Losing the error related negativity (ERN): an indicator for willed action

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Abstract

When people make errors in a discrimination task, a negative-going waveform can be observed in scalp-recorded EEG that has been coined the error-related negativity (ERN). We hypothesized that the ERN only occurs with slips, that is unwilled action errors, but not if an error is committed willingly and intentionally. We investigated the occurrence of the ERN in a choice reaction time task that has been shown to produce an ERN and in an error simulation task where subjects had to fake errors while the EEG was recorded. We observed a loss of the ERN when errors were committed in willed actions but not in unwilled actions thus supporting the idea that the production of the ERN is tied to slips in unwilled actions but not mistakes in willed actions.

Slips of the tongue such as the example by Freud of a hotel boy, who, knocking at the bishop's door, nervously replied to the question "Who is it?" "The Lord, my boy!", are a common observation in everyday communication. These errors, or slips, are actions that have escaped our conscious control and are committed unintentionally and unwillingly. Slips not only occur in speech but also with the incorrect executions of appropriate motor programs [1]. Consider a task in which one has to reply by pressing a button with the left finger if the letter H occurs on a computer screen and with the right finger if it is an S. If the letters are presented relatively fast, at times, one simply cannot help it but the wrong finger presses the button. If EEG is recorded at the same time when the error is made, a negative-going waveform usually followed by a positivity can be identified in the averaged EEG time-locked to the incorrect responses in comparison to the correct responses. This negative going waveform that occurs between 40 to 100 ms post keypress has been coined the error-related negativity (ERN or Ne) and the following positivity the Pe [2, 3, 4, 5, 6] (for an example see waveform (a) in Figure 1). Although it has been noted that the ERN only occurs with slips and not with mistakes, that is an inappropriate response selection based, for example, on faulty knowledge [1], this observation has not received much attention. Functionally, both the ERN and the Pe have been related to error-processing [7, 8]. The ERN is generally viewed as reflecting error detection but the functional significance of the Pe is less clear [7]. While the signal that gives rise to the ERN may be based on non-willed actions, it is generally assumed that the ERN is not dependent on whether the detection of the error is internally driven or signaled by external cues, as long as there is awareness that an error has occurred [6, 9] (for a different view see [10]).

Based on the assumption that the ERN reflects error detection, or, more precisely, is related to slips, we hypothesized that if an error is committed willingly, that is on purpose and intentionally, no ERN will occur. In order to test this hypothesis we investigated the performance of five subjects on a regular ERN eliciting task and subsequently on the same task when the task instruction was changed such that the subject was to deceive the experimenter and intentionally 'build in' errors.

The ERN was elicited using a choice reaction time task in which the subjects were required to press a button with the left index finger when the letter S appeared in the centre of a 5-letter array on a computer screen and the right index finger when H appeared while the EEG was recorded from five electrode sites (Fz, Pz, Cz, C3, C4 referenced to ear lobes). There was a total of 480 trials, and each array remained on the screen for 250 ms followed by an inter-stimulus interval of 1000 ms. Signals were amplified using a 32-channel-DC-amplifier (MES) and the SCAN software packet (NeuroScan). Data were sampled at a rate of 256 points per second with a 70 Hz low pass filter and a time constant of 5s. Horizontal and vertical eye movements were recorded from standard locations. Impedance for EEG and electrooculogram (EOG) electrodes was kept below 10 kOhm.

For each ERN trial, an EEG epoch beginning 800 ms before and ending 800 ms after response was selected. Eye-movement artifacts were corrected by regression analysis, waveforms with signals greater than ±100 µV were eliminated and a low pass filter of 20 Hz applied. The EEG epochs were time-locked to the response on each trial and averaged separately for correct and incorrect trials for each participant. The waveforms were examined at frontal (Fz), central (Cz) and parietal (Pz) midline sites. The response times were calculated from stimulus onset to button press, with averages based on those greater than 100 ms.

In the error simulation paradigm, the subjects were instructed to deceive the experimenter as best as they could by intentionally making about 30% errors. To ensure that the trials were not contaminated by real errors (slips), in a preceding experiment stimulus duration and the inter-stimulus interval had been individually established such that the subject could achieve 100% accuracy. The stimulus duration and interstimulus-interval that had been established for each individual subject was used, and stimulus duration was set to 350 ms for four and to 400 ms for one subject and the inter-stimulus interval ranged from 1200 to 1500 ms. At the end of the experiment each subject was asked how many real errors (slips) had occurred and whether they had had any particular strategy for committing willed mistakes.

When comparing the averaged error trials with correct trials in the regular ERN paradigm, all subjects showed a clear ERN followed by a Pe with maximum amplitudes at Cz in the error trials in agreement with previously reported findings (Figure 1a). The situation was, however, different in the error simulation task where no ERN occurred in the error trials (Figure 1b). When comparing the error waveforms of the regular ERN paradigm and the simulation paradigm, a significant reduction in amplitude in the ERN and Pe time window was found (Figure 2). Both, the ERN and the Pe waveform had virtually disappeared. Furthermore, a slowly rising negativity akin to the readiness potential was observed that was more pronounced in the simulation paradigm than in the regular ERN paradigm. This slowly rising negativity showed the highest voltage at Cz and Pz recording sites with no clear difference between these sites.

Figure 1. Averaged waveforms at Cz of error trials and correct trials for 5 subjects in the regular ERN paradigm and in the simulation paradigm.

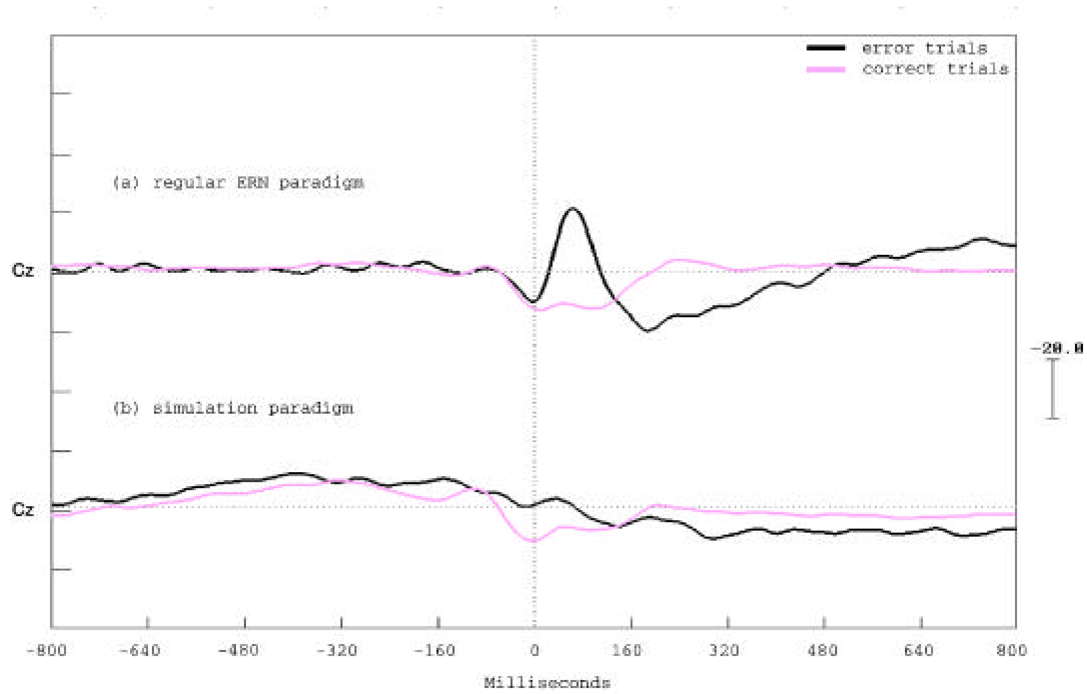
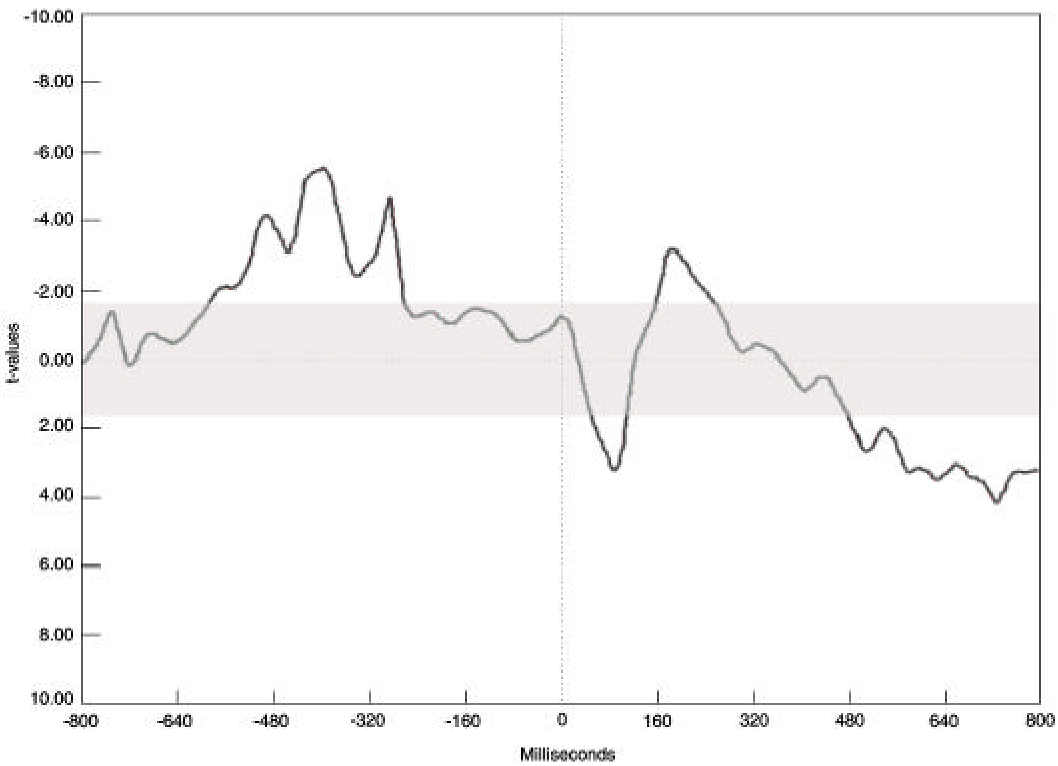
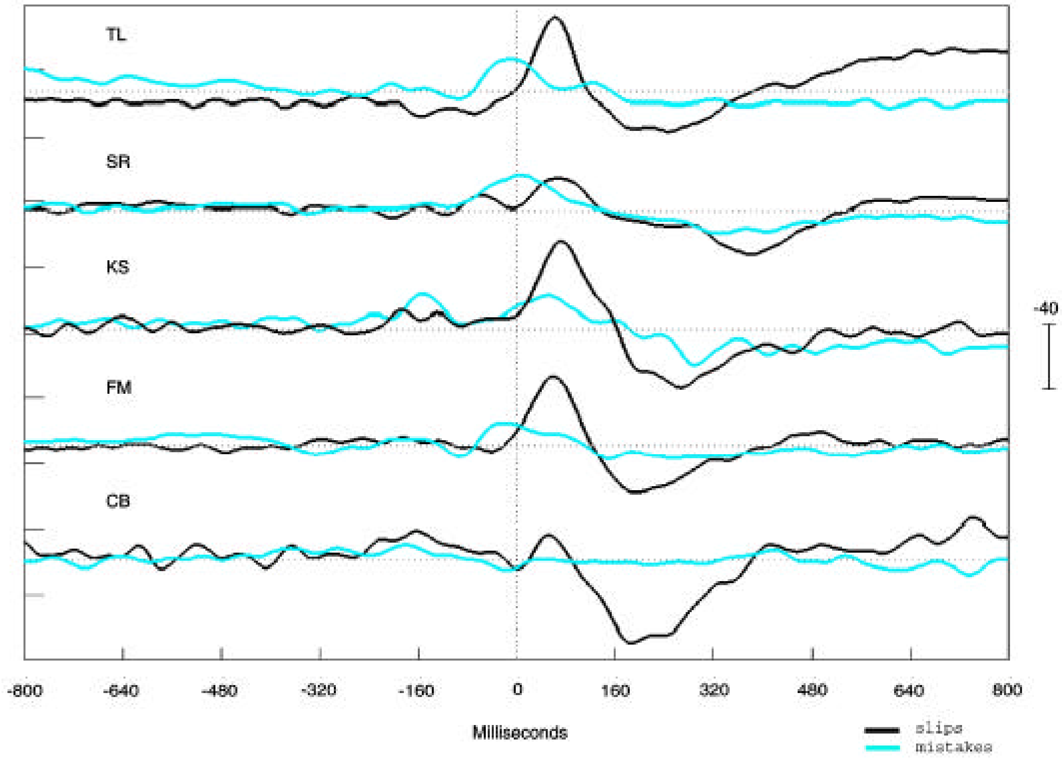


Figure 2. T-values at Cz when comparing the averaged error waveforms of the ERN paradigm and the simulation paradigm. All data points outside the gray area are p = 0.05.



For better comparison between the unwilled action errors (slips) and the willed mistakes, we computed the difference waveforms (error minus correct trials) for each paradigm and subject (Figure 3). In the simulation paradigm, a weak negativity around the time of the keypress but not in the ERN time window was observed with some individual variation. In one subject no negativity occurred at all, and the other four subjects showed a small negativity that peaked around the time of the keypress.

Figure 3. Overlay of the ERN difference waveform and the simulation difference waveform for each subject at Cz.



In sum, we observed the loss of the ERN, a prominent electrophysiological marker related to error processing, when errors were committed in willed actions in contrast to unwilled actions. Our findings support the idea that the production of the ERN is tied to slips in unwilled actions but not to mistakes in willed actions. Loss of the ERN was accompanied in some subjects by a more pronounced slow negative rise before the action, possibly indicative of the subject's intention of a future action. In four subjects a weak negativity at the time of the reaction was observed which is most likely related to the motor response that closely precedes the ERN. Our findings may have practical implications. For example, if individuals willingly try to deceive the investigator in an error task, loss of the ERN would be indicative of faking performance.

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