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Oscillatory brain responses in spoken word production reflect lexical frequency and sentential constraint

Vitória Piai [a,b,*], Ardi Roelofs [a], Eric Maris [a]

[a] Radboud University Nijmegen, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Montessorilaan 3, 6525 HR Nijmegen, the Netherlands
[b] International Max Planck Research School for Language Sciences, Wundtlaan 1, 6525 XD Nijmegen, the Netherlands

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ABSTRACT

Two fundamental factors affecting the speed of spoken word production are lexical frequency and sentential constraint, but little is known about their timing and electrophysiological basis. In the present study, we investigated event-related potentials (ERPs) and oscillatory brain responses induced by these factors, using a task in which participants named pictures after reading sentences. Sentence contexts were either constraining or nonconstraining towards the final word, which was presented as a picture. Picture names varied in their frequency of occurrence in the language. Naming latencies and electrophysiological responses were examined as a function of context and lexical frequency. Lexical frequency is an index of our cumulative learning experience with words, so lexical-frequency effects most likely reflect access to memory representations for words. Pictures were named faster with constraining than nonconstraining contexts. Associated with this effect, starting around 400 ms pre-picture presentation, oscillatory power between 8 and 30 Hz was lower for constraining relative to nonconstraining contexts. Furthermore, pictures were named faster with high-frequency than low-frequency names, but only for nonconstraining contexts, suggesting differential ease of memory access as a function of sentential context. Associated with the lexical-frequency effect, starting around 500 ms pre-picture presentation, oscillatory power between 4 and 10 Hz was higher for high-frequency than for low-frequency names, but only for constraining contexts. Our results characterise electrophysiological responses associated with lexical frequency and sentential constraint in spoken word production, and point to new avenues for studying these fundamental factors in language production.

1. Introduction

Speaking is one of our most highly exercised psychomotor skills (Levelt, 1989). Seemingly simple and effortless, the production of language relies not only on fast and accurate linguistic processes, such as the access of concepts and lexical representations in long-term memory (Indefrey & Levelt, 2004; Levelt, Roelofs, & Meyer, 1999), but also on precise motor preparation and execution (Hickok, 2012). Although psycholinguistic models have provided a detailed description of the cognitive architecture underlying language production (e.g., Caramazza, 1997; Dell, 1986; Levelt, 1989; Levelt et al., 1999; Roelofs, 1992, 1997), only recently electrophysiological markers of the postulated cognitive processes have been explored (e.g., Aristei, Melinger, & Abdel Rahman, 2011; Eulitz, Hauk, & Cohen, 2000; Strijkers, Costa, & Thierry, 2010; Strijkers, Holcomb, & Costa, 2011; see for review Ganushchak, Christoffels, & Schiller, 2011). In the present study, we examined electrophysiological brain responses that are induced by two fundamental factors known to affect the planning of spoken words: lexical frequency and sentential constraint (e.g., Griffin & Bock, 1998; Levelt, 1989).

Studies investigating lexical memory access in word production have made extensive use of the picture-naming paradigm. This line of investigation builds on the following two ideas: (1) the picture represents the concept to be expressed, and (2) producing the picture name requires access to lexical memory (i.e., lemmas and word forms, e.g., Levelt et al., 1999). A typical finding in picture-naming studies is that pictures whose names occur more frequently in the language (e.g., ‘house’ or ‘dog’) are named more quickly than pictures whose names occur less often in the language (e.g., ‘spear’ or ‘globe’), a finding known as the *lexical-frequency effect* (e.g., Jescheniak & Levelt, 1994; Oldfield & Wingfield, 1965). Since word frequency is an index of our cumulative learning experience with words, the lexical-frequency

* Correspondence to: Radboud University Nijmegen, Donders Institute for Brain, Cognition and Behaviour, Centre for Cognition, Spinoza Building B.01.05, Montessorilaan 3, 6525 HR Nijmegen, the Netherlands. Tel.: +31 24 3612635; fax: +31 24 3616066.
E-mail addresses: v.piai@donders.ru.nl (V. Piai), a.roelofs@donders.ru.nl (A. Roelofs), e.maris@donders.ru.nl (E. Maris).

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effect is an important marker of long-term memory processes and likely reflects the access of lexical memory representations (e.g., Almeida, Finkbeiner, Knobel, & Caramazza, 2007; Jescheniak & Levelt, 1994; Kittredge, Dell, Verkuilen, & Schwartz, 2008; Monaco, Abbott, & Kahana, 2007; Ullman, 2001). Lexical access is assumed to consist of lexical selection and word-form encoding, which is further divided into morphological, phonological, and phonetic encoding (Levelt et al., 1999). All of these stages have been shown to be sensitive to frequency (e.g., Cholin, Dell, & Levelt, 2011; Jescheniak & Levelt, 1994; Piai, Roelofs, & van der Meij, 2012; Roelofs, 1998; Strijkers et al., 2010). Lexical access takes place between about 200 ms post picture-onset and about 145 ms before articulation onset (Indefrey, 2011; Indefrey & Levelt, 2004).

Everyday language production, however, usually involves sentences. The conceptual content of the message to be expressed (i.e., the semantic context) guides the access to memory and the activation of associated lexical candidates (e.g., Griffin & Bock, 1998; Levelt, 1989; Levelt et al., 1999). Contextual cues constrain possible word candidates, thereby modulating the ease of lexical access and word production (Griffin & Bock, 1998). Sentential constraint is a major determinant of fluency in spontaneous speech production (Levelt, 1989).

In the present study, participants read sentences that were either contextually constraining towards one final word (e.g., 'During the camping vacation, he was rarely in the') or not (e.g., 'During the day, he was rarely in the'). The final word of the sentence ('tent') was presented as a picture, which participants had to name. The lexical-frequency range of the picture names was varied (cf. Griffin & Bock, 1998). In short, sentential constraint and lexical frequency were manipulated in order to investigate the electrophysiological signatures of these factors in spoken word production. Ideally, effects of lexical frequency and sentential constraint are assessed in spontaneous speech, but this is still no option for language production research. Griffin and Bock (1998) stated, "Clearly, one cannot directly assess either the redundancy of message specifications for word selection or the onset of word-production processes in spontaneous speech. Hence, the task used in this study consisted of naming pictures which were preceded by sentence frames. It thereby combined an estimate of the onset of processing for a particular picture name with a quantifiable manipulation of contextual constraint. The weakness of the task is that the sentence contexts were read by participants rather than being generated by them. Although reading sentence frames differs from generating messages, the product of comprehension should be similar to the conceptual representations that speakers normally develop." (p. 329).

Using this paradigm and measuring picture-naming response time (RT), Griffin and Bock (1998) observed that pictures following a constraining context were named more quickly than pictures following a nonconstraining context (for other studies using a similar task, see e.g., Badecker, Miozzo, & Zanuttini, 1995; Blom & Vasić, 2011; Caramazza & Hillis, 1989; Gollan et al., 2011). Moreover, it was found that the lexical-frequency effect, commonly found with standard picture naming (e.g., Oldfield & Wingfield, 1965), was only present in the naming latencies for pictures following nonconstraining contexts, but absent for pictures following constraining contexts. According to Griffin and Bock (1998), the activation of word-form representations in memory follows a logistic function with high-frequency words having a higher resting level of activation than low-frequency words. Sentential constraint is assumed to affect lexical (i.e., lemma) selection, which is supposed to have a bigger impact on low-frequency than high-frequency words because of the logistic activation of word forms. However, since naming latencies were the only measure in that study, no information could be obtained about processes that occurred before the picture was presented. In particular, it is unclear whether the interaction between lexical frequency and sentential constraint occurred after picture presentation onset (Griffin & Bock, 1998) or already before it. That is, the narrower context may have given lexical access a head start (i.e., access may have started earlier in time, possibly already before picture onset) rather than affecting activation levels of word forms after picture onset, as Griffin and Bock (1998) assumed. In the present study, we investigated the effects of lexical frequency and sentential constraint on spoken word production using the electroencephalogram (EEG), which allows us to investigate cognitive processes as they unfold in time, revealing whether or not effects occur already before picture presentation onset.

Electrophysiological studies of language production have mainly focused on single-word production using event-related potentials (ERPs, see for a recent review Ganushchak et al., 2011). In contrast, in the present study, we focus on brain oscillations. Oscillations are a common type of activity generated by neuronal populations (Buzsáki, 2006). Depending on the size of these populations and their degree of synchronisation, this neuronal activity can be recorded with EEG (Nunez & Srinivasan, 2006). This oscillatory activity is typically categorised into different frequency bands. Different cognitive functions have been associated with frequency-specific changes in oscillatory power (e.g., Engel & Fries, 2010; Hanslmayr, Staudigl, & Fellner, 2012; Jensen & Mazaheri, 2010; Khader & Rösler, 2011; Van Ede, de Lange, Jensen, & Maris, 2011).

Very little is known about oscillations in language production, especially with overt vocal responses (Ewald, Aristei, Nolte, & Abdel-Rahman, 2012; Laaksonen, Kujala, Hultén, Liljeström, & Salmelin, 2012; Piai et al., 2012; Piai, Roelofs, Jensen, Schoffelen, & Bonnefond, 2013). The few studies that did examine oscillations addressed diverse questions, using different paradigms and experimental manipulations. Therefore, no clear pattern has yet emerged characterising the oscillatory components associated with cognitive processes underlying language production.

Importantly, it has been shown that ERPs and oscillations can be complementary in the type of information they provide (e.g., Bastiaansen & Hagoort, 2003; Chen et al., 2012; Davidson & Indefrey, 2007; Donner & Siegel, 2011; Laaksonen et al., 2012). Yet, at present, almost all existing knowledge of the electrophysiology of language production is based on ERPs only (e.g., Aristeiet al., 2011; Eulitz et al., 2000; Laganaro et al., 2009; Laganaro, Valente, & Perret, 2012; Strijkers et al., 2010, 2011; see for review Ganushchak et al., 2011). A characterisation of oscillatory activity has been fruitful in other cognitive domains, such as memory and motor control (see for reviews Engel, Fries, & Singer, 2001; Schroeder & Lakatos, 2009; Uhlhaas, Roux, Rodriguez, Rotarska-Jagiela, & Singer, 2010). By characterising the oscillatory activity underlying spoken word production, language production can be understood in a broader context of how cognitive processes are implemented in the brain, possibly providing ways to link findings from the language production literature with other domains of cognition.

In other tasks not involving language production, oscillatory brain responses have been better identified and some of these findings are relevant for the present study (i.e., language comprehension, long-term memory access, and motor preparation). In particular, theta-band (4–8 Hz) activity has often been observed in relation to memory processes (e.g., Jacobs, Hwang, Curran, & Kahana, 2006; Khader & Rösler, 2011; see for reviews Düzel, Penny, & Burgess, 2010; Klimesch, 1999; Nyhus & Curran, 2010), also involving the retrieval of lexical-semantic information during language comprehension (e.g., Bastiaansen, van der Linden, Ter Keurs, Dijkstra, & Hagoort, 2005; Bastiaansen, Oostenveld, Jensen, & Hagoort, 2008). Oscillations in the alpha band (8–15 Hz) have been associated with a variety of cognitive processes, including