Neural Mechanisms Supporting Sequence Learning and Language

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Introduction

- Evidence from recent studies in neuroscience suggests that language development is associated with broader domain-general neural mechanisms such as sequence learning (Christiansen, Conway, & Onnis, 2011).
- Sequential learning (SL) refers to the implicit ability to recognize patterns in the environment that unfold over time (Cleeremans et al., 1998; Conway, 2012).
- SL processing is evolutionarily advantageous because it allows humans to pre-engage the appropriate cognitive mechanisms in order to facilitate the efficient integration of upcoming sensory input (Barr, 2007).
- SL abilities seem to be essential for learning motor, social, and linguistic knowledge; however there is little direct neural evidence supporting this claim.
- In this study, healthy adult participants completed a visual SL task and a language task.
- The purpose of this study was to better understand the relationship between SL and language processing by examining the neural mechanisms underlying these cognitive processes.

Method

Participants:

- N=32 (Ages 18-22). All spoke English as their first language.

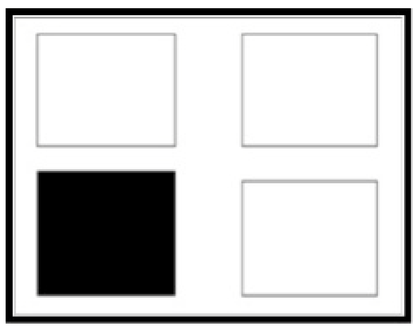
Event Related Potentials (ERP):

- Event Related Potentials (ERPs) were extracted from continuous EEG recordings at the scalp. ERPs measure electrical activity within the brain and are time-locked to the presentation of specific stimuli or cognitive event of interest (Fig 1).

Figure 1 - Figure 1 shows the 128-channel EEG sensor net used for gathering the ERP data.

Measure of SL:

- 5-item sequences of black squares appearing 1 at a time, in 1 of 4 possible quadrants on the screen.
- Artificial grammar was used to generate the order of stimuli.



- 4 blocks: Practice Phase (2 seqs), 2 Learning Phases (8 grammatical seqs, 5x), Test Phase (8 gram-trained 2x, 8 gram-untrained 2x, 16 ungram 2x).
- **ERP time-locked** to the presentation of a stimulus that violated the sequence grammar & was compared to a stimulus in a similar position in a sequence that was grammatical.

Method (cont.)

Measure of Language:

- Consisted of 80 sentences.
- Sentences were presented 1 word at a time.
- Grammatically correct sentences and sentences with syntactic violations.

The furry kittens **played** with the string.
The furry kittens **plays** with the string.

- **ERP time-locked** to the presentation of a word in the sentence that violated the syntactic structure & was compared to a word in a similar position in a sentence that was grammatical.

ERP Components of Interest

Measure of SL:
P3a (measured from frontal sensors)
- Evoked during paradigms consisting of involuntary attention (Courchesne et al., 1975).
- Associated with stimulus-driven paradigms requiring attentional focus (Comerchero & Polich, 1999).

P3b (measured from parietal sensor)
- Reflects the evaluation of incoming information & the updating of contextual representations (Ferdinand et al., 2008).

Measure of Language:
P600 (measured from central/parietal sensors)
- Associated with processing of syntactic violations (Lelekov et al., 2000).

Results

- ERP results for the SL task showed a typical P3a component 270-330ms after the violation onset in the central [$t(31) = 3.968$, $p < .001$], frontal [$t(31) = 3.321$, $p = .002$], and right anterior [$t(31) = 2.303$, $p = .028$] regions (Fig 2 and 3).
- ERP results for the language task showed a late positivity P600 component 525-925ms after the syntactic violation onset in the central [$t(31) = 6.616$, $p < .001$], right posterior [$t(31) = 2.880$, $p = .007$], left posterior [$t(31) = 5.360$, $p < .001$], right anterior [$t(31) = 7.610$, $p < .001$], left anterior [$t(31) = 2.902$, $p = .007$], and left central [$t(31) = 3.433$, $p = .002$] regions (Fig 2 and 4).
- The topographic images illustrate the scalp distribution of electrical activity for each component and reflect the beginning, middle, and later stages of the associated neural activity (Fig 5).

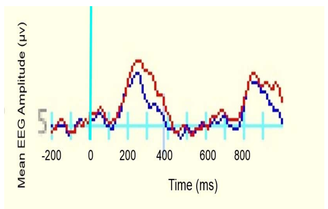


Figure 3 - Figure 3 shows the P3a component from a selected sensor located in the frontal region.

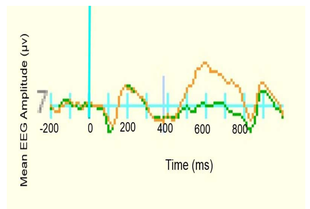


Figure 4 - Figure 4 shows the P600 component from a selected sensor located in the central/parietal region.

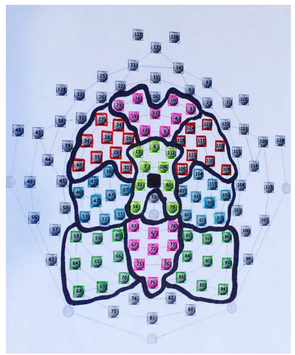


Figure 2 - Figure 2 shows the 128-channel sensor net used for gathering the differences in electrical potential for ERP recording. The channels are grouped into nine regions of interest (ROIs), each consisting of nine channels.

- Of particular interest, the early phase of the P600 (525-580ms) resembles the P3a component and was indeed significant in the frontal [$t(31) = 6.172$, $p < .001$] and right anterior [$t(31) = 4.020$, $p < .001$] regions.
- A Spearman's correlation between these particular timeframes of interest revealed a positive correlation between the P3a and the early P600 in the right anterior region [$r(32) = .291$, $p = .106$].

Results (cont.)

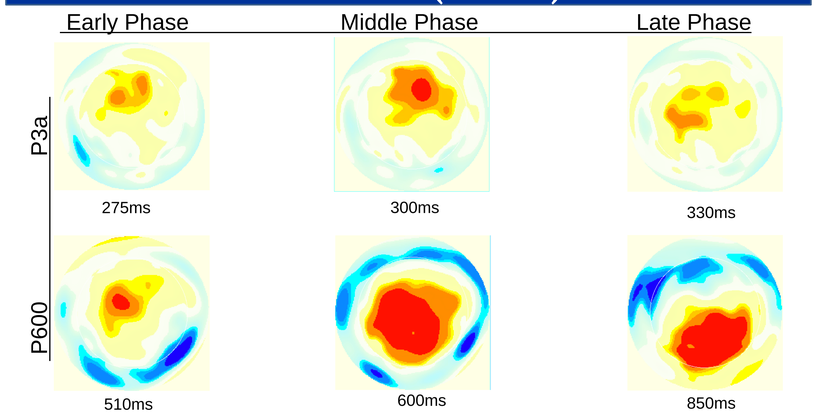


Figure 5 - Figure 5 shows the topographic evolution of neural activity detected at the scalp over the course of the ERP components.

Conclusions

- The ERP findings for the language task are not surprising given that the P600 component has often been evoked by paradigms that involve processing of syntactic violations.
- The results from the sequential learning task indicate that learning structural regularities results in a P3a effect when ungrammatical items are observed. Previous research indicates that the P3a component is associated with tasks designed to measure response preparation in the brain (as would be expected if learning is taking place).
- The correlation results are consistent with previous research suggesting a close relationship between SL mechanisms and language processing (Christiansen, Conway, & Onnis, 2011). Since the P3a closely resembles the early phase of the P600, it might be a potential indicator of the P600. This suggestion makes sense given both of these processes involve the detection of violations.
- The P3a engages a more confined area of the brain. This finding may be due to the relative unfamiliarity and limited exposure to the task, whereas the wide scalp distribution of the P600 might be the result of the extensive and prolonged exposure humans have had with language (both evolutionarily as a species and through their lifetimes as individuals).
- Overall, these findings suggest that language processing is based in part on domain-general sequential learning mechanisms. These findings in turn might demonstrate the feasibility of improving language functions by improving SL.

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Acknowledgements: Anne Walk, J.D. Purdy, Sonia Singh, & Joanne Deocampo

Funding: NIH R01DC012037