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Lateralized electrical brain activity reveals covert attention allocation during speaking

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ABSTRACT

Speakers usually begin to speak while only part of the utterance has been planned. Earlier work has shown that speech planning processes are reflected in speakers' eye movements as they describe visually presented objects. However, to-be-named objects can be processed to some extent before they have been fixated upon, presumably because attention can be allocated to objects covertly, without moving the eyes. The present study investigated whether EEG could track speakers' covert attention allocation as they produced short utterances to describe pairs of objects (e.g., "dog and chair"). The processing difficulty of each object was varied by presenting it in upright orientation (easy) or in upside down orientation (difficult). Background squares flickered at different frequencies in order to elicit steady-state visual evoked potentials (SSVEPs). The N2pc component, associated with the focusing of attention on an item, was detectable not only prior to speech onset, but also during speaking. The time course of the N2pc showed that attention shifted to each object in the order of mention prior to speech onset. Furthermore, greater processing difficulty increased the time speakers spent attending to each object. This demonstrates that the N2pc can track covert attention allocation in a naming task. In addition, an effect of processing difficulty at around 200–350 ms after stimulus onset revealed early attention allocation to the second to-be-named object. The flickering backgrounds elicited SSVEPs, but SSVEP amplitude was not influenced by processing difficulty. These results help complete the picture of the coordination of visual information uptake and motor output during speaking.

1. Introduction

Speaking seems easy, but successfully transforming a thought into speech, and saying the right words in the right order, requires the coordination of several complex processes (e.g., Bock and Levelt, 1994; Dell, 1986; Garrett, 1980; Fromkin, 1971). Speakers usually plan the first few words of an utterance and then begin to speak while planning the rest of the utterance, although the scope of advance planning depends on many factors (e.g., Costa and Caramazza, 2002; Konopka, 2012; Lee et al., 2013; Martin et al., 2010; Oppermann et al., 2010; Smith and Wheeldon, 1999; Wagner et al., 2010).

A particularly useful technique for addressing questions about how speakers coordinate processes involved in speaking is eye-tracking. In eye-tracking studies of language production, speakers typically describe displays featuring visually presented objects while their eye movements are recorded. Eye movements generally are a reliable reflection of the allocation of visual attention: they are directly preceded by attention shifts, and it is difficult, if not impossible, to move the eyes to one location and attend to a different location (Deubel and Schneider, 1996; Hoffman and Subramaniam, 1995). Focusing attention on an object likely facilitates the retrieval of associated information, including the object's name, suggesting that visual attention plays an important role in speaking (Griffin, 2004; Meyer and Lethaus, 2004). Indeed, eye movements have been found to be closely linked to speech planning processes (e.g., Griffin and Bock, 2000; Meyer et al., 1998). For instance, the speakers gaze at each object in the order of mention, and keep their gaze longer at objects associated with low frequency names than with high frequency names (Griffin, 2001; Meyer et al., 1998). Effects of word frequency and of phonological priming suggest that speakers shift gaze to the next object after having encoded the name of the previous object at the level of the phonological form (e.g., Meyer and van der Meulen, 2000). Thus, the eye movement record is thought to provide a window into the coordination of visual information uptake and motor output.

Of particular interest to the present study is evidence that, as speakers name each object in succession, to-be-named objects can be

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processed to some extent before they have been fixated upon. Some of the evidence for this comes from gaze-contingent display changes (Pollatsek et al., 1984; Rayner, 1975). This is a technique in which, during the saccade from one object to the next, the object on which the saccade would have landed (the interloper) is replaced by a different object (the target). It has been observed that gaze durations on the target were shorter when the target and the interloper were identical, or each other's mirror image, or associated with the same name than when target and interloper were unrelated (Meyer et al., 2008; Morgan and Meyer, 2005; Schotter et al., 2013). This suggests that speakers processed the interloper prior to fixating on its location. Further evidence comes from studies where participants named pairs of objects that varied in processing difficulty, while the display remained constant. Gaze durations to the first object were shorter when the name of the second, not yet fixated, object was difficult to retrieve (and presumably interfered little with the retrieval of the name of the first object) than when the name of the second object was relatively easy to retrieve (Malpass and Meyer, 2010; see also Morgan et al., 2008).

Effects on processing of objects that have not been fixated upon likely arise because attention can be allocated to objects covertly, without moving the eyes. However, the nature and time course of covert attention shifts during speaking is unknown. This study examined whether additional information can be gleaned from direct measures of speakers' covert attention. These measures were derived from lateralized EEG activity, which has been well characterized in the attention literature.

1.1. Electrophysiological signatures of covert attention allocation

The EEG record is usually segmented into epochs, which are aligned in time and averaged point-by-point to create event-related potentials (ERPs), which are waveforms containing multiple components associated with various cognitive processes (for review, see Luck and Kappenman, 2011). In visual search tasks, shifting attention to a part of space in a display with multiple objects elicits an N2pc (N2 posterior-contralateral), a negativity that is larger over the hemisphere contralateral to an attended item than over the hemisphere ipsilateral to the attended item (Luck and Hillyard, 1990, 1994). The component occurs over lateral occipital electrode sites (dissociating it from other related components; Praamstra and Kourtis, 2010), usually begins around the time of the N2 wave, and has been associated with the allocation of spatial attention. In particular, because the N2pc is elicited when other distractor objects are present in the display, but not when distractors are absent, it has been associated with attentional filtering processes that suppress competing information in the environment (Luck and Hillyard, 1994). Although there is some controversy regarding the exact functional interpretation of the N2pc in terms of distractor suppression versus target processing (e.g., Eimer, 1996; Hickey et al., 2009; Mazza et al., 2009), or more generally competition resolution (Luck, 2012), there is broad consensus that the N2pc indexes covert attention allocation. Because the EEG is a direct reflection of neural activity, the onset latency of the N2pc can be interpreted as the latest moment at which attention was focused on an item.

Another electrophysiological signature of covert attention allocation is the phenomenon of steady-state visual evoked potentials (SSVEPs), which are continuous oscillatory responses at the frequency of regularly repeating visual stimuli (Regan, 1989; Wilson and O'Donnell, 1986; for review, see Vialatte et al., 2010). SSVEPs have been used to track attention allocation in sustained attention paradigms, in which a different visual stimulus is shown in each visual field, and participants attend to the stimuli in one hemifield for the duration of a block of trials. The stimuli, or small background squares on which the stimuli are superimposed, flicker at different frequencies, eliciting SSVEPs at each frequency. Importantly, it has been observed that the SSVEP amplitude is greater for attended than unattended locations (Morgan et al., 1996; Müller et al., 1998a). In addition, when a central cue directs attention to a particular stimulus on a trial-by-trial basis, SSVEPs evoked by the attended stimulus also increase in amplitude (Müller et al., 1998b). SSVEPs have been interpreted as reflecting a gain-control mechanism that enhances discriminability by increasing the signal-to-noise ratio of attended stimuli (Müller et al., 1998b). An advantage of SSVEPs is that, whereas the N2pc is a contralateral minus ipsilateral difference waveform and therefore a relative measure of attention across both hemifields, SSVEP "frequency tagging" allows for tracking the allocation of attention to individual objects separately. In sum, at least two measures of covert attention allocation have been documented that could help elucidate the nature and time course of attention shifts during speaking.

1.2. The present study

This study recorded EEG while speakers described pairs of objects using short utterances, such as "dog and chair". Speakers named the objects from left to right or from right to left depending on the objects' colors, while fixating on a central fixation cross. The objects were superimposed onto background squares which flickered at different frequencies. This allowed for addressing several related questions.

First, we examined whether the N2pc and SSVEPs are detectable when speakers name pairs of objects. One hurdle in the electrophysiology of language production is the contamination of the signal by muscle activity, which can affect almost all electrodes on the scalp (Goncharova et al., 2003; for experimental paradigms that avoid speech muscle activity, see Habets et al., 2008; Jescheniak et al., 2002; van Turennout et al., 1998). Such muscle activity could reduce the signal-to-noise ratio, making it more difficult to observe the effects of interest.

However, there are several reasons to assume that the signals of interest will be detectable. By now, a number of studies has recorded EEG in overt speech production tasks (for examples and review, see Eulitz et al., 2000; Ganushchak et al., 2011; Piai et al., 2012; Strijkers et al., 2011). The N2pc and SSVEPs have the advantage of being distributed over electrode sites contralateral to the direction of attention, such that motor activity should cancel out after collapsing across left-to-right and right-to-left naming directions. While the N2pc has to our knowledge not previously been applied to language production research, it has reliably been observed both in typical visual search studies, in which a target is displayed along with many distractor objects, and in studies with displays more similar to ours, in which a target is presented along with a single distractor (Eimer, 1996). Furthermore, SSVEPs have been recorded in a great variety of situations (Vialatte et al., 2010) and also concurrently with the N2pc (Müller and Hillyard, 2000). Thus, we hypothesized that our paradigm would elicit an N2pc and SSVEPs.

We further investigated whether, like overt attention in the form of eye movements, covert attention can also provide a window into the coordination of visual information uptake and motor output. If so, covert attention as reflected by the N2pc and SSVEPs would be expected to shift to the first to-be-named object after the onset of the stimuli, followed by a shift to the second to-be-named object.

The evidence discussed above, that the second to-be-named object can be processed before it has been fixated upon, raises certain hypotheses concerning covert attention, but these hypotheses are difficult to evaluate using eye movements alone. Direct and continuous measures of covert attention allocation could significantly improve our understanding of the time course of processing objects in a naming task. Thus, in addition, we orthogonally varied the processing difficulty of each object by presenting it in upright orientation (easy) or in upside-down orientation (difficult). This manipulation has clear effects on naming latencies (Malpass and Meyer, 2010) without affecting the visual complexity of the pictures. This enabled us to examine at what points in time properties of each object influenced the allocation of attention, in particular, whether the effects of first object difficulty and