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Research article

Effects of sound pressure level and visual perceptual load on the auditory mismatch negativity

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HIGHLIGHTS

- Bayesian hypothesis testing provides moderate evidence for effects of load on the MMN.
- Further, moderate evidence against effects of SPL and load by SPL interaction on the MMN.
- In an updated meta-analysis, perceptual load decreases MMN amplitude.

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ABSTRACT

Auditory change detection has been studied extensively with mismatch negativity (MMN), an event-related potential. Because it is unresolved if the duration MMN depends on sound pressure level (SPL), we studied effects of different SPLs (56, 66, and 76 dB) on the duration MMN. Further, previous research suggests that the MMN is reduced by a concurrent visual task. Because a recent behavioral study found that high visual perceptual load strongly reduced detection sensitivity to irrelevant sounds, we studied if the duration MMN is reduced by load, and if this reduction is stronger at low SPLs. Although a duration MMN was observed for all SPLs, the MMN was apparently not moderated strongly by SPL, perceptual load, or their interaction, because all 95% CIs overlapped zero. In a contrast analysis of the MMN (across loads) between the 56-dB and 76-dB groups, evidence (BF = 0.31) favored the null hypothesis that duration MMN is unaffected by a 20-dB increase in SPL. Similarly, evidence (BF = 0.19) favored the null hypothesis that effects of perceptual load on the duration MMN do not change with a 20-dB increase in SPL. However, evidence (BF = 3.12) favored the alternative hypothesis that the effect of perceptual load in the present study resembled the overall effect in a recent meta-analysis. When the present findings were combined with the meta-analysis, the effect of load (low minus high) was −0.43 μV, 95% CI [−0.64, −0.22] suggesting that the duration MMN decreases with load. These findings provide support for a sensitive monitoring system of the auditory environment.

1. Introduction

Hearing is not as spatially restricted as other senses, so it is suitable as an early warning system to monitor the surrounding environment for novel or deviant events [2,10]. In electroencephalography, deviance detection is commonly measured with the mismatch negativity (MMN) [8,19]. The MMN is an event-related potential that is obtained by subtracting the event-related response to a *standard* stimuli from the response to *deviant* stimuli. The deviants typically differ from the standards in frequency, duration, intensity, or spatial location. The MMN is characterized by a negativity at frontal electrodes (e.g., Fz) and a positivity (polarity reversal) at the mastoids. The MMN amplitude usually peaks around 200 ms from the stimulus onset and is generated by temporal and frontal areas.

Deviance detection may vary with sound pressure level (SPL). Whereas the intensity MMN decreases with lower SPL, the frequency MMN appears to be unaffected [24]. It is unresolved if the duration MMN also decreases with lower SPL. Therefore, the primary aim of the study was to investigate effects of SPL (56, 66, and 76 dB) on the duration MMN. Here, the duration MMN was studied with a deviant that was shorter than the standard because the duration MMN is stronger for short deviants than long deviants [1].

Furthermore, deviance detection is important even if the individual is focusing on another task. Supporting evidence comes from research that found an MMN even though individuals performed a concurrent, demanding visual task [for review, see 9, see also

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30]. The degree of visual demands is central to Load theory [13,14]. According to Load theory, attentional resources are limited and targets compete with distractors for attentional resources. If a main task consumes all of the available attentional resources (i.e., high perceptual load), attention is not drawn to distractors and they are thus processed less. In support, a recent study found that high visual perceptual load strongly reduced ability to detect auditory stimuli [21]. Participants performed a letter detection task (find *X* or *N*) on a ring of six letters. During low load, the six letters were identical, and during high load, the six letters differed from each other. Simultaneously, very soft tones (1025 Hz pure tone at 28 dB SPL alone, or masked with white noise at 48 dB SPL) were occasionally presented. On each trial, subjects had to perform the visual search task and also report whether an auditory stimulus was presented. Although participants were instructed to pay attention to the tones, they could not detect them correctly during high perceptual load (i.e., lower *d*').

The results by [21] showed that high visual perceptual load strongly reduced the ability to detect concurrent auditory stimuli. When we adapted their method to investigate load effects on the duration MMN, results showed clear evidence of a duration MMN for both low and high loads, but the MMN did not decrease with high load (95% CI [−0.91, 0.85]) [30]. In a subsequent meta-analysis [30] of relevant studies ($k = 6$), MMN amplitudes were more negative during low load than high load (for the MMN difference of low minus high load, 95% CI [−0.72, −0.20]), suggesting that load decreases the MMN.

However, the true effect for an effect of load on the MMN might be overestimated. For example, effect sizes are often inflated in studies that report significant results despite small sample sizes [11]. Previous studies had small sample sizes ($n = 13$ on average). Therefore, another aim was to perform a follow-up study with a large sample size ($N = 65$) to obtain a better estimate of the true effect of perceptual load on MMN.

Furthermore, because Load theory [12] implies that weaker distracters are easier to ignore than strong distracters [but see 17,23,27], we used lower SPLs (56 and 66 dB) to test if perceptual load would decrease the MMN more strongly for soft than loud stimuli.

We presented auditory stimuli at two SPLs (56 and 66 dB) and recorded the duration MMN in an oddball paradigm to address three questions: First, are MMN amplitudes influenced by SPL? Second, does perceptual load decrease the MMN? Last, does the effect of load depend on SPL?

2. Experimental procedure

The procedure is described in the Data in Brief [29]. Participants ($N = 65$; mean age = 26.34, $SD = 6.61$; 43 women) were students from local universities in Stockholm, Sweden. One group was presented with sounds at 56 dB ($n = 32$) and the other at 66 dB ($n = 33$). Our recent study employed the same task but with sounds at 76 dB [30], and those subjects ($n = 28$) were reanalyzed (from scratch) together with the present subjects ($N = 93$). The study was approved by the Stockholm section of the Central Ethical Review Board in Sweden and was conducted in accordance with the guidelines in the Helsinki Declaration. After excluding ten participants because of excessive ERP artifacts, the final sample consisted of 83 participants (56 dB, $n = 30$; 66 dB, $n = 28$; 76 dB, $n = 25$).

2.1. Procedure and stimuli

In a speeded letter detection task, participants detected the letter X (on 20% of trials). Each trial lasted 1 s and consisted of a 6-letter ring shown for 100 ms. In the low load condition, the six letters were identical, whereas in high load, they were different. Simultaneously with letter onset, tones were presented with over-ear headphones. Participants were instructed to ignore the sounds. The standard tone (75 ms) and the deviant tone (30 ms) were complex tones with f0 = 500 Hz (higher harmonics at 1000 Hz and 1500 Hz with a drop of 3 dB/harmonic) and 5 ms fade-in and fade-out.

2.2. EEG recording

EEG data were recorded from Fpz, Fz, Cz, M1, and M2 and re-referenced to the tip of the nose.

2.3. ERP analysis

ERPs were computed for correct rejections. Epochs were extracted from 100 ms before tone onset to 400 ms after and were baseline corrected with the pre-tone interval. To identify the MMN, a difference wave was computed by subtracting the mean ERP to standards from that of deviants across both load conditions. Across subjects, there was an apparent negativity at the frontal electrodes and a polarity reversal at the mastoids between 160 and 220 ms after tone onset. For this interval (160–220 ms), mean amplitudes were extracted for Fz, Cz, and mastoids.

2.4. Data analysis

In the behavioral analysis, responses faster than 200 ms were excluded. For each condition (stimulus by load), hit rates and false alarm rates were used to compute *d*' [16].

A large p value (e.g., $p > 0.30$) does not necessarily imply that the H_0 is supported. We computed the Bayes factor (BF) to capture how much more likely the data are given H_1 rather than H_0 [3]. In calculating the BF, H_1 needs to capture predictions of the theory. Although default values are available [22], we defined H_1 mainly on the basis of previous research, as recommended [3,5].

The data were analyzed in *Matlab R2015b* (The MathWorks, Inc., Natick, Massachusetts, United States), *R* (Version 3.2.2) [20], *JASP* (Version 0.7.5) [15], and Dienes online calculator [4] to compute the BF for H_1 versus H_0.

3. Results

Grand mean ERP waveforms are presented elsewhere [29]. Table 1 shows means (and *SD*) for behavioral results and ERP mean amplitudes for standards and deviants, separately for the load by SPL conditions.

3.1. Behavioral

For detection performance, a mixed-design ANOVA of *d*' with SPL (56, 66, and 76 dB) as a between-subjects factor, and load (low, high) and stimulus (standard, deviant) as within-subjects factors showed that performance decreased with perceptual load, mean difference in $d' = -1.53$, 95% CI [−1.69, −1.37], $F(1, 80) = 337.51$, $p < 0.001$. Furthermore, the distracting effect of deviants (vs standards) was larger during low load ($M = -0.28$, $SD = 0.43$) than high load ($M = -0.12$, $SD = 0.34$); mean difference in $d' = -0.15$, 95% CI [−0.27, −0.04], $F(1, 80) = 6.66$, $p = 0.01$. This provides a manipulation check for perceptual load [7].

3.2. Event-related potentials (MMN)

Fig. 1 shows the mean MMN amplitudes at Fz, Cz, and the mastoids for each load, separately for each SPL and across SPLs. All conditions showed clear evidence for an MMN: A negativity at Fz and Cz, and a positivity (i.e., polarity reversal) at mastoids