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Removing speech artifacts from electroencephalographic recordings during overt picture naming

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ABSTRACT

A number of electroencephalography (EEG) studies have investigated the time course of brain activation during overt word production. The interpretation of their results is complicated by the fact that articulatory movements may mask the cognitive components of interest. The first aim of the present study was to investigate when speech artifacts occur during word production planning and what effects they have on the spatio-temporal neural activation pattern. The second aim was to propose a new method that strongly attenuates speech artifacts during overt picture naming and to compare it with existing methods. EEG and surface electromyograms (EMGs) of the lips were recorded while participants overtly named pictures in a picture–word interference paradigm. The comparison of the raw data with lip EMG and the comparison of source localizations of raw and corrected EEG data showed that speech artifacts occurred mainly from ~400 ms post-stimulus onset, but some earlier artifacts mean that they occur much earlier than hitherto assumed. We compared previously used methods of speech artifacts removal (SAR) with a new method, which is based on Independent Component Analysis (SAR-ICA). Our new method clearly outperformed other methods. In contrast to other methods, there was only a weak correlation between the lip EMG and the corrected data by SAR-ICA. Also, only the data corrected with our method showed activation of cerebral sources consistent with meta-analyses of word production.
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Introduction

The act of speaking is complex. Even the production of the simplest utterances, for instance saying 'dog' as a response to a picture of a dog, involves a diverse set of cognitive processes. Though current models of word production characterize these processes somewhat differently (Caramazza, 1997; Goldrick and Rapp, 2002; Indefrey, 2011; Levelt et al., 1999), there is good consensus that word production involves several steps, from conceptual processing over selection of a lexical representation, to phonological and phonetic encoding processes.

A powerful research tool in current psycholinguistics is electroencephalography (EEG), which allows researchers to gain insight into the precise time course of the cognitive processes involved. However, EEG research of word production has been hampered by the fact that speech artifacts might contaminate the cognitive components of interest (Brooker and Donald, 1980; Grözinger et al., 1975; Wohlert, 1993). For instance, prevocalization potentials have been found to be severely affected by artifacts from the temporalis and masseter muscles. Both are used for closing the lower jaw. The temporalis spreads widely over the frontal/temporal/parietal junction of the brain (Brooker and Donald, 1980), and the masseter is located between the cheekbone and the jaw.

Many event-related potential (ERP) studies investigating the time course of word planning have therefore relied on covert speech planning (i.e., speakers were asked to plan words without producing them), metalinguistic tasks (e.g. deciding whether a word includes a target sound), or delayed naming (i.e., naming once a cue is given) rather than immediate overt speech production (e.g., Hauk et al., 2001; Jescheniak et al., 2002; Laganaro et al., 2009, 2011; Schiller et al., 2003; Schmitt et al., 2000; Van Turennout et al., 1997, 1998). Though these studies have led to important insights, they have their limitations. For instance, in covert speech experiments it is not possible to guarantee that participants actually follow the instructions, and these tasks either do not include all cognitive steps involved in overt speech production or the timing of the steps is altered. Thus, in many contexts the use of immediate overt production tasks is preferable.

Studies using overt production tasks have generally focused on early processes of word planning that occur within 400–600 ms after stimulus presentation, with the assumption that those processes are artifact-free because they occur before actual speech (for an overview see Christoffels et al., 2007; Costa et al., 2009; Ganushchak et al., 2011; Strijkers et al., 2010; Strijkers et al., 2011; Verhoef et al., 2009). But no study to date has investigated the exact timing of speech artifacts during

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picture naming, and we know of only two studies that have given some indication of how speech artifacts have affected ERPs (Laganaro and Perret, 2011; Riès et al., 2013).

The first aim of the present study was therefore to investigate when speech artifacts actually occur during word production planning and what effects they have on the spatio-temporal neural activation pattern. To answer the former question, we examined electromyograms (EMGs) of the lips during a word production study. To answer the latter question, we compared the relationship of the lip EMG with the raw ERP data recorded during the same experiment. A strong correlation between the lip EMG and the raw data would indicate that ERP data during word production studies are highly affected by speech artifacts. Furthermore, we conducted source-localization analyses of the ERP data, before and after speech artifact attenuation. The source localization analysis of the ERPs of the raw data can reveal the extent to which the spatio-temporal pattern of the ERPs is a reflection of cognitive processes or speech movements. Indefrey and Levelt (2004) conducted a comprehensive meta-analysis of behavioral word production studies to estimate the time-course of naming a picture and combined the results with brain imaging findings within the word production literature (82 experiments). This resulted in a map of the involved brain areas and the time course of their activation (see also the update by Indefrey, 2011). Their estimates for simple picture naming predict a progression from early occipital and ventral–temporal activation during conceptual preparation (0 and 175 ms), via activation at the left middle temporal gyrus during lemma retrieval and lemma selection (150–250 ms) and posterior temporal lobe during phonological code retrieval (including Wernicke's area, 250–330 ms) to frontal activation during syllabification and articulation (400–600 ms, including Broca's area) (see also Hultén et al., 2009; Levelt et al., 1998; Salmelin et al., 1994; Sörös et al., 2003; Vihla et al., 2006). Localizing ERPs should show such a progression if the ERPs truly reflect cognitive processes. Source localization is therefore an excellent tool to reveal in how far and during which processing time step the speech artifacts contaminate the raw data.

The recording of EMG from orofacial speech muscles is not new even if it has not typically been used in combination with EEG recordings. Instead, it has been used to study, for instance, silent recitation (Livesay et al., 1996), speech in stutterers (Choo et al., 2010), covert verbal hallucinations in schizophrenia (Rapin et al., 2013), and articulation by aging participants (Rastatter et al., 1987b) and by articulatory disordered children (Rastatter et al., 1987a). The muscle complex that has typically been focused on is the orbicularis oris (OO), which is situated in the lips and controls lip posture during overt speech. It consists of four sub-muscles, the left and right orbicularis oris superior (OOS) in the upper lip and the left and right orbicularis oris inferior (OOI) in the lower lip. The fibers of the lip muscles are not clearly separated from surrounding muscles. It is therefore not possible to obtain a signal that stems exclusively from the OO (Blair and Smith, 1986). However, Blair and Smith (1986) argue, and subsequent studies have shown, that useful data can be obtained if electrodes are placed at the same place across participants. We therefore chose to record EMG from the OO in our study.

The second aim of this study was to propose a new method that strongly attenuates speech artifacts during overt picture naming and to compare it with existing methods. While the majority of overt speech production studies have not attempted to remove speech artifacts, there are exceptions. Some studies have removed the strongest articulation-driven potentials by excluding responses whose acoustic onsets fell within the time-window of interest (e.g., Strijkers et al., 2011; Costa et al., 2009). However, as evident in the present investigation, articulators move much earlier than the acoustic onset. Such a procedure therefore does not necessarily lead to artifact-free data. Others applied filters: a low-pass filter of 12 Hz (Ganushchak and Schiller, 2008) or a band-pass filter of 0.2–20 Hz (Laganaro and Perret, 2011). Laganaro and Perret (2011) report that their filter did not make much of a difference to their results. However, the frequency content of facial muscle artifacts can overlap to a large extent with that of brain signals. Filtering therefore means that brain signals might be partly filtered out and results might nevertheless change (for a discussion see De Vos et al., 2010; Friedman and Thayer, 1991). To overcome this problem, De Vos et al. (2010) proposed a blind source separation method based on Canonical Correlation Analysis (BSS-CCA) to separate cortical sources from electromyographic (EMG) responses. Their method appears to be the most promising approach and has been implemented, for instance, in studies by Riès et al. (2011, 2013). In the current study we introduced a new method of speech artifact removal, based on an Independent Component Analysis (ICA) procedure (Barbati et al., 2004), appropriately modified to fit the problem under investigation. For simplicity, we will refer to this approach as speech artifact removal by ICA (SAR-ICA).

We compared the artifact attenuation performance of our new SAR-ICA method with that of previously applied methods, namely BSS-CCA and the two filters 0.1–12 Hz (Ganushchak and Schiller, 2008) and 0.2–20 Hz (Laganaro and Perret, 2011). For validation purposes we conducted the following two analyses.

First, we compared the different methods (0.1–12 Hz, 0.2–20 Hz, BSS-CCA, and SAR-ICA) with regard to the relationship of the lip EMG with the ERP data. A large reduction in the correlation strength between the lip EMG and the ERP data due to artifact attenuation suggests that a method is well suited to remove artifactual ERP components that are strongly related to articulatory muscle movements during word planning. As an additional validation of our SAR-ICA method, we investigated the relationship of the lip EMG with the ICA component of speech artifacts. A strong correlation between the artifact ICA component and the lip EMG together with a weak correlation between the lip EMG and the corrected data would confirm that our ICA method indeed separated and identified the components that are strongly related to speech artifacts during word planning.

Second, as another validation method for the artifact attenuation procedures we used the results of the aforementioned source localisation analyses of the raw data and compared them with source localizations of the corrected data. Results are reported for our SAR-ICA procedure and the most promising other artifact attenuation method, the BSS-CCA procedure. As explained above, for picture naming one expects a progression from early occipital and ventral–temporal activation via activation at the left middle temporal gyrus and posterior temporal lobe to frontal activation (Indefrey, 2011; Indefrey and Levelt, 2004). Consequently, a successful artifact attenuation procedure should reveal such a progression.

The speech production data that we used for all these analyses were the responses in a paradigm that is very typical for the study of word production planning and that has been used in several ERP and brain imaging studies with overt responses, namely the picture–word interference paradigm. In this paradigm participants name pictures with superimposed distracter words (Schriefers et al., 1990). We used visually distracters that were either semantically related (e.g. orange) or unrelated (e.g. arrow) to the name of the picture (e.g. banana). Analyses of the distracter manipulation, including effects of distracter attenuation on the results, are not the focus of this study and will be reported elsewhere.

Materials and methods

Ethical approval for the research was obtained from the Ethics Board of the School of Psychology at Birmingham University.

Participants

Eighteen monolingual native English speakers (mean age 23.3, SD 3.7, 10 males) took part in the experiment and received either course credit or £20 for their participation. All were right-handed as determined by the Edinburgh handedness inventory (Oldfield, 1971) and all had normal or corrected-to-normal vision.

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