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Automaticity of higher cognitive functions: Neurophysiological evidence for unconscious syntactic processing of masked words

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ABSTRACT

Models of language comprehension assume that syntactic processing is automatic, at least at early stages. However, the degree of automaticity of syntactic processing is still controversial. Evidence of automaticity is either indirect or has been observed for pairs of words, which might provide a poor syntactic context in comparison to sentences. The present study investigates the automaticity of syntactic processing using event-related brain potentials (ERPs) during sentence processing. To this end, masked adjectives that could either be syntactically correct or incorrect relative to a sentence being processed appeared just prior to the presentation of supraliminal adjectives. The latter could also be correct or incorrect. According to our data, subliminal gender agreement violations embedded in a sentence trigger an early anterior negativity-like modulation, whereas supraliminal gender agreement violations elicited a later anterior negativity. First-pass syntactic parsing thus appears to be unconsciously and automatically elicited. Interestingly, a P600-like modulation of short duration and early latency could also be observed for masked violations. In addition, masked violations also modulated the P600 component elicited by unmasked targets, probably reflecting that the mechanisms of revising a structural mismatch appear affected by subliminal information. According to our findings, both conscious and unconscious processes apparently contribute to syntactic processing. These results are discussed in line with most recent theories of automaticity and syntactic processing.

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1. Introduction

Brain processes are traditionally divided into those that are automatic and those that are controlled (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1984). Automatic processes require little attentional control, are faster, do not use limited capacity recourses and therefore they do not engage the executive control systems. In contrast, controlled processes involve conscious attention, are slower, and engage limited capacity and executive control resources. Most recent theories of automatic processing propose more flexibility and context-adaptability of unconscious automatic processing than the classical theories do, by considering a bidirectional interaction between unconscious and executive control processes that might facilitate this adaptability (for a review see: Kiefer, 2002).

An open question in neurolinguistics is to determine the degree of automaticity of the syntactic processing. At first glance, syntax analyses seem to be very fast and not requiring conscious control or attention (e.g., Hasting & Kotz, 2008). In this regard, most widely accepted models propose that syntactic processing is automatic at least at early stages (Fodor & Frazier, 1980; Friederici, 1995; Friederici & Kotz, 2003; Gorrell, 1995; Inoue & Matsuzawa, 2007). However, according to recent evidence it remains unclear to what extent syntactic parsing might be performed automatically even in a first-pass and whether it needs the continuous contribution of conscious perception (Batterink, Karns, Yamada, & Neville, 2010; Hasting & Kotz, 2008).

Research on syntactic processing has led to two types of models: serial and interactive. Serial approaches propose that initial parsing processes are automatic, restricted to syntactic knowledge and phrase structure rules, and are independent of semantic and pragmatic information (e.g., Frazier & Fodor, 1978; Hahne & Friederici, 1999). Interactive models, in turn, propose that different

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aspects of language interact continuously during sentence comprehension (e.g., MacDonald, 1993; McClelland and Rumelhart, 1981; Boutonnet, Athanasopoulos, & Thierry, 2012). The main aim of this article is to investigate the automaticity of syntactic processing by presenting subliminal adjectives either syntactically correct or incorrect embedded in consciously perceived sentences that could also be syntactically correct or incorrect. As discussed below, unconscious stimulation ensures automatic processing, although both conscious and unconscious stimulation may contribute to automatic processing.

The automaticity of syntax can be approached by means of event related potentials (ERP) due to their high temporal resolution. To date, two functionally distinct ERP components related to syntax have been analyzed; anterior negativities and P600.

According to some authors, two types of anterior negativities with different onsets appear depending on the type of syntactic violation. A left anterior negativity (LAN) is typically seen to morphosyntactic errors, such as gender, number, or subject–verbs agreement violations (e.g. "The athletes is running"), typically appearing between 300 and 500 ms in left frontal electrodes. However, the laterality and anterior location of the component are not consistent across studies (e.g., Guajardo and Wicha, 2014; Hagoort, 2003a; Kutas Van Petten, & Kluender, 2006), so that more anterior and central distributions are also commonly reported (e.g., Barber & Carreiras, 2003, 2005; Molinaro, Vespignani, & Job, 2008). On the other hand, an ELAN (for early LAN), appearing between approximately 100 and 300 ms, is usually observed in response to word category violations, with phrase structure violations such as "the pizza was in-the eaten" (Hahne & Friederici, 1999, 2002). Whether LAN and ELAN conform two functionally different modulations remains unclear, however. For example, the LAN has also been found for word-category violations (Friederici & Meyer, 2004; Hagoort, 2003a; Hinojosa, Martin-Loeches, Casado, Muñoz, & Rubia, 2003). In addition, early anterior negativities are also observed for morphosyntactic violations (Hagoort, 2003b; Münte & Heinze, 1994) and specifically for gender agreement violations (Deutsch, Bentin, & Katz, 1999). Accordingly, the functional dissociation between LAN and ELAN might not apply (e.g., Hagoort, 2003a; Kaan, 2007; Steinhauer & Drury, 2012).

Anterior negativities seem to reflect first parsing processes, the detection of a morphosyntactic mismatch, difficult or rare processing of correct grammatical structure, the inability to assign the incoming word into the current phrase structure (Friederici, 1995; Hagoort, 2003a; Hahne & Friederici, 1999; Rösler, Pechmann, Streb, Rder, & Henninghausen, 1998), or some aspects of working memory operation (King & Kutas, 1995; Makuuchi et al., 2009; Martin-Loeches, Munoz, Casado, Melcon, & Fernandez-Frias, 2005; Weckerly & Kutas, 1999). The P600, a late component traditionally observed to syntactic anomalies but also reported to semantic anomalies (van Herten, Kolk, & Chwilla, 2005), appears between 600 and 900 ms after the onset of the anomaly in centro-parietal electrodes. This component is supposed to reflect costs of repair and revision of structural mismatches and/or integration processes between semantic and syntactic information (Friederici, 2002; Kuperberg, 2007; Martin-Loeches, Nigbur, Casado, Hohlfeld, & Sommer, 2006).

Most probably, anterior negativities reflect the most automatic and unaware part of the syntactic processing, as this component, in contrast to the P600, seems neither affected by the probability of encountering a violation (Hahne & Friederici, 1999) nor by task demands (Hahne & Friederici, 2002). The P600 may index therefore the more controlled mechanisms associated with syntactic processing (Münte, Heinze, & Mangun, 1993). Friederici (1995, 2002) has suggested a neurocognitive model of language comprehension mainly based on ERP findings. According to this model, syntax processing takes place in three consecutive phases: structure building based on word category information (reflected on ELAN component), syntactic-relational processing (LAN), and revision and repair processes (P600). However, this model would not hold if, as mentioned, the functional dissociation between ELAN and LAN were not applicable, and indeed Hasting and Kotz (2008) have reported highly automatic early ERP effects for morphosyntactic anomalies. They presented two types of violations local subject–verb agreement and word category violations implemented in two-word utterances with strictly controlled acoustic properties and identical violation points. In two experiments with varying task demands, anterior negativities with an onset at 100 ms were elicited in response to both violation types and independently of the allocation of attentional resources. As also mentioned, recent evidence also suggests that even first-pass syntactic parsing might not be performed automatically (Hasting & Kotz, 2008), while it has been questioned whether the continuous contribution of conscious perception is necessary for syntactic processing (Batterink et al., 2010). Consequently, the necessity of further research into the automaticity of syntactic processes seems warranted.

A suitable way of inquiring into the automaticity of syntactic processes can be approached by means of the dissociation between conscious and unconscious perception. Indeed, whereas automatic processes can be triggered by both conscious and unconscious stimuli, it can be ensured that processing occurs automatically for unconscious perception (Kiefer, Schuch, Schenck, & Fiedler, 2007). In this regard, several authors have successfully investigated the automaticity of brain processes by presenting masked visual stimuli. Interestingly, moreover, it is well demonstrated that masked unconscious stimuli trigger cognitive processes that can influence decision and action (Kiefer, 2007; Kiefer, Adams, & Zovko, 2012). The main goal of the current study is to investigate the automaticity of the syntactic processing of sentences using a masked priming paradigm, where syntactic violations were presented under subliminal viewing conditions to ensure that processing occurs automatically, with no contribution of intended, controlled processes.

To this aim, subliminal adjectives, which could be either correct or incorrect relative to the sentence being processed supraliminally (gender agreement violations between the supraliminal noun and the subliminal adjective) were shortly presented prior to the presentation of supraliminal adjectives that could in turn also be correct or incorrect relative to the sentence in progress. Accordingly, the sentences structure was: [determiner] – [noun] – [subliminal adjective] – [mask (#####)] – [supraliminal adjective] – [verb]. To minimize physical mismatch the same adjective was subliminally and supraliminally presented, though it could vary in a 2×2 factorial design as a function of the morphosyntactic correctness value relative to sentential structure. Thus, a supraliminal correctness $\times$ subliminal correctness factor design was used, where each sentence could be presented in 4 different conditions: (1) subliminal correct – supraliminal correct (C–C), (2) subliminal correct – supraliminal incorrect (C–I), (3) subliminal incorrect – supraliminal correct (I–C), and (4) subliminal incorrect – supraliminal incorrect (I–I) (Table 1). Gender agreement violations were specifically used to minimize physical mismatch between conditions, as in Spanish the final letter of the word usually marks the gender ("o" for masculine and "a" for feminine in most cases).

According to theories of automaticity of syntactic processing, particularly at its earlier stage, anterior negativities should be expected not only for conscious violations but also for unconscious violations. Accordingly, subliminal agreement violations should exhibit anterior negativities despite the supraliminal correctness of the sentences. Recent theories (for a review see: Kiefer, 2002) that propose a bidirectional interaction between the automatic processing and the executive control settings that modulate later

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