

## N400 and P600 effects evoked by a scalar implicature violation in a sentence-picture verification paradigm.

In this paper we investigate the processing of the scalar implicature *nicht alle* (*not all*) of the German quantifier *einige* (*some*) with the use of electroencephalography (EEG). We adopted a sentence-picture verification paradigm to examine event-related potentials (ERPs) that are associated with a violation of this implicature. We were particularly interested whether such a violation elicits an N400 or a P600 effect, i.e. amplitude difference between the EEG signals in the compared conditions recorded ca. 400/600 ms after the onset of the stimulus. The former effect is known to be linked to the recognition of a semantic incongruence in the language [4], the latter has been recently suggested to reflect a general reprocessing of the stimulus [3]. It has been shown that both effects can be elicited by a pragmatic violation [1], [6].

Previous studies [7], [6] have focused on the N400 effect triggered by a pragmatic infelicity of the use of the quantifier *some* in so-called underinformative sentences, e.g. *some people have lungs* compared to informative sentences, such as *some people have pets*. Whereas the first sentence is logically true (there are people who have lungs) but pragmatically infelicitous (since all people have lungs the use of the quantifier *all* would have been more informative), the second one is both pragmatically felicitous and logically true. In the considered sentences, whose truth-value can be evaluated in reference to our world-knowledge, the semantic congruency of the critical word (i.e. the predicate) depends not only on the pragmatic felicity of the use of the quantifier but also on the lexical-semantic relationship between the subject and the predicate (the frequency of their co-occurrence in the contexts), which is usually stronger in the underinformative sentences than in the informative sentences. In contrast, our purpose in using a sentence-picture verification paradigm was to dissociate the process of implicature calculation from world-knowledge-based or semantic memory-based sentence evaluation and record ERPs elicited by pragmatic violations that are based on short-term memory. In a recent study [9] the authors also applied a paradigm in which a felicity of the use of a quantifier *some* is evaluated with respect to a picture model, however they measured ERPs on the onset of the quantifier and not of the predicate, which does not allow for a direct comparison of their results with the results of the above-mentioned studies that use underinformative sentences. In our experiment by measuring ERPs on the onset of the predicate we focused on the felicity of the use of this predicate in given sentences with *some* or *all* in the context of the visually presented models. Furthermore, by gathering truth-value judgments we aimed at measuring individual differences in implicature processing that depend on subjects' more logical or pragmatical reasoning profiles.

We measured 54 neurotypical right-handed German native speakers (age: 18-44, 28 women) using 64 channel BrainAmp acticap EEG recording system. They were also screened with two parts of the Wechsler intelligence test: the matrix test (logical intelligence) and working memory (digit span) test. Sentences of the form *Some/All pictures contain Cs*, with *C* being a critical noun and denoting a target object, were evaluated with respect to arrays of 5 pictures. Each array contained two different objects: one occurring in each of the pictures, the other occurring only in 2 or 3 of the pictures. In each trial subjects were first presented with the beginning of the sentence, then the pictures, and after that the critical noun, which determined the logical truth and the pragmatical felicity of the sentence. The ERPs were measured on the onset of the critical noun. There were three truth-conditions for each of the two quantifiers. For the quantifier *some* these were: *true and felicitous* (*ET*), *true and infelicitous* (*EI*), and *false* (*EF*). For *all* there was one *true* condition (*AT*), and two *false* conditions: when the critical noun was primed by the pictures (*AF*) and when it was not primed (*AF2*). *EI* and *AT* corresponded to the case when *C* denoted the object that was contained by each of the pictures in the array, *ET* and *AF* – to the case when *C* denoted the object that was contained by only a subset of the pictures, finally *EF* and *AF2* – to the case when *C* denoted an object that was not displayed in any of the pictures.

The analysis of subjects' truth-value judgements revealed that our participants were divided into two subgroups: those who more consistently accepted the quantifier *some* in the infelicitous case (N=28, referred henceforth as "logicians") and those who rejected *some* in this condition (N=26, "pragmatists"). This result is consistent with the data reported in the literature [2]. Our criterion to consider

someone a pragmatist or a logician was that this person has at least 70% responses of a given type.

In order to determine significance as well as latency (onset and offset) of the N400 and P600 effects, we conducted a re-sampling procedure called a cluster-based permutation test [5]. This procedure revealed that in the sentences with the quantifier *some* the critical words elicited more negative ERPs in the *infelicitous* condition (*EI*) compared to the *true* condition (*ET*) ( $p < .001$ ) in the time window of 262 – 438 ms post-onset (“pragmatic” N400 effect). This effect was followed by a significant (“pragmatic”) P600 effect (502 – 626 ms,  $p < .01$ ). The comparison between the *false* (*EF*) and the *true* (*ET*) conditions for *some* resulted as well in a significant N400 effect (238 – 494 ms,  $p < .0001$ ) followed by a significant P600 effect (522 – 1000 ms,  $p < .0001$ ). A significant N400 effect was obtained also for the comparison between conditions *EF* vs. *EI* (256 – 516 ms,  $p < .0001$ ). The effects for the quantifier *all* fit the general pattern: there were significant N400 effects followed by significant P600 effects for the comparisons of each false condition (*AF2* or *AF*) with the *true* condition (*AT*). The comparison between the two false conditions (*AF2* vs *AF*) resulted also in a significant N400 effect, which we interpret as an effect of priming.

The most interesting results come from the follow-up analysis indicating that pragmatists and logicians show different pattern of effects. The pragmatists had a significant pragmatic N400 effect (*EI* vs *ET*), followed by a pragmatic P600 effect, whereas the logicians had no significant effects for this comparison. An independent t-test comparing these effects between the two groups revealed that the pragmatic N400 effect was significantly larger for the pragmatists than for the logicians:  $t(39.727) = 3.459, p = .001$ . Furthermore, there was a significant correlation of the behavioral responses (measured as a percentage of pragmatical responses) and the pragmatic N400 effect:  $r = .434, p = .001$ . Additionally, there was a correlation between subjects’ working memory value and the pragmatic P600 effect, in the frontal area:  $r = -.296, p = .030$ . Let us note that subjects’ working memory was correlated with their logical intelligence:  $r = .442, p = .001$ , although the latter did not show any correlation with the P600 effect.

The results of our experiment confirmed the hypothesis that the violation of a scalar implicature can elicit a N400 effect of a similar sort as any other semantic violation. In all conditions in which the tested sentences were evaluated as false with reference to the model the critical words triggered significantly more negative ERPs ca. 400 ms after their onset than in the conditions in which they were evaluated as true. The same effect was observed when sentences with *some* were pragmatically infelicitous with respect to the model, even though in this case subjects were divided with respect to their truth-value judgments. We showed that the logicians did not get any significant pragmatic N400, i.e. for the comparison between the *infelicitous* and the *true* conditions for the quantifier *some*.

Let us note that P600 effects followed N400 effects only in those cases in which the *false* condition was compared to the *true* condition. Thus, the semantic priming of the critical word elicited only an N400 effect but not a P600 effect. In our experiment P600 effects could be linked to the reprocessing of a sentence that has to be evaluated as false about the model. The correlation of the pragmatic P600 effect with working memory is especially interesting as it can suggest that in this case the P600 reflects not only a logical reprocessing (evaluation of a sentence as false) but also some kind of pragmatical reprocessing which is less effortful for the subjects with larger working memory span.

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