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Motivation and semantic context affect brain error-monitoring activity: An event-related brain potentials study

Lesya Y. Ganushchak[a,*] and Niels O. Schiller[a,b]

[a] *Department of Cognitive Psychology, Leiden Institute for Brain and Cognition, Leiden University, Institute for Psychological Research (LU-IPR), Wassenaarseweg 52, 2333 AK Leiden, The Netherlands*
[b] *Maastricht University, The Netherlands*

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During speech production, we continuously monitor what we say. In situations in which speech errors potentially have more severe consequences, e.g. during a public presentation, our verbal self-monitoring system may pay special attention to prevent errors than in situations in which speech errors are more acceptable, such as a casual conversation. In an event-related potential study, we investigated whether or not motivation affected participants' performance using a picture naming task in a semantic blocking paradigm. Semantic context of to-be-named pictures was manipulated; blocks were semantically related (e.g., *cat*, *dog*, *horse*, etc.) or semantically unrelated (e.g., *cat*, *table*, *flute*, etc.). Motivation was manipulated independently by monetary reward. The motivation manipulation did not affect error rate during picture naming. However, the high-motivation condition yielded increased amplitude and latency values of the error-related negativity (ERN) compared to the low-motivation condition, presumably indicating higher monitoring activity. Furthermore, participants showed semantic interference effects in reaction times and error rates. The ERN amplitude was also larger during semantically related than unrelated blocks, presumably indicating that semantic relatedness induces more conflict between possible verbal responses.

Keywords: Speech production; Verbal self-monitoring; Semantic blocking; ERN; Semantic relatedness; Motivation

Introduction

Speaking is a very fast and seemingly effortless process. In overt speaking, we produce up to 150 words per minute. However, the speech error rate in normal individuals is not more than one error in every 1000 words (Levelt, 1989). Such low error rates may be the result of a verbal self-monitor that detects and corrects errors. The most prominent theory of verbal monitoring is the *perceptual-loop theory* proposed by Levelt (1983, 1989). According to this theory, there is a single, central verbal monitor that checks the message for its appropriateness, inspects the speech plan, and detects errors prior to its articulation via the speech comprehension system (Postma and Noordanus, 1996; Schiller, 2005, 2006; Schiller, Jansma, Peters, and Levelt, 2006; Wheeldon and Levelt, 1995; Wheeldon and Morgan, 2002), as well as after speech has become overt (Postma, 2000).

As stated above, the error rate under normal circumstances is very low indicating that verbal monitoring generally has low susceptibility to interference. However, there may be specific circumstances that produce interference with the working of the monitor. For instance, it is possible that in situations in which speech errors potentially have more significance because they are less acceptable, e.g. during giving an interview vs. having a casual conversation, the verbal self-monitoring system works harder in order to prevent errors. One question to ask is about the role of the verbal context in which a conversation takes place. If we hear or see information that is related to what we are planning to say, does that information interfere with verbal monitoring, thereby leading to more erroneous speech output? We will try to answer this question in the present study.

One way to study monitoring is by looking at error monitoring. An electrophysiological measure related to error processing is the so-called *error-related negativity* (ERN; Falkenstein et al., 1991; Gehring et al., 1993), a component of the event-related potential (ERP) that has a fronto-central scalp distribution and peaks about 80 ms after an overt incorrect response (Bernstein et al., 1995; Holroyd and Yeung, 2003; Scheffers et al., 1996). Originally, the ERN was thought to reflect conscious error detection (Bernstein et al., 1995). However, according to the conflict hypothesis, the ERN arises not due to error detection *per se* but rather as a result of response conflict that arises when multiple responses compete for selection (Botvinick et al., 2001; Carter et al., 1998). Presence of conflicting responses reflects situations in which errors are likely to occur. Thus, according to the conflict hypothesis error detection is not an independent process but based on the presence of response conflict.

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[*] Corresponding author. Fax: +31 71 5273783.
E-mail address: lganushchak@fsw.leidenuniv.nl (L.Y. Ganushchak).

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Alternatively, the reinforcement-learning theory proposed that the ERN may reflect a negative reward–prediction error signal that is elicited when the monitor detects that the consequences of an action are worse than expected. This reward–prediction error signal is coded by the mesencephalic dopamine system and projected to the anterior cingulated cortex (ACC), where the ERN is elicited (Holroyd and Coles, 2002).

Interestingly, a number of studies demonstrated the influence of emotional/motivational factors on the ERN (e.g., Boksem et al., 2006; Luu et al., 2000; Pailing and Segalowitz, 2004; Ullsperger and Von Cramon, 2004). The general finding is that the ERN increases when monetary incentives are offered for accuracy (Gehring et al., 1993; Hajcak et al., 2005; Pailing and Segalowitz, 2004). For instance, Pailing and Segalowitz (2004) manipulated value of response error by selectively financially rewarding one type of response over another in a four-choice letter task. Pailing and Segalowitz found that more costly types of errors were associated with higher amplitude of the ERN. However, this dependency was only present for participants who scored high on neuroticism. Hajcak and colleagues (2005) also investigated whether the ERN is sensitive to value of errors. They manipulated motivational significance or errors by administrating monetary punishment for them. Consistent with previous studies, these authors showed that the ERN was significantly larger on high-value errors than low-value errors. Consistently with the EEG studies, Ullsperger and Von Cramon (2004) performed an fMRI study in which they also modulated the relevance of errors by a financial reward manipulation. Ullsperger and Von Cramon found that error-related activation in posterior fronto-medial cortex, previously shown to be involved in performance monitoring, was modulated by error relevance.

Most studies on the ERN investigate the working of action monitoring. In the present study, however, we use the ERN to explore the workings of the *verbal* monitoring system. There are only few studies that looked at the ERN after verbal errors (see Ganushchak and Schiller, 2006, in press; Masaki et al., 2001; Möller et al., 2007; Sebastián-Gallés et al., 2006), which we will briefly review below.

Masaki and colleagues (2001) examined whether or not the ERN occurs in relation to speech errors in the Stroop color–word task. Participants in their study were instructed to overtly name the color of each stimulus as quickly and accurately as possible. Masaki and colleagues found an ERN-like response after speech errors, e.g. when participants named the wrong color.

Sebastián-Gallés and colleagues (2006) assessed Spanish-dominant and Catalan-dominant bilinguals using an auditory lexical decision task in Catalan. The authors showed that Spanish-dominant bilinguals had great difficulty in rejecting experimental non-words and did not show an ERN in their erroneous non-word decisions either. According to Sebastián-Gallés et al., this suggests that Spanish-dominant bilinguals activated the same lexical entry from experimental words and non-words (in the experimental stimuli, the vowel change involved a Catalan-specific /e–ɛ/ contrast) and therefore showed no differences between correct and erroneous responses. In contrast, Catalan-dominant bilinguals demonstrated a clear ERN.

Recently, Möller et al. (2007) employed a laboratory task known to elicit speech errors to investigate verbal monitoring. In this task, participants are presented with inductor word pairs such as '*ball doze*', '*bash door*', and '*bean deck*', which are followed by a target word pair such as '*darn bore*' (see Motley et al., 1982). The reversal of initial phonemes in the target pair compared to the inductor pairs is supposed to lead to speech errors such as '*barn door*'. Möller and colleagues asked their participants to covertly read the inductor word pairs and vocalize the target word pair immediately preceding a response cue. They found a negative deflection on error trials, as compared to correct trials, preceding the response cue. Möller et al. proposed that this activity reflects the simultaneous activation of competing speech plans. However, these authors do not make an explicit link between the negativity they found in their study and the ERN.

Ganushchak and Schiller (2006) used a phoneme-monitoring task to investigate the effects of verbal monitoring under time pressure. Participants were presented with pictures and had to indicate whether the target phoneme was present in the name of the picture. For example, if the presented picture was *table* and target phoneme was /t/, then participants had to press a button; however, if the target phoneme was /m/, they had to withhold their response. Ganushchak and Schiller obtained an ERN following verbal errors that showed a typical decrease in its amplitude under severe time pressure.

In more recent study by the same authors (Ganushchak and Schiller, in press), a similar phoneme-monitoring task was employed to investigate the effect of auditory distractors on verbal monitoring. Participants were requested to press a button when a target phoneme was present in the pictures' name. However, simultaneously with the picture participants heard a semantically related distractor, a semantically unrelated distractor, or no distractor at all. Ganushchak and Schiller (in press) observed a larger ERN when auditory distractors were semantically related to the picture than when distractors were unrelated or no distractors were present at all. Presence of distractors, by activating more related concepts, presumably increased conflict at the time of response and therefore led to higher amplitudes of the ERN. This result may indicate that the ERN after verbal errors, as well as after general performance errors, is sensitive to conflict present at the time of response (see Botvinick et al., 2001). The goal of the present study was to further investigate the relationship between the ERN and verbal monitoring.

In the study described above, Ganushchak and Schiller (in press) used a phoneme-monitoring task in which button-press responses were required, and not pure verbal responses. In contrast, in the current study, we employed a blocked picture naming task in which recorded responses were overt verbal responses. The blocked naming paradigm manipulates the context in which to-be-named pictures appear. In semantically related blocks, pictures from the same semantic category appear on successive trials, for example *table*, *chair*, *couch*, and *closet*. In contrast, in semantically unrelated, mixed blocks, pictures from different semantic categories appear one at a time, for instance *table*, *snake*, *apple*, and *car*. Speakers take longer to name pictures from the same semantic category than from different categories. This increase in naming latencies is attributed to the increased competition for lexical selection from semantically related competitors (Belke et al., 2005; Damian et al., 2001; Levelt et al., 1999; Schnur et al., 2006).

In our own study, we employed this semantic blocking picture naming paradigm to investigate the effects of the semantic context on verbal self-monitoring and the ERN. How does semantic blocking relate to the verbal self-monitor? According to the Levelt's perceptual loop theory (1983, 1989), the verbal self-monitoring system not only monitors for errors, but also for semantic appropriateness/correctness. In semantically related