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Response retrieval and motor planning during typing

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ABSTRACT

Recent work in language production research suggests complex relationships between linguistic and motor processes. Typing is an interesting candidate for investigating further this issue. First, typing presumably relies on the same distributed left-lateralized brain network as handwriting and speech production. Second, typing has its own set of highly specific motor constraints, such as internal keystroke representations that hold information about both letter identity and spatial characteristics of the key to strike. The present study aims to further develop research on typed production, by targeting the dynamics between linguistic and motor neural networks. Specifically, we used a typed picture-naming task to examine the interplay between response retrieval and motor planning. To track processes associated with both linguistic processing and keystroke representation, we manipulated, respectively, the semantic context in which the target appeared and the side of the first keystrokes of the word. We recorded high-density electroencephalography (EEG) continuously from the presentation of a picture, to the typing of its name, and computed both event-related potentials (ERP) and beta-band power analyses. Non-parametric data-driven analysis revealed a clear pattern of response preparation over both hemispheres close to response time, in both the ERP and beta-band power modulations. This was preceded by a left-lateralized power decrease in the beta-band, presumably representing memory retrieval, and an early contrast in ERP, between left and right keystrokes' preparation. We discuss these results in terms of a dynamic access approach for internal keystroke representations, and argue for an integrative rather than separatist view of linguistic and motor processes.

1. Introduction

Language communication through keyboard typing is, unsurprisingly, a rapidly-growing form of peer-to-peer interaction, and it is becoming our main writing modality. The cognitive and motor aspects of such communication have been insufficiently researched at this point, especially in the neuroscience literature. The present study aims to further develop research on typed production by characterizing linguistic and motor processes with electroencephalography (EEG).

A handful of brain imaging studies have provided a first view of the neural networks that may be recruited during typing (Gordon, Lee, Flament, Ugurbil, & Ebner, 1998; see also Magrassi, Bongetta, Bianchini, Berardesca, & Arienta, 2010; Purcell, Napoliello, & Eden, 2011). These studies revealed left hemisphere networks previously associated with handwritten and oral language production, including the inferior frontal gyrus, inferior temporal/fusiform gyrus, posterior intraparietal sulcus, and superior/middle frontal gyrus (Planton, Jucla, Roux, & Démonet, 2013; Price, 2012; Rapp & Lipka, 2011; see especially Purcell et al., 2011). Such coincidence could seem trivial under the view that the same kind of language processing similarly channels into very different kinds of language production modalities (e.g., motor modes of speaking, signing, writing and typing). However, this description might be too simplistic, as attested by current interest in language research to clarify the relationship between linguistic and motoric processes, and to dovetail motor planning at large (e.g. pre-motor, motor, monitoring, etc.) with the language production network (e.g. Bohland, Bullock, & Guenther, 2010; Hickok, 2014). Typing for instance, is an interesting candidate for investigating this issue, as it has its own set of highly specific motor constraints, such as internal keystroke representations and inter-keystroke dependencies (discussed in more detail later).

The pioneering brain imaging studies of typing have provided only indirect clues on the dynamic organization of a supposedly more complex underlying neural process. Previously, behavioral studies have been the preferred method to investigate the specifics

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of typing. They provided evidence that typing execution is notably constrained by physical aspects (Gentner, Larochelle, & Grudin, 1988) and relies on successful bimanual coordination (Logan & Crump, 2009), just as in the hierarchical organization of larger movement sequences (Rosenbaum, Kenny, & Derr, 1983). Furthermore, nonphysical aspects are also highly relevant. For example, standard psycholinguistic manipulations, such as word frequency, also yield facilitatory effects on several typing-related measures (such as response time, Nottbusch, Grimm, Weingarten, & Will, 2005, typing durations, Inhoff, 1991, and interkeystroke intervals, Gentner et al., 1988; Pinet, Ziegler, & Alario, submitted for publication). These results, involving manipulations of both central and peripheral processes, can be captured by well-constrained cognitive theoretical frameworks (Logan & Crump, 2011; Rumelhart & Norman, 1982).

For example, one comprehensive model of typing (Rumelhart & Norman, 1982) postulates that successful typing relies on keystroke schemata (i.e. keystroke representations) that hold a letter's identity, as well as which hand, finger, and movement sequence are required to type it on a keyboard. These representations are retrieved when a word to-be-typed is parsed into letters, and then converted into the appropriate motor programs. A number of behavioral studies provide data that support such notions of keystroke representations (e.g., Kozlik & Neumann, 2013; Logan, 2003). A more integrative view of typing behavior has also been proposed, in which peripheral processes may constitute one level of processing, which is embedded into a higher level that entails central linguistic processes, such as word retrieval (Logan & Crump, 2011). In this integrative view, the translation from words into keystroke motor plans is thought to happen in parallel. This kind of hierarchical organization, with a distinction between response retrieval and motor planning, has accounted well for precedent behavioral data.

The cognitive framework we just described (Logan & Crump, 2011; Rumelhart & Norman, 1982) can guide future neurophysiological research in typing. For instance, the two-stage cognitive model can be extrapolated to predict the neurophysiological signature of typing, for which very scarce evidence is available (Baus, Strijkers, & Costa, 2013; Logan, Miller, & Strayer, 2011; Pinet, Hamamé, Longcamp, Vidal, & Alario, 2015; regarding EEG studies of handwritten production, see e.g. Perret & Laganaro, 2012). This signature can be expected to be manifest in both beta-band power and event-related potentials (ERP) modulations, which have been found to be relevant dependent variables for characterizing language and motor processing (e.g., Ganushchak, Christoffels, & Schiller, 2011; Weiss & Mueller, 2012).

With regard to beta-band power activity, its desynchronization appears to be an established marker of motor preparation and execution (e.g., Engel & Fries, 2010). During sequence production tasks in general (Bai, Mari, Vorbach, & Hallett, 2005), and particularly during typing (Pinet et al., 2015), both hemispheres present a strong event-related desynchronization (ERD) in time windows associated with response preparation and execution, whether the sequence to produce is unimanual or bimanual. Furthermore, beta band ERD is also associated with stimulus processing and long-term memory retrieval (Hanslmayr, Staudigl, & Fellner, 2012). Thus, in typewritten word production, we hypothesized that ERD effects in the beta band should be observed in relation to response retrieval, as well as motor programming. In addition, our study sought to assess the extent of temporal separation between these processes.

ERP components, in contrast, have been extensively used to trace linguistic processing (e.g., Kutas & Federmeier, 2011). Particularly, in spoken word production, response retrieval is evidenced in early ERPs components by manipulating prior semantic context (e.g. Janssen, Carreiras, & Barber, 2011), in keeping with the idea that production of a semantic competitor specifically influences subsequent word retrieval behavior (Wheeldon & Monsell, 1994). Previous research has also shown that ERP components are reliable indices of motor programming. In single movement execution, a lateralized pattern is observed prior to the response (Lateralized Readiness Potential; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988), with converging evidence suggesting that the motor cortex ipsilateral to the response is inhibited prior to a single movement (Burle, Vidal, Tandonnet, & Hasbroucq, 2004; Vidal, Grapperon, & Bonnet, 2003). The same kind of phenomena has been recently explored in typing tasks (Logan et al., 2011; Pinet et al., 2015). In this context, we hypothesized that word retrieval and motor programming should be evidenced in the previously described components, and sought to assess the extent of their temporal separation.

1.1. The current study

In short, previous work suggests that the dynamic activity underlying typing should be efficiently traced with EEG, in modulations of beta-band power and ERP components. Because previous investigations of typing were mainly focused on motor preparation processes, they do not inform us on the dynamic interplay of response retrieval and motor planning. To address this question, a full investigation of the neural dynamics starting from central processes (e.g. stimulus processing) up to response execution, remains to be conducted.

To do so, we recorded and analyzed EEG continuously from the presentation of a picture, to the typing of its name, to characterize processes between stimulus evaluation to response execution. In order to introduce an index for the difficulty of linguistic processing, we manipulated the semantic context in which words were to be produced. In order to track processes associated with keystroke representation and motor preparation, we manipulated the side of the first keystroke of the words to be produced.

Based on the available evidence, we a priori hypothesized that response retrieval and response execution should be reflected in the beta band ERD and early ERP components. Notably, response execution should be associated with a characteristic lateralized ERP pattern. The extent of temporal separation between indices of response retrieval and programming was an open question. With these hypotheses in mind, the relative novelty of the task motivated a data-driven approach for signal processing, which does not restrict the analysis to pre-defined electrodes, time-windows or components. While the available literature directed time-frequency analysis towards beta band, the analysis within this frequency band was also conducted without a priori restrictions.

2. Methods

2.1. Participants

Thirty-one participants (12 males) were recruited for their ability to type fast (see below) without the use of looking at their hands. This ability to type without intermittent finger gazing, was particularly important in order to prevent eye movements during the interval between picture presentation and first keystroke, which could have contaminated the EEG signal. Four participants were excluded from the experiment: one for technical problems during the recording and three due to poor signal quality. This left 27 participants whose data were included in the analysis. All were right-handed French native speakers (mean age: 27.8 years; range = 20–37 years) and typed on average 3.8 h a day. Three reported having had formal training. Their typing skills were assessed using a typing test described below. All participants