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Event-Related Potentials and the Stroop Effect

Olay-İlişkili Potansiyeller ve Stroop Etkisi

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Abstract

In this manuscript, the researches on the Event-Related Potentials (ERP) elicited by the standard Stroop effect were reviewed. For the sake of clarity, only the parts of the manuscripts that reported the standard Stroop effect - ERPs relation were taken into consideration.

Keywords: Stroop effect, event-related potentials (ERP), intentional and automatic processes, response competition, motor response, interference

Öz

Bu makalede standart Stroop etkisi sonucu ortaya çıkan olay-ilişkili potansiyeller (OİP) üzerine yapılan çalışmalar incelenmiştir. Bu ilişkinin özünü vurgulamak amacıyla yapılan çalışmaların yalnızca standart Stroop etkisi - OİP ilişkisi göz önüne alınmıştır.

Anahtar Kelimeler: Stroop etkisi, olay-ilişkili potansiyeller (OİP), istemli ve otomatik işlemler, tepki rekabeti, motor yanıt, enterferans

Introduction

In 1886, McKeen noticed that it took longer to say the color of red patches than it did to read the word "red" [1]. This observation paved the way for one of the most widely known experiments in psychology, known as the Stroop Effect. It is named after John Ridley Stroop, who first published this effect in 1935 [2]. In a typical Stroop experiment an individual is presented with a stimulus having two dimensions (e.g., a *color-word* written in a specific *font-color*) and required to respond (e.g., vocalise) to one of the two aspects of the stimulus (e.g., is required to name the color of the font) and ignore the other (i.e., ignore the word). Under these circumstances it takes longer time for a subject to *name* the *color* of a color-word (e.g., the *word* "RED"), the font of which is written in a *different* font-color (e.g., the word "RED" written in BLUE fonts); than in naming the color of the same color-word ("RED"), the font of which is written in the *same* font-color ("RED" written in RED fonts). In other words, when the two aspects of the stimulus are in harmony with each other, the response time shortens.

The importance of the Stroop effect is that it appears to cast light into the essential operations of cognition, thereby offering clues to fundamental cognitive processes and their neuro-cognitive architecture. Stroop effect is also utilized to investigate various psychiatric and neurological disorders. Extensive reviews on the Stroop effect have been published by several authors [3-5].

Psychological Background

The behavior of the human beings is based on a stimulus-response relationship. The environmental sensory information is encoded and evaluated by the brain and an appropriate response is put into action via the muscular (motor) system. Here, the brain is faced with the problem of deciding the appropriate action to be taken in response to a certain stimulus. The problem arises from the fact that the information-processing system functions in a sequential manner; that is, each stage must be completed before the next; so inevitably at the response stage all information comes together forming a *bottle-neck* that renders the information processing into a single-channel system.

Another aspect of the stimulus-response chain is the relation between the *intentional* and *automatic* processes. Intention can be defined as a determination to act in a certain way. Automaticity, on the other hand, is a process that can be carried out rapidly and without effort or intention; this often occurs when a behavior has been practiced repeatedly. Most of the time in everyday life, these two processes compliment each other and the appropriate action is carried out for the specific goal in question. But, when intentional and automatic processes contradict each other, errors in the reaction to a specific stimulus may arise; that is, if the automatic and the intentional reactions to the stimulus differ, then there arises the possibility that the automatic reaction may override the intentional reaction.

When the brain encounters two stimuli *contradicting* with each other and is obligated to make a choice between them,

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there will be a slowing down in the reaction time, because the intentional reaction must first overcome the automatic reaction in order to give the correct response. This can be explained by *interference*, a delay caused by the *competing* functions in the brain.

The most prominent example of this phenomenon is the Stroop Effect. As mentioned in the introduction, this effect is based on the conflict between color-word *reading* and font-color *perception*. Although the subject is required to vocalise (to name) the color of the font-color, he/she is more prone to name the color-word. Here, the intentional reaction is to vocalise the color of the font; but, since people are more practiced at word-reading, the subject is confronted with the dilemma of choosing between perception of color and reading the word. If the font-color is incongruent with the color-word that represents the font-color in question (e.g., the word "RED" written in BLUE fonts), the intentional process of color-naming clashes with the automatic process of word reading. In short, the color and word interferes with each other leading to a conflict at the response stage.

Methodology

The stimulus used in Stroop experiments is word-colors printed in incongruent color-font. Presenting the stimulus (words, colors etc) began with displaying cards to the subject. In his original experiment [2], Stroop used three cards: a word card (W) on which color-words were printed in black ink on a white background; a color-patch card (C); and a card on which color-words, whose fonts were printed in colors not in line (incongruent) with the color-word (CW). He arranged the words and color-patches in a 10x10 matrix format of evenly spaced rows and columns; and they were distributed in a random manner, that is, any regularity was avoided for both words and patches. The colors he used were red, blue, green, brown and purple printed on a white background; and every color is displayed equal number of times.

As in all researches, in Stroop experiments the crucial point is to establish the appropriate reference to make comparisons against. Stroop first compared reading a list of words printed in *black* with reading the same list of words printed in *incongruent colors*. Stroop then compared the naming of colors for a list of *solid color squares* with the naming of font-colors for a list of words printed in *incongruent colors* [2].

The researchers who followed his steps based their experiments on the variations of this scheme. Although the colors used did not vary much, other parameters such as the background color of the cards, the size of the fonts, the patterns of the non-word color- patches, the number of times a stimulus displayed varied substantially.

The variations especially occurred in the patterns of color-patches used for comparisons. For instance, in the 1959 experiment of Gardner et al. [6], the C card was made up of colored asterisks which matched the length of the words on the W card. Other investigators used a series of Xs [7], non-word color patchles [2], or infrequently used words [8] as non-word color stimuli. There are also researchers who used word-picture interference, where the subject was required to name the picture of an object on which an incongruent word was superimposed [9]. But still there is no single paradigm adopted by the researchers.

With the advent of computers, monitors replaced the cards, and the stimulus presentation modes increased many fold. Computers also enabled the stimuli to be displayed in a sequential manner; that is, words and patches are displayed one at a time, instead of in a matrix format as in the case of card reading. Apart from stimulus presentation, the response modes of the subject varied, too; besides naming the color, key-press type of responses became possible. Also, the usage of computers provided the researchers with precise timing of the responses; moreover, besides measuring the total response interval, they provided the opportunity of measuring the response time of every single response in a session.

The computers also enabled detailed analysis of the physiological data, such as galvanic skin resistance and cardiac activity [10] of the subjects during a Stroop session. Especially, the recording of the electrical cortical activity, which is the subject matter of this review; and the fMRI [e.g., 11, 12] provided objective evaluation of the psychological responses evoked by the Stroop paradigms in conjunction with the subjective data obtained.

Event-Related Potential Studies

The main problem in studying the Stroop effect arises from the dilemma of whether the interference arises in the stimulus-encoding stage or during the response-production. Although the response time (RT) of the subject can be measured objectively, there is no way of determining how long it takes for a stimulus to be encoded in the brain. Here the role of brain evoked potentials comes into play in the Stroop effect studies. It is well known that the component of an evoked potential, called the event-related potential (ERP), is sensitive to psychological processes associated with a sensory stimulus. The latency of this component, the P300 wave, reflects the *duration* of the stimulus-evaluation and is independent of the RT.

In this review we only took into consideration the parts of the ERP studies based on the standard Stroop test, that is, the word-color conflict; and omitted the results related to the variations on this test, such as reverse Stroop effect (i.e., reading the word instead of its color), picture-word conflict [e.g., 9], emotional Stroop tasks [e.g., 13], numerical Stroop studies [e.g., 14], psychological disorders [e.g., 15, 16] and Chinese characters-color conflict [e.g., 17].

The first study on the effects of Stroop paradigm on brain potentials began with the works of Duncan-Johnson and Kopell in 1980's. In their 1981 paper [18], they used red and blue colors, in congruent and incongruent conditions; and the word "town" as the neutral (reference) stimulus. They measured both the RT of the subjects and recorded their P300 waves from Pz, Fz and Cz locations.

They reasoned that if Stroop interference was due to a delay in *stimulus identification* rather than the *RT*, then the latency of P300 elicited by incongruent stimuli would have been delayed relative to that elicited by congruent or neutral stimuli; and this latency would have changed in parallel to the changes in the RT. But, conversely, if the interference occurred *after* the stimulus evaluation, then the P300 latency would have stayed relatively stable across all conditions; but, this time RT to the incongruent stimuli would have been delayed relative to P300. Thus, by comparing the RTs and P300 latencies, it would have been possible to determine at which stage the interference had occurred.

For all three stimulus conditions (congruent, incongruent and neutral) they recorded a P300 component. They found no differences between the latencies of the three P300 traces; but, the RT to the incongruent stimulus was slower compared to the neutral stimulus. This latency invariance showed that the Stroop effect occurred at a time *later* than the stimulus evaluation; which, in turn, indicated that the color and word were processed in *parallel*, with interference arising from competition among conflicting (congruent vs incongruent) responses.

Rebai et al. [19], using the standard four colors (red, green, yellow and blue) and non-verbal signs (Xs), studied the N400 wave in response to congruent, incongruent and neutral stimuli. In one of the tasks the subjects were instructed to *vocalize* the color of the word; and in another task to name the colour *mentally*. The ERPs were recorded from Fz, Cz, Oz and left/right parietals. They did not find any late negative components both in the ERPs when there was no conflict in naming the color of a concordant stimulus or in naming the color of the neutral sign. They have recorded an N400 wave when the subjects had to mentally evoke the names of colors in a discordant stimuli. They concluded that the automatic reading could corrrespond to an expectancy-induced priming which facilitated the process of expected targets.

In their 1998 paper Ilan and Polich, too, [8] recorded P300 waves from Pz, Fz and Cz locations in response to congruent, incongruent and neutral stimuli. They used red, green, blue and yellow colors for congruent and incongruent conditions; and their neutral stimuli consisted of very infrequently used words *sol*, *helot*, *eft* and *abjure* presented in each of the four colors.

They reported that the RT was shortest for the congruent condition and longest for the incongruent; and RT to neutral stimuli took its place between these two extremes. As for the P300 waves, they found no significant effect of incongruence on latency across the electrode sites. For the P300 amplitude, they made two observations: first, the amplitudes increased from Fz to Pz for all stimuli conditions; second, significant differences were observed from Fz to Pz; the differences being greatest at Pz. They recorded the greatest amplitude for the congruent condition, and smallest for the incongruent.

They concluded that the word-color congruence facilitated the RT of the subjects; and, on the other extreme, the strongest interference was observed in the incongruent condition. This gradual increase in RTs from congruent through neutral to incongruent showed that although the subjects were told to respond only to the color and not to read the word, the words were *read* and their meanings were *accessed*; in other words, they were unable to ignore the meaning, although it was irrevelant to task performance. On the other hand, the constancy of the P300 latencies for all stimulus conditions indicated that these latencies were unaffected by the color-word conflict. When these two facts are taken together, their work showed that the Stroop effect on RT was produced after the evaluation of the stimulus; and facilitation and interference occured in later response production stages after the P300 has been elicited.

West and Alain [7] required subjects to respond in a key-press manner to the red, green, blue and yellow in congruent and incongruent situations and they used coloured Xs as the neutral stimulus. The ERPs were recorded from 47 electrode sites of the 10-20 system. The latency of the response to incongruent stimuli was significantly longer compared to the congruent and neutral stimuli as was also shown by the other researchers. The electrophysiological data showed that all trial types elicited a series of *negative-positive-negative* peaks with latencies of 170 ms, 230 ms and 300 ms, respectively; and these peaks were maximal at parietal and occipital regions. The smaller amplitude ERPs over the left parietal regions to incongruent stimuli compared to the higher amplitude ERPs over the right parietal suggested that the left parietal is not fully active in word-color conflicts.

Liotti et al. [20] again used the four colours, namely, red, green, blue and yellow presented on a dark gray background in congruent, incongruent and neutral conditions; and the neutral stimulus consisted of light gray colour words. Their work consisted of three conditions: in the *covert* condition the subjects were required to say the color of the word *silently* in their mind; in the *overt* condition they were asked to say the color *aloud*; and in the *manual* condition they gave a key-press type of response. To record the ERPs they used 64 channel cap.

In the RT analysis, a strong Stroop-color word interference effect was obtained for both the vocal versions and manual version of the task; and the RTs for both conditions were not statistically different. The RTs to the congruent stimuli were the same as RTs to the neutral stimuli. ERPs were elicited between the 350 - 500 ms time window for the congruent and incongruent stimuli; and the negative peak at 410 ms was greater for the incongruent compared to the congruent at the FCz and Cz positions both in the overt and covert tasks. Also, a prolonged positivity recorded between 500 - 800 ms interval on left temporo-parietal scalp. The dipole source analysis indicated that the Stroop effect first activated the anterior cingulate cortex within the 350 - 500 ms time-window; and then the left temporo-parietal cortex (500 - 800 ms) associated with the processing of the meaning of the word.

Atkinson et al. [21] used the words red, green and blue as stimuli and these word were written in white fonts in a colored rectangle (red, green and blue) on a black background; as for the neutral stimuli they used the words *low*, *case* and *since*. The subjects were required to give appropriate key-press type of responses. They recorded ERPs from 14 sites according to the 10-20 system. The behavioral results showed that there was a significant delay in the responses to the incongruent stimuli as compared to the congruent and the neutral stimuli. They found no significant differences between the latencies of P300 components for all stimuli conditions; and claimed that for the first time they showed that Stroop stimuli modulated the early-attention related posterior N100 and P100 components.

Bekçi and Karakaş in their 2009 study [22] used the Turkish equivalents of the color names blue, yellow, red and green; and recorded ERPs from 30 electrode sites according to the 10-20 system. The subjects were required to respond in a key-press manner. They reported that the number of correct responses to incongruent stimulus was higher compared to that of the responses to the congruent stimulus; and on the other hand, the RTs were longer in the case of incongruent stimuli. The ERPs from the three midline electrodes (Fz, Pz and Cz) showed that the amplitudes of the P300 and N400 waves in response to the incongruent stimuli were greater compared to the waves elicited by the congruent stimuli. These differences in amplitudes reflected the information processing in relation to the *meaning* of the stimulus, a process which can be defines as conflict detection.

Zurron et al. [23] used the Spanish equivalents of the words blue, green, red and gray colors on a black background for both conditions; and the subjects were required to give a key-press type of response. They recorded the activity from 30 electrode sites corresponding to the 10-20 system. The task performance indicated that the RT to the incongruent stimuli was significantly longer than to that of the congruent stimuli. As for the ERPs, they recorded two components of the P300 wave, namely *first* P3 (i.e., P3a) and P3b from Fz, Cz and Pz positions. The amplitudes of these two components in response to incongruent stimuli were smaller compared to that of the congruent. Since P3 amplitudes were inversely related to the difficulty of the task, they concluded that the decrease in amplitudes was the result of the semantic conflict generated by the incongruent stimuli. As for the latencies of the waves, no difference was found between the two modalities. This lack of difference led to the conclusion that the processes prior to the response stage had no influence on the generation of the Stroop effect.

Szücs and Soltesz [24] in their ERP part of the study they recorded a peak between 140 and 190 ms and interpreted this as the consequence of different semantic processing of words relative to non-words. The second effect was recorded between 220 and 320 ms which was an interval after the semantic processing of the words. The third peak appeared between the 360 and 420 ms time interval which indicated a congruent / incongruent discrepancy. The N450 wave they recorded was interpreted as the consequence of the stimulus conflict.

Ergen et al. [25] used the Turkish equivalents of the words red, green and blue as stimuli and the participant were required to give a key-press type of response and their ERPs were recorded from 30 electrode sites according to the extended 10-20 system. Their behavioral data displayed that RTs to incongruent stimuli was longer compared to the results of the congruent. They found no significant difference in P300 amplitude and latency for both conditions; but the N450 was found to be more negative for the incongruent stimuli and this difference was maximal over the parietal region. For both conditions N450 amplitude reached its maximum on frontal electrodes. Also, in the incongruent condition they recorded a late slow potential over the parietal region which was maximal around 600 ms.

Conclusion

The common points in these ERP studies are mainly the colors used as stimuli, namely, red, green, blue and yellow (some researchers omitting yellow); and the electrode locations. All the authors recorded potentials from Fz, Cz and Fz positions; some included other electrode sites according to 10-20 system.

On the other hand, the type of neutral stimuli used; and the parameters used in the timing of the stimulus presentation, such as the duration of stimulus, the inter-stimulus interval differed a great deal. Another dissimilarity between the studies is the response modes the subjects were required to give. The main response modalities are vocalising the name of the color or mentally naming it. The other type of motor response is the key-press; that is, the subject pressing a key corresponding to a specific color. The type of key-press action also differed in itself from study to study.

All the results show that the RT to the incongruent stimulus is longer compared to congruent stimulus. The main contribution of the ERPs to this research field is to demonstrate the physiological mechanisms underlying the Stroop effect. ERP studies elucidated the interplay between the sensory processes and the motor responses in the Stroop phenomenon. The common point in ERP results is that the latency of the P300 component is unaffected by the incongruent stimuli; a result which suggests that the Stroop effect on RT was produced after the evaluation of the stimulus; and facilitation and interference occured in later response production stages after the P300 has been elicited. But the amplitudes of the P300 waves reported differed between studies. Also, a prolonged negativity was reported by some authors [20, 22, 24, 25].

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