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N400-effects to task-irrelevant environmental sounds: Further evidence for obligatory conceptual processing

Guido Orgs*, Kathrin Lange, Jan-Henryk Dombrowski, Martin Heil

Department of Experimental Psychology, Heinrich-Heine-University Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf, Germany

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ABSTRACT

We assessed conceptual priming for environmental sounds in two tasks using pairs of a visually presented word (prime) and an environmental sound (probe). In the physical task, participants indicated to which ear the sound was presented. In the semantic task, participants judged whether a word labeled a sound correctly. The physical always preceded the semantic task to exclude semantic carry-over effects. In both tasks prime word color indicated whether a response was required (Go/NoGo-trials). An N400-effect for unrelated vs. related sounds was observed in all four conditions resulting from the combination of both tasks with response requirement. However, the N400-effect was reduced in the physical task and in NoGo-trials. Hence, meaning of environmental sounds may be processed obligatorily. Both automatic and controlled processes mediate the analysis of sound meaning.

Conceptual relationships can be examined in the semantic priming paradigm. Typically, a response to a word occurs faster if preceded by a semantically related word, than if preceded by a semantically unrelated word [18,19]. In event-related potentials (ERPs), unrelated words produce a larger negative amplitude than related words around 400 ms post-stimulus: the N400-effect [3]. Functionally, the N400-effect may reflect stimulus processing in relation to a previously established semantic context [14], or else the attempt to extract semantic information from an otherwise meaningless stimulus, for which a semantic context may not exist [7]. The majority of research on semantic priming – and the N400-effect – has been conducted with words and sentences. However, studies on conceptual relationships between verbal and nonverbal stimuli are relevant to the notion of multimodal conceptual representations [9]. Whereas in the typical semantic priming paradigm word pairs are semantically associated (e.g. table-chair), in conceptual priming two different stimuli refer to the same concept (e.g. the word "table" paired with the picture of a table). In one line of research, conceptual priming for environmental sounds has been observed using behavioral [1] as well as electrophysiological measures [6,21,22,26]. In these studies, conceptual priming for environmental sounds was observed using word-sound pairs [21,22,26] or picture-sound pairs [6]. Sounds (probe stimuli) that followed unrelated words or pictures (prime stimuli) led to larger N400-amplitudes than sounds that followed related words or pictures. These results mirror those that are usually observed with word probes. However, a behavioral priming effect was only found in two of these studies [21,26], suggesting that the N400-effect may be more sensitive to semantic processing than behavioral measures [12].

In a previous experiment [22] we examined conceptual priming for sounds under task instructions inducing different levels of processing (physical vs. semantic). In the physical task participants judged presentation side of the sound, thus sound meaning was irrelevant. In the semantic task participants explicitly judged conceptual relatedness between word and sound. The absence of an N400-effect in physical tasks has been interpreted as a sign that the N400 primarily reflects controlled processes [2,5] whereas an intact N400-effect in physical tasks is consistent with automatic semantic processing [12,23]. In our study, we observed an N400-effect of similar time-course and electrode distribution in both tasks. Thus semantic features seemed to be processed obligatorily in the physical task. Still, as physical and semantic tasks switched randomly from trial to trial, it cannot be fully excluded that carry-over effects have influenced our results to some extent. Participants may have processed semantic features of the sounds in the physical task even if they were task-irrelevant.

In the present experiment, we prevented the occurrence of semantic carry-over effects by presenting each task in a separate block with the physical task always *preceding* the semantic one. In addition to this, NoGo-trials were included in both tasks [13,24] with prime word color indicating response requirement, that is Go vs. NoGo-trials. Thus, prime color and – as a consequence [15] – prime meaning were processed in all trials, but the probe sound was completely irrelevant in NoGo-trials of both tasks. Even in

* Corresponding author. Tel.: +49 211 811 4566; fax: +49 211 811 3490.
E-mail address: orgs@uni-duesseldorf.de (G. Orgs).

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Go-trials of the physical task, only presentation side but not meaning was relevant. Semantic carry-over effects, if present, may be observed between Go- and NoGo-trials of the semantic task, but should be absent in the physical task. If semantic features of a sound are indeed processed obligatorily, a N400-effect for sounds should be present in all four conditions resulting from the combination of both tasks with Go- and NoGo-trials. Its size, however, might vary as a function of task and of response requirement.

Sixteen volunteers participated in the study after signing informed consent. However one data set had to be excluded from analysis due to the amount of eye movement artifacts. The remaining participants (11 women, 4 men, all right handed) were 20–29 years old (mean age: 24). All participants were native German speakers and reported normal hearing sensitivity. Participants received a monetary compensation or fulfilled course requirements.

Stimuli were identical to the ones previously used [22] and comprised 40 environmental sounds collected from the Internet and commercially available sound CDs. All sounds were trimmed to a duration of 300 ms (rise and fall time 20 ms) and were standardized for sound quality (44.100 kHz, 16 bit, stereo) using Adobe® Audition™ 1.5. Twenty sounds were instruments (e.g. violin, saxophone), and 20 sounds were everyday sounds (e.g. bell ringing, coughing). Stimulus pairs were formed, in which the prime was a visually presented word and the probe was a related or an unrelated sound, resulting in 80 stimulus pairs per block (task). In related stimulus pairs words labeled the sound correctly (e.g. the word *engine* was followed by the sound of starting an engine). In unrelated stimulus pairs an incorrect word label from the other category was randomly assigned to a sound for each block and each experimental session (e.g. the word *piano* was followed by the sound of starting an engine). All related stimulus pairs were correctly identified at a rate of at least 80%, as determined by a previously reported pilot experiment [21]. For each block, 160 word-sound pairs (with half of them related) were presented to the right ear and 160 word-sound pairs were presented to the left ear, adding up to 320 stimulus pairs per block. Half of these trials were NoGo-trials. Thus each block consisted of 320 trials and altogether each stimulus was presented eight times. To minimize systematic repetition effects, the order of related and unrelated trials was randomized for each participant and within each block.

All participants performed two tasks: in the physical task (first block) participants judged whether the sound was presented to the right or to the left ear. In the semantic task (second block) participants judged whether word and sound fitted together semantically. The tasks were *not* counterbalanced in order to prevent semantic carry-over effects in the physical task. For each trial the prime word color (blue or red) indicated if participants had to make a response or not (Go/NoGo). Participants needed to consider the word color to know whether a response was required, hence processing of the prime was ensured. Assignment of word color to Go/NoGo-trials was counterbalanced across participants. A trial was initiated by a button press and a central fixation cross appeared on the screen. After a random interval that varied between 400 and 900 ms (rectangular distribution) a word was presented visually for 300 ms ($3.6^\circ \times 0.6^\circ$ visual angle on average, 90 cm distance). Participants were instructed not to move or blink during a trial and to keep their gaze on the fixation cross. A sound with a duration of 300 ms was presented 1000 ms after the onset of the word via headphones to the left or to the right ear. In Go-trials participants had to make a response within 2300 ms by pressing one of two buttons. In the physical task (first block) button press and presentation ear always corresponded to each other (left ear, left button). In the semantic task (second block) assignment of Yes/No responses to buttons was counterbalanced across participants. Prior to each block, participants completed 32 practice trials with sounds not used in the experiment proper.

Table 1
Behavioral results in Go-trials

Task	Reaction times (ms)		Error rates (%)	
	Physical	Semantic	Physical	Semantic
Related	504 (45.4)	600 (48.2)	5.2 (2.1)	7.0 (1.5)
Unrelated	512 (44.9)	638 (47.8)	4.6 (1.9)	2.8 (0.7)

Mean reaction times and error rates in the semantic and the physical task, standard errors are written in parentheses. Error rates in NoGo-trials were all below 1%.

Participants were seated in an electrically shielded, dimly lit room. The electroencephalogram (EEG) was recorded from six Ag/AgCl electrodes placed at Fz, Cz, Pz, Oz, P3 and P4, based on the international 10-20 system. All Electrodes were attached directly to the scalp and were referenced to digitally averaged earlobes. Impedance was kept below 5 kΩ. To control for eye movement artifacts vertical and horizontal electrooculogram (EOG) was recorded. A ground electrode was placed at the forehead. The digitization rate was 250 Hz and an online band pass was set from DC to 100 Hz. An offline filter was set from 0.5 to 40 Hz. Trials with eye or body movement artifacts were discarded according to the following criteria: the maximal allowed voltage step between two sampling points was 50 μV and the minimal or maximal absolute amplitude should not exceed −100 or +100 μV.

ERPs to sounds were extracted by averaging single trials with correct responses separately for subjects and experimental conditions (on average 65 trials were included, corresponding to an average of 15% of trials lost due to incorrect responses or artifacts). Epochs started 100 ms before presentation of a sound and had a length of 1000 ms. Based on previous studies [21,22], N400-amplitudes were quantified as the mean voltage in the time window 200–500 ms after onset of the sound. A repeated measures analysis of variance (ANOVA) was conducted with the factors electrode position (six levels), task (two levels), response requirement (two levels) and relatedness (two levels). ANOVA results were corrected for sphericity using the Greenhouse-Geisser epsilon where appropriate (uncorrected df are reported with corrected p values). Mean reaction times (only correct responses) and error rates in Go-trials were analyzed using repeated measures ANOVA with task (two levels) and relatedness (two levels) as within-subject factors. As an index of effect size squared partial eta is reported (η_p^2) for all significant results.

In both tasks reactions were faster to related than to unrelated sounds (main effect of relatedness: $F(1,14) = 13.75$, $p = .002$, $\eta_p^2 = .5$), see Table 1. However as indicated by a significant interaction with task (task × relatedness: $F(1,14) = 7.83$, $p = .014$, $\eta_p^2 = .4$) a statistically reliable relatedness effect could be observed in the semantic task only (main effect of relatedness in the semantic task: $F(1,14) = 16.11$, $p = .001$, $\eta_p^2 = .5$, in contrast to the physical task: $F(1,14) = 1.5$, p = n.s.). Aside from that participants reacted on average 100 ms faster in the physical than in the semantic task, as revealed in a main effect of task ($F(1,14) = 35.78$, $p = .0001$, $\eta_p^2 = .7$).[1]

Error rates showed no overall difference between physical and semantic task. However, in the semantic task participants made more errors judging relatedness in related than in unrelated trials (task × relatedness $F(1,14) = 7.2$, $p = .018$, $\eta_p^2 = .3$). Participants made a response in less than 1% of all NoGo-trials in both tasks.

[1] In order to control for an influence of overall reaction time level on the relatedness effect, we also analysed log-transformed reaction times. However the pattern of results is not different from the results with untransformed data, that is a relatedness effect was observed in the semantic task ($F(1,14) = 17.47$, $p = .0009$, $\eta_p^2 = .6$) but not in the physical task: $F(1,14) = 3.74$, p = n.s.).