz) on a NeuroScan Synamp2 amplifier by using an electrode cap with 64 Ag/AgCl electrodes mounted in accordance with the extended international 10–20 system and referenced to the tip of nose. Vertical and horizontal electrooculograms (EOG) were recorded with two pairs of electrodes, one was placed above and below the right eye, and the other was placed 10 mm from the lateral canthi. Electrode impedance was maintained below 5 k $\Omega$  throughout the experiment. The EEG was segmented into 500 ms epochs with the 100 ms pre-stimulus epoch serving for baseline correction. The EOG artifacts were corrected using the method proposed by Semlitsch et al. (1986). Epochs including an EEG or EOG change exceeding  $\pm 75$   $\mu$ V and the EEG to the first 15 standard stimuli were omitted from averaging.

## Data Processing and Statistical Analysis

One subject was excluded from the analysis because of very many artifacts; thus, 39 participants were analyzed (20 HSS, 19 LSS). The MMN components were calculated by subtracting the ERPs elicited by standard stimuli from those elicited by deviant stimuli. Figure 2 shows the six MMNs elicited for each deviant stimulus, considering the distinct pattern between MMNs to the intensity-decrement (49, 56, and 63 dB) and intensity-increment deviants (77, 84, and 91 dB). The mean number of artifact-free trials of each condition for HSS and LSS group was as follow: HSS group (from 49 dB to 91 dB): 127, 129, 131, 130, 128, and 128; LSS group (from 49 dB to 91 dB): 127, 134, 136, 135, 134, and 131. Based on previous studies and visual inspection, the mean amplitude of the MMN elicited by the intensity-decrement deviants was measured within the time range of 130 ms to 230 ms post-stimulus onset, whereas the mean amplitude of the MMN elicited by the intensity-increment deviants was calculated between 50 and 150 ms post-stimulus onset. Therefore, statistical analysis was separately conducted for intensity-increment and intensity-decrement deviants. In the frontocentral area, these measurements were examined by mixed-model ANOVA, with the groups (HSS and LSS) as the between-subject factors and the deviance magnitude (10%, 20%, and 30%), hemisphere (left, middle, and right), and site (AF3/F3/FC3/C3, AFz/Fz/FCz/Cz, and AF4/F4/FC4/C4) as within-subject factors. For the temporal area, four-way ANOVA of Group (HSS, LSS)  $\times$  Deviant Intensity (10%, 20%, and 30%)  $\times$  Hemisphere (left, right) was conducted. The degrees of freedom for the within-subject factors were corrected for non-sphericity by using Greenhouse-Geisser adjustment.

## Results

The MMNs elicited by the six deviant stimuli are shown in Figure 2. As shown in Figure 2, each deviant stimulus elicited MMN. The MMN exhibited two characteristics (Figures 2 and 3). First, the amplitude of MMN increased and its peak latency decreased with intensity increment in the deviant stimulus. However, the statistical analysis on peak latency revealed no significant difference among different deviant levels; therefore, latency analysis was not reported in the Results part. Second, the MMN over the right hemisphere was larger than that over the left. Group differences were observed for MMNs elicited by intensity-decrement deviants but not for those elicited by intensity-increment deviants.

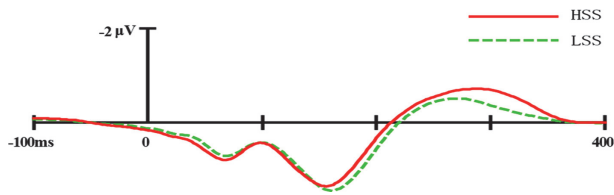


Figure 1. Grand-average ERPs to standard stimuli at FCZ electrode.

## Standard Stimuli

In order to assess whether group differences might also be present in the general response to sounds, we compared ERPs to the standard stimuli between HSS and LSS group. Mixed-model ANOVA, with the groups (HSS and LSS) as the between-subject factors and deviance magnitude (10%, 20%, and 30%), hemisphere (left, middle, and right), and site (AF3/F3/FC3/C3, AFz/Fz/FCz/Cz, and AF4/F4/FC4/C4) as within-subject factors, was conducted for mean amplitudes every 0–300 ms after stimulus onset. As shown in Figure 1, none of the main effects or interaction effects involving group were significant (all  $p > .1$ ), which suggested that HSS and LSS did not respond differently to sound in general.

## Intensity-Decrement Deviants

As shown in Figure 2, the main effect of the groups (HSS and LSS) was significant,  $F(1, 37) = 4.67$ ;  $p < .05$ ,

$\eta^2 = 0.11$ , in the frontocentral area, which showed that the mean MMN of the HSS group ( $-0.75 \pm 0.12 \mu\text{V}$ ) was larger in amplitude than that of the LSS group ( $-0.37 \pm 0.12 \mu\text{V}$ ). A significant main effect,  $F(2, 74) = 6.81$ ;  $\epsilon = 0.95$ ,  $p < .01$ ,  $\eta^2 = 0.16$  of the deviant stimulus ( $-7$ ,  $-14$ , and  $-21$  dB) was also observed. The MMN amplitudes were  $-0.27 \pm 0.13$ ,  $-0.43 \pm 0.13$ , and  $-0.98 \pm 0.16 \mu\text{V}$  for  $-7$ ,  $-14$ , and  $-21$  dB, respectively, indicating that the MMN amplitude increased with the increment of deviant-stimulus difference. As shown in Figure 3B, the main effect of the hemisphere was also significant,  $F(2, 74) = 10.36$ ;  $\epsilon = 0.63$ ,  $p < .01$ ,  $\eta^2 = 0.22$ , but qualified by the interaction of group with hemisphere,  $F(2, 74) = 8.81$ ;  $\epsilon = 0.63$ ,  $p < .05$ ,  $\eta^2 = 0.13$ . However, this interaction was not significant,  $F(2, 74) = 2.15$ ;  $\epsilon = 0.67$ ,  $p > .05$ ,  $\eta^2 = 0.04$  when the amplitudes were normalized by the method of McCarthy and Wood (1985) to ensure that the interaction is not just due to a larger MMN in the HSS group. As shown in Figure 3A, a significant main effect of the site was also observed,  $F(3, 111) = 3.83$ ;  $\epsilon = 0.48$ ,  $p < .05$ ,  $\eta^2 = 0.09$ , indicating the largest amplitudes at the anterior-frontal electrode sites ( $-0.63 \pm 0.097 \mu\text{V}$ ). No other effect reached significance ( $F_s < 1$ ).

Similar to the pattern over the frontocentral electrodes, as shown in Figures 3A and 3B, all main effects at the temporal sites except for the group effect reached significance,  $F(2, 74) = 12.06$ ;  $\epsilon = 0.99$ ,  $p < .01$ ,  $\eta^2 = 0.41$ ,  $F(1, 37) = 9.61$ ;  $p < .01$ ,  $\eta^2 = 0.21$ ; significance of Deviant Intensity and Hemisphere, respectively. No significant interactions were found.

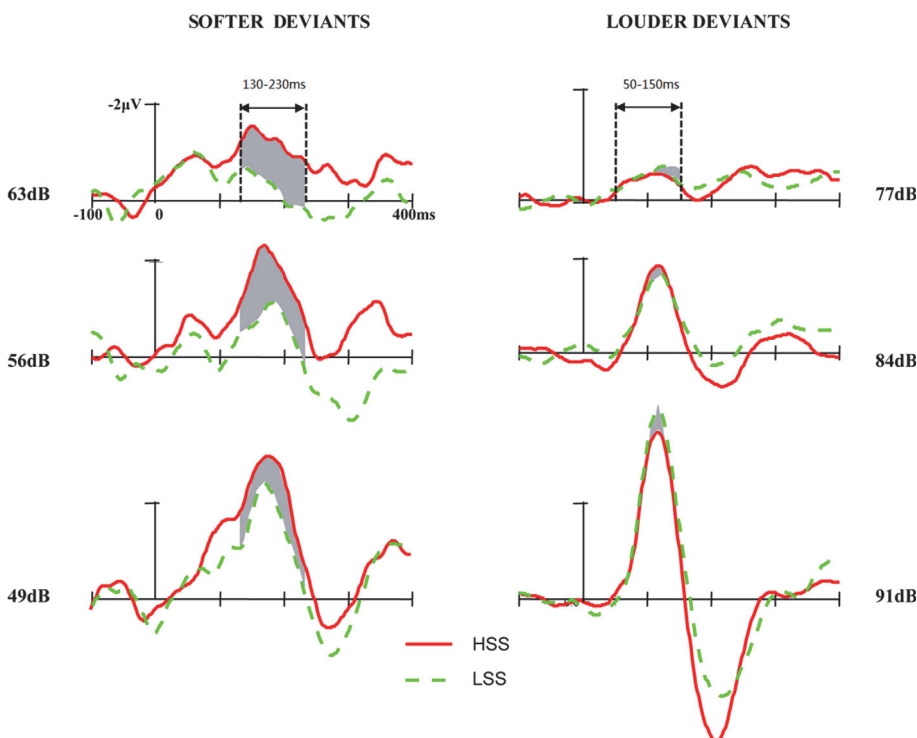
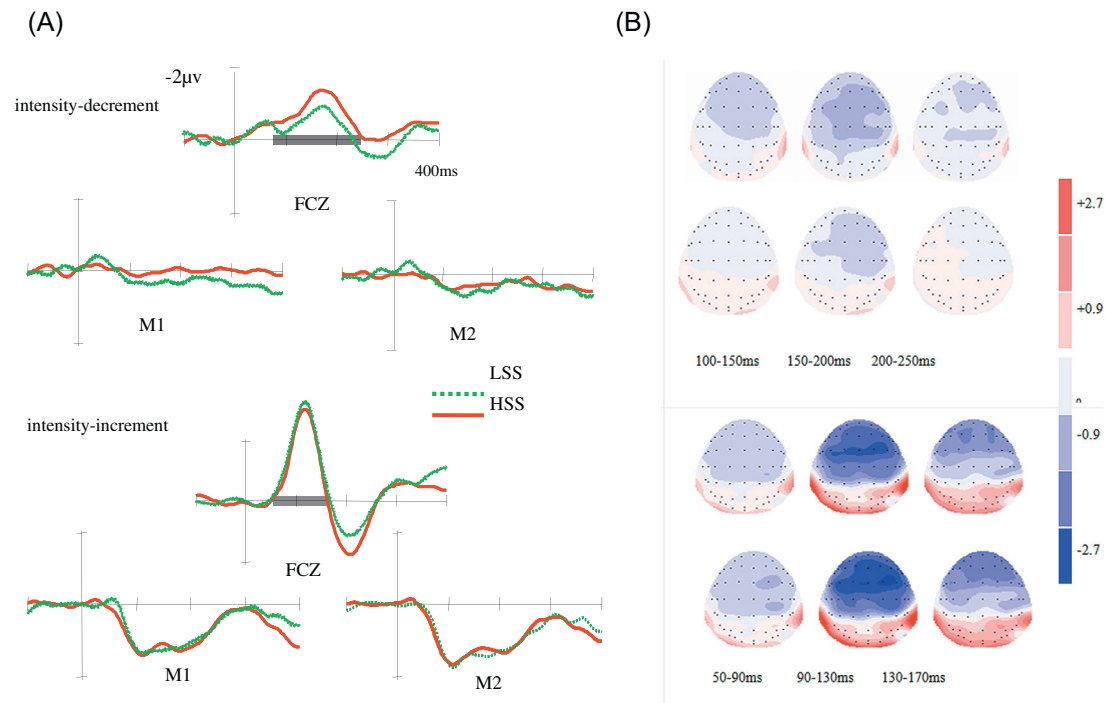


Figure 2. Grand-average MMNs elicited by six types of deviant stimuli (49, 56, 63, 77, 84, and 91 dB) at frontocentral area (FCZ).



**Figure 3.** Grand-average MMNs across intensity-increment and intensity-decrement deviants at frontocentral (FCZ) and temporal (M1 and M2) areas. Electrical waves and 2D scalp topography are shown in the left (A) and right (B), respectively.

## Intensity-Increment Deviants

Similar to the analysis of intensity-decrement deviants, as shown in Figure 2, a significant main effect of the deviant-stimulus difference,  $F(2, 74) = 56.06$ ,  $\epsilon = 0.84$ ,  $p < .01$ ,  $\eta^2 = 0.6$ , was observed in the frontocentral area, indicating that the MMN amplitudes were enhanced ( $-1.12 \pm 0.13$ ,  $-2.27 \pm 0.176$ , and  $-4.26 \pm 0.34 \mu\text{V}$  for 77, 84, and 91 dB, respectively) by the increment of deviant intensity. As shown in Figure 2B, the main effect of hemisphere also was significant,  $F(2, 74) = 14.91$ ,  $\epsilon = 0.71$ ,  $p < .01$ ,  $\eta^2 = 0.23$ , but qualified by the interaction of the group with the hemisphere,  $F(2, 74) = 8.62$ ;  $\epsilon = 0.71$ ,  $p < .05$ ,  $\eta^2 = 0.13$ . However, this interaction was not significant,  $F(2, 74) = 3.29$ ;  $\epsilon = 0.69$ ,  $p > .05$ ,  $\eta^2 = 0.08$ , when the amplitudes were normalized by the method of McCarthy and Wood (1985). A significant main effect of site,  $F(3, 111) = 21.91$ ;  $\epsilon = 0.54$ ,  $p < .01$ ,  $\eta^2 = 0.31$ , was also observed, indicating the largest amplitude at the anterior-frontal electrode sites ( $-2.51 \pm 0.17 \mu\text{V}$ ). No other effect reached significance ( $F_s < 1$ ).

Similar to the pattern over the frontocentral electrodes, as shown in Figures 3A and 3B, all main effects at the temporal sites except for the group effect were significant,  $F(2, 74) = 6.30$ ;  $\epsilon = 0.98$ ,  $p < .01$ ,  $\eta^2 = 0.13$ ,  $F(1, 37) = 13.01$ ;  $p < .01$ ,  $\eta^2 = 0.29$ ; main effects of Deviant Intensity and Hemisphere, respectively. No significant interactions were found.

## Discussion

This study generated six kinds of deviant stimuli by changing the intensity of standard stimulation. The characteristics of the MMN in the present study are consistent with previous results (Kujala, Kallio, Tervaniemi, & Näätänen, 2001; Pakarinen, Takegata, Rinne, Huotilainen, & Näätänen, 2007; Titova & Näätänen, 2001). Deviating from most of the previous studies, the present study investigated the MMN in both directions of change by employing intensity-decrement and -increment deviants. The results revealed that the amplitude of MMN generated by the intensity decrements in high-sensation seekers is significantly larger than that of low-sensation seekers. However, with regard to deviant-increment stimulation, no distinctive difference was found, which might be due to a ceiling effect on the MMN amplitude and overlap by the afferent N1 component (cf. Rinne, Särkkä, Degerman, Schröger, & Alho, 2006).

We assume that the present findings are due to the pre-attentive change-detection ability of high-sensation seekers being more sensitive than that of low-sensation seekers. In conclusion, this study indicated that high-sensation seekers demonstrated a more sensitive pre-attentive change-detection response than low-sensation seekers. This result may be associated with the fact that high-sensation seekers are inclined to prefer continuously changing environments. Some studies on the pre-attention processing of personality

traits relating to SS have indirectly supported the current results. For example, Sasaki, Campbell, Gordon Bazana, and Stelmack (2000) discovered that the amplitude of MMN elicited by changes in frequency in extrovert subjects was larger than that in introvert ones. Franken, Nijs, and Strien (2005) revealed that the scores of self-report impulsivity and the amplitude of MMN elicited by changes in frequency were positively correlated. Hansenne et al. (2003) disclosed that a harm avoidance personality correlated negatively with the amplitude of MMN elicited by changes in duration. Bar-Haim, Marshall, Fox, Schorr, and Gordon-Salant (2003) showed that the amplitude of MMN elicited by changes in frequency was smaller in social-withdrawal children than in control subjects. Given that SS traits positively correlate with impulsivity and extroversion but negatively correlate with introversion, harm avoidance, and social withdrawal (Montag & Birenbaum, 1986), our results may reveal that MMN increases in participants with traits positively correlated with SS but decreases in participants with traits negatively correlated with SS. Therefore, high-sensation seekers demonstrate greater ability to automatically detect the auditory intensity change than low-sensation seekers.

The model-adjustment hypothesis provides a possible explanation for these results with respect to the neural mechanism (Garrido, Kilner, Stephan, & Friston, 2009; Winkler, Karmos, & Näätänen, 1996). According to this hypothesis, MMN reflects the updating and adjustment of the memory trace when the deviant stimuli appear. The adjusted memory trace would treat the deviant as stimuli that might appear in future, therefore the MMN would become smaller or even vanish if the deviants continually appear in future. High-SS might be more inclined to be refractory to the stimuli appeared with larger probability (standard stimuli) and be more sensitive to changed stimulus (deviant stimulus), which leads to larger MMN for high SS compared to low SS.

The evolution hypothesis proposed by Zuckerman (1994) provided another possible explanation for why the ability to automatic detection of stimulus change was greater for high SS compared to low SS from the perspective of evolution and adaption. According to this hypothesis, when individuals faced sudden changes in their environment in ancient days, they probably demonstrated two types of reactions as follows: some individuals may take changes as signals of new partners, food, and so on. Other individuals may have taken changes as signals of danger, such as enemy, harm, and so on. The former took an approach strategy, and the latter took a withdrawal strategy. Whichever strategy was adopted, the changing environment can be either beneficial (e.g., new partners and food) or detrimental (e.g., unexpected enemies and danger of death). The one who benefited from environmental change will tend to

utilize approach strategy, and the other who failed will tend to adopt withdrawal activities. High SS individuals adopted an approach strategy to changes while low SS individuals adopted a withdrawal strategy to changes in their adaption to changes in the environment (Zuckerman, 1990). In the neural level, the neural activities of high SS might be stronger when changes were detected than low SS and lead to larger MMN, which reflects automatic detection of changes in the environment, for high SS groups. But this view is still a hypothesis and needs more support from experimental studies.

However, Wang, Shete, Spitz, and Swann (2001) found that MMN elicited by tone intensity deviance for healthy subjects was negatively correlated with Experience seeking (ES, a subdivision of SS), which was contrary to the results of our study. We assumed that this departure was caused by differences in experimental procedures. First, their study used linked-mastoid as reference whereas we used the tip of nose. As seen in Figure 3A, the amplitude of MMN for LSS in the polarity inversion at temporal sites tended to be more positive than HSS, although this difference was not significant. Thus, the use of linked-mastoid as reference might reduce the difference of frontal MMN between HSS and LSS group when the tip of nose was used as reference, which might cause the departure between their study and the present study. Second, they used correction analysis to explore the relationship between SS and MMN whereas we compared MMN between high SS and low SS groups. In addition, this relationship was not replicated in patients with chronic primary insomnia, which casts doubts on the repeatability of this result. Third, they found correction between MMN and ES but not total score of SS questionnaire, yet we used the total score to split participants into high SS and low SS groups. However, this departure indicated that further studies are still needed to investigate the relationship between SS and MMN, for example to investigate the relationship between MMN and different subdivisions of SS.

For the deviant-increment stimulus, the amplitude of MMN showed no difference between high- and low-SS subjects. This study showed that in terms of pre-attention processing of intensity change, the MMN elicited by a deviant-decrement stimulus performed differently from that induced by a deviant-increment stimulus (Rinne et al., 2006). Rinne et al. (2006) suggested that with Oddball paradigm, the MMN reflected from pre-attention processing actually presented two subcomponents, namely, pure MMN and N1. Between the two, N1 serves to be sensitive to the exogenous physical characteristic of the stimulus, whereas pure MMN is mainly related to the stimulus change based on sensory memory. N1 appears at 100 ms or higher, and pure MMN appears at 150 ms or higher (Näätänen et al., 2007). Consistent with previous studies,

we also used the classic Oddball paradigm in our experiment. The MMN induced by the deviant-increment stimulus appears during 50–160 ms, and the wave peak is at 120 ms, but the MMN induced by the deviant-decrement stimulus appears at 80–230 ms, in which the wave peak is at 180 ms. Although both conditions can elicit N1 and pure MMN components, the MMN induced by the deviant-increment stimulus is mainly N1 but attributed to the deviant-decrement stimulus, MMN is mainly pure MMN. Sussman (2007) showed that elicitation of MMN involves two distinct but interrelated processes: standard formation and deviance detection. The latter is fully dependent upon the former. While high SS subjects produce higher amplitude responses, we cannot be sure whether this stems from creating a stronger representation of the standard or a larger error signal when detecting a deviant signal. Further experiment should be conducted using the procedure proposed by Ruhnau, Herrmann, and Schröger (2012), in which a regular cascading sequence is used as a control to the deviant, to exclude the effects of the physical attributes of the stimulus (N1) and elicit pure sensory memory based MMN.

Additionally, considering the specificity of auditory information processing, the results may be accurate only in the auditory channel. Some researchers (De Pascalis, Valerio, Santoro, & Cacace, 2007) have focused on the autonomic responses to somatosensory stimuli and found that high Impulsive-Sensation Seeking (Imp-SS) participants had a lower pre-stimulus skin conductance level (SCL) and smaller skin conductance responses (SCRs) to deviant stimuli compared to low Imp-SS participants. Additionally, their heart rate (HR) acceleration was smaller in anticipation of the first and the deviant tones whereas their decelerator response was larger relative to the HR changes observed for the low Imp-SS participants. However, there was no study on visual and somatosensory modality using ERP approach. Thus, further research is needed to use ERP to determine whether the same change exists in the visual and somatosensory modality, verifying whether this characteristic of pre-attention information processing of the sensation-seeking trait is universal. Another limitation of the present study is that we only investigated the MMN elicited by changes in intensity feature. It is not clear whether the results of this study can be extended to MMN elicited by changes in other sound features, for example, duration. Further studies should be done to investigate the relationship between SS and MMN elicited by other sound features.

## Conclusion

This study indicated that based on pre-attention reflected by the MMN, high-sensation seekers demonstrate a more sensitive change-detection processing of auditory stimulus

than low-sensation seekers. This result may be attributed to the fact that high-sensation seekers are inclined to pursue an ever-changing behavior.

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## Ethics and Disclosure Statements

All participants of the study provided written informed consent and the study was approved by the Ethics Committee of the Human Research Ethics Committee of Central China Normal University.

The authors disclose no actual or potential conflicts of interest including any financial, personal, or other relationships with other people or organizations that could inappropriately influence (bias) their work.

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