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Using the readiness potential of button-press and verbal response within spoken language processing

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HIGHLIGHTS

- Detection of readiness potential onset represents a preconscious measure for end-of-turn anticipation in a language dialogue.
- Even if it is a language task it can be applied equally well to both verbal and finger movement responses.
- In contrast to behavioural reaction time tasks the EEG-measurement produces more reliable data for the anticipation performance in end-of-turn-detection.

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ABSTRACT

Background: Even though research in turn-taking in spoken dialogues is now abundant, a typical EEG-signature associated with the anticipation of turn-ends has not yet been identified until now.

New method: The purpose of this study was to examine if readiness potentials (RP) can be used to study the anticipation of turn-ends by using it in a motoric finger movement and articulatory movement task. The goal was to determine the preconscious onset of turn-end anticipation in early, preconscious turn-end anticipation processes by the simultaneous registration of EEG measures (RP) and behavioural measures (anticipation timing accuracy, ATA). For our behavioural measures, we used both button-press and verbal response ("yes"). In the experiment, 30 subjects were asked to listen to auditorily presented utterances and press a button or utter a brief verbal response when they expected the end of the turn. During the task, a 32-channel-EEG signal was recorded.

Results: The results showed that the RPs during verbal- and button-press-responses developed similarly and had an almost identical time course: the RP signals started to develop 1170 vs. 1190 ms before the behavioural responses.

Comparison with existing methods: Until now, turn-end anticipation is usually studied using behavioural methods, for instance by measuring the anticipation timing accuracy, which is a measurement that reflects conscious behavioural processes and is insensitive to preconscious anticipation processes.

Conclusion: The similar time course of the recorded RP signals for both verbal- and button-press responses provide evidence for the validity of using RPs as an online marker for response preparation in turn-taking and spoken dialogue research.

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1. Introduction

A number of different neural substrates involved in language processing account for the high efficiency needed in human

communication processes, for example in sound discrimination and perception, semantic-pragmatic analysis or meaning constitution (Friederici, 2004; Indefrey and Levelt, 2004; Müller, 2006). For example, the transfer of meaning in natural utterances can be detected already about 120 ms after articulation has started (Müller and Kutas, 1996). Considering, however, the amount of sequential information included in the acoustic signal (at the level of phonemes, syllables, words, phrases, utterances, etc.), it is obvious that the auditory system needs more processing time than that. In fact, the processing time required by the auditory system is

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almost as long or even longer than the time needed for articulation. The question why we can nevertheless communicate so quickly and efficiently is a puzzle that has been the centre of much theoretical and experimental research (see e.g., [Levinson, 2000](#); [Ford and Thompson, 1996](#)). This high efficiency of communication and, especially, the time course of the different parallel and sequential stages of language processing has been a main topic of research over the last couple of years. Results show that cognitive parsing of the perceived utterances follow the acoustic speech signal within a few tenths of a second (see e.g., [Friederici, 2004](#); [Indefrey and Levelt, 2004](#); [Müller, 2006](#)). To achieve such a short timeframe in a spoken dialogue, the prediction and anticipation of one interlocutor's turn-end is required ([De Ruiter et al., 2006](#)).

1.1. Realistic time frames for turn-end-detection

Since [Sacks et al. \(1974\)](#) developed their turn-taking model of conversation, several studies have examined key aspects of conversation ([De Ruiter et al. 2006](#)), and found that listeners must perform several tasks simultaneously during conversation. Besides other things, a listener must comprehend the speaker's turn, while at formulating a reply and pre-planning the onset of its articulation. The latter process requires quite precise timing, to minimize gaps and overlaps ([Stivers et al., 2009](#); [Magyari and De Ruiter, 2008, 2012](#)). These studies found, among other things, that gaps and overlaps are usually shorter than 250 ms. As it is not possible to sequentially listen to a turn, comprehend it, prepare a response, and initiate this response within such a short time window (especially in case of overlaps), the authors assume that interlocutors use incremental and possibly overlapping processes to be able to time an appropriate response sufficiently accurate. Further evidence for this assumption comes from the famous shadowing task by [Marslen-Wilson \(1973, 1985\)](#), in which people were able to repeat another speaker's sentences with a time delay of only 250 ms. Finally [Pulvermüller](#) resumes that early indexes of lexical, syntactic and semantic processes have been found after 100–250 ms in written and spoken language processing which reflects almost parallel processes ([Pulvermüller, 2005](#); [Pulvermüller et al., 2009](#)). Both behavioural studies ([Marslen-Wilson, 1985](#)) as well as the results of the underlying functional neuroanatomical studies are therefore roughly comparable to the observed behavioural inter-turn delays of about 120–250 ms. However, the frequently occurring precise or even premature initiation of subsequent turns (e.g., [De Ruiter et al., 2006](#)) can only be explained by anticipation.

The time course of language processing is often estimated on the basis of the observation of behavioural output. As neurocognitive evidence reveals, though, language processes are faster and start much earlier than behavioural data might suggest. [Müller and Kutas \(1996\)](#), for example, showed that the initial 100–120 ms of words already provide enough information in order to decide whether a sound is the beginning of a noun or a name. In another study [McGregor et al. \(2012\)](#) investigated the crucial point of word recognition in spoken words versus pseudowords. They wanted to find out about the point in time when the acoustic information allows word recognition. Results showed that this crucial point occurs 50–80 ms after presentation ([McGregor et al., 2012](#)). In a word reading task that compared different semantic word classes with similar physical appearance by using textual characters (Chinese), electrical brain activation differed significantly for each semantic word class. For these visually presented Chinese characters, the earliest neural signature appeared 80 ms after stimulus onset ([Skrandies et al., 2004](#)). [Dell'Acqua et al. \(2010\)](#) achieved similar results when they studied the activation time of semantic and phonological representation. The obtained ERP results showed a primary component and a later, distinct component. This has led to the assumption of

a bimodal distribution of scalp activity for the semantic effects. The primary component was characterized by a fast onset with a sharp increase during the first 50 ms past stimulus onset and a decrease after 200 ms ([Dell'Acqua et al., 2010](#)). Although this working group usually focuses on a variety of components, their results correspond with those from the previously mentioned studies regarding the timing of processing. Irrespective of the specific nature of the language processing task, all examples show that processing starts between 50 and 200 ms post stimulus onset. Therefore, it is reasonable to suspect that turn-end anticipation follows a similar time course.

In contrast to the aforementioned findings about the time course of language comprehension, the results of word production experiments reveal that much more time is needed for processing. For instance, [Indefrey and Levelt \(2004\)](#) found that it takes the production system 600–1200 ms to get from an intention to speak to the actual articulation of words. During natural language processing, especially in interactive situations like dialogue, there are a number of simultaneous processes required, for example comprehension and production processes. Almost all of these processes are very fast, and overlap in time, which is presumably possible because of the massive, fine-grained parallelism in the neural computations in the brain.

The subject of our investigation is the time course of the preconscious processing that takes place before the behavioural response. It is important to define the latter carefully, because even though we can measure the behavioural response well, in anticipation processes the exact start of the associated “stimulus” is unknown. This means that the behavioural responses we are interested in do not correspond with reaction times as found in psycholinguistic tasks such as lexical decision or picture naming. Therefore, our primary behavioural dependent measure is the Anticipation Timing Accuracy (ATA), which is defined as the point in time at which the response is recorded, minus the point in time that the stimulus (the presented turn) actually ends. So if a participant's timing is perfect, the ATA is 0, if the participant responds too early (i.e., before the end of the turn), it is negative, and if they respond too late (after the end of the turn), it is positive. This dependent measure is the same as what [De Ruiter et al. \(2006\)](#) termed BIAS.

1.2. Previous EEG studies

An EEG-study by [Magyari et al. \(2011\)](#) used a spectral analytic technique for analysing EEG-recordings in a behavioural task of anticipation processes in turn-taking. They presented conversational turns with an average duration of 2.9 s that varied in the predictability of their ending while recording EEG data. ATA was evaluated by a button-press at the turn-end and were indeed found to be more precise for the turns with more predictable endings. Furthermore, they identified a beta power decrease in the predictable condition 1700 ms before the actual button-press as well as a beta power increase during the same time interval. These results support the assumption that the accuracy of turn-end anticipation is related to the accuracy of predictions about upcoming words. In another EEG-study ([Galgano and Froud, 2008](#)) event-related potentials in preparation for voice onset as well as exhalation were analyzed in a stimulus-induced voluntary movement task. The results showed a slow, increasingly negative cortical potential in the time window preceding the onset of phonation. These results reveal the benefits of RPs as a slow negative-going cortical potential correlated with the preparation of voluntary movements, especially with voice-related initiation ([Galgano and Froud, 2008](#)). Since the discovery of the RP (“Bereitschaftspotential”) in 1965 ([Kornhuber and Deecke, 1965](#)) several studies have provided evidence for a RP preceding speech-related volitional motor acts (e.g., [Galgano and Froud, 2008](#)). Therefore, the RP is defined as an ERP-component, which

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