Brain & Language 153–154 (2016) 27–37

Contents lists available at ScienceDirect

Brain & Language

journal homepage: www.elsevier.com/locate/b&l

Alpha and gamma band oscillations index differential processing of acoustically reduced and full forms

Linda Drijvers [a,b,*], Kimberley Mulder [a], Mirjam Ernestus [a,c]

[a] Radboud University, Centre for Language Studies, Erasmusplein 1, 6525 HT Nijmegen, The Netherlands
[b] Radboud University, Donders Institute for Brain, Cognition, and Behaviour, Montessorilaan 3, 6525 HR Nijmegen, The Netherlands
[c] Max Planck Institute for Psycholinguistics, Wundtlaan 1, 6525 XD Nijmegen, The Netherlands

ARTICLE INFO

Article history:
Received 18 May 2015
Revised 4 January 2016
Accepted 23 January 2016
Available online 12 February 2016

Keywords:
Speech comprehension
Neuronal oscillations
Speech reduction
Cognitive load
Semantic integration

ABSTRACT

Reduced forms like *yeshay* for *yesterday* often occur in conversations. Previous behavioral research reported a processing advantage for full over reduced forms. The present study investigated whether this processing advantage is reflected in a modulation of alpha (8–12 Hz) and gamma (30+ Hz) band activity. In three electrophysiological experiments, participants listened to full and reduced forms in isolation (Experiment 1), sentence-final position (Experiment 2), or mid-sentence position (Experiment 3). Alpha power was larger in response to reduced forms than to full forms, but only in Experiments 1 and 2. We interpret these increases in alpha power as reflections of higher auditory cognitive load. In all experiments, gamma power only increased in response to full forms, which we interpret as showing that lexical activation spreads more quickly through the semantic network for full than for reduced forms. These results confirm a processing advantage for full forms, especially in non-medial sentence position.

1. Introduction

Natural, conversational speech is characterized by an incredible amount of variation in the pronunciation of words. One of the reasons for this variation is that speakers reduce words in casual speech by producing words with fewer or altered segments (for an overview, see Ernestus & Warner, 2011). For instance, in conversational English, words like *yesterday* and *hilarious* are often reduced to something like /jɛʃeɩ/ and /hlɛrɛs/, respectively (Ernestus, 2000; Johnson, 2004). Native listeners seem to understand reduced word forms effortlessly in connected speech. This paper contributes to the research on how native listeners understand these forms.

So far, the processing of reduced word forms has been addressed in several corpus-based studies and in several behavioral production and comprehension studies. One of the most consistent findings is that reduced forms are processed less easily than full forms. Listeners need more time and more linguistic context to comprehend reduced word forms than full forms (e.g. Ernestus & Baayen, 2007; Ernestus, Baayen, & Schreuder, 2002; Janse, Nooteboom, & Quene, 2007; Tucker & Warner, 2007; Ernestus, 2014) and speakers need more time to name objects if they are instructed to produce reduced forms rather than full forms (Bürki, Ernestus, & Frauenfelder, 2010).

After listeners have identified a reduced word form, it also seems to take longer before the corresponding semantic network is activated than when the word is pronounced in full. Van de Ven, Tucker, and Ernestus (2011) performed a lexical decision experiment in which consecutive stimuli functioned as primes and targets and prime–target pairs differed in their semantic relatedness. The researchers only analyzed those targets that were correctly classified as real words and were preceded by primes that were also correctly classified as real words. They observed a clear difference between responses to targets that were primed by full forms and responses to targets that were primed by reduced forms. If the targets were presented 1000 ms after the responses to the primes, only the primes that were fully articulated produced priming effects. However, if the targets were presented 1500–1600 ms after the responses to the primes, both full and reduced forms produced priming. These results strongly suggest that reduced forms may take longer than full forms to activate their semantic networks after they have been identified.

In all studies reporting a processing advantage for full forms over reduced forms, the words were presented in isolation (e.g. Ernestus et al., 2002; Janse et al., 2007; Ranbom & Connine, 2007; Tucker & Warner, 2007) or at the end of simple sentences

* Corresponding author at: Radboud University, Centre for Language Studies, Donders Institute for Brain, Cognition and Behaviour, Wundtlaan 1, 6525 XD Nijmegen, The Netherlands.

E-mail address: linda.drijvers@mpi.nl (L. Drijvers).

http://dx.doi.org/10.1016/j.bandl.2016.01.003
0093-934X/

(e.g. Bürki et al., 2010; Ranbom & Connine, 2007). This raises the question whether full forms still have a processing advantage over reduced forms if these forms occur in the middle of full sentences, that is, in the position in which they occur most frequently (e.g. Pluymaekers, Ernestus, & Baayen, 2005).

There are several reasons for why we may expect that the processing advantage for full forms disappears in connected speech. First, it seems counter-intuitive that word forms that are highly frequent are hard to process. Second, Bürki et al. (2010) showed that full forms lose some of their special status when they are preceded by possessive pronouns instead of just definite articles. Finally, a few off-line behavioral studies show that listeners rely on all types of cues in the context, ranging from subtle phonetic cues (e.g. Janse & Ernestus, 2011) to semantic information (e.g. Van de Ven, Ernestus, & Schreuder, 2012). If this information is available, as is the case in natural conversations, listeners may process reduced forms as easily as full forms.

This hypothesis is difficult to test with behavioral experimental paradigms. In many experimental paradigms, including the lexical decision task, words are presented in isolation or at the end of simple sentences. In tasks in which words can occur in the middle of sentences, like identity cross-modal priming, the words are presented together with their orthographic transcriptions, which typically correspond to and therefore introduce a bias towards the full forms. Finally, an experimental task like the visual world paradigm severely restricts the possible words that can be tested because the words have to be depictable.

The present study investigates the processing of full and reduced pronunciation variants by analyzing neuronal oscillations induced by these forms. We investigate whether there are qualitative and quantitative differences in the alpha and gamma bands for full and reduced forms, and whether these differences are modulated by linguistic context. To our knowledge, no other study has compared the oscillations involved in the processing of full and reduced speech.

Neuronal oscillations predominantly reflect the extent to which the underlying neuronal activity synchronizes in the brain. These changes in oscillatory synchronization are thought to provide a window into the dynamics of the coupling and uncoupling of networks involved in cognitive processing (e.g. Hipp, Engel, & Siegel, 2011; Bastiaansen, Mazaheri, & Jensen, 2012; Varela, Lachaux, Rodriguez, & Martinerie, 2001). By studying oscillatory dynamics, we aim to gain insight into whether different processes are involved in the comprehension of full and reduced forms, in different contexts.

Alpha oscillations (8–12 Hz) are thought to reflect a mechanism that functionally inhibits task-irrelevant brain areas or distracting neural activity (Foxe & Snyder, 2011; Jensen & Mazaheri, 2010; Mazaheri et al., 2014), whereas suppression of alpha activity seems to remove this inhibitory gating and allows for higher frequencies (e.g., gamma oscillations) to occur.

Functional inhibition has been observed in tasks involving working memory and selective attention in the (audio)visual domain, but also in studies on language comprehension, such as studies on degraded speech processing (e.g. Adrian, 1944; Foxe, Ca, & Ahlfors, 1998; Fu et al., 2001; Jensen & Mazaheri, 2010; Klimesch, Sauseng, & Hanslmayr, 2007; Obleser & Weisz, 2012; Obleser, Wöstmann, Hellbernd, Wilsch, & Maess, 2012; Strauß, Kotz, Scharinger, & Obleser, 2014). For example, in the audiovisual domain, Foxe et al. (1998) reported a 10-Hz parietal–occipital enhancement over visual areas when participants were cued to attend to an auditory stimulus (a beep) instead of a visual stimulus (a flash). In preparation for the anticipated and attentionally more relevant auditory input, the visual attentional system was functionally inhibited to allocate attentional resources to the auditory modality.

Recent studies on degraded speech processing have argued that the suppression of alpha oscillations is associated with more effective language processing whereas alpha power remains high when the language processing network is inhibited (Obleser & Kotz, 2010, 2011; Obleser & Weisz, 2012; Obleser et al., 2012; Strauß, Kotz, et al., 2014). The lack of alpha suppression that arises after participants listened to severely degraded speech could reflect neural oscillators that keep alpha power high to rule out erroneous activations in relevant language- and meaning-related areas (Obleser & Weisz, 2012) and is mostly observed after a full linguistic utterance (Klimesch et al., 2007; Shahin, Picton, & Miller, 2009). Another recent study demonstrated a parametric suppression in alpha band activity as items increasingly matched real words, with lowered functional inhibition for more word-like input (Strauß, Kotz, et al., 2014). Strauß and colleagues propose that the observed enhanced alpha power seems to 'gate' words towards lexical integration and alpha oscillations can be seen as an indicator of cognitive load in audition (Strauß, Wostmann, & Obleser, 2014). Thus, alpha oscillations could provide a window into whether reduced form processing causes more auditory cognitive load than full form processing.

As the behavioral literature shows that reduced forms are harder to process than full forms, we expect that alpha power will increase more during reduced form processing than during full form processing. This larger increase in alpha power in response to reduced forms could reflect the listener's greater need for functional inhibition towards integration with the appropriate meaning representation and more effortful speech processing, resulting in a higher auditory cognitive load compared to full form processing. Since we assume that reduced forms are more easily understood in sentence medial context than in isolation or in sentence final position, we expect that alpha power will increase the least for reduced words presented in mid-sentence position.

In contrast to alpha oscillations, gamma oscillations (30–100 Hz) are related to the maintenance of working memory representations and active cognitive processing (e.g. Jokisch & Jensen, 2007). In language comprehension studies, gamma power increases have been associated with semantic unification operations such as the integration of the meaning of an incoming word in a given speech context, access to the mental lexicon (Bastiaansen et al., 2012), the activation of local functional networks supporting semantic representations (Mellem, Friedman, & Medvedev, 2013) and the predictability of an upcoming word based on the preceding sentence context (Wang, Zhu, & Bastiaansen, 2012).

For instance, gamma power increases were observed in response to words that were semantically appropriate in a given sentence context, but not when the word induced a semantic violation in the sentence (Hald, Bastiaansen, & Hagoort, 2006), and when participants were presented with sentences in their native language, but not when they were presented with sentences in phonologically related or unrelated languages (Peña & Melloni, 2012). Finally, an increase in gamma power was observed when participants had successfully comprehended a degraded speech signal (Hannemann, Obleser, & Eulitz, 2007). In this latter study, the increase in gamma power has been taken to indicate successful matching of degraded speech to lexical memory traces.

On the basis of these studies on gamma band power and the behavioral study by Van de Ven et al. (2011), we can formulate predictions about how gamma band power may differ between when listeners hear reduced versus full forms. Van de Ven and colleagues showed that reduced words only prime semantically related words if the time-interval between the two words is not very short. This suggests that reduced forms take longer to activate their semantic networks. If this interpretation is correct, we expect that gamma power increases are smaller, delayed or even absent for reduced