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Brain Potentials to Sexually Suggestive Whistles Show Meaning Modulates the Mismatch Negativity

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Abstract

Electroencephalographic data suggest that spoken words produce an enhanced output of the brain's automatic deviance detection system, as reflected by the mismatch negativity (MMN). Using meaningful and non-meaningful whistles, we sought to distinguish the effect of semantic content on the brain's deviance detection system from language-specific stimulus features. In the meaningful condition, subjects heard a human "wolf whistle," which is commonly interpreted as an unsolicited expression of sexual attention. In the non-meaningful condition subjects heard an acoustically identical, but digitally rearranged, version of the wolf whistle. MMN amplitude was significantly larger when the infrequent stimulus was meaningful relative to when it was meaningless. These data suggest that enhanced MMN magnitude was due to the semantic valence of the eliciting deviant.

Keywords

deviance detection; mismatch negativity; event-related potentials; meaningful non-speech stimuli

Introduction

Recent studies have reported that the detection of acoustic deviance in the early processing of auditory information is modulated by the linguistic status of a stimulus [1–5]. These studies advanced the idea that long-term memory traces for phonemes or words in a subject's language are activated during the automatic processing of spoken language and modulate the intensity of the output of the deviance detection system. Normally, responses of the brain's deviance detection system increase in proportion to the degree of physical acoustic dissimilarity between two stimuli. However, Näätänen [3] reported that within-language phonemes elicited a stronger output of the automatic deviance detection system than foreign phonemes despite an inverse correspondence of physical acoustic deviance. These results were interpreted as direct evidence of the effect of cortical traces for long term memories for phonemes on the deviance detection system. This was thought to lend weight to the idea that linguistic status determines the salience of a stimulus to the auditory deviance detection system. In another study, Pulvermüller et al [4] reported that meaningful words elicited greater output of the deviance detection system than meaningless pseudowords and concluded that their data provided evidence that the auditory deviance detection system was modulated by the activation of traces for whole words. The question we sought to answer was whether the semantic content of non-linguistic stimuli could also elicit greater output of the deviance detection system and, if so, whether it is a function of the semantic content (as opposed to linguistic status) of the eliciting event. Hence,

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we considered whether the deviance detection system could be modulated by the semantic status of non-speech stimuli.

Many researchers have used the mismatch negativity (MMN), an event-related potential (ERP) indicator of acoustic change detection, as a measure of language specific brain activity. Previous ERP studies have shown that infrequent deviant sounds occurring randomly amid a sequence of frequently occurring standard sounds elicit a negative deflection in the ERP termed the MMN [6]. Early studies reported the elicitation of an MMN by varying the acoustic parameters of simple tone pips [7]. MMNs were found to deviations based on frequency, intensity, [6], duration [8], inter-stimulus interval [9] and many other physical variables. A consensus view emerged that the MMN system effected automatic acoustic change detection by comparing the transient afferent input of deviant stimuli to the neural trace of standard stimuli that was built up over time [10]. It has also been shown that the MMN system can detect deviants that reflect “higher order” abstract rules such as the order of the tonal frequency of tone pairs independent of absolute pitch [11,12]. Since the elicitation of the MMN is independent of a subject’s attention and can be recorded while the subject reads a book or watches a silent movie, it provides a good indicator of automatic, acoustic discriminatory processes [13]

Several studies have reported that the MMN reflects higher order processing of the phonological and lexical properties of speech sounds [3,14] In the present study, we investigated whether meaningful non-speech, alexical auditory information can also reflect higher order processing. In a passive listening oddball paradigm, subjects heard a human-uttered “wolf whistle,” a two-note whistle commonly interpreted as an unsolicited expression of sexual attention, as the meaningful infrequent stimulus. An acoustically identical, but digitally rearranged, version of the same whistle formed the frequent meaningless stimulus. In another condition, further digitally rearranged versions of these stimuli were presented in an exclusively meaningless context. By using a meaningful whistle as a non-linguistic, semantic proxy for words, we specifically sought to isolate the modulating effect of semantic content on early auditory processing from language-specific stimulus features.

Methods

Participants were 16 right-handed, young adults (9 female; mean age = 23) who reported themselves to be in good mental and physical health with normal auditory acuity. All participants signed informed consent according to the guidelines provided by the New York State Psychiatric Institute’s Institutional Review Board and received payment for participating.

Stimuli were whistles first presented under ignore conditions while subjects watched a Charlie Chaplain silent film. There were two conditions, each presented separately, with the order counterbalanced across participants, meaningful (corresponding to the word condition of [5]) and meaningless (corresponding to the pseudoword condition of [5]). The infrequent deviant in the meaningful condition was a whistle highly familiar to most listeners, commonly referred to as a “wolf whistle.” A native male English speaker produced a series of bi-segmental wolf whistles that were digitally recorded at a sampling rate of 44.1 kHz. Recordings were produced monophonically with a cardioid-pattern dynamic microphone in a sound-proofed room. Exemplars of the first and second segments of all recorded wolf whistles were selected to form a primary stimulus, from which all others were constructed. The two chosen exemplar segments were digitally pasted together with a silent gap between them. The gap was normalized via digital, non-linear editing software (Sound Forge; <http://www.sonicfoundry.com/>) to 200 ms and 0 db. Standards and deviants in each condition shared the same prefix. In order to produce the prefix shared by the standard and deviant in the meaningless condition, the prefix of the meaningful condition was temporally reversed using digital methods. In this way, both standard

and deviant prefixes shared the identical frequencies, duration and overall sound energy in the two experimental conditions. Suffixes in both conditions were identical for standards and deviants. In order to produce the suffix for the standard, the deviant suffix was digitally cut into thirds and rearranged with no intervening gaps. As for the prefixes, both standard and deviant suffixes shared the identical frequencies, duration and overall sound energy (Figure 1).

The duration of prefix and suffix were, respectively 360 and 800 ms. Including the 200 ms silent inter-segment gap, total stimulus duration was 1360 ms. The ISI was 640 ms. Standards occurred with a probability of 88 percent, and deviants 12 percent. For each block of trials, there were 238 standards and 33 deviants, yielding a total of 2710 standards and 330 deviants for the 10 blocks of each condition. Including application of the electrocap, the experiment took approximately 4 hours.

After the EEG recordings, a behavioral discrimination task was administered, in which one block from each of the meaningful and non-meaningful conditions was re-administered. Participants were asked to attend to the auditory stimuli and press a button in response to the deviant. The order of the assignment of left and right response buttons to the deviant stimuli was counterbalanced across participants, with an acceptable response occurring between 200 and 1360 ms following the second segment.

EEG recordings were obtained with Synamp amplifiers (DC; 100 Hz high-frequency cutoff; 500 Hz digitization rate) from a 62-channel montage placed according to the extended 10–20 system [15] using sintered Ag/AgCl electrodes mounted in an elastic cap (Neuromedical Supplies). All leads were referred to nose tip. Horizontal and vertical electrooculograms (EOG) were recorded bipolarly with electrodes placed, respectively, at the outer canthi of both eyes, and above and below the left eye. Eye movement artifacts were corrected off-line [16].

Results

Figure 2 depicts, at 4 midline sites and the mastoids, the ERPs elicited by standards and deviants in the meaningful (left column), and non-meaningful (middle column) conditions, and the deviant minus standard difference waveforms (right column). In the unsubtracted data, the first segment, common to both standard and deviant, elicits a positivity at approximately 250 ms that does not appear to differ in amplitude between the standard and the deviant in either condition, and is clearly absent in the difference waveforms (right column). In each condition, the deviant elicits a negativity, the MMN, which is markedly larger than that elicited by the standard. The right-column data suggest that the MMN is larger in the meaningful compared to the non-meaningful condition. Note that at the mastoids there is a clear reversal of polarity for the negativities in each condition, a characteristic that has been used as evidence that a MMN is present.

The MMN was measured in the standard minus deviant difference ERPs as an averaged voltage between 240 and 340 ms following the onset of the second segment (using the 100 ms of the silent gap prior to the second segment as baseline). To determine the statistical reliability of the observed effects, the significance of the MMN values from 0 was assessed at FPz, Fz, FCz, Cz and left and right mastoids. With the exception of the MMNs at FPz, FCz, and Cz for the non-meaningful deviant, after Bonferroni correction for the number of tests, all of the remaining MMNs were reliably different from 0 ($ts > 3.91$, $Ps < 0.001$). To assess differences between conditions, a repeated-measures ANOVA (SPSS version 12 with Greenhouse-Geisser epsilon (ϵ) correction [17]), was performed on the difference mean averaged voltages from the two conditions at the 4 midline sites depicted in Figure 2. The Condition by Electrode Location ANOVA indicated that the meaningful deviant (Mean = -1.75) gave rise to a larger MMN than

the non-meaningful deviant (Mean = -1.07 ; $F(1,15) = 4.89$, $P < 0.047$). The Condition by Electrode Location interaction ($F(3,45) = 3.99$, $P < .02$, $\epsilon = 0.79$) indicated, as shown by Tukey HSD post-hoc tests, that the between-condition differences at each electrode site were reliable, but were greatest at FCz and Cz.

Following the ignore blocks, subjects completed a questionnaire on the content of the movie, on which they were very accurate (mean = $96.2\% \pm 7$). This indicates that, as instructed, all volunteers paid attention to the movie. During the attend blocks, subjects were highly accurate in detecting deviants in both conditions (meaningful = 97% ; non-meaningful = 99% ; $t(1,15) = -1.5$, $P > 0.10$). Reaction time following the onset of the second segment was 607 ms for meaningful and 601 ms for non-meaningful deviants ($t(1,15) = 0.41$, $P > 0.10$).

Discussion

We found that meaningful whistles elicited larger amplitude MMNs than did meaningless whistles, suggesting that the brain's deviance detection system can reflect the semantic status of a stimulus outside the context of speech or language. While previous studies have reported enhanced MMNs to words, the results of our study suggest that those findings could be attributed to the semantic content of the stimuli. Our findings indicate that varying the meaning of a stimulus can by itself modulate the amplitude of the MMN.

The behavioral data show that there was no significant difference in the hit rate for detecting meaningful vs. non-meaningful deviants (97 and 99 percent, respectively). Reaction times were also not significantly different, being slightly faster for the meaningless whistle than the wolf whistle (601 and 607 ms, respectively). This indicates that the enhanced MMN in the meaningful condition was not due to the meaningful deviant being more discriminable from the standard than the meaningless deviant.

The effect of cortical memory traces for speech sounds on the amplitude of the MMN was first reported in a study that compared subjects' brain responses to deviant phonemes within and outside a subject's native language [3]. An enhancement of the MMN to within-language phonemes was attributed to activation of long term memory traces for phonemes in the left-hemisphere of the brain. A similar study compared the brain responses of Finnish infants to foreign and within language phonemes at several months after birth and at one year of age [2]. A left lateralized enhancement of the MMN was reported to demonstrate the existence of traces for phonemes in the developing infant brain.

It should be mentioned that the study of Näätänen et al. [3] involving phonemic stimuli was conducted in a so-called "phonetic" language (Finnish) and employed phonemic stimuli that were identical to the names of specific letters of the Finnish alphabet. Since the names of the letters of any alphabet constitute meaningful nouns, it remains a possibility that the enhanced MMN and hemispheric lateralization reported to phonemic stimuli may in fact be a function of the semantic content of the stimuli.

In the case of Cheour et al.'s study [2], the ostensibly pre-linguistic state of the subjects makes it harder to attribute the enhanced MMN to the semantic content of alphabetic phonemes. It is possible, though, that familiarity with within-language phonemes, rather than long-term memory traces for phonemes, contributed to the enhanced MMN.

An enhancement in the amplitude of the MMN to meaningful word deviants vs. pseudoword deviants was the basis of a claim that the amplitude of the MMN is modulated by the effects of long term memory traces for words in the subjects' language [5]. Whistle stimuli provide a unique window on the MMN system. While certain whistles, like spoken words, convey semantic information, they are devoid of phonological structure and exist outside the bounds

of what is normally considered language. The results of our experiment suggest that the finding described by Pulvermüller [5] may be a function of semantic valence rather than lexical properties per se. The experiments of Pulvermüller et al. [4,5,18] have demonstrated the general case that semantic information modulates the MMN. In Pulvermüller et al. [4] the enhanced MMN was attributed to the lexical status of the deviant. Our results suggest that these findings could be reasonably explained by other features of the stimulus, such as general semantic valence or acoustic familiarity.

Acoustic familiarity is a plausible explanation for the enhanced MMN effect. If enhanced MMN is due to the increased salience of the meaningful deviant, it is conceivable that acoustic familiarity in its most general sense is modulating MMN amplitude. However, in a study comparing the amplitude of the MMN between familiar vs. non-familiar musical triads [19], it was found that long-term familiarity of complex non-speech sounds did not facilitate their processing by the MMN system and did not lead to MMN enhancement.

While some triads, like a C major chord may be more familiar to a listener's ear than others that involve uncommon intervals, it cannot be said that any one triad has more semantic content than any other [20]. The common thread that links the findings reported by Pulvermüller et al. [4,5,18] and now by our group is that the deviant stimulus in all studies was semantically salient. We have shown that the enhanced MMN is elicitable by meaningful, non-linguistic whistles and therefore have demonstrated that semantic content and/or familiarity alone is capable of modulating the amplitude of the MMN.

After our data had been collected and analyzed, we became aware of a similar study in which brain responses to meaningful non-speech stimuli were investigated in a similar paradigm [21]. They found that familiar, everyday sounds (e.g., chimes, dishes breaking) elicited enhanced MMNs relative to non-meaningful reversal of these sounds. The authors of this study concluded that they could not distinguish the cause of the enhancement of the MMN as being due to meaning or familiarity.

If familiarity were a critical variable in our study, it would be expected that performance would be better for the familiar than for the unfamiliar deviants. However, it was found that hit rates and reaction times were equivalent for unfamiliar and familiar deviants. Nevertheless, the issue of familiarity in MMN studies that use linguistic stimuli and meaningful non-linguistic stimuli in general warrant further investigation.

Conclusion

Our results suggest that meaningful, nonlinguistic stimuli can elicit enhanced output of the early, automatic, acoustic deviance detection system.

References

1. Alho K, Sinervo N. Preattentive processing of complex sounds in the human brain. *Neurosci Lett* 1997;233(1):33–36. [PubMed: 9324233]
2. Cheour M, Ceponiene R, Lehtokoski A, et al. Development of language-specific phoneme representations in the infant brain. *Nat Neurosci* 1998;1(5):351–353. [PubMed: 10196522]
3. Naatanen R, Lehtokoski A, Lennes M, et al. Language-specific phoneme representations revealed by electric and magnetic brain responses. *Nature* 1997;385(6615):432–434. [PubMed: 9009189]
4. Pulvermuller F, Kujala T, Shtyrov Y, et al. Memory traces for words as revealed by the mismatch negativity. *Neuroimage* 2001;14(3):607–616. [PubMed: 11506534]
5. Pulvermuller F, Shtyrov Y, Kujala T, Naatanen R. Word-specific cortical activity as revealed by the mismatch negativity. *Psychophysiology* 2004;41(1):106–112. [PubMed: 14693005]

6. Naatanen R, Gaillard AW, Mantysalo S. Early selective-attention effect on evoked potential reinterpreted. *Acta Psychol (Amst)* 1978;42(4):313–329. [PubMed: 685709]
7. Hari R, Hamalainen M, Ilmoniemi R, et al. Responses of the primary auditory cortex to pitch changes in a sequence of tone pips: neuromagnetic recordings in man. *Neurosci Lett* 1984;50(1–3):127–132. [PubMed: 6493619]
8. Naatanen R, Paavilainen P, Reinikainen K. Do event-related potentials to infrequent decrements in duration of auditory stimuli demonstrate a memory trace in man? *Neurosci Lett* 1989;107(1–3):347–352. [PubMed: 2616046]
9. Ford JM, Hillyard SA. Event-related potentials (ERPs) to interruptions of a steady rhythm. *Psychophysiology* 1981;18(3):322–330. [PubMed: 7291450]
10. Naatanen R. The mismatch negativity: a powerful tool for cognitive neuroscience. *Ear Hear* 1995;16(1):6–18. [PubMed: 7774770]
11. Saarinen J, Paavilainen P, Schoger E, Tervaniemi M, Naatanen R. Representation of abstract attributes of auditory stimuli in the human brain. *Neuroreport* 1992;3(12):1149–1151. [PubMed: 1493229]
12. Paavilainen P, Jaramillo M, Naatanen R, Winkler I. Neuronal populations in the human brain extracting invariant relationships from acoustic variance. *Neurosci Lett* 1999;265(3):179–182. [PubMed: 10327160]
13. Naatanen R. Mismatch negativity outside strong attentional focus: a commentary on Woldorff et al (1991). *Psychophysiology* 1991;28(4):478–484. [PubMed: 1745727]
14. Aaltonen O, Niemi P, Nyrke T, Tuhkanen M. Event-related brain potentials and the perception of a phonetic continuum. *Biol Psychol* 1987;24(3):197–207. [PubMed: 3663795]
15. Sharbrough F, Chatrian GE, Lsner RP, Luders H, Nuwer M, Picton TW. *Guidelines for Standard Electrode Position Nomenclature* Bloomfield: American EEG Society; 1990.
16. Semlitsch HV, Anderer P, Schuster P, Presslich O. A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. *Psychophysiology* 1986;23:695–703. [PubMed: 3823345]
17. Jennings JR, Wood CC. The e-adjustment procedure for repeated measures analyses of variance. *Psychophysiology* 1976;13:277–278. [PubMed: 1273235]
18. Pulvermuller F, Shtyrov Y. Automatic processing of grammar in the human brain as revealed by the mismatch negativity. *Neuroimage* 2003;20(1):159–172. [PubMed: 14527578]
19. Neuloh G, Curio G. Does familiarity facilitate the cortical processing of music sounds? *Neuroreport* 2004;15(16):2471–2475. [PubMed: 15538177]
20. Trehub SE. The developmental origins of musicality. *Nat Neurosci* 2003;6(7):669–673. [PubMed: 12830157]
21. Jacobsen T, Schroger E, Winkler I. Familiarity affects the processing of task-irrelevant auditory deviance. **Journal of Cognitive Neuroscience** in press.

Figure 1.

Intensity envelopes of the standard and deviant whistle stimuli in each condition. Time in ms is on the abscissa. The ordinate reflects the percent of maximal sound volume relative to 0 dB.

Figure 2.

Grand mean, across-subject ERPs depicted with a 100 ms baseline prior to the onset of the first segment and 1900 ms subsequently. *Left column.* Standards and deviants in the meaningful condition; *Middle column.* Standards and deviants in the non-meaningful condition; *Right column.* Standard minus deviant difference waveforms in the two conditions. The short vertical arrow marks the onset of the initial segment; long vertical lines mark the onset of the second segment. Time lines every 500 ms. LM = left mastoid; RM = right mastoid.