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Research report

Domain-general neural correlates of dependency formation: Using complex tones to simulate language

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ABSTRACT

There is an ongoing debate whether the P600 event-related potential component following syntactic anomalies reflects syntactic processes per se, or if it is an instance of the P300, a domain-general ERP component associated with attention and cognitive reorientation. A direct comparison of both components is challenging because of the huge discrepancy in experimental designs and stimulus choice between language and ‘classic’ P300 experiments. In the present study, we develop a new approach to mimic the interplay of sequential position as well as categorical and relational information in natural language syntax (word category and agreement) in a non-linguistic target detection paradigm using musical instruments. Participants were instructed to (covertly) detect target tones which were defined by instrument change and pitch rise between subsequent tones at the last two positions of four-tone sequences. We analysed the EEG using event-related averaging and time-frequency decomposition. Our results show striking similarities to results obtained from linguistic experiments. We found a P300 that showed sensitivity to sequential position and a late positivity sensitive to stimulus type and position. A time-frequency decomposition revealed significant effects of sequential position on the theta band and a significant influence of stimulus type on the delta band. Our results suggest that the detection of non-linguistic targets defined via complex feature conjunctions in the present study and the detection of syntactic anomalies share the same underlying processes: attentional shift and memory based matching processes that act upon multi-feature conjunctions. We discuss the results as supporting domain-general accounts of the P600 during natural language comprehension.

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1. Introduction

The functional role of the P600 event-related potential (ERP) component during natural language comprehension (e.g., Osterhout & Holcomb, 1993) has recently gained new attention. The P600 is a centro-parietally distributed positivity and has a peak latency of 500–1000 msec. The current discussion is primarily centred on whether the P600 reflects syntactic processes per se, e.g., syntactic reanalysis or repair following syntactic anomalies (Friederici, 2011; Goueva, Phillips, Kazanina, & Poeppel, 2010; Kaan, 2007; Osterhout & Hagoort, 1999), or if it is an instance of the P3 (Sutton, Braren, Zubin, & John, 1965; c.f. Verleger, Jaskowski, & Wascher, 2005, for a comprehensive review of the P3), a domain general component with a peak latency of 250–1200 msec and a similar scalp distribution as the P600 (Coulson, King, & Kutas, 1998a, 1998b; Münte, T., Heinze, Matzke, Wieringa & Johannes, 1998; Vissers, Kolk, van de Meerendonk, & Chwilla, 2008; Bornkessel-Schlesewsky et al., 2011; Sassenhagen, Schlesewsky, & Bornkessel-Schlesewsky, 2014; Sassenhagen & Bornkessel-Schlesewsky, 2015). The P3 usually follows subjectively salient events, including, for example, events that are anticipated, infrequent, and motivationally significant (Johnston & Holcomb, 1980). It is also influenced by attention (e.g., Spencer, Dien, & Donchin, 2001). As discussed in detail elsewhere (e.g., Sassenhagen et al., 2014; Coulson et al., 1998a), the P600 is sensitive to similar experimental manipulations, for instance the frequency of syntactic violations (Coulson et al., 1998b) or motivational factors such as the relevance of the experimental task (Gunter & Friederici, 1999).

The similarity of the P3 and P600 is further supported by results from time-frequency analyses. Common frequency components of the P3, an increase in theta activity (4–7.5 Hz) and delta activity (1–4 Hz; e.g., Başar-Eroglu, Başar, Demiralp, & Schürmann, 1992; Knyazev, 2007), have also been reported in language studies on syntactic (e.g., Bastiaansen & Hagoort, 2003; Bastiaansen, Magyari, & Hagoort, 2010) or semantic anomalies (Roehm, Bornkessel-Schlesewsky, & Schlesewsky, 2007; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider, 2004). Changes in the theta band are usually associated with an increase in mental workload (Klimesch, 1999; Scerbo, Freeman, & Milkulka, 2003; Smith, Gevins, Brown, Karnik, & Du, 2001), especially apparent at frontal sites with increasing memory load or attention (e.g., Başar, Başar-Eroglu, Karakaş, & Schürmann, 2000; Gundel & Wilson, 1992; Holm, Lukander, Korpela, Sallinen, & Müller, 2009; Mecklinger, Kramer, & Strayer, 1992; Onton, Delorme, & Makeig, 2005), while changes in the delta band are reported to reflect target detection (Gilmore, Malone, Bernat, & Iacono, 2010; Schürmann, Başar-Eroglu, Kolev, & Başar, 1995) or reward processing (Bernat, Nelson, Steele, Gehring, & Patrick, 2011; Nelson, Patrick, Collins, Lang, & Bernat, 2011). These and further similarities between the P3 and the P600 have led a number of researchers to advocate a P600-as-P3 perspective (for detailed recent discussions, see Sassenhagen et al., 2014; Sassenhagen & Bornkessel-Schlesewsky, 2015).

With the present EEG study, we address an important assumption made in the P3/P600 debate, namely that the P3 and P600 can be sufficiently distinguished on the basis of their elicitation preconditions. While the P3 results from features rendering the stimulus salient or subjectively significant, structural relations in the sense of syntactic structure are argued to be preconditions of a P600 response (Osterhout & Hagoort, 1999; Goueva et al., 2010; see Coulson et al., 1998b, a for a different view). However, a direct comparison of the P3 and the P600 is challenging. One reason for this is that language is inherently meaningful, i.e., there is no structural (or syntactic) information without conceptual (or semantic) information. This means that it is impossible to study structural processing devoid of semantic processing during natural language comprehension. In the ERP domain, an additional confound arises from this, as every meaningful stimulus elicits an N400 component (Kutas & Federmeier, 2011), similar in shape (although of opposite polarity) to the P3.

Common approaches to this problem such as artificial grammar learning (cf. Petersson, Folia, & Hagoort, 2012, for a review of artificial grammar learning and natural language syntax), though useful for research on abstract (explicit or implicit) regularity learning, do not consider the (multiple) interactions of different levels of linguistic structure that are inherent to natural language. Building blocks of natural language syntax involve word-category-based predictions (e.g., Neville, Nicol, Barss, Forster, & Garret, 1991; Friederici, Pfeifer, & Hahne, 1993; Friederici, Steinhauer, & Frisch, 1999; Hahne & Friederici, 1999; cf. Steinhauer & Drury, 2012, for a critical review), sequential, word-order-based predictions (see word-order preferences in German; e.g., Mecklinger, Schriefers, Steinhauer, & Friederici, 1995) as well as relational information (e.g., case information or agreement, cf. Frisch & Schlesewsky, 2001). For example, in order to resolve local case ambiguities in German transitive embedded clauses (e.g., dass die Freundinnen.plural die Frau.singular grüß-en.plural/grüß-t.singular that the friends greet the woman/that the woman greets the friends), morphological number marking on the sentence final verb has to be matched with morphological number marking on the preceding noun phrases to resolve the local ambiguity regarding argument roles. In such constructions, the verb and its morphological marker can be considered highly informative since they provide the feature necessary to establish the intended relations between the verbal arguments. In this sense, the sentence-final verb is a complex target with respect to at least word category and morphological information.

1.1. *The present study*

In the present study we developed a new approach to mimic this interplay of categorical and relational information in natural language in a non-linguistic target detection paradigm. In particular, we investigated the influence of complex, i.e., multi-feature interactions similar to relational information in natural language (e.g., word category, morphological marking) on the P3. Our design is inspired by the observation that the anterior superior temporal cortex is selectively sensitive to different musical instruments irrespective of their specific acoustic features (Leaver & Rauschecker, 2010). Similar findings exist for the processing of words and phrases, which is associated with activation in the anterior superior