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Perceptual Conflict and Response Competition: Event-Related Potentials of the Stroop Effect*

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Abstract

Objective: *The aim of the present study was to analyze electrophysiological activity associated with the Stroop effect.*

Method: *The sample included 50 healthy volunteer adults (23 female and 27 male) from the university population. Stimulation, recording and analyses were carried under NeuroScan 4.2 hardware-software system. The effect of the experimental variables (stimulus congruency, response accuracy and electrode location) on event-related potentials (ERPs) was studied using 2×2×3 analysis of variance for repeated measures.*

Results: *The Stroop effect was demonstrated as prolonged reaction time to incongruent stimuli and increased total number of missed stimuli. Principal components analysis (PCA) showed that Stroop performance was related such factors as selective attention, interference, and resistance to interference. The electrophysiological Stroop effect was demonstrated as increased amplitude of P3 and N4 peaks for incongruent stimuli, and of N2, P3, N3, and N4 peaks for incorrect responses.*

Conclusion: *Increased amplitude of P3 and N4 peaks associated with stimulus-related activation has been suggested to reflect conflict detection process. The variations in amplitudes for incorrect responses were complicated. While the amplitude of the N2 and P3 components increased only for incongruent stimuli, those of the N3 and N4 components increased for both congruent and incongruent stimuli. It was concluded that these earlier and later activations were associated with response competition and error detection processes, respectively. In this respect, these findings support both the perceptual conflict and the response competition hypotheses of Stroop interference.*

Key words: *Stroop effect, perceptual conflict, response competition, event-related potentials*

INTRODUCTION

The Stroop effect is demonstrated when naming color words printed in incongruous colored ink (e.g. the word red printed in blue ink). The Stroop effect occurs because automatic response tendency of reading interferes with color naming; therefore, response duration increases (Stroop, 1935; MacLeod, 1992).

Stroop tests evaluate the ability to change perceptual configuration in the direction of changing demands while subjected to interference, and to repress a familiar behavioral pattern and perform an unusual behavior (Spreen and Strauss, 1991). There are many different Stroop tests designed to measure the response time to color names printed in a color different than that expressed by the word's meaning. Stroop interference is a reliable behavioral phenomenon because it occurs in all conditions where facilitatory and inhibitory factors exist under different stimuli and response circumstances (Santos and Montgomery, 1962; MacLeod, 1991).

Two hypotheses have been introduced to explain the Stroop effect: The perceptual conflict hypothesis and the response competition hypothesis (Doehrman et al., 1978). Both of these hypotheses explain the delay in response time to Stroop test tasks based on different infor-

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mation processing stages (stimulus processing stage and response stage).

The perceptual conflict hypothesis asserts that the word and the incongruent color in which the word is printed create conflict, and that this conflict overloads the information processing system. This condition causes delay in reaction time, as a limited capacity system is used in processing the information related to both the word and the color (Doehrman et al., 1978).

According to the response competition hypothesis, two competing responses have to use a single response channel in the response-initiating stage. The color stimulus has to be converted from perceptual to verbal code, whereas the word stimulus does not require such a process. Therefore, the word information reaches the response-initiating stage before the color information does, and this condition causes a delay in reaction time (Doehrman et al., 1978).

To sum up, according to the perceptual conflict hypothesis, Stroop interference occurs because of the conflict created by the stimulus condition during the perception stage. On the other hand, according to the response competition hypothesis, it occurs because of the competition that is created during the response stage.

Stroop interference has been a very interesting behavioral phenomenon (for review, see MacLeod, 1991); the Stroop test/task is one of the most intensively studied paradigms in neuroscience, as well as in cognitive psychology. Below, the literature on the event-related potentials (ERPs) of the Stroop effect in cognitive electrophysiology is summarized.

Event-Related Potentials (ERPs) of the Stroop Test

The electrical activity recorded from scalp electrodes reflects sensory and cognitive functions. Neuro-electrical responses are created in the brain in response to external stimuli, and a functional relationship exists between the external stimuli and the responses. Consequently, the related potentials are known as ERPs. ERPs that appear as positive and negative peak series, and show variations in amplitude, latency, duration, and topography are reliable indications of both brain and cognitive psychological processes (Gaillard, 1988; Başar, 1999). In the Stroop test there are incongruent trials (incongruent stimuli) in which the word for a color is printed in a color differing from the color expressed by the word's meaning, congruent trials (congruent stimuli) in which the color of a word is printed in the same color expressed by the word's meaning, and neutral trials (neutral stimuli) in which a non-color word is printed in different colors. Electrical activity measured during Stroop performance can be analyzed according to the stimuli category (congruent, incongruent, and/or neutral stimuli) and response accuracy (correct response or false response). The variation in electrical responses, with regard to the psychophysiological parameters (amplitude, latency, etc.), provides information about the cognitive/psychological processes related to Stroop performance.

While the majority of studies conducted on the Stroop effect have only considered stimuli congruency, others have focused only on response accuracy (Warren and Marsh, 1979; Grapperon et al., 1998; Ilan and Polich, 1999; DeSoto et al., 2001; Masaki et al., 2001; Alain et al., 2002; Hajcak and Simons, 2002; Kerns et al., 2004; Lansbergen et al., 2007; Mager et al., 2007). In this sense, the Stroop effect is explained by two hypotheses that focus either on stimuli congruency or response accuracy conditions. In these studies the inclination to conclude that stimuli categorization-related variations reflect perceptual conflict, whereas response-related variations reflect the response competition process is remarkable.

During Stroop test performance, among the electrophysiological activities related to the process of evaluating the meaning of stimuli, the following results have been reported: 350-450 ms after stimuli presentation, greater negativity was observed, and about 450-550 ms after stimuli presentation, greater positivity for incongruent stimuli than for neutral and congruent stimuli were observed (Markela-Lerenc et al., 2004); increased negativity was recorded in the frontocentral region and increased positivity was recorded in the frontopolar region (West and Alain, 2000); slow temporoparietal waves for congruent stimuli, and 500-800 ms-latency positivity was recorded in the left temporoparietal cortex for congruent and incongruent stimuli (Liotti et al., 2000).

In addition to findings that show the congruency condition of stimuli influences brain electrophysiology during the Stroop test, other findings show that the Stroop effect occurs after stimulus evaluation and that it is related to the response competition caused by the stimulus characteristics. The limited number of studies suggested that Stroop interference originates from response competition grounded their arguments on findings showing that the congruency condition of the stimuli did not affect P300 latency, that premotor negativity occurred 400 and 205 ms before pushing the button in the incongruent trials, that ERP peaks related to reading were recorded from the occipital electrodes, and that ERP peaks related to naming were recorded from the frontal electrodes in congruent trials (Warren and Marsh, 1979; Grapperon et al., 1998; Ilan and Polich, 1999). One study (Karakaş et al., 2005) that analyzed the stimulus congruency condition and response accuracy effect together reported an effect related to response accuracy, but did not observe any direct evidence concerning the stimulus congruency condition.

To sum up, a number of studies have explained the Stroop effect based on the perceptual conflict hypothesis (Liotti et al., 2000; West and Alain, 2000; Atkinson et al., 2003; Kerns et al., 2004; Mager et al., 2007;), while others used the response competition hypothesis, offering direct and indirect evidence that this effect appears on the response level (Warren and Marsh, 1979; Rebai et al., 1997; Ilan and Polich, 1999; Karakaş et al., 2005).

AIM OF THE STUDY

The aim of the present study was to evaluate the validity of the perceptual conflict and the response competition hypotheses in explaining the Stroop effect. Previous studies of the Stroop effect did not consider whether the Stroop effect was based on stimuli or response factors. Stroop test performance does not only include the processes of sensing and perceiving the related stimuli, it also encompasses the processes of regulating and controlling motor activity when a demand contradicts a perceptual configuration at the same time (Burke and Light, 1981). As such, the hypothesis of the present study was that during the Stroop test, ERP peaks would not only change according to stimulus condition (congruent or incongruent), but also vary according to response correctness.

METHOD

Participants

The study included 50 healthy volunteer adults aged 18-29 years with ≥ 12 years of education. Mean age was 21.56 ± 2.64 years, and 23 of the participants were female and 27 of them were male. The entire sample consisted of right-handed individuals. In order to determine the dominant hand of the participants were asked the question, "if you have to throw a stone, which hand would you use?" Participants that reported a neurological or psychological disorder, those that were using drugs that could potentially affect cognitive processes, and those that reported having used these drugs for a time and then stopped, were excluded from the study. The sample consisted of volunteer participants that provided informed consent.

Instruments and Procedures

The Stroop test was administered via computer using a NeuroScan 4.2 STIM system. The test consisted of 24 words that expressed colors (blue, red, yellow, and green) and the stimulant words were formatted in 45-point Ariel font using ImageWord. The stimuli appeared on a black background on a 19" computer screen, and were viewed from a distance of 100 cm. During the test, two types of stimulus words appeared in equal number: words printed in the color congruent with the color expressed by the word's meaning (C) and stimulus words printed in a color incongruent with the color expressed by the word's meaning (I). The inter-stimulus interval (ISI) was 1 s and the stimulus duration was 0.750 s for these two types of words.

The participants were asked to give motor responses using a StimPad device. The task was to give fast and accurate responses by pressing the number 1 key in response to the congruent stimulus condition and the number 2 key in response to the incongruent stimulus condition. Before the test was administered, the participants were given a practice test that consisted of 8 stimuli in order to make sure that they understood the task.

During the Stroop test the number of correct (C/C) and false responses to congruent stimuli (C/F), and the number of correct (I/C) and false responses to incongruent stimuli (I/F) was calculated. In addition, reaction time was also calculated during the test. Reaction time was measured as the period between when the stimulus appeared on the screen and when the participants responded by pressing a key. In this way reaction times for each correct (C/C-RT) and false response to congruent stimuli (C/F-RT), and reaction times for each correct (I/C-RT) and false response to incongruent stimuli (I/F-RT) were calculated.

Instruments and Procedures Related to Electrophysiological Measurements

Stimulus presentation, recording, storage, and analysis were carried out using a 32 channel EEG/EP NeuroScan system (28 EEG channels, 4 channels for eye-movement). EEG recordings were made in an electrically shielded, sound-proof chamber. EEG activity was recorded with 30 electrodes placed according to the international 10-20 system. For the recordings the US-

FDA-approved QuickCap with Ag-Ag/Cl was used (ref.: linked mastoid; ground: forehead). In order to identify eye-movement artifacts, electrodes were placed on both eyes (VEOG, HEOH). EEG signals were filtered between 0.16 and 100 Hz, and sampling rate was 512 Hz. Impedance was ≤ 10 K ohms in all recording sites. EEG recording was observed for 1024 ms before stimulus and for 1022 ms after stimulus; 2046 ms in total.

Analysis of Electrophysiological Data

ERPs of the brain consist of peaks created by amplitude variations on the time axis. In the present study as well, the electrophysiological records were analyzed in the time-domain. Average ERPs related to correct responses to congruent stimuli (C/C), false responses to congruent stimuli (C/F), correct responses to incongruent stimuli (I/C), and false responses to incongruent stimuli (I/F) were calculated for midline electrodes. For each participant, peak latency was determined in ms, regarding its projection on the X-axis, and peak amplitude was determined in microvolts (μV), regarding its projection on the Y-axis. Peaks were referred to N1, N2, P3, N3, and N4, according to their order of appearance (1-4) and polarity (negative: N, positive: P). Before the analyses data obtained under the related condition combinations were subjected to univariate outliers analysis. For this reason, in the z distribution, 3.00, which correspond to $\alpha/2 = 0.001$ in the two-tailed hypothesis test, was considered the critical z value, and the data with a z value ≥ 3.00 were discarded. Two outliers were excluded from the analysis. Following these procedures the sample consisted of 48 participants.

In the analyses of significance, analysis of variance (ANOVA) suitable for a repeated measure design was used. Greenhouse-Geisser adjustment was applied for evaluating the results of the main effect and interaction that did not meet the sphericity assumptions; degrees of freedom and significance levels related to this adjustment were reported. In the post hoc analyses conducted for determining the source of significant main effects, Bonferroni adjustment was used to decrease type I error that could have been a result of the multiple comparison effect.

RESULTS

Behavioral Results

Mean ± SD values obtained with the Stroop test are presented in Table 1. Table 1 shows that the number of correct responses to the incongruent stimulus condition was higher than to the congruent stimulus condition. In terms of the reaction time scores, longer durations were noted in the incongruent stimulus condition than in the congruent stimulus condition, independent of response accuracy.

TABLE 1. Arithmetic means (m) and standard deviations (SD) for response frequency and reaction time under combinations of conditions of the Stroop test.

		Congruent Stimulus M ± SD	Incongruent Stimulus M ± SD	
Correct Response	Total Score	10.917 ± 1.164	11.313 ± 0.854	*
	Reaction time (ms)	0.615 ± 0.068	0.648 ± 0.074	***
False Response	Total Score	1.021 ± 1.194	0.500 ± 0.684	**
	Reaction time (ms)	0.558 ± 0.104	0.599 ± 0.079	NS

*P < 0.05 **P < 0.01 ***P < 0.001
NS: Not Significant

Analysis of variance (ANOVA) for repeated measures was applied to the behavioral data obtained in the congruent and incongruent stimulus conditions of the Stroop test. The independent variable in the design was the congruency of the stimulus (congruent, incongruent). Total response number (frequency) and reaction time measurements were considered as dependent variables in the analyses. Analyses were conducted separately for correct and false responses, and reaction time scores.

The correct responses to the stimulus condition variable had a significant effect on total response number ($F_{(1,47)} = 5.568$, $P \leq 0.022$) and reaction time ($F_{(1,47)} = 20.152$, $P \leq 0.0001$). Accordingly, total response number and reaction time to the incongruent stimulus condition were higher than those to the congruent stimulus condition. The false responses to the stimulus congruency condition variable had a significant effect on total response number ($F_{(1,47)} = 8.055$, $P \leq 0.00$, but did not have a significant effect on reaction time. In addition, the effect of the congruency on the number of stimuli that were missed (omission error), was significant ($F_{(1,49)} = 4.096$, $P \leq 0.048$). According to this finding, more stimuli were missed in the incongruent stimulus condition.

In the present study PCA was applied to the data in order to identify the factor structures of the Stroop test scores. Analysis was conducted on correct and false response scores to congruent and incongruent stimuli (respectively, C/C, C/F, I/C, and I/F) with their reaction time scores (respectively, C/C-RT, C/F-RT, I/C-RT, and I/F-RT).

TABLE 2. PCA results applied to Stroop test scores. A: PCA results applied to correct and false response scores, with reaction time scores for congruent and incongruent stimulus conditions. B: PCA results applied to correct and false response scores, with total response duration scores for congruent and incongruent stimulus conditions.

A	Factor 1:	Factor 2:	Factor 3:
C/F	0.889	0.000	0.000
C/C	–0.889	0.000	0.000
C/C-RT	0.851	0.000	0.000
I/C-RT	0.842	0.000	0.406
I/C	0.000	–0.917	0.000
C/F-RT	0.380	0.845	0.000
I/F-RT	0.000	0.000	–0.760
I/F	0.000	0.422	0.650
Eigenvalue	3.159	1.909	1.429
Explained Variance (%)	39.483	23.863	17.860
Cumulative Variance (%)	39.483	63.346	81.206

B	Factor 1: Selective Attention	Factor 2: Interference	Factor 3: Resistance to Interference
C/F	0.994	0.000	0.000
C/C	–0.994	0.000	0.000
C/F-duration	0.974	0.000	0.000
C/C-duration	–0.435	0.400	0.407
I/F	0.000	0.955	0.000
I/F-duration	0.000	0.922	0.000
I/C	0.337	0.000	0.909
I/C-duration	0.000	–0.364	0.704
Eigenvalue	3.284	2.063	1.532
Explained Variance (%)	41.053	25.786	19.146
Cumulative Variance (%)	41.053	66.839	85.985

C/C: Congruent stimulus correct response; C/F: congruent stimulus false response; I/C: incongruent stimulus correct response; I/F: incongruent stimulus false response; C/C-RT: congruent stimulus correct reaction time; C/F-RT: congruent stimulus false reaction time; I/C-RT: incongruent stimulus correct reaction time; I/F-RT: incongruent stimulus false reaction time; C/C-Duration: congruent stimulus correct response total response duration; C/F-Duration: congruent stimulus false response total response duration; I/C-Duration: incongruent stimulus correct response total response duration; I/F-Duration: incongruent stimulus false response total response duration.

Table 2A shows the factorial structure obtained for the Stroop test scores with PCA. As can be seen in Table 2A, 3 factors that explained 0.81% of total variance were not consistent for the Stroop test. Response duration score of the standard Stroop test was measured as the time between the response given to the first stimulus and the response given to the last stimulus. In this manner, total response duration scores for each condition were used in the new analyses instead of average reaction time scores. Total response duration was the sum of reaction time **for each response category under** both stimulus **conditions.** According to PCA results, variance explained by the model was 0.86% (Table 2B). All the scores for congruent stimuli were loaded on the first factor (explained variance: 41.053%). False response scores for incongruent stimuli constituted the second factor (explained variance: 25.786%). The last factor included correct responses to incongruent stimuli (explained variance: 19.146%).

Event-Related Potentials (ERPs)

For the Stroop test, mean values of ERP components for each participant were determined in four conditions, which consisted of correct and false responses to congruent and incongruent stimuli (C/C, I/C, C/F, I/F). Figure 1 presents the grand average ERP waveforms for C/C, I/C, C/F, and I/F conditions for midline electrodes (Fz, Cz, Pz). The ERP graphs in Figure 1 show N1 (latency: 86.71-98.15 ms), N2 (latency: 175.42-188.58 ms), P3 (latency: 213.37-232.08 ms), N3 (latency: 413.67-448.61 ms), and N4 (latency: 755.15-829.46 ms) peaks, according to their time order and polarity.

Statistical analyses were conducted on average ERPs of the participants for midline electrodes. The effects of congruency (congruent, incongruent), response accuracy (correct, incorrect), and recording site (Fz, Cz, Pz) on amplitudes of the ERP peaks (N1, N2, P3, N3, N4) were tested using 2 x 2 x 3 factorial design with repeated

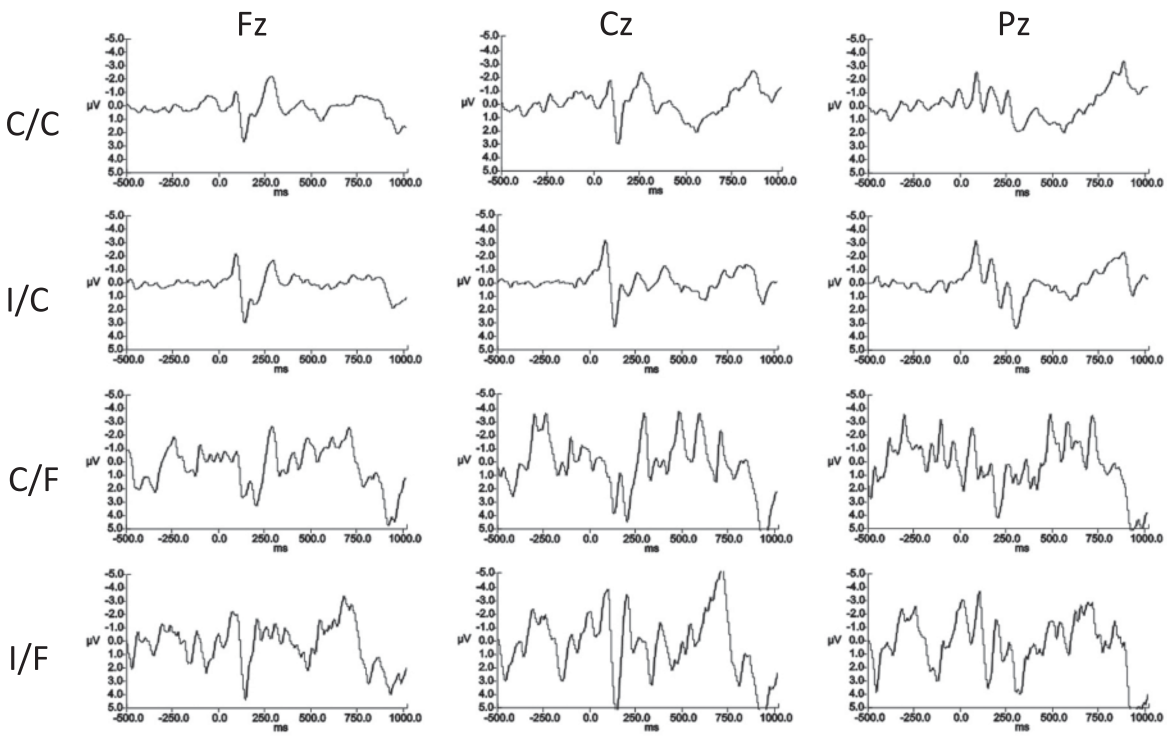

FIGURE 1. Grand average event-related potentials (ERP) for the Stroop test congruent stimulus correct response: C/C (row 1); incongruent stimulus correct response: I/C (row 2); congruent stimulus false response: C/F (row 3); incongruent stimulus false response: I/F (row 4) for Fz (column 1), Cz (column 2), and Pz (column 3). Stimulation onset was marked with “0”.

measures. The dependent variables in the variance analysis were amplitude and latency values of the related responses, and analyses were conducted separately for amplitudes and latencies belonging to each peak.

The main effect of the congruency of stimulus variable was significant for the amplitude of the P3 and N4 peaks (P3: $F_{(1,12)} = 5.781$, $P \leq 0.033$; N4: $F_{(1,12)} = 8.936$, $P \leq 0.011$). The main effect of the response accuracy variable included N2, P3, N3, and N4 peaks (N2: $F_{(1,12)} = 13.527$, $P \leq 0.003$; P3: $F_{(1,12)} = 10.155$, $P \leq 0.008$; N3: $F_{(1,12)} = 16.218$, $P \leq 0.002$; N4: $F_{(1,12)} = 17.558$, $P \leq 0.001$). The main effect of the recording site was significant only for the amplitude of the P3 peak ($F_{(2,24)} = 3.887$, $P \leq 0.034$). Interaction effect of the congruency

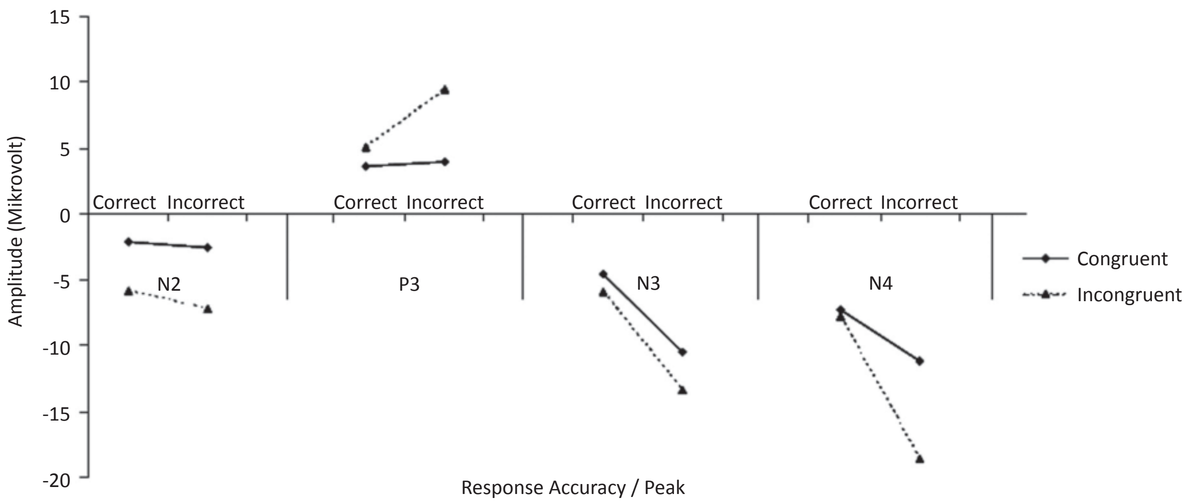

FIGURE 2. Line graph related to the N2, P3, N3, and N4 amplitudes obtained for the Stroop test congruent and incongruent stimulus conditions, and correct and false response.

and response accuracy was significant for the amplitude of the N4 peak ($F_{(1,12)} = 5.276$, $P \leq 0.040$). Additionally, the interaction effect of response accuracy and recording site was significant for the amplitude of the P3 peak ($F_{(2,24)} = 5.430$, $P \leq 0.011$), and the interaction effect of the congruency, response accuracy, and recording site were significant for the amplitude of the N3 peak ($F_{(2,24)} = 4.409$, $P \leq 0.024$).

In the post hoc analyses conducted for significant main effects, the amplitudes of the P3 and N4 peaks for incongruent stimuli were higher than those for congruent stimuli (P3: $P \leq 0.017$; N4: $P \leq 0.011$), and the amplitudes of the N2, P3, N3, and N4 peaks for false responses were higher than those of the peaks for correct responses (N2: $P \leq 0.003$; P3: $P \leq 0.008$; N3: $P \leq 0.002$; N4: $P \leq 0.001$). After Bonferroni adjustment, the main effect of recording site on the amplitude of the P3 peak was not significant. Figure 2 shows the line graph of the amplitudes of the N2, P3, N3, and N4 components obtained for the Stroop test correct and false responses for the congruent and incongruent stimulus conditions.

In the variance analysis where latency was used as the dependent variable, the main effect of the stimulus congruency was only significant for the N4 peak ($F_{(1,12)} = 7.916$, $P \leq 0.016$); the main effects of response accuracy and recording site were not significant. Moreover, the interaction effect of the response accuracy and recording site variables were significant for the N2 and P3 peaks (N2: $F_{(2,24)} = 3.793$, $P \leq 0.037$; P3: $F_{(2,24)} = 5.552$, $P \leq 0.010$).

DISCUSSION

The present study aimed to evaluate the validity of two hypotheses used to explain the Stroop effect by analyzing the correct and false responses in congruent and incongruent stimulus conditions. Responses included ERPs recorded from scalp, as well as behavioral responses. In accordance with the within-subject design of the study, measurements were obtained from each participant in every condition of the study, and several confounding variables caused by the participants' characteristics, which could influence related electrophysiological responses were controlled for. Additionally, the study included precise experimental and electrophysiological data analysis procedures. In the related procedures several variables that might have influenced electrophysiological responses (Polich and Kok, 1995) were controlled for by elimination and constancy techniques (see Bekçi, 2007 for the details about the experimental procedures used in the study). Considering these characteristics, the present study was experimental in design and analyzed the neuro-electrical peaks triggered by Stroop performance based on a standard neuropsychological task and cognitive procedures represented by these peaks.

Behavioral Findings and Related Comments: Possible Cognitive Processes in Stroop Test Performance

The literature contains several Stroop tests based on subjects saying the color of color words written in different colors. The Stroop test in the present study used a computerized version of the test (NeuroScan 4.2). In the congruent and incongruent stimulus conditions of the Stroop test, participants had to decide whether the color expressed by the color word was congruent or incongruent with the color the word was printed in, and press a key to indicate their decision. Under these conditions it was possible to give correct or false responses for these two stimulus types. Additionally, with this version of the test stimuli were presented in series, independent of their responses, and the participants had to respond quickly to the stimuli. If a participant provided a late response, the next stimulus appeared and the stimulus that the participant responded to late was considered as missed.

In the Stroop test the reaction time to incongruent stimuli, for both correct and false responses, was longer than the reaction time to congruent stimuli; this difference was statistically significant for correct responses (Table 1). Additionally, the present study also considered the number of stimuli that participants responded to late; in other words, missed stimuli (omission error). This number was statistically higher for incongruent stimuli than for congruent stimuli. Therefore, in the present study, the interference effect on behavior was indicated by longer duration for response to incongruent stimuli and a higher number of missed stimuli.

PCA analysis results of correct and false response scores, with respect to reaction time scores, were not as expected; a consistent factorial structure for Stroop test scores was not obtained. Nonetheless, considering the test structure, the scores for congruent and incongruent stimuli were expected to cluster under separate factors. As to reaction speed, using response duration scores instead of reaction time scores yielded both a consistent and original factorial structure.

The results of the analysis show that all the Stroop test scores for congruent stimuli were loaded on the first factor. This factor, which is the main process related to the Stroop test (MacLeod, 1991; 1992) and is considered the 'gold standard' of attention, was referred to as selective attention. The false response scores for incongruent stimuli took place in the second factor, and the correct response scores for incongruent stimuli were in the third factor. The last two factors draw attention to an interesting and new finding by highlighting two different psychological processes that changed, depending on response accuracy (correct or false) in the incongruent stimuli condition. The second factor, which consisted of false response scores for incongruent stimuli, was considered the interference factor. The last factor consisted of correct response scores for incongruent stimuli and was referred to as the resistance to interference factor. The factorial pattern obtained in this manner was compatible with selective attention and interference processes previously reported for the Stroop test (Glaser and Glaser, 1989; MacLeod, 1991; Helmstaedter et al. 1996). Moreover, it included an original factor, resistance to interference. Thus, the Stroop test used in the present study included the characteristics that it sought to measure, and this form was deemed valid for measuring the Stroop effect.

Event-Related Potential Results of the Stroop Test and Related Comments

The Stroop effect was indicated at the electrophysiological level by the amplitude and latency variations in ERP components that appeared in the congruent and incongruent stimulus conditions, and the correct and false conditions. As was mentioned previously, the Stroop effect has been explained by two hypotheses; one that is based on stimulus congruency conditions and the other on response accuracy conditions. Nevertheless, considering the within-subject design of the present study, both stimulus congruency and response accuracy conditions had to be considered together in order to determine whether the perceptual conflict or response competition hypothesis was supported by the findings. Thus, in the present study ERPs for correct responses to congruent stimuli (C/C), false responses to congruent stimuli (C/F), correct responses to incongruent stimuli (I/C), and false responses to incongruent stimuli (I/F) were determined.

The Perceptual Conflict Hypothesis is Valid in Explaining the Stroop Effect

In the present study all the peaks measured in the Stroop test conditions, except N1, had higher amplitude values in incongruent stimulus condition than in congruent stimulus condition. This amplitude variation was statistically significant in terms of P3 and N4 peaks. Consistent with the findings in the literature (West and Alain, 2000; Liotti et al., 2000; Atkinson et al., 2003; Lansbergen et al., 2007; Mager et al., 2007;), these findings show that the stimulus congruency condition influenced brain electrophysiology, and amplitudes of incongruent stimuli were higher than those of congruent stimuli. Accordingly, the amplitude increase in P3 and N4 peaks (Figure 2) was related to the information processing of stimulus meaning, and reflected the conflict detection process.

Response Competition Hypothesis is Valid in Explaining the Stroop Effect

The arguments asserting that the Stroop effect occurs after stimulus evaluation and that the effect is related to the response competition caused by stimulus characteristics, in other words the motor system, were already mentioned in this paper (Warren and Marsh, 1979; Rebai et al., 1997; Ilan and Polich, 1999; Alain et al., 2002; Hajcak and Simons, 2002). In a study conducted by Karakaş et al. (2005) the amplitudes of late negative peaks in the false response condition (GN1 and GN2) were higher than in the correct response condition.

The present study shows amplitude variation related to response accuracy as well, which is consistent with previous findings. Higher amplitude values that were statistically significant were observed for N2, P3, N3, and N4 peaks in false response conditions than in correct response conditions. These findings showing that the response accuracy effect was relatively obtained for early N2 and P3 peaks indicate that information processing occured regarding the response accuracy in all phases of Stroop test performance. Nonetheless, the term information processing is a general term. Stroop test performance also includes complex characteristics, as expected, as it is a test of executive functioning (Lezak, 1995). Accordingly, variations in electrical response related to the response accuracy effect, evaluation of the cognitive processes that they correspond to, and the effects of congruent stimulus and response accuracy variables on peak amplitudes should be considered together.

From this perspective the response accuracy and stimulus congruency variables took place together on peaks N2, P3, N3, and N4 (Figure 2). As can be seen in Figure 2, relatively early amplitude increase related to false responses was obtained only for incongruent stimuli in N2 and P3 latency. Amplitude increases in the event-related potential peaks (N2 and P3) for incongruent stimulus conditions, where interference existed and response had to be inhibited, was thought to reflect response competition. On the other hand, amplitude increases for false responses in N3 and N4 latency that appeared late were obtained for both congruent and incongruent stimuli. Because it appeared late and existed in congruent stimulus conditions without interference, the amplitude increases in the related peaks were thought to be related to decision/evaluation about behavior accuracy, reflecting the error detection processes.

Perceptual Conflict Interacts with Response Competition in Stroop Test Performance

Another finding of the present study was that stimulus congruency interacted with response accuracy, in terms of the N4 peak. As Figure 2 shows, amplitude increases in false response conditions changed according to stimulus type; amplitude increases for incongruent stimuli were higher than for congruent stimuli. The fact that decision about response accuracy is also related to stimulus meaning evaluation can be expected in terms of the Stroop test performance. Indeed, the Stroop test used in the present study (NeuroScan 4.2) included the perception of colors and words, decisions about congruency, recall of a response for each condition, executing related motor behavior, and congruency evaluation between executed behavior and behavior that should have taken place. In this sense, perceptual conflict and response competition did not separately intervene in the Stroop effect; perceptual conflict and response competition interacted with each other. This finding is consistent with modern models and theories suggesting that human cognitive processes consist of neural networks in the brain that work in an integrative fashion (Cohen et al., 1990; Fernandez-Duque et al., 2000).

Findings of the present study generally indicate that predictions about processes that took place between a stimulus and response during a particular cognitive activity could not have been related to behavioral responses alone, and that it was necessary to refer to brain activity in the analysis of cognitive activities. Finally, ERP peaks obtained during the Stroop test performance did not only change according to stimulus condition (congruent or incongruent), but also varied according to whether or not response to the stimulus was correct or false. In other words, brain responses did not only have a stimulus effect, but also affected the accuracy of the response given by an individual. Accordingly, the electrical responses that appeared during Stroop performance reflected both perceptual conflict related to stimulus characteristics and activities related to the response competition processes; both perceptual conflict and response competition hypotheses were valid, in terms of the Stroop effect (Karakaş et al., 2005; Schmidt and Cheesman, 2005).

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