Summary
Relationships between Wisconsin Card Sorting Test and Event-Related Brain Potentials

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Wisconsin Card Sorting Test (WCST) was first developed by Berg (1948) and was revised by Heaton (1981). WCST is used quite extensively in the evaluation of certain functional problems associated with brain damage. As a neuropsychological test, WCST has been shown sensitive to frontal lobe functions. There is a variety of evidence about the functions that WCST measures. Among these abstract thinking, the WCST is related with concept formation (Milner, 1963), perseveration, rule application (Stuss & Benson, 1984), conceptual thinking, attention, and concentration (Karzmark, 1992), attention shift (Barcelo, Munoz-Cespedes, Pozo, & Rubia, 1997), feature detection, rule learning (Perrine, 1993) can be included.

Brain imaging studies on healthy and patient groups showed that WCST performance associated with dorsolateral prefrontal cortex (DLPFC) as well as a complex neural network activities covering inferior parietal and temporal lobe, visual association cortex and some parts of cerebellum (Berman, Osrem, Randolph, Herscovitch, & Weinberger, 1991).

In the ERP studies, differences between late and early responses were found to be associated with a slow-wave especially in the left fronto-temporal areas. Also for the late responses significant P3b peaks (positive peak occurring at 300 ms time interval) were obtained in the middle parietal areas. It was seen that the amplitude value of P3b peaks obtained for the late responses (slow-wave response) were greater than the early responses. These characteristics of P3b under the WCST were interpreted as the WCST is associated with the functions of working-memory such as template matching and template formation. On the other hand, it was emphasized that perseveration errors are associated with frontal region activity, while the other types of errors are associated with extra striate areas.

In general, N2-P3 wave forms are obtained under the response-locked circumstances. These early responses with the negative acceleration appearing 100- 150 ms after the incorrect response are called error negativity (EN). A peak obtained 280-550 ms after the incorrect response has given is called error positivity (EP) (Gehring, Goss, Coles, Meyer, & Donchin, 1993). There are two models that stress the relationship between EN and EP components and the cognitive processes. According to the Error Detection Model (Gehring, Coles, Meyer, & Donchin, 1990,1993) a N2-P3 complex peak is obtained after incorrect responses. In contrast, the Response Competition Model proposes that EN and EP responses are obtained under positive responses and may represent the evaluations made about correct and incorrect responses.

In the light of these findings, the first aim of this current study is to investigate ERP correlates of correct and incorrect responses during the WCST. In addition, the second aim of the study is to investigate abovementioned models, namely EN and EP and to make contributions to the explanations regarding validity of the models.

Method

Participants

A total of 30 volunteer university students (21 female and 9 male) between the ages of 19 and 24 participated in this study. They had normal or corrected-to-normal vision and no history of neurological deficits. Subjects were informed of all aspects of the research and signed a consent form approved by the Ethical Committee of the Bahcesehir University.

Wisconsin Card Sorting Test (WCST)

Computerized version of classical WCST which was developed by Berg (1948) was used in this study. WCST was applied using NeuroScan 4.2/Stim system (Stim, NeuroScan Inc., Texas). In the computerized

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version of WCST, four target/stimulus cards that contain different numbers, colors, and shapes were located at the top of the computer screen in the horizontal plane. A deck of response cards, on the other hand, was on the lower right corner of the screen. Each of the target and response cards contained different colors (red, green, blue, and yellow), and amount (one, two, three, and four) of shapes (plus, circle, star, and triangle). The goal of the WCST was to match the top card of the deck (stimulus) with the proper target card located at the top of the screen. Participants have matched the cards using a response device with four buttons. After every match, participants received feedback appearing at the top of the screen that indicates the initial response was "CORRECT" or "INCORRECT". After every 10 correct responses matching category was changed by the computer without any feedback to the participants.

Matching categories were presented to the participants in two sets in the same order (color, shape, and amount respectively). Similar to the previous studies, in the current study the ERP's during correct and incorrect responses were calculated in the light of the proposed hypotheses. The software calculated the correct and incorrect scores and also response times for each participant automatically.

Electrophysiological Recording and Analyses

Stimulus presentation, recording, storage, and analysis were carried out using a 32-channel EEG/EP 4.2 NeuroScan system. EEG recordings were made in an electrically shielded, soundproof chamber. EEG activities were recorded with 30 electrodes placed according to the international 10-20 systems. General and individual average scores were calculated separately for the ERP's of the brain consist of peaks created by amplitude variations on the time axis. The electrophysiological records were analyzed in the time-domain. All these calculations were done separately for correct and incorrect answers.

Results

Analysis of variance (ANOVA) was conducted for 3 (electrode location: Fz, Cz, Pz) x 2 (response type: correct and incorrect) independent samples factorial design. Two ANOVAs were conducted separately for latency and amplitude values.

Behavioral findings showed that reaction time for incorrect responses were significantly longer than correct responses, on the other hand the number of correct responses were higher than incorrect responses.

Even though our fist hypothesis was ERP peaks under the correct and incorrect responses are different, correct and incorrect WCST responses revealed similar
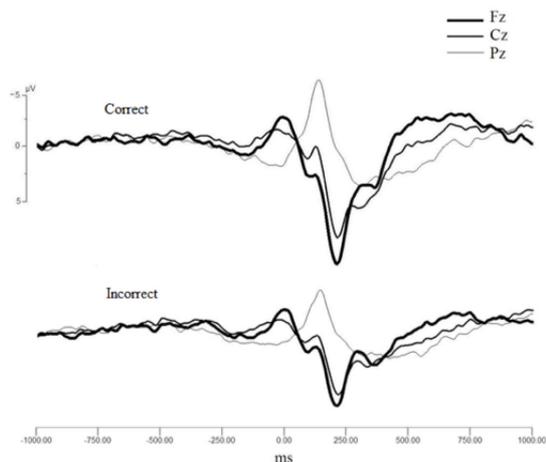

Figure 1. Grand Average ERPs to Correct (Top) and Incorrect (Bottom) WCST Responses Under Fz, Cz, and Pz Electrode Locations

Note. Stimulation applied at "0 ms" time point.

peaks. Furthermore, ANOVA results indicated that response type main effect was significant on N2 latency, N1 and N2 amplitude. Electrode location main effect was significant on latency and amplitude of N1, N2; amplitude of P2 and latency of P3. In addition the interaction effect was significant on latency and amplitude of N1, N2, and P2, and also P3 latency (see Figure 1 and Figure 2).

The second hypothesis of the study was latency and amplitude values of ERP responses under correct and incorrect WCST responses were different. In general, amplitude and latency values of correct responses were greater than incorrect responses.

Results indicated that the highest amplitude values of N1, P2, and P3 peaks were obtained in the Fz ($M = -1.61$, $SD = .132$, $M = 2.81$, $SD = .215$, respectively) electrode locations, whereas the highest amplitude value of N1 peak was obtained in the Pz ($M = -2.37$, $SD = .153$) location. In addition, latency values for Fz ($M = 81.82$, $SD = 6.25$, $M = 209.13$, $SD = 3.63$, $M = 333.17$, $SD = 5.08$, for N1, P2, P3 respectively) locations were longer than Cz ($M = 102.74$, $SD = 3.98$, $M = 219.87$, $SD = 2.57$, $M = 325.77$, $SD = 3.4$, for N1, P2, P3 respectively) and Pz ($M = 109.95$, $SD = 3.55$, $M = 334.29$, $SD = 4.99$ for N1 and P3 respectively) locations.
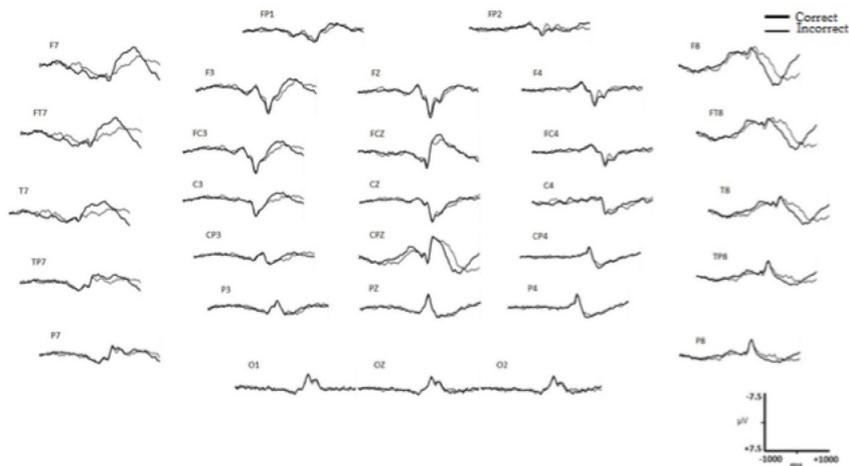
Figure 2. ERP Grand Average Waveforms of 30 Electrodes Recorded During Correct (Thick Line) and İncorrect (Thin Line) WCST Responses

Note. Stimulation applied at "0 ms" time point.

Discussion

Positive and negative ERP peaks were found quite strong especially in the frontal and central electrode locations. These basic findings were found consistent with the previous findings that suggest strong relationships between WCST performance and the frontal areas (Cabeza & Nyberg, 2000; Dao-Castellana et al., 1998; Nyhus & Barchelo, 2009; Volz et al., 1997). Also, one of the hypotheses of this study was to find different ERP peaks under correct and incorrect WCST responses and to provide evidence to the Error Detection Model. However, similar ERP's obtained under different responses and the results did not support the hypothesis. On the other hand these findings were interpreted as a support to the Response Competition Model.

Our results showed that correct and incorrect responses during the WCST performance reveal N2-P3 complex waveform. These peaks were seen to have reached different amplitude and latency values during correct and incorrect responses. In general, initial assessments of the correct and incorrect responses were found associated with N2 and P2 peaks represented in 200 ms time interval. Further, results that show a P3 (or P3b) peak in 300 ms time window suggested an ongoing cognitive evaluation of correct and incorrect responses. Barcelo and colleagues (1997) have found that WCST performance is associated with a slow-wave obtained in the fronto-temporal regions, and characterized by P3b component obtained in the medial parietal regions. In this current study, strong P3 peaks under the correct and incorrect responses were obtained in the anterior and posterior regions. The peak that appeared in the peak time interval of P3 under the WCST was interpreted as an analog to P3b. In compliance with the literature, we can conclude that cognitive process made in the first time window regarding correct and incorrect responses are associated with the response itself, whereas the peaks emerging in the second time window are associated with the evaluation process of correct and incorrect responses.

Lastly in this current study the reaction time for incorrect responses were longer than correct responses. Also the numbers of incorrect responses were found less than the correct responses. These findings were found compatible with the previous behavioral findings in the literature (e.g., Karakaş, Irak, Kurt & Erzengin, 1999) and provided evidence in terms of psychometric validity of the computerized version of WCST.