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LEARNING WORDS WHILE LISTENING TO SYLLABLES: INSIGHTS FROM NEUROSCIENCE

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Abstract

Understanding the processes by which children acquire language so quickly and effortless is one of the most important issues that science is still trying to answer today. Several approaches have been adopted. From early observational studies involving the collection of data from a small number of children through parental diaries to large scale cross-sectional and longitudinal studies involving the collection of different measures of receptive and productive language skills from children at different developmental stages, recent studies, adopting an experimental approach, have taken advantage of noninvasive brain activity measures to get new insights into one of the most amazing human skills. In this work, we present event-related potentials (ERP) data collected from 24 children while they were exposed to a continuous auditory stream made of the repetition of three-syllable nonsense words with different levels of predictability (high vs. low) under implicit and explicit conditions, to illustrate how the use of brain monitoring techniques can provide exciting data into the processes and mechanisms underlying language acquisition.

Keywords: *Speech segmentation, statistical learning, language acquisition, artificial language, neuroscience.*

1. Introduction

Language is extremely complex, yet before five-years-old most children master the fundamentals of their native language even without having been "taught" to do so. So, it is not surprising that many authors consider language the 'miracle' of human nature, and that unraveling the processes and mechanisms underlying language acquisition is one of the most important issues scientists are still trying to answer today. This is a huge conceptual and methodological problem, particularly with pre-verbal children. The advent of brain functioning techniques that are safe and non-invasive, such as event-related potentials (ERP), made it possible to analyze how the brain responds to language stimuli even in the absence of any behavioral response, making it an exceptional tool to study language acquisition.

In this paper, we aimed to illustrate how the use of ERPs may provide valuable insights into the processes and mechanisms underlying this capacity, focusing on the analysis of one of the biggest challenges children face from birth, i.e., to discover where a word begins and ends in a continuous acoustic input - speech. It has been argued that children rely on what has been called statistical learning (SL), a form of implicit learning that occurs as children are exposed to the language spoken around them, allowing the extraction of the structure underlying the succession of speech sounds (Saffran et al., 1996), although the techniques that have been used to test it in young children present several flaws (see Soares et al., 2021). Here, we demonstrated how the use of ERPs can overcome these limitations, providing valuable insights into the origins of the language faculty.

2. Method

2.1. Participants

Twenty-four children (Mage = 5;7; range 5;1 to 6;5) from a longitudinal study conducted to study the developmental trajectories of preschool children with and without Developmental Language Disorder (Grant PTDC/PSI-ESP/28212/2017) participated in the study. All participants were native speakers of European Portuguese, with normal hearing and no history of language disabilities. Written informed consent was obtained from their parents.

2.2. Stimuli

Sixteen three-syllable nonsense words taken from Soares et al. (2020) were used in the familiarization phases of the implicit and explicit versions of the SL tasks (eight per task). In each task, four ‘words’ presented Transitional Probabilities (TPs) of 1.00 (high-TP ‘words’), and four TPs of .33 (low-TP ‘words’). For example, the nonsense word ‘*tucida*’ corresponds to a high-TP ‘word’ as the syllables it entails only appear in that ‘word’, while the nonsense word ‘*migedo*’ corresponds to a low-TP ‘word’ as the syllables it entails also appear in other ‘words’ as ‘*gemiti*’ and ‘*tidomi*’ (see Soares et al., 2020 for details). In each SL task, the nonsense words were presented with no pauses between each other. For the test phases, the 16 foils created by Soares et al. (2020) were used in the two-alternative forced-choice (2-AFC) tasks (eight per task) typically used to test SL. The foils were made up of the same syllables used in the high and low-TP ‘words’, although they were never presented together during exposure (TPs=0).

2.3. Procedure

Data collection was performed in an electric-shielded and sound-attenuated room. EEG was recorded with 64 channels BioSemi Active-Two system (BioSemi, Amsterdam, The Netherlands) according to the international 10–20 system and digitized at a sampling rate of 512 Hz.

Participants performed first the implicit version of the SL task and, after a break, the explicit version of an analogous SL task. In each task, each word was repeated 60 times in two blocks of 30. Stimuli were presented via headphones. After exposure, participants performed a 2-AFC task, in which they had to choose between two triplets presented consecutively which “sounded more familiar”. The 2-AFC task comprised 16 trials where each of the eight ‘words’ was paired with two different foils. The explicit task mimicked the implicit except that, before exposure, participants were explicitly instructed about the ‘words’ (different from the ones used in the implicit version) they will be listening to during familiarization.

2.4. Data analyses

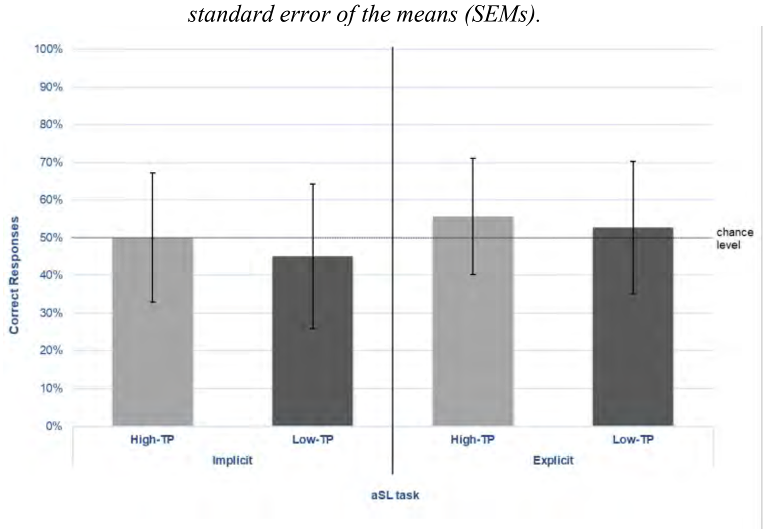
EEG data processing was conducted with the Brain Vision Analyzer 2.1.1. Mean amplitudes were calculated for the 80-120 ms (N100), and 400-500 ms (N400) time windows, taken as the neural signatures of words’ segmentation in the brain (see Abla, 2008; Cunillera et al., 2006; De Diego Balaguer et al., 2007; Soares et al., 2020), in the topographical regions where amplitudes were maximal (fronto-central and central regions). The % of correct responses was also computed for each of the 2-AFC tasks and separately for the high- and low-TP ‘words’. Behavioral and ERP analyses were performed in the 27.0 IBM-SPSS® software.

3. Results

3.1. Behavioral data

The means % of correct responses in each 2-AFC task per condition are presented in Figure 1. Results from one-sample t-tests against chance level showed that children’s performance did not differ from chance in either of the aSL tasks and type of ‘words’ (all *p*s > .115). The results from the ANOVA considering aSL task (implicit vs. explicit) and type of ‘word’ (High-TP vs. Low-TP) also failed to show any significant effects across conditions.

Figure 1. % correct responses in the 2-AFC tasks (implicit and explicit) per type of ‘word’. Bars indicate the standard error of the means (SEMs).



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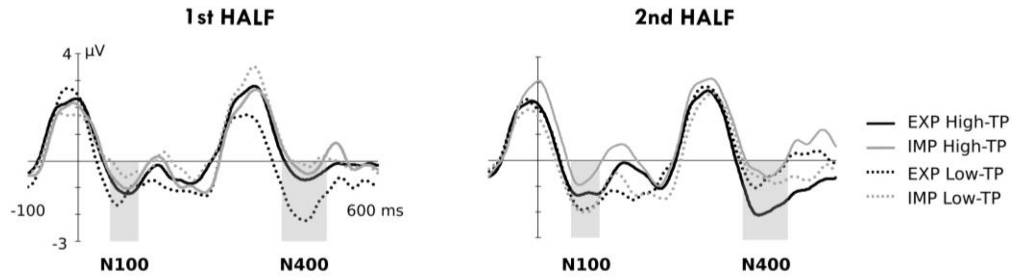
3.2. ERP data

The ANOVA considering SL task (implicit vs. explicit), Type of 'word' (high-TP vs. low-TP), and Length of exposure (1st half vs. 2nd half) as within-subject factors, showed a main effect of the length of exposure, $F(1,19)=5.22$, $p=.034$, $\eta_p^2=.215$, indicating that, regardless of the SL task and type of 'word', children showed a larger N100 amplitude in the 2nd half than the 1st half of the SL tasks. In the N400 component, the ANOVA showed a main effect of SL task, $F(1,19)=8.23$, $p=.010$, $\eta_p^2=.302$, indicating an enhancement in the SL task performed under explicit than implicit conditions. The three-fold interaction was also significant, $F(1,19)=4.65$, $p=.044$, $\eta_p^2=.197$. Pairwise comparisons showed a higher amplitude of the N400 component under explicit than implicit conditions for low-TP 'words' in the 1st half of the task ($p=.030$), and for the high-TP 'words' in the 2nd half of the task ($p=.027$). Moreover, a larger amplitude was found for the low-TP vs. high-TP 'words' in the 1st half of the explicit SL task ($p=.041$). Finally, the effect of length of exposure reached significance for low-TP 'words' under explicit instructions, resulting in a larger N400 amplitude in the 1st half than in the 2nd half of the SL task ($p=.022$).

Figure 2. Effects in the N100 and N400 ERP components for the high-TP and low-TP words in the implicit and explicit learning conditions.



4. Conclusions

Although the behavioral results indicate that there was no learning due to exposure to the auditory streams presented both under implicit and explicit conditions, the electrophysiological data have allowed us to observe effects due to the extraction of the statistical structure embedded in the speech streams as exposure unfolds. The effects in the N100 and N400 ERP components replicate previous findings observed with adult participants, hence supporting the view that they can be taken as online indexes of the emergence of a pre-lexical trace of 'words' in the brain (see Abla, 2008; Cunillera et al., 2006; De Diego Balaguer et al., 2007; Soares et al., 2020). In sum, our results join to others showing that the 2-AFC task is not suitable for assessing SL in young children. The absence of behavioral results does not mean they are not able to extract the regularities embedded in the input, but simply shows that children do not yet have the necessary skills to perform the 2-AFC task appropriately. The use of noninvasive brain activity measures such as ERPs can thus be a valuable tool to overcome these limitations, providing new insights into the processes and mechanisms underlying one of the most amazing human skills.

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