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ERPs reveal individual differences in morphosyntactic processing

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ABSTRACT

We investigated individual differences in the neural substrates of morphosyntactic processing among monolingual English speakers using event-related potentials (ERPs). Although grand-mean analysis showed a biphasic LAN-P600 pattern to grammatical violations, analysis of individuals' ERP responses showed that brain responses varied systematically along a continuum between negativity- and positivity-dominant ERP responses across individuals. Moreover, the left hemisphere topography of the negativity resulted from component overlap between a centro-parietal N400 in some individuals and a right hemisphere-dominant P600 in others. Our results show that biphasic ERP waveforms do not always reflect separable processing stages within individuals, and moreover, that the LAN can be a variant of the N400. These results show that there are multiple neurocognitive routes to successful grammatical comprehension in language users across the proficiency spectrum. Our results underscore that understanding and quantifying individual differences can provide an important source of evidence about language processing in the general population.

1. Introduction

Successful language comprehension requires the rapid integration of multiple information sources. The meanings of incoming lexical items must be accessed, morphosyntactic cues must be identified and linked together to form a syntactic representation of the sentence, and all of this information must be integrated into a coherent semantic representation at the sentence and discourse levels. Decades of research have now shown that these processes occur incrementally, as the linguistic input unfolds over time (e.g., Rayner & Clifton, 2009). One particular focus in neurocognitive research on language comprehension has been identifying the neural mechanisms supporting morphosyntactic integration (i.e., the processing of grammatical rules or constraints). Indeed, a number of recent neurocognitive models of language comprehension based on recordings of event-related brain potentials (ERPs) have been put forth to explain how morphosyntactic processes unfold in real time (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2008; Friederici, 2002; Friederici & Weissenborn, 2007; Hagoort, 2003; Molinaro, Barber, & Carreiras, 2011; Ullman, 2004).

The validity of these models rests upon the assumptions that proficient, literate native speakers of a language show a relatively homogenous profile of brain responses during language comprehension, and that the grand mean response reflects this normative brain response across individuals. However, some recent research has begun to show neurocognitive processing differences among native speakers of a language, and characterizing these individual differences and their theoretical consequences has become an increasingly important goal (Pakulak & Neville, 2010; Prat, 2011). In the study reported here, we use novel metrics to quantify individual variation in language-related ERP effects, which show that qualitative individual differences in brain responses exist among proficient monolinguals processing morphosyntactic dependencies with little semantic content. This is a linguistic domain and population where individual differences in ERPs have not previously been reported. Moreover, we show that, while failure to account for individual differences in brain responses can lead to spurious conclusions about language processing in the general population, understanding and quantifying these differences can provide an important source of evidence regarding the nature of language processing mechanisms.

Recordings of brain activity using ERPs have been useful in identifying the nature and time course of language comprehension processes, as different ERP components have been reliably associated with the processing of different types of linguistic information.

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For example, the processing of meaningful stimuli (including words) has been shown to elicit a negative-going component prominent over centro-parietal scalp regions with a peak around 400 ms after stimulus presentation (the N400 component). The amplitude of this peak co-varies with a number of factors, such as a given word's frequency or conceptual integratability into a sentence or discourse context (the N400 effect: Hagoort, Hald, Bastiaansen, & Petersson, 2004; Kutas & Hillyard, 1980, 1984; Lau, Phillips, & Poeppel, 2008; Van Berkum, Hagoort, & Brown, 1999). On the other hand, a variety of morphosyntactic anomalies, such as agreement and tense violations, frequently elicit a biphasic pattern characterized by a left anterior negativity (LAN) between 300 and 500 ms followed by a broadly distributed positivity with a centro-parietal maximum beginning around 500 ms (the P600 effect: Friederici, Hahne, & Mecklinger, 1996; Hagoort, Brown, & Groothusen, 1993; Molinaro et al., 2011; Osterhout & Mobley, 1995). Overall this differential pattern of neural responses to linguistic manipulations suggests that lexical and morphosyntactic processes are in many circumstances neurocognitively distinct, as violations of each elicit a characteristic pattern of brain responses.

While the exact functional interpretation of the N400 and LAN/P600 effects is still being debated (see e.g., Bornkessel-Schlesewsky & Schlesewsky, 2008; Brouwer, Fitz, & Hoeks, 2012; Kim & Osterhout, 2005; Kuperberg, 2007; Kutas & Federmeier, 2011; Van de Meerendonk, Kolk, Vissers, & Chwilla, 2010), some neurocognitive models of syntactic processing ascribe different processes to the two phases of the LAN-P600 complex (Batterink & Neville, 2013; Friederici & Weissenborn, 2007; Hagoort, 2003; Molinaro et al., 2011; Pakulak & Neville, 2010; Ullman, 2004). Although the exact details of these syntactic processing models differ, a common feature of them is the assumption that the LAN reflects automatic detection of syntactic violations during first pass parses, while the P600 reflects later controlled attempts to reanalyze or unify the ungrammatical parse.

An important implication of these syntactic processing models is that morphosyntactic violations should elicit biphasic LAN-P600 responses in most or all individuals. If the LAN is a singular component reflecting the detection of anomalies, detection should be a prerequisite for reanalysis. Extrapolating to the context of individual differences, this would predict that the extent to which individuals differ in their neural responses to morphosyntactic violations, the magnitude of any individual's P600 effect (reflecting reanalysis or continued attempts to unify the initial failed parse) should be a function of the strength of that individual's detection of the anomaly (indexed by the LAN). However, while P600s are nearly uniformly elicited in studies of morphosyntactic processing, the presence and scalp topography of LANs have been extremely variable across studies. While many studies have reported typical LAN effects between approximately 300 and 500 ms, others have reported syntactic negativities preceding the P600 over bilateral frontal sites (e.g, Gouvea, Phillips, Kazanina, & Poeppel, 2010; Hagoort, Wassenaar, & Brown, 2003), left temporal sites (e.g., Kaan & Swaab, 2003a; Rodriguez-Fornells, Clahsen, Lleó, Zaake, & Münte, 2001), right temporal sites (e.g., Osterhout & Nicol, 1999), or broadly distributed negativities with a right frontal maximum (e.g., Dillon, Nevins, Austin, & Phillips, 2012; Silva-Pereyra & Carreiras, 2007). Despite this variability in topography, many researchers have presumed that these disparate negativities (sometimes referred to more broadly as anterior negativities, or ANs) reflect the same basic underlying process indexed by the canonical LAN. Additionally, some studies of morphosyntactic processing have reported large P600 effects, but failed to find any earlier negativity (e.g., Allen, Badecker, & Osterhout, 2003; Nevins, Dillon, Malhotra, & Phillips, 2007; Osterhout, Mckinnon, Bersick, & Corey, 1996), while others have shown that the presence of the LAN may be modulated by presentation modality (visual versus auditory: Hagoort & Brown, 2000) or participant task (acceptability judgment versus passive reading: Osterhout & Mobley, 1995).

Some work has attempted to explain some of the apparent variability in the LAN. One suggestion is that the presence or absence of LAN effects may be a function of the morphological richness of a language: sentence comprehension in languages with relatively free word order and rich inflectional systems (e.g., German and Italian) may require stronger engagement of automatic morphosyntactic processing mechanisms than sentence comprehension in languages with fixed word order and residual inflectional systems (e.g., English: Friederici & Weissenborn, 2007). A second suggestion is that methodological considerations like choice of reference site for ERP analysis may play a crucial role in the presence or absence of a LAN (Molinaro et al., 2011). Molinaro and colleagues argue that LAN effects are most likely to occur with linked or averaged mastoid references, as opposed to left mastoid references, which may disproportionately subtract out left hemisphere effects like the LAN. However, even these explanations fail to capture all of the variability: LAN effects have been reported in languages with impoverished inflectional systems (English) using left mastoid references (Coulson, King, & Kutas, 1998; Osterhout & Mobley, 1995), whereas others have failed to find a LAN in morphologically rich languages (Hindi) with linked mastoid references (Nevins et al., 2007). Thus, despite the centrality of the LAN to numerous models of sentence comprehension as an integral index of failure in morphosyntactic processing, the enormous variability in scalp topography across studies suggests that it may not reflect a single underlying neurocognitive process with a consistent neuroanatomical source. Moreover, as P600 effects have been found in the absence of earlier LAN or other negativities, the syntactic processes indexed by the P600 may not crucially depend on the earlier detection of an anomaly, as indexed by the LAN.

An important remaining issue is therefore resolving the functional nature of the LAN and the factors related to its presence or absence. One possibility that has received little attention is the role that individual variability in ERP responses may play (though see Osterhout, McLaughlin, Kim, Greewald, & Inoue, 2004). Some studies have shown that biphasic negative–positive grand mean ERP waveforms can sometimes be a result of averaging over individuals who show different ERP response profiles. Individual differences in brain responses have been reported to anomalous content words in garden path sentences (e.g., *The boat sailed down the river sank*), where some individuals showed a P600 effect and others an N400 effect (Osterhout, 1997). The result after averaging was a statistically reliable biphasic response in the grand mean that was not representative of most individuals' brain responses. More recent research has shown that violations of verb-argument animacy constraints (*The box is biting*…) elicited an N400 in individuals with lower verbal working memory (WM) span, but a P600 in participants with higher verbal WM span (Nakano, Saron, & Swaab, 2010; see also Oines, Miyake, & Kim, 2012). Others have shown that interactions between sentence complexity and individual differences in cognitive control (as measured by a color-word Stroop task) can modulate the polarity of ERP responses (negative- vs. positive-going) to sentences containing conflicts between world knowledge and syntactic ordering of constituents (Ye & Zhou, 2008). In these cases, the linguistic anomalies were signaled by both semantic (e.g., lexical associations, animacy, world knowledge) and syntactic (e.g., inflectional morphology, syntactic position) information. The results suggest that some individuals may focus more on lexical information and show N400s while others focus more on combinatorial information and show P600s, and moreover, that these individual differences can be mediated by WM or cognitive control. Importantly,