BRAIN RESEARCH 1373 (2011) 131–143

available at www.sciencedirect.com

ScienceDirect

www.elsevier.com/locate/brainres

BRAIN RESEARCH

Research Report

Expectancy modulates a late positive ERP in an artificial grammar task

Ángel Tabullo[a], Yamila Sevilla[b], Guillermo Pasqualetti[a], Sergio Vernis[a], Enrique Segura[a], Alberto Yorio[a], Silvano Zanutto[a,c], Alejandro Wainselboim[a,*]

[a]Instituto de Medicina y Biología Experimental, Conicet, Buenos Aires, Argentina
[b]Instituto de Lingüística, Facultad de Filosofía y Letras, Universidad de Buenos Aires, Buenos Aires, Argentina
[c]Instituto de Ingeniería Biomédica, Facultad de Ingeniería, Universidad de Buenos Aires, Buenos Aires, Argentina

ARTICLE INFO

Article history:
Accepted 8 December 2010
Available online 15 December 2010

Keywords:
ERP
Late positive component
Artificial grammar
Expectancy modulation

ABSTRACT

A wide range of studies have found late positive ERP components in response to anomalies during processing of structured sequences. In language studies, this component is named Syntactic Positive Shift (SPS) or P600. It is characterized by an increase in potential peaking around 600 ms after the appearance of the syntactic anomaly and has a centroparietal topography. Similar late positive components were found more recently in non-linguistic contexts. These results have led to the hypothesis that these components index the detection of anomalies in rule-governed sequences, or the access to abstract rule representations, regardless of the nature of the stimuli. Additionally, there is evidence showing that the SPS/P600 is sensitive to probability manipulations, which affect the subjects' expectancy of the stimuli. Our aim in the present work was to address the hypothesis that the late positive component is modulated by the subject's expectancy of the stimuli. To do so, we employed an artificial grammar learning task, and controlled the frequency of presentation to different kind of sequences during training. Results showed that certain sequence types elicited a late positive component which was modulated by different factors in two distinct time windows. In an earlier window, the component was higher for sequences which had a low or null probability of occurrence during training, while in a later window, the component was higher for incorrect than correct sequences. Furthermore, this late window effect was absent in those subjects whose performance was not significantly above chance. Two possible explanations for this effect are suggested.

1. Introduction

In the last 20 years, a wide range of studies have found late posterior ERP components in response to anomalies during processing of structured sequences. In the linguistic domain, this component has been named Syntactic Positive Shift (SPS) or P600 (Hagoort et al., 1993; Osterhout and Holcomb, 1992; Osterhout et al., 1994), and is characterized by an increase in potential peaking around 600 ms after the appearance of the anomaly. The P600/SPS has a centroparietal topography and is observed after a variety of syntactic anomalies, such as violations of subcategorization (Ainsworth-Darnell et al., 1998; Osterhout and Holcomb, 1992), number, tense, gender or case agreement (Allen et al., 2003; Gunter et al., 1997; Hagoort et al.,

* *Corresponding author*. Vuelta de Obligado 2490 (1428), Ciudad Autónoma de Buenos Aires, Argentina. Fax: +54 11 4786 2564.
E-mail address: awainselboim@ibyme.conicet.gov.ar (A. Wainselboim).

0006-8993/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.brainres.2010.12.023

1993; Münte et al., 1997; Nevins et al., 2007) and phrase structure (Neville et al., 1991; Osterhout and Holcomb, 1992). In these cases, it is typically preceded by left anterior negativities – ELAN (100–300 ms) (Friederici et al., 1993; Lau et al., 2006) or LAN (300–500 ms) (Friederici et al., 1993; Gunter et al., 2000; Hagoort et al., 1993) according to their latency. The syntax-related ERPs have been interpreted as the neural correlates of a staged parsing process: while anterior negativities would be reflecting early and automatic processing, the SPS/P600 would be associated to a later and more controlled process (Hahne and Friederici, 1999). Furthermore, it has been proposed that the SPS/P600 could be a correlate of syntactic reanalysis and repair processes (Friederici, 1995; Osterhout and Holcomb, 1992) or an index of syntactic integration difficulty (Kaan et al., 2000).

Other similar late positive components have been found in diverse non-linguistic contexts. A study that compared ERPs evoked by harmonic anomalies and language sentences found a late positive component with similar latency and topography in both cases (Patel et al., 1998). In addition, ERPs similar to the P600 in latency and scalp distribution have been found after anomalies in sequences of geometric stimuli of increasing or decreasing sizes (Besson and Macar, 1987), arithmetic series (Núñez-Peña and Honrubia-Serrano, 2004), equations (Niedeggen et al., 1999), and abstract sequences (Lelekov et al., 2000). Furthermore, Lelekov-Boissard and Dominey (2002) compared ERPs evoked by anomalies in French sentences and linear letter sequences that followed an abstract rule. A frontocentral late positivity was observed, with a left distribution for linguistic structure violations and a right distribution for abstract structure violations. This was interpreted as evidence of a partial overlap between language syntax and abstract rule processing. These results have led to the hypothesis that these late positive components index the detection of anomalies in rule-governed sequences, or the access to abstract rule representations, regardless of the linguistic nature of the stimuli.

In addition, there is evidence to suggest that the SPS/P600 is sensitive to probability manipulations, which affect the subject's expectancy of the stimuli. Studies that compared conditions where syntax violations were relatively rare (20–25% of the trials) or frequent (75% 80% of the trials) showed that the P600 was absent or reduced when syntax anomalies were more frequent (Gunter et al., 1997; Coulson et al., 1998; Hahne and Friederici, 1999). Under these circumstances, grammatical sentences may elicit a P600 when compared to syntax violations (Coulson et al., 1998). Furthermore, it has been proposed that P600 effects observed in garden path sentences could be explained by subject's expectancy of possible verbal complements, derived from the main verb's subcategorization information (Osterhout et al., 1994).

Within non-linguistic contexts, two studies of arithmetic anomalies (Niedeggen et al., 1999; Núñez-Peña and Honrubia-Serrano, 2004) found results that could be accounted for by subject's expectancy modulation. In one of the studies (Niedeggen et al., 1999), a late positive centroparietal component was observed when subjects observed incorrect results in equations of the type $a \times b = c$. In this study, the magnitude of the component increased proportionally to the numerical distance between c and the correct result, which led the authors to suggest that "LPC amplitude is a function of the implausibility of a presented solution, a possibility that fits with the well-established interpretation that the LPC amplitude is always inversely proportional to the subjective probability of its evoking event."

Given the aforementioned results, our aim in the present work was to address the hypothesis that the late positive component elicited by structured sequence processing (SPS/P600) is modulated by the subject's expectancy of the presented stimuli. Since subjective expectancy is modulated by the frequency of exposure to the presented items, the best way to examine this question is by directly manipulating frequency of presentation to different kind of stimuli during training, something that has not been controlled in previous experiments. In order to do so, we employed an artificial grammar consisting of a series of probabilistic transitions between a specific set of stimuli that allowed generating different sequences of items. Previous evidence suggests that processing anomalies in artificial grammars elicits a late posterior component similar to P600 (Bahlmann et al., 2006). In the present study, we manipulated the frequency of presentation of two different types of sequences during artificial grammar training, so that one sequence type became more expected than the other. In the test stage, subjects were instructed to classify new sequences as "correct" or "incorrect," whether they complied or not with the grammar's possible item combinations. If the late positive component is modulated by the subject's previous frequency of exposure to the sequences, then correct and frequent sequences should generate the smallest component; incorrect sequences should generate the largest positive component (since they had a null probability of occurrence during training, and should be the most unexpected events); and finally, correct but infrequent sentences should generate intermediate components, as their probability of occurrence is higher than that of incorrect sequences, but lower than correct and frequent sequences.

2. Results

2.1. *Behavioral data*

The proportion of correct and incorrect responses during testing was analyzed for each subject with a G-test of goodness of fit (Zar, 1999), in order to determine if performance was significantly above chance (50% correct answers). Subjects were assigned to different groups according to whether they responded significantly better than chance or not (Learners and Non-learners, respectively). Following this criterion 13 out of 20 subjects were considered as Learners ($G > 3.8$; $p < .05$). The percentage of correct responses was significantly higher ($T(18) = 2.874$, $p < .01$) for Learners (mean = 66.27% ± 9.1) than Non-learners (mean = 55.54 ± 4.58).

Mean percentage of correct responses was calculated for each group and experimental condition (Table 1). These data were analyzed with a repeated measures ANOVA involving Frequency (Frequent, Infrequent) and Violation Type (Correct, Conjunction violation, Category violation) as within-subject factors, and Group (Learners, Non-learners) as the between-subject factor. No main effects of frequency or violation type