ARTICLE IN PRESS

International Journal of Psychophysiology xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

International Journal of Psychophysiology

journal homepage: www.elsevier.com/locate/ijpsycho

Registered Reports

When birds and *sias* fly: A neural indicator of inferring a word meaning in context

Pablo Rodríguez-Gómez[a], Natalia Martínez-García[a], Miguel A. Pozo[a], José A. Hinojosa[a,b], Eva M. Moreno[a,b,*]

[a] Human Brain Mapping Unit, Instituto Pluridisciplinar, Universidad Complutense de Madrid, Spain
[b] Facultad de Psicología, Universidad Complutense de Madrid, Madrid, Spain

A R T I C L E I N F O

Keywords:
ERPs
Inferences
N400
Language
Pseudowords
Predictive inferences

A B S T R A C T

Inference generation is a crucial skill in language comprehension. Recent research suggests that readers use both the contents from prior written text and their background knowledge, stored in long-term memory, to generate predictive inferences about what will come up next in a sentence. We recorded Event-Related Potentials (ERPs) to examine the reader's ability to make online inferences even in the presence of pseudowords (orthographically legal, but meaningless letter strings), that is, in the presence of referents with no a priori match to vocabulary stored knowledge. As expected, a large and sustained negativity (250–900 ms) was elicited by the target word '*fly*' when preceded by the pseudoword '*Sias*' in the sentence '*Sias fly*.' relative to when preceded by '*Birds*' in the sentence '*Birds fly*'. However, when readers were provided with an initial statement inviting to make an inference: '*Sias have wings*', the word '*fly*' in '*Sias fly*' only elicited a negative voltage deflection over 100 ms period (250–350), rapidly falling down to baseline. This result indicates that participants rapidly generated online inferences even with a hindered access to a referent's meaning (i.e. not knowing what '*Sias*' are). Remarkably, brainwave traces to the access to a word's meaning in long-term memory (access to a well-known fact such as '*Birds fly*') only diverged from ERPs for an inferred-from-reading knowledge ('*Sias fly*') for 100 ms. We conclude that a fundamental search for across sentence coherence drives fast inference making processes in reading tasks. This pattern of brain response is critical to understand the rapid acquisition of new vocabulary when learning first and second languages.

1. Introduction

Inference generation is a crucial skill for language comprehension. The Landscape Model of reading (van den Broek et al., 1999) posits that two types of comprehension processes (i.e., passive memory-based and active constructive ones) operate during reading comprehension. Both mechanisms interact to provide semantic coherence to reading passages. Strategic constructionist processes (i.e., elaboration) comes into play when the activations that result from the automatic memory-based processes fail to yield a sufficient coherence. The degree of activation of concepts either mentioned in a text or retrieved from background knowledge, constantly fluctuate as a reader proceeds through a text (Yeari and van den Broek, 2011). Psycholinguistic theories have traditionally made a distinction between necessary inferences (e.g. anaphoric reference, backward bridging inferences) and elaborative or optional inferences (e.g. propositional logic inferences, instrumental inferences, predictive inferences) (Cook and O'Brien, 2015). An example of a necessary inference is pronoun resolution. After reading the sentence: "*Paul and Mary went to the gym. He really wanted to exercise*" the reader needs to infer that the pronoun "*He*" refers back to Paul and not to Mary. The automatic activation of our world knowledge (e.g. male and female proper nouns) allows the inference. In this example, optional inferences might additionally be made on whether they both ended up exercising or not, whether they went to the gym by car or walking, and so on. Making this type of "optional" inferences might facilitate the processing of upcoming words later in the discourse.

Despite the fact that inference making is a fairly common process during reading, the neural mechanisms that allow it have only recently been explored. Brain imaging techniques have found that the left inferior frontal gyrus (LIFG) and the right lingual gyrus are involved in predictive inference generation (Jin et al., 2009). Also, dorsomedial prefrontal cortex activation has been implicated in coherence building, and the left frontal lobe region has been involved in knowledge-based inferences (Ferstl, 2015). Research using the Event-Related Potential

* Corresponding author at: Human Brain Mapping Unit, Instituto Pluridisciplinar, Universidad Complutense de Madrid, Paseo Juan XXIII 1, 28040 Madrid, Spain.
E-mail address: emmoreno@ucm.es (E.M. Moreno).

http://dx.doi.org/10.1016/j.ijpsycho.2017.09.015
Received 24 January 2017; Received in revised form 19 September 2017; Accepted 25 September 2017
0167-8760/

Please cite this article as: Rodríguez-Gómez, P., International Journal of Psychophysiology (2017), http://dx.doi.org/10.1016/j.ijpsycho.2017.09.015

(ERP) technique supports the view that readers anticipate upcoming words in discourse while reading (Kutas et al., 2011; Van Berkum et al., 2005). However, it is still a matter of debate under what circumstances predictions are made and how robust predictions can be (Ito et al., 2016).

1.1. Event-related brain potential studies of inference generation

A critical issue is how fast inferences, even elaborative/optional ones, not required for comprehension to proceed, are made in reading comprehension tasks. Due to its high temporal resolution, the ERP technique is ideally suited to explore the point in time at which inferences were most likely drawn during reading. It provides a continuous measure of ongoing electrical brain activity from the onset of a critical word in a reading passage. A pioneering ERP study on inference generation (St George et al., 1997), used the amplitude of the N400 component (Kutas and Hillyard, 1980a), sensitive to semantic priming and context integration processes, to show that readers were able to make fast online inferences during reading tasks. When the final sentence of a paragraph stated explicitly an inference that readers were invited to make based on earlier context, the N400 averaged peaks to the words in the final sentence were reduced. Similarly, the establishment of causal coherence across sentences, was marked by a attenuation of the N400 response to words that were inserted in highly causally related scenarios relative to those inserted in causally unrelated scenarios (Kuperberg et al., 2010; Kuperberg et al., 2011). According to Yang et al. (2007) word-to-text integration processes also occur across sentence boundaries (e.g. a reduction in the N400 for the word ‘rain’ in a sentence preceded by a coreferent paraphrase: ‘storm’). Moreover, lexical decision tasks on probe words that could have been inferred after reading a sentence elicited an attenuated N400 and a larger late positivity (P600) probably indexing a causal coherence inference generation (Steele et al., 2013). Finally, in a study by Burkhardt (2007), the need to establish causal coherence across sentences was indexed by an incremental amplitude of the P600 in response to a word that represented addition of new information to an statement made earlier. Specifically, an incremental larger P600 amplitude was found to the word ‘*pistol*’ in the sentence: “the press reported that the *pistol* was probably…” when preceded respectively by: Yesterday a Ph.D. student was: (1) shot down (2) killed and (3) found dead downtown. Overall, these studies reveal that inference generation can be traced down by measuring the ERP responses to target words that carry information that could have been inferred based on prior text information and/or on prior knowledge. All above mentioned studies have made use of meaningful contexts and targets and meaningful discourse. However, the real need to make an inference is when the comprehension system is challenged by the use of a lexical entry that has no access to vocabulary stored knowledge. Pseudowords (e.g. *sias*) follow orthographical rules and resemble real words. However, they are devoid of links to long term memory stored knowledge. A recent study by Batterink and Neville (2011) embedded pseudowords in narrative contexts that either allowed or not the inference of what the word meaning might be. In one condition pseudowords were embedded in the text always replacing a real word whereas in condition 2 the replacement was pseudorandom, lacking thus a consistent link to meaning across the text. According to brain responses, pseudowords in inference supportive contexts seemed to acquire meaning across ten consecutive presentations, showing a reduction in N400 amplitude. Nonetheless, constant repetition of the same pseudoword target had an impact in itself on brainwave responses (an additional N400 reduction). The interaction of these two effects made facilitation due to the type of context produce no additional effect over the sixth through the eight presentation of the pseudoword.

1.2. The present study

The current study measured the response to the final real word of the sentence depending on whether it was preceded by a word or a pseudoword referent. In addition, it used a two-block design in order to control for the repetition of pseudowords. In the first block, words or pseudowords were presented in an isolated sentence whereas in a second block they were preceded by an inference inviting sentence. Critically, participants either saw the real word in block 1 and the pseudoword in block 2, or viceversa. Thus, our aim was to explore how the brain responds to sentence final word endings (e.g. “*fly*”) when prior world knowledge is available (*Birds fly*) and compare it to when an inference making process ought to be implemented for comprehension to proceed (e.g. *Sias fly*). In the later example, no long-term memory (LTM) trace is available for the meaning of the lexical entry ‘*Sias*’. However, if we stated in a preliminary sentence that ‘*Sias* have wings. *Sias* fly’ (block 2), regardless of our lack of knowledge of what ‘*sias*’ are, we may be ready (or not) to make an inference on its meaning, thus anticipating the word: ‘fly’. Our ability to make fast online inferences (Steele et al., 2013) could thus be extended to unknown pseudoword referents and affect the successful prediction of meaningful upcoming words in discourse. Thus, according to prior literature on inference making, an N400 reduction or absence is expected for the final word of the second sentence (in block 2), i.e. when, regardless of word status, an inference supportive sentence was included. However, the inclusion of a pseudoword referent in the initial sentence (block 1) might distort or prevent the process of anticipation of sentence word endings, in which case the target word ‘fly’ in the context ‘Sias have wings. Sias fly’ would still show an N400 effect. Thus, we measured the brain responses to both the final word of the sentence (e.g. *fly*) which will remain constant across conditions, as well as the response to the word/pseudoword referents themselves (e.g. *birds*/*sias*).

Regarding the second aim, prior literature shows that ERPs to words and pseudowords differ in the amplitude of the N400 component, starting at about 200 ms (Kutas and Van Petten, 1994). Most studies showing this lexicality effect (a larger N400 for pseudowords than words) have used paradigms of lexical/semantic priming and decisions tasks on single words. A recent lexical decision study (Bermudez-Margaretto et al., 2015), reports that repeated exposure to meaningless pseudowords produces an increase in the Late Positivity Complex (LPC), while a frontal N400 component (FN400), larger for pseudowords relative to words, is unaffected by repetition.

Thus, as a secondary goal, we explored how the ERP response to words and pseudowords evolves in time at each of their occurrences during the reading session: (1) as the subject of the unique sentence (block 1), (2) as the subject of the first sentence (block 2), and (3) as a subject of the second sentence (block 2). Initially, at block 1, a larger N400 is expected to be elicited by pseudowords relative to words (i.e., lexicality effect). In addition, we anticipate an N400 reduction with each word presentation (N400 word repetition effect) (see review by Kutas and Federmeier, 2000). Finally, an increase in the LPC component for the repetition of pseudowords, would replicate the findings for the repetition of isolated pseudowords in lexical decision tasks (Bermudez-Margaretto et al., 2015).

2. Method

2.1. Participants

Twenty-four native Spanish speakers (7 males, mean age = 19.7 years, range = 18–26 years) volunteered to participate in the study in exchange for course credits. All participants gave written informed consent and reported being right-handed. The average handedness score (Oldfield, 1971) was + 78.9 (range, + 41 to + 100). All participants reported normal or corrected-to-normal vision and none had a history of neurological or psychiatric disorders. The local ethics committee approved the experimental procedures.