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Stroop Color-Word Task as a Measure of Selective Attention: Efficiency in Closed-Head-Injured Patients*

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ABSTRACT

Deficits in attention and concentration are reported to be among the most common symptoms following head injury. Various underlying mechanisms of selective attention such as excitation, inhibition, and habituation have been isolated in recent studies. In the present study 27 control and 25 closed-head-injured (CHI) subjects were compared on four conditions based on the Stroop color-word task (neutral, habituation, Stroop, and negative priming). Cross-comparison of the different tasks enables examination of the various components of selective attention. The hypothesis that the control group's overall reading time would be faster than that of the CHI group was confirmed. Also confirmed was the hypothesis that the overall reading time pattern between task conditions would be neutral < habituation < Stroop < negative priming. The prediction that the CHI patients, due to their impaired inhibitory mechanism, would not show a slower reading time on the negative priming as compared to the Stroop condition, was confirmed as well. The theoretical and diagnostic implications of the results are discussed.

Deficits in attention and concentration are reported to be among the most common symptoms following head injury (Binder, 1986; McKinlay, Brooks, Bond, Martinage, & Marshall, 1981; Oddy, Coughlan, Tyerman, & Jenkins, 1985; Stuss et al., 1985; Van Zomeren & Van Den Burg, 1985). Severity of the symptoms is related to severity of the injury, as defined by duration of PTA (Wrightson & Gronwall, 1981) or coma (Rimel, Giordani, Barth, Boll, & Jane, 1981). Longitudinal studies of severe head injury suggest that, although attentional problems are reduced over time, they may linger even several years posttrauma (for review, see Gronwall, 1987).

Different aspects of attention have been identified, such as selective-focused attention, divided attention, sustained attention, and so forth (Gronwall, 1987; Van Zomeren & Brouwer, 1987). Not all aspects of attention appear to be equally impaired. Indeed, results are not always consistent, even within the same aspect of attention (Van Zomeren & Brouwer, 1987). Ponsford and Kinsella (1992), studying different aspects of attention in severe closed-head-injured (CHI) patients, reported that there was no evidence of impairment in focused attention, sustained attention, or supervisory attentional control. However, they found clear reduction in the speed of information processing.

Selective attention is a case in point. Using visual reaction time Van Zomeren (1981) tested selective attention after head injury. When distraction was presented, severe CHI patients needed significantly more time to overcome the interference.

Several studies have tested selective attention in the head-injured with the Stroop color-word test (Stroop, 1935). In the standard administration of the Stroop color-word task, subjects

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are presented with a list of words that are color names (e.g., green, red, etc.). Each word is printed in different colored ink. The order of words and colors is random, and subjects are asked to name the color while ignoring the conflicting word. A few studies have used this test to assess selective attention in adults many years after a head injury (Ponsford & Kinsella, 1992; Stuss et al., 1985). These investigators report an overall slower reading speed by the CHI subjects relative to the control group. However, both groups were similarly affected by the interference.

Of particular interest to the present study is a report by McLean, Temkin, Dikmen, and Wyler (1983) in which they divided their sample of CHI patients according to severity, as defined by length of PTA (that is, more or less than 24 hr). They found that the interference task affected the less impaired patients just as much as it did the control group. However, the more impaired patients were more distracted by the interference task. Test results 6 months after injury showed no difference between the CHI group and controls.

Recent studies have attempted to isolate the underlying mechanisms of selective attention. Neill (1977) has suggested a dual mechanism: *excitatory*, where the selected object receives further analysis, and *inhibitory*, where the distractor that evokes competing responses is actively inhibited. Lorch and Horn (1986) have proposed an additional mechanism, *habituation*, which occurs when stimuli are presented repeatedly. However, Tipper and Cranston (1985) have argued that the inhibitory mechanism could account for habituation.

One paradigm frequently used to evaluate efficiency of the inhibitory mechanism is negative priming. Negative priming is the slowing down of response to a target stimulus that had been a distractor on the previous trial, when the response was inhibited. Thus, the process of selective attention involves an inhibitory mechanism that suppresses response to distractors. The more efficient this mechanism is, the stronger the negative priming effect, since the response to the new target (which had been the distractor) must overcome stronger inhibition. Accordingly, the absence of negative priming effect is viewed as evidence of an impaired inhibitory mechanism (Neill, 1977; Tipper, 1985).

The Stroop color-word task (Stroop, 1935), described above as a measure of selective attention, is also used as a measure of negative priming (Lowe, 1985; Tipper, Bourque, Anderson, & Brehaut, 1989). In order to elicit the negative priming effect, the distractor in the previous display (that is, the word) is the same as the subsequent target color. Thus, in order to respond correctly, one must first inhibit an overlearned response to a meaningful word that automatically activates the word's meaning. In the next item, subjects are required to respond to the same, previously inhibited color (Neill, 1977; Tipper, 1985).

Using the Stroop color-word task (Lowe, 1985; Tipper et al., 1989) and a Stroop-like task (Tipper, 1985), this negative priming effect was found in young subjects. On the other hand, Tipper et al. (1989), using the Stroop color-word task, reported findings of impaired inhibitory mechanism in young children, based on the lack of negative priming. Hasher, Stoltzfus, Zacks, and Rypma (1988) and McDowd and Oseas-Kreger (1991) have used a Stroop-like task (using letters instead of words) to test younger and older adults. Both studies have reported a lack of negative priming in the elderly, which they interpreted as an indication of impaired inhibitory mechanism.

The goal of the present experiment was to test different components of selective attention in CHI patients using the Stroop color-word task, replicating the paradigm used by Tipper et al. (1989). The primary interest was in CHI group performance on the negative priming component as a measure of inhibitory mechanism efficiency. Many studies have shown that the frontal lobes are particularly susceptible to closed-head injury (for review see Mattson & Levin, 1990). One of the hallmarks of frontal lobe lesions is impairment of the inhibitory mechanism (for review see Stuss & Benson, 1984). Thus, a particular impairment in negative priming may be expected in CHI patients. In addition to the negative priming and interference conditions, this paradigm includes two other conditions: habituation and neutral conditions.

We tested the habituation condition because of its theoretical implication when compared with the negative priming condition. Tipper et al. (1989) have reported a dissociation in young children between habituation and inhibition mechanisms, since habituation (but not inhibition) functions just as it does in adults. This finding was interpreted to support Lorch and Horn's (1986) claim that habituation is an attentional mechanism distinct from inhibition.

In light of this finding, we addressed the same question in CHI patients: Will the same dissociation be evident in CHI patients? Or does the breakdown of selective attention in CHI patients occur simultaneously in all components?

We tested the neutral condition without any interfering stimuli, to serve as a baseline for the control subjects and CHI patients. In order to measure the interference effect in the case of conflicting inputs (one of which should be ignored), we compared performance on this task to performance on the Stroop color-word task.

We found the paradigm used by Tipper et al. (1989) suitable for the purposes of the present study. This paradigm consists of four tasks: neutral, Stroop, habituation ('repeated ignored' in Tipper's terminology), and negative priming ('ignored repetition' in Tipper's terminology). These tasks are described further in the Method section.

It was hypothesized that overall control group reading time would be faster than that of the CHI group. The reading time pattern of the tasks for the control group was predicted to be as follows: neutral < habituation < Stroop < negative priming. For the CHI group, the following pattern was predicted: neutral < habituation < Stroop = negative priming. In other words, it was predicted: (1) When groups are compared on the neutral and Stroop conditions, the CHI group is expected to have not only slower overall reading time, but it is further expected that these subjects will be slowed down more by the Stroop task than will the control group. A similar pattern of results is expected even when the distractor is constant. It was also predicted (2a) that when groups are compared on neutral and habituation conditions or (2b) on the Stroop and habituation conditions, the CHI group will derive less advantage from consistency of distractors than the control group. In order to examine the dissociation between habituation and inhibition (3), both groups were compared on the negative priming and the habituation tasks. Finally, (4) when both groups are compared on the Stroop and negative priming tasks, an interaction was expected. Due to the inhibition effect, the control group was expected to show a slower reading time on the negative priming task as compared to the Stroop color-word task. However, due to their impaired inhibitory mechanism, the CHI group was not expected to exhibit such a difference.

METHOD

Subjects

Two groups of subjects participated in the present study: a normal control group (non-brain-damaged) and a CHI group. The control group consisted of 27 volunteers whose ages ranged from 18 to 35 years ($M = 23.37$; $SD = 4.10$), and whose educational level ranged from 11 to 15 years of schooling ($M = 12.6$; $SD = .93$). The CHI group included 25 patients whose ages ranged from 18 to 48 years ($M = 27.04$; $SD = 8.70$), and whose educational level ranged from 8 to 14 years of schooling ($M = 11.88$; $SD = 1.20$). The groups did not differ significantly in age, but the control group had significantly more years of schooling, $t(50) = 2.40$, $p < .03$. Table 1 provides a more detailed description of the patient group. Subjects were recruited for the study from a population of patients admitted to the Loewenstein Hospital (Israel) for rehabilitation following closed-head injury incurred in a motor vehicle accident. None of the participants had a history of alcohol or drug abuse or psychiatric illness.

Apparatus and Materials

The paradigm used in this experiment is an exact replication of that used by Tipper et al. (1989), with the single exception that, in our study, we used Hebrew instead of English words. The experiment included four conditions: neutral, habituation, Stroop, and negative priming. Each condition consisted of 90 stimuli. Words were printed in different colored ink and in varying order according to the condition, as follows:

Table 1. Demographics of the Head-Injured Patient Group.

Patient	Age	Sex	H	Ed	TAO	COMA	GCS
M.G.	26	M	R	12	30	10-D	7
H.V.	20	F	R	12	40	30-D	4
D.D.	18	F	R	11	48	*	4
S.M.	28	M	R	12	18	14-D	7
T.S.	22	M	R	12	26	4-D	6
K.M.	28	M	R	12	24	4-D	7
Y.T.	41	F	R	12	56	21-D	4
P.G.	35	M	L	12	36	-	15
C.S.	35	M	R	14	13	4-D	*
L.G.	19	M	R	12	40	60-D	4
G.A.	22	M	R	12	7	8-D	*
T.L.	20	M	R	13	3	5-H	13
A.Y.	22	M	R	12	29	5-D	9
K.J.	48	F	R	12	3	3-H	13
M.A.	32	M	R	12	32	56-D	4
S.L.	22	M	R	12	20	14-D	4
B.L.	23	M	R	12	12	10-D	8
R.Y.	23	M	R	12	20	14-D	7
T.S.	22	M	R	12	22	2-D	8
Y.Z.	23	M	R	13	4	4-D	6
B.M.	22	M	R	12	7	14-D	7
K.O.	20	M	R	10	14	10-D	3
E.S.	44	M	R	10	11	5-D	3
K.Y.	41	M	R	8	5	3-D	11
L.Y.	20	M	R	14	5	1-D	7

Ed = education (years); *H* = Handedness; *TAO* = time after onset (weeks); *COMA* = Length of coma, *D* = in days, *H* = in hours; *GCS* = Glasgow Coma Scale, on admission to hospital; * = Information not found in medical records.

Neutral – The stimuli were 3 to 5 Xs (XXXX) printed in different colors.

Stroop – The stimuli were names of colors printed in conflicting colored inks, but there was no relationship between successive items on the list.

Habituation – The stimulus was the word GREEN printed several times in different colors.

Negative priming – The color of the print was the same as the printed color name in the previous trial.

The stimuli were printed on white cards that measured 23 cm x 16.5 cm. They consisted of the words BLACK, BLUE, GREEN, RED, YELLOW, and BROWN, as well as the row of Xs. Stimuli measured 1 cm in height, the width varied between 2-3.5 cm, and the space between them was 1 cm. Each condition consisted of three cards, with 30 stimuli on each card, arranged in three columns of 10 items each. No color appeared successively throughout a list, except when required by the condition. In addition to these cards, we composed a color verification card as a test for color blindness. This card consisted of rows of Xs in the six colors used in the test. An additional card consisting of four examples, one from each condition, served as a practice card.

Procedure

The subjects were tested individually. At the beginning of the session, subjects were presented with the color verification card and asked to name the color of each row of Xs. All subjects passed this test. Subjects were then told that they would have to name the color in which each word is printed, going from the right to the leftmost column and from top to bottom in each column (which is the reading direction in Hebrew). They were asked to do this as quickly and as accurately as possible. Furthermore, they were told to continue if they made a mistake, and not to stop. Subjects were then presented with the practice list to test their comprehension of the instructions.

The order of the different testing conditions was counterbalanced. For each condition, the researchers said 'Start' and, when the first color was named, they activated the stopwatch. When the subject named the last color on the list, the watch was stopped. Reading time was recorded by the experimenter at the end of each trial. Errors were not recorded because, in most studies, error analysis yields the same pattern of results as does reading time.

RESULTS

Mean reading times (and Standard Deviations) on the neutral, habituation, Stroop, and negative priming conditions for the control and the CHI groups are presented in Table 2.

A mixed design ANOVA was conducted to analyze the effect of group (control and CHI) by four testing conditions (neutral, habituation, Stroop, & negative priming), the former being a between-subjects factor and the latter two within-subjects factors. Both main effects were found to be significant. Since the interaction between them was significant as well, main effect should be interpreted cautiously: Group $F(1, 50) = 47.66$, $p < .001$, overall the control group reading faster than the CHI group; Testing conditions $F(3, 150) = 126.55$, $p < .001$, as can be seen in Table 2, reading time under the neutral condition was the fastest, and under the negative priming, was the slowest. The significant group by testing conditions interaction $F(3, 150) = 9.76$, $p < .001$, suggests that the increase in reading time from one condition to the other was not identical for both groups.

Five separate 2 x 2 mixed analyses of variance (ANOVA) were conducted in order to test each of the a priori predictions made above. The first analysis was conducted in order to examine the effect of distractors on the groups. Reading time scores of the two groups (control and CHI) for two of the testing conditions (neutral and Stroop) were subjected to a two-way mixed analysis of variance with repeated measures on the second factor. Analysis of the results shows that the Group x Condition interaction reached significance: $F(1, 50) = 15.26$, $p< .001$. The interaction is the result of a steeper increase in reading time from the neutral to the Stroop condition for the CHI group, as compared to the control group. Both main effects reached significance as well: $F(1, 50) = 52.64$, $p< .001$, and $F(1, 50) = 120.44$, $p< .001$, for group and testing condition, respectively. Examination of group members' performance revealed that all of the control and CHI subjects systematically demonstrated the expected trend of results; that is, slower reading time on the Stroop condition as compared to the neutral condition. The next three analyses were conducted in order to examine both groups' ability to inhibit attention to a

Table 2. Mean Reaction Times (and Standard Deviations) on the Neutral, Habituation, Stroop, and Negative Priming Conditions for the Control and CHI Groups.

	Group			
	Control ($n = 27$)		CHI ($n = 25$)	
Reading Condition	*M*	*SD*	*M*	*SD*
Neutral	54.70	(11.12)	88.54	(21.80)
Habituation	70.24	(15.89)	114.42	(38.27)
Stroop	83.64	(19.40)	149.48	(49.42)
Negative Priming	99.37	(24.81)	154.29	(36.30)

repeated irrelevant stimuli--habituation compared with the other conditions.

In the first analysis, groups were compared on the habituation and neutral testing conditions. The Group x Condition interaction reached significance $F(1, 50) = 4.40$, $p < .05$. The interaction is the result of a steeper increase in reading time from the neutral to the habituation condition for the CHI group as compared to the control group. Both main effects were found to be significant as well: $F(1, 50) = 40.77$, $p < .001$ and $F(1, 50) = 70.71$, $p < .001$, for group and testing condition, respectively. Examination of group members' performance revealed that all of the control subjects systematically showed the expected trend of results: that is, slower reading time on the habituation condition as compared to the neutral condition. In the CHI group, however, three of the patients' reading times on the neutral task were slower than on the habituation task.

In the second analysis, groups were compared on the habituation and Stroop testing conditions. The Group x Condition interaction reached significance: $F(1, 50) = 12.62$, $p < .001$. This interaction results from a steeper increase in reading time from the habituation to the Stroop condition for the CHI group as compared to the control group. Both main effects reached significance as well: $F(1, 50) = 40.05$, $p < .001$ and $F(1, 50) = 63.23$, $p < .001$, for group and testing condition, respectively. Examination of group members' performance revealed that all but two of the control subjects and three of the CHI patients systematically showed the expected trend of results: that is, slower reading time on the Stroop condition as compared to the habituation condition.

In the third analysis, groups were compared on the habituation and negative priming testing conditions. The main effect for group was significant, with the control group performing faster overall than did the CHI group: $F(1, 50) = 41.17$, $p < .001$. The main effect for condition was also significant: $F(1, 50) = 129.52$, $p < .001$. Overall reading time for the negative priming task was slower than for the habituation condition. The Group x Condition interaction was close to reaching significance: $F(1, 50) = 3.13$, $p < .08$. The interaction tendency is the result of a steeper increase in reading time from the habituation to the negative priming condition for the CHI group as compared to the control group. Examination of group members' performance revealed that all of the control and CHI subjects systematically showed the expected trend of results: that is, slower reading time on the negative priming condition as compared to the habituation condition.

Finally, groups were compared on the Stroop and negative priming conditions in order to test the fourth prediction. The Group x Condition interaction reached significance as well: $F(1, 50) = 3.98$, $p < .05$. This interaction is due to the fact that, while the control group performed significantly more slowly on the negative priming task as compared to the Stroop task ($t(26)=7.89$, $p < .001$), CHI group performance did not differ significantly in the two conditions: $t(24)=.91$, $p > .3$. Both main effects reached significance as well: $F(1, 50) = 44.51$, $p < .001$, and $F(1, 50) = 14.08$, $p < .001$, for group and testing condition, respectively. Examination of group members' performance revealed that all but two of the control subjects systematically showed the expected trend of results: that is, slower reading time on the negative priming condition as compared to the Stroop condition. In the CHI group, however, there was no clear trend of results. Eight of the patients' reading times on the Stroop task were slower than on the negative priming task.

In order to control for the groups' differences in educational level, analyses were also conducted with educational level as a covariate. Results with education as a covariate were the same as those reported above without covariance. Furthermore, as expressed in the absence of significant correlations, performances on the different attentional scores were not related to educational level. These findings suggest that the differences found between the groups are not due to their different educational levels.

DISCUSSION

The overall pattern of results predicted was supported. More specifically, as hypothesized, the control group's reading time was faster than that of the CHI group. This conclusion is based on both the significant group main effect in the overall analysis and the more specific comparisons of the different testing conditions. As can be seen in Table 2, both groups showed the same pattern of results. Reading was slower in habituation than in the neutral condition, and Stroop was slower than the habituation condition. However, when the Stroop and negative priming conditions are compared, the groups differed from each other. While the control group was slower in the negative priming condition than in the Stroop condition, the CHI group's performance was equal in these two conditions. This pattern of results was supported as well when the group members' performance was examined. That is subjects of both groups showed the same trend of results with the exception of the relations between the Stroop and the negative priming conditions.

Neill (1977) and Tipper (1985) viewed the lack of negative priming effect as evidence of inhibitory mechanism impairment. Thus, the contribution of the present study was the identification of the inhibitory mechanism component of selective attention as that impaired following closed-head injury. This impairment can be seen as part of a more general impairment following closed-head injury. As mentioned earlier, disinhibition is one of the hallmarks of patients with frontal lesions, including CHI patients (Stuss & Benson, 1984).

Further study is required to discover whether this measure of inhibition is related to better known and better documented behavioral expressions of inhibition/disinhibition. Should such a correlation be found, negative priming would have a very important diagnostic and prognostic value.

Another aspect of the findings is that both groups showed the same pattern of results between the Stroop and habituation conditions, but not between the Stroop and negative priming conditions. Furthermore, when groups were compared on habituation and negative priming, the control group's reading time was faster overall than was that of the CHI group, and reading time for both groups in the habituation condition was faster than that in the negative priming condition. There was a tendency for the performance of the CHI group to be more interfered with by the negative priming condition than was that of the control group. This dissociation between habituation and negative priming is of theoretical interest. The implications bear upon the question of whether habituation is a separate attentional mechanism (Lorch & Horn, 1986) or a product of the inhibitory mechanism (Tipper & Cranston, 1985). Our results support the former view, since habituation was dissociated from negative priming. Similar results led Tipper et al. (1989) to the same conclusion.

In our study, the CHI patients as compared to control subjects were disproportionately affected by the interference condition (i.e., Stroop task). This finding is not in accordance with the results of some of the studies reviewed herein that reported that, although CHI patients were slower than control subjects on the Stroop task, they were not disproportionately affected by interference (Ponsford & Kinsella, 1992; Stuss et al., 1985). However, McLean et al. (1983) have directed attention to the effect of severity of injury, as well as to the effect of the time elapsed from injury to testing. Unlike less severely injured patients (defined by length of PTA), severe CHI patients did show a disproportionate effect of interference on the Stroop task. This difference between the two CHI groups disappeared when tested 6 months after injury.

Most of the patients in the present study were reportedly unconscious for at least 48 hr, and were, therefore, considered to have suffered severe to very severe closed-head injuries (Jennett & Teasdale, 1981). Furthermore, all of the patients were tested within the first year of injury. These characteristics of our group of patients may be the reason that they were disproportionately affected by interference. However, when the CHI group was divided into two subgroups according to their position above or below the median score of any of the parameters of severity of injury, that is, length of coma, time after onset, and the Glasgow Coma Scale scores, the two subgroups did not differ on any of the measures used in this study. Nor did any of these severity measures correlate significantly with the attentional measures. The range of severity may possibly be too narrow to allow for the effect to emerge. Further study is required to test systematically the effect of severity of injury on the different attentional components.

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