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Electrophysiological evidence for automatic processing of erroneous stimuli ☆

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ABSTRACT

In a paradigm combining color-word Stroop and misspelled words processing, spelling mistakes were placed in half the Stroop stimuli. Participants were presented with words written in different ink colors and asked to identify the color of the ink while ignoring the word meaning. Importantly, whether the word was correctly spelled or not was completely irrelevant to the task. The spelling manipulation did not change the phonology or semantic meaning of the words. Congruency and spelling correctness were manipulated orthogonally and interacted at the behavioral level. Event-related potentials showed a very early processing of misspelled words. The present findings are in line with the idea of anterior cingulate cortex (ACC) involvement in cognitive monitoring, expressed mainly in the theta frequency band. The present study demonstrates that this monitoring mechanism is elicited automatically, in other words, this mechanism perceives erroneous stimuli even when they are absolutely irrelevant to the participant's task. At later processing stages, the same central monitoring mechanism is also involved in the detection/resolution of conflict.

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1. Introduction

The ability to detect erroneous information in our surroundings is a necessary and adaptive quality required to properly evaluate and understand the environment and to act within it. Perception of erroneous information can be seen as a subtype of error monitoring. Mistakes can be committed by the person himself or alternatively, can originate in the surroundings that a person is exposed to. Perceived stimulus-related violations can appear in many domains – mathematical, orthographical, semantic, grammatical, musical, and so forth – and can be seen as violating the expectations of the individual, which are based on a situational setting and/or his semantic knowledge. The phenomenon of *violation of expectation* is present in early infancy, both at the behavioral level and the brain activity level (Berger, Tzur, & Posner, 2006).

A growing body of research supports the idea that the monitoring process involved in perceived erroneous information processing is mainly reflected in theta frequency activity involving the anterior cingulate cortex (ACC); it seems to compare the similarities and differences between an expected stimulus/action and a presented/performed stimulus/action, and therefore reacts to a violation of expectations (Berger et al., 2006; Castellar, Kühn, Fias, & Notebaert, 2010; Cavanagh, Figueroa, Cohen, & Frank, 2011; Oliveira, McDonald, & Goodman, 2007; Tzur, 2008; Tzur & Berger, 2007, 2009; Tzur, Berger, Luria, & Posner, 2010). For example, when a participant is presented with an incorrect solution to a simple equation (e.g., after being presented with the equation "1+2=__", the participant is presented with the solution "4"), there is a middle-central negative wave on the scalp that reflects an increase in the power of theta brain activity (Tzur & Berger, 2007, 2009). The theta effect begins at about 100 ms after stimulus onset and ends at about 400 ms after stimulus presentation. This effect clearly involves the ACC and depends on the salience of the violation: The larger the conflict/mismatch between the expected and the presented stimulus, the stronger the theta activity that is elicited (Tzur et al., 2010). The scalp distribution, brain source localization, and theta band frequency characterize the brain response to perception of erroneous information; it is parallel, and even undistinguishable, to the classic error negativity (Ne, Falkenstein, Hohnsbein, Hoormann, & Blanke, 1990) or error related negativity (ERN; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Holroyd & Coles 2002; Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Luu, Tucker, & Makeig, 2004; van Veen, Holroyd, Cohen, Stenger, & Carter, 2004) found for committed errors (self-made errors) and feedback response negativity (FRN; Luu et al., 2003) found after feedback to erroneous responses. Moreover, it has been suggested that this same brain activity is also found in novel situations and violations of expectations (Wessel, Danielmeier, Morton, & Ullsperger, 2012).

The aim of the present study was to further explore the nature of the processing of violations of expectations, and to determine whether this control monitoring process is *automatic*. Tzelgov (1997) defined an

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automatic process as a process that runs autonomously. Thus, one of the best ways to evaluate the automaticity of a given process is by testing whether it is elicited *unintentionally* (Tzelgov, 2000). The goal was to test whether the process would occur when it was irrelevant to the demands of the participant's task. A common demonstration of such automaticity is found in the case of reading, as shown in the Stroop color-word task (Stroop, 1935). In the Stroop paradigm, the participant's task was to name the color of the ink in which the presented words were written while ignoring the meaning of the words. The congruency between the ink color and the word meaning was manipulated: In congruent trials, the word was the name of the ink color; in the incongruent trials, the word was a different color name than the ink color; and in the neutral trials, the word was either a meaningless string of letters or a neutral word, such as the name of an animal. The Stroop effect, which is the interference of the word meaning to the color naming, suggests that access to the word meaning is an autonomous/automatic process since participants fail to fully filter out this irrelevant dimension (Henik & Salo, 2004; MacLeod, 1991; MacLeod & MacDonald, 2000). Hanslmayr et al. (2008) showed, using the event-related potential (ERP) technique that the Stroop conflict is related to the middle-frontal N400 component and involves the ACC as well as the dorsal–lateral prefrontal cortex (DLPFC). Hanslmayr et al. (2008) also suggested that an early ACC activation is critical for conflict monitoring and interference detection and that it engages the control mechanisms of the PFC. Such localization is fully consistent with a significant body of imaging studies that show that these two brain areas seem to operate together in tasks involving conflict (Bush, Luu, & Posner, 2000; Carter et al., 2000; Fan, Wu, Fossella, & Posner, 2001; MacDonald, Cohen, Stenger, & Carter, 2000; Peterson et al., 2002). Kerns et al. (2004) even demonstrated a correlation between ACC activity ascribed to the Stroop task incongruent-condition and activity in the prefrontal cortex on a subsequent experimental step. These correlations suggest that the ACC is active for conflict conditions and show that the ACC affects executive function and cognitive control activity in the frontal areas of the brain.

According to the described logic of the Stroop color-word task, the idea of the present study was to test the automaticity of erroneous stimuli processing by inserting spelling mistakes within words that were supposed to be ignored. Tzelgov (2000) defined automaticity as processing that is elicited autonomously and without intention, even when the subject tries to avoid it. As such, in the Stroop task the reading of the word occurs even though the participant intends to name the ink color while ignoring the word meaning; therefore, the reading process is defined as automatic. In the current study, the logic was that both the orthography and the semantic meaning of the words were completely irrelevant to the participant's task, which was to name the ink color of the stimuli; therefore, any behavioral and electrophysiological effects related exclusively to the misspelled words would be defined as automatic. We used the ERP technique to explore the timing and estimated source localization of the involved processes. Finding an early electrophysiological effect differentiating between words spelled correctly and words spelled incorrectly would be consistent with an automatic processing of perceived erroneous information.

2. Method

2.1. Subjects

Nineteen students (13 female and 6 male, mean age 23.31 [$SD = 1.13$]) took part in the study at Ben-Gurion University. Two subjects were removed from the analysis due to excessive noise in their EEG recording. All of the subjects were first year psychology students and took part in the experiment as partial fulfillment of course requirements. All the subjects were native Hebrew speakers, right-hand dominant, were not diagnosed with any learning or neurological disorders, and had normal or corrected-to-normal vision. Consent forms were obtained from all subjects prior to enrollment in the experiment.

2.2. Stimuli

Participants were exposed to 540 color-word Stroop stimuli, divided into six blocks of 90 trials each. These blocks were preceded by a short, 60-trial practice block. The stimuli were Hebrew words presented in different colors on the screen. The words were divided equally into three categories: congruent, incongruent, and neutral (i.e., 180 trials for each level). In congruent and incongruent trials the words red, blue, and yellow were displayed. For example, the word red written in a red font was considered congruent, whereas the same word written in a blue font was considered incongruent. The words chosen for the neutral condition were chicken, rabbit, and sheep. These words were taken from a single semantic category (animals) and were of similar frequency in occurrence as the color names in Hebrew.

For the manipulation of the *misspelled* conditions, in half of the stimuli for each congruency condition the first or second letter of the word was replaced with a different letter that did not change the phonological or semantic aspects of the word. For example, for the English word "cat" we would have used the word "kat" as the misspelled word. We chose Hebrew words that were suitable for this kind of manipulation. Stimuli were randomized with no replacements within blocks to have equally distributed stimuli in each block of 90 trials (i.e., 15 from each of the six conditions).

2.3. Procedure

A typical trial consisted of the following steps: A fixation cross ($1.43^\circ \times 1.43^\circ$) was displayed for 1000 ms at the center of the screen. Afterward, a single word was displayed in the center of the screen (length in degrees was 5.72°–7.15°; height in degrees was 1.91°) until a response was recorded, but not for more than 1500 ms. After the response an inter trial interval (ITI), in this case a black screen, was displayed for a variable amount of time (200 ms, 400 ms, or 600 ms). The subjects were instructed to respond as quickly as possible while maintaining accurate responses. The subjects' used the three middle fingers of their right hand to respond.

2.4. Behavioral analysis

To ensure that data sampling was sufficient for finding small to moderate effects, posthoc power analysis was performed. Behavioral data analysis included an average of the subjects' response times in all six conditions. Recorded response times were further analyzed using repeated-measure analysis of variances (ANOVA) to reveal the main effects and interactions for both the congruency conditions (congruent, incongruent, and neutral) and for the spelling conditions (correct and incorrect). The dependent variable was the mean reaction time of each participant in each category, after exclusion of the trials in which the response was inaccurate or faster than 100 ms long.

2.5. EEG recordings

Electroencephalographs (EEGs) were recorded using an EGI Geodesic sensor net and system; 129 electrodes were distributed on the subject's scalp according to an adapted 10–20 method and were sampled at a rate of 250 Hz (Tucker, 1993). Recording frequency band was constant at 0.1–100 Hz. The electrode impedance level was kept under 40 KΩ, which is an acceptable level for this system (Ferree, Luu, Russell, & Tucker, 2001; Electrical Geodesics, 2003). During EEG recording, all measures were referenced to an electrode located above CZ (according to the 10–20 method).

2.6. ERP analysis

EEG data was analyzed using the toolbox of Net Station software version 4.4.3 by Electrical Geodesic Inc. (Electrical Geodesics, 2003). EEG recordings were cut into segments of 900 ms, starting 200 ms before and ending 700 ms after the stimulus presentation onset (stimulus-locked). Segments were divided into six categories according to congruency and spelling conditions. Data was filtered with a 40 Hz low-pass filter in one analysis and with a 4–12 Hz band-pass filter – theta and alpha bands – in the second analysis. The purpose of this 4–12 Hz analysis was to find an early and automatic component that was attributable to the detection of a misspelled word. The 4–12 Hz frequency range was examined based on Tzur and Berger (2007, 2009), Tzur et al. (2010), and Hald, Bastiaansen, and Hagoort (2006). Tzur and Berger's (2007, 2009) studies examined the detection of violations of arithmetic rules, whereas Hald et al., 2006 research examined violation of semantic rules. These studies all showed significant results in the 4–12 Hz frequency bands.

In the next stage of the analysis, segments were automatically scanned for ocular artifacts (the criterion for an ocular artifact was an amplitude difference of

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