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Stroop interference and disorders of selective attention

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Abstract—Fourteen patients with a right-hemisphere CVA and 8 patients with a left-hemisphere CVA were examined for selective attention deficits using a variant of the Stroop color–word task: the picture–word interference task. Experiments 1 and 2 first compared the performance of the two patient groups and a control group in three tasks of increasing difficulty: picture–word detection, word reading, and picture naming. The results showed that (a) the two patient groups were significantly slower than the control group, but did not differ from each other, and (b) the difference in mean RT between the two patient groups and the control group did not increase with task difficulty. In Experiment 3, the subjects were required to name pictures while ignoring accompanying distractors: nonletter symbols, unrelated words or semantically related words. In this task, the right hemisphere patients showed a much larger semantic interference effect than both the left hemisphere patients and the control group. It is argued that this finding most probably reflects problems in visual selective attention with the right hemisphere patients.

Key Words: Stroop interference; selective attention deficits; cognitive functioning.

Introduction

There are many factors that may interfere with an optimal functioning of the brain, in particular with the processing of information. One can think, for instance, of neurological diseases, the consequences of accidents resulting in damage of neurological tissue, the use of psychopharmaca or alcohol, psychiatric disorders, and the exposition to poisonous substances in industrial settings. Clinical studies looking at the consequences of these conditions for cognitive processes practically always include an assessment of attentional problems. In test batteries of many clinical studies evaluating cognitive functioning in subjects with demonstrable or suspected brain disorders, tasks are typically included to assess selective, divided, and sustained attention. Perhaps the best known among the tasks that are supposed to detect selective attention deficits is the Stroop task.

The traditional procedure to assess problems in selective or focused attention with the Stroop task is as follows [8]. A subject is given a card (Card A) with rows of color words and he is requested to read these aloud. He is then given a second card (Card B) with rows of colored rectangles and he is asked to name these aloud. Finally, he is presented with color words printed in colors that do not match with the meaning of the words (Card C) and has to name the colors in which the words are printed. The time to complete each of these cards is registered. In general, it takes more time to name the colors of the words on Card C than the colors of the rectangles on Card B. Sometimes, the difference in time between Card C and Card B is referred to as Interference Time.

Van Zomeren and Brouwer [20] mention the Stroop task as a measure to investigate focused attention, i.e. the capacity to selectively attend to specific stimuli or aspects of a stimulus and ignore irrelevant information. In the Stroop task subjects are required to concentrate on the color of the printed words, while ignoring the word. According to such a description of the task, a subject has to select a particular type of information, namely color, and consider the orthographic information as irrelevant. It therefore seems the task has face validity as an instrument to assess selective attention. Moreover, the fact that Card C requires longer naming

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times than Cards A and B suggests that selection is taking place, requires time, and may sometimes even lead to (overt or covert) "selective attention deficits" (according to Shiffrin and Schneider's [17] terminology). When a subject demonstrates a particularly large interference effect, one is tempted to assume that it is caused by a problem in focusing on the relevant information and that it can therefore be concluded that this patient has a disorder of selective attention.

However, one must be careful to draw such a conclusion. The most important reason is that in some patient groups all cognitive processes may be slowed down. In general, it has proven quite difficult to demonstrate attentional disturbances that cannot be interpreted as conditioned by a decrease in processing rate. The observed increase in response latency may then depend on the complexity of the task: a complex task will show a larger increase in mean response latency than a relatively simple task. So a larger Stroop interference effect in some patient groups could be the result of a general slowing down, and one should therefore correct the interference effect for the general rate of cognitive processing.

Within experimental psychology, at least four different proposals have been made with respect to the locus of the Stroop interference effect. First, the distractor word may disrupt the identification of the color by diverting attention from it [4]. This interpretation is generally rejected on the basis of the finding that congruent distractor words (e.g. the word red printed in red ink) do not cause any interference. Second, the distractor word may hamper the semantic encoding of the target stimulus. In this view, advanced by Seymour [16], the interference is due to an ambiguity that arises when color and word activate closely related concepts in semantic memory. This interpretation has been criticized on the basis of results that show that Stroop interference strongly diminishes or even disappears when nonverbal reactions to the colors are required [21]. Third, the interference has been attributed to a competition between the distractor word and the name of the color at a response output level (response competition, see, e.g. Keele [5]). While it is generally acknowledged that response competition plays a role in Stroop interference, the major part of Stroop interference has recently been attributed to the process of word retrieval. In this fourth account, it is assumed that the distractor word hampers the activation or selection of the name of the target color in the mental lexicon [3, 6, 13, 15].

Whereas the question of the locus of Stroop interference has received much attention (see MacLeod [12], for a review), less research has been devoted to the question of how the conflict is resolved. However, in all proposals selective attention plays some role in this process, either by active suppression of irrelevant information [19] or by the selective enhancement of relevant information in memory [1, 11].

In addressing the processes that underlie Stroop interference effects, experimental psychologists have developed a number of modifications of the original Stroop task, three of which are important for our present purposes. First, instead of the original massed presentation technique, Stroop stimuli are presented individually. This allows for more precise reaction time measurements, the mixing of conditions, and the elimination of nuisance factors like the presence of surrounding items. Second, Stroop-like tasks have been introduced that generalize the phenomenon to other semantic domains and allow for a better control of a number of variables. Examples are the naming of pictures with superimposed words [2, 14], the naming of faces of famous people with superimposed names [22], and the naming of definitions followed by distractor words [7]. Third, the number of distractor conditions has been increased, which allows for a decomposition of the "overall" Stroop interference effect into effects that can be attributed to, for instance, membership of the distractor word in the response set, and the semantic similarity between target and distractor word [6].

In the present study we use a picture–word interference task with individual presentation of the stimuli to investigate (a) whether patients with verified brain lesions show an increased amount of Stroop-like interference in comparison with a group of control subjects, (b) whether such an increase is obtained for all components of the Stroop interference effect, including the semantic component, and (c) whether the increased interference can be attributed to problems in selective attention or is the result of a general slowness in processing. The same group of patients and control subjects participated in three experiments. In the first two experiments simple tasks were administered that were supposed to increase in difficulty: picture and word detection, word reading, and picture naming. These experiments make it possible to examine (a) whether the patient were capable of performing these type of reaction-time tasks, (b) whether the patient groups show larger mean response latencies than the control group, (c) whether this difference increases with task difficulty, and (d) whether the left and the right hemisphere patients differ in these respects. In the third experiment a picture–word interference task is presented that allows for an examination of two interference effects: interference due to the presence of an unrelated word and interference due to the presence of a word that is semantically related to the to-be-named picture. This experiment makes it possible to examine whether besides a general slowness of responding, the two patient groups show an increase in interference values in comparison with the control group. In all experiments the same subjects were tested: eight patients with a left hemisphere lesion (the LH group), 14 patients with a right hemisphere lesion (the RH group) and 14 control subjects.

Experiment 1: Picture and word detection

In this experiment the subjects were required to react as fast as possible (by saying "yes") to the appearance of a word, a picture, or a control stimulus in the display, irrespective of the nature of the stimulus. The stimuli presented are the words and pictures that will be used in the reading and naming tasks of Experiment 2, and in the picture–word interference task of Experiment 3. If there is a general slowness in responding in the patients groups, this should become evident in this simple detection task.

Method

Subjects. Two groups of patients admitted to the stroke rehabilitation ward of the Cooperating Rehabilitation Centres of Limburg in Hoensbroek (The Netherlands) were included in the study. All patients were right-hand dominant and the infarct or hemorrhage was located in the left hemisphere for 8 patients and in the right hemisphere for 14 patients. The patients in these groups were, on average, 57.6 years of age (S.D. = 7.4) and 57.7 years of age (S.D. = 9.1), respectively. Other details of the patients, including the localization of the infarction or hemorrhage are given in Table 1.

According to several speech pathologists' reports 3 out of 8 patients with left hemisphere lesions had no language disorders at all, 2 were dysarthric and, 3 were moderately aphasic. The aphasic symptoms encompassed moderate sentence comprehension problems but no word comprehension disorders. Only one out of 8 patients with left hemisphere damage had minor naming problems and moderate sentence production problems. For clinical purposes 3 of these patients underwent neuropsychological testing. Of the RH group 10 out of 14 patients were tested for clinical purposes. The results of these tests are given in Table 2.

According to Table 2, 5 patients had left-sided spatial neglect symptoms, as measured with 3 conventional subtests of the Behavioral Inattention Test (line crossing, letter cancellation and star cancellation). All these patients underwent rehabilitative training for their hemi-inattentive disorder. The control subjects were healthy relatives of the patients in the

Table 1. Patient characteristics

Patient	Sex	Birth (year)	CVA (year)	Recidive	Medication	Localization	Left/Right hemisphere
1	M	1928	1991	No	No	Brain stem and cerebellum infarction	Left
2	F	1949	1992	No	No	Extensive middle cerebral artery infarction	Left
3	M	1928	1992	No	No	Middle cerebral artery infarction extending to capsula interna	Left
4	M	1931	1992	No	No	Middle cerebral artery infarction extending to basal ganglia	Left
5	M	1931	1992	No	No	Middle cerebral artery hemorrhage extending to putamen	Left
6	F	1931	1992	No	No	Cerebral infarction with tissue damage laterally of the sella media	Left
7	M	1933	1992	Yes	Prothiaden Prozac	Middle cerebral artery hemorrhage extending to basal ganglia	Left
8	F	1944	1992	No	No	Frontal temporal infarction	Left
9	M	1937	1991	No	Neuleptil	Extensive middle cerebral artery infarction	Right
10	F	1944	1992	No	No	Cerebral infarction with right frontal temporal tissue damage extending to basal ganglia	Right
11	F	1915	1992	No	Nortrilen	Lacunair infarction in corona radiata	Right
12	M	1925	1992	No	No	Middle cerebral artery infarction	Right
13	F	1932	1992	Yes	No	Temporo-parietal infarction	Right
14	M	1939	1992	No	Diphantoïne Noctamid	Middle cerebral artery hemorrhage extending to capsula interna	Right
15	F	1941	1992	No	No	Middle cerebral artery infarction	Right
16	M	1926	1992	No	No	Middle cerebral artery infarction extending to capsula interna	Right
17	M	1935	1992	Yes	Normison	Middle cerebral artery infarction extending to basal ganglia	Right
18	M	1930	1992	No	Ludiomil	Temporal infarction at capsula interna and globus pallidus level	Right
19	M	1934	1992	No	Tegretol	Parieto-occipital infarction	Right
20	F	1949	1992	No	No	Cerebral infarction with right temporal tissue damage	Right
21	F	1927	1992	No	No	Middle and anterior cerebral arteries infarction (fronto-parietal tissue damage)	Right
22	M	1942	1991	No	Trazolan Seresta	Middle cerebral artery infarction with extension to sella media	Right

Table 2. Available neuropsychological test scores

Patient	Lesion (site)	Stroop interference (sec)	Left-side omissions in B.I.T. cancellation tasks: Line	Letter	Star	Rivermead Behavioral Memory Test (screening score)
2	LH	N.A.	0	3	0	N.A.
3	LH	N.A.	0	1	3	7
5	LH	44	N.A	N.A.	N.A.	N.A.
9	RH	77	0	2	5	12
10	RH	N.A.	N.A.	N.A.	N.A.	6
14	RH	70	0	3	25	N.A.
15	RH	42	0	0	0	6
16	RH	170	0	15	27	7
17	RH	146	0	3	1	N.A.
18	RH	N.A.	N.A.	N.A.	N.A.	3
19	RH	83	0	1	6	9
21	RH	130	0	6	9	11
22	RH	N.A.	0	0	0	11

Note. Patient numbers correspond to those in Table 1. N.A.: no information available.

rehabilitation ward (8 males and 6 females, on average 49.7 years of age, S.D. = 13.4).

Stimuli. The stimuli in the picture-detection tasks consisted of 15 line drawings of the following objects: train, bicycle, car, piano, trumpet, guitar, hammer, saw, pincers, mouse, dog, duck, lamp, clock, and feather. In addition a stimulus was used consisting of the series ><><><. This stimulus was only included to familiarize the subjects with its presence (the string was used as a control distractor in Experiment 3), and the corresponding results will not be reported here. The stimuli in the word-detection task were the Dutch names of the 15 target pictures, presented in capital letters: TREIN, FIETS, AUTO, PIANO, TROMPET, GITAAR, HAMER, ZAAG, TANG, MUIS, HOND, EEND, LAMP, KLOK, and VEER. Again, a stimulus consisting of the series ><><>< was added. The stimuli were presented at the center of the display. The pictures were scaled and centered in an imaginary rectangle with the dimensions 48 mm (length) × 36 mm (height). The words were also centered in the display. Their length varied between 19 mm and 33 mm. The stimuli were presented in white against a dark background. Viewing distance was approximately 150 cm.

Apparatus. The stimuli were presented on a VGA-color monitor connected to a MS-DOS computer (Compaq-386SX). Verbal reaction times were measured by means of a voice key connected to a counter/timer card with an accuracy of 1 msec.

Procedure. Subjects were tested individually in a dimly illuminated room. At the start of the session, the subjects were instructed to look at the central fixation point and to react as fast as possible with the verbal response "ja" (yes) when a stimulus (a word, picture, or the control stimulus) appeared on the screen. They were told not to pay any attention to the nature of the stimulus. The time interval between the disappearance of the fixation point and the presentation of the target stimulus varied randomly between 250 and 1500 msec. The experimenter registered failures to respond to the stimuli (misses). Inappropriate triggering of the voice key apparatus was also registered. The subjects started with a practice series of 32 trials in which all stimuli were presented once. Next, an experimental series of 96 experimental trials was run, preceded by four randomly selected warm-up trials. In the experimental series each of the 32 stimuli (15 pictures, 15 words, and 2 control strings) was presented three times. The 96 stimuli were presented in random order. The complete session, including instruction and training, took about 20 min.

Results

The raw data were treated in the following way. First, RTs obtained when the voice key was triggered inappropriately ("voice-key errors") and RTs longer than 3000 msec were excluded. Next, to reduce the variance in the data, RTs that deviated more than 2 standard deviations (S.D.s) from their cell mean per subject per condition were excluded. In the picture-detection task, the voice key errors, the 3000 msec criterion and the 2 S.D. criterion accounted for 4.3, 0.3, and 3.1% of the data, respectively. In the word-detection task these values were 2.9, 0.7, and 4.2%, respectively. The data-trimming procedure resulted in roughly the same rejection rates in the three subject groups. The remaining RTs were used in the calculation of the means per subject per condition. The mean RTs and the mean percentages of errors of the three groups of subjects are shown in Table 3.

Analyses of variance (ANOVAs) were performed on the detection times for words and pictures separately. The word-detection times differed significantly between groups of subjects, [F (2, 33) = 10.7, $P < 0.001$]. A Newmann–Keuls *post hoc* analysis showed that the control group differed significantly from each of the two patient groups ($P < 0.05$). In comparison with the control group, the LH group and the RH group showed an increase in word-detection time of 195 and 177 msec, respectively. The difference between the two patient

Table 3. Mean detection latencies in milliseconds (RTs) and percentages of misses (%E) in Experiment 1

Group	Word detection (RT)	Word detection (%E)	Picture detection (RT)	Picture detection (%E)
Control	434	0.0	418	0.0
Left hemisphere	629	0.3	608	0.0
Right hemisphere	611	0.0	601	0.0

groups failed to reach significance. The picture-detection times showed a similar pattern. The three groups differed significantly, [F (2, 33) = 12.1, $P < 0.001$], and the Newmann–Keuls analysis indicated a significant difference between the control group and each of the two patient groups ($P < 0.05$). In comparison with the control group, the LH group and the RH group showed an increase in picture-detection time of 190 and 183 msec, respectively. The number of errors (misses) was too small to allow a useful analysis.

In summary, the data show that the two patient groups are significantly slower in this simple detection task than the control group. The increase in RT was similar for both patient groups. Averaged over word and picture detection, the increases amounted to 193 msec in the LH group and 180 msec in the RH group. The next experiment examines whether this difference between patient groups and control group increases when more complex tasks like word naming and picture naming are used.

Experiment 2: Word and picture naming

In this experiment the subjects were asked to react as fast as possible to the stimuli presented by reading words aloud and by naming pictures. If the slowness of responding observed with the two patient groups in Experiment 1 depends on the difficulty of the task, larger differences in mean RT between the control group and the two patient groups are to be expected.

Method

Subjects. The same subjects participated in this experiment as in Experiment 1.

Stimuli. The stimuli were identical to those in Experiment 1, except for the fact that no control stimuli were used. So, 15 pictures were presented for naming and the corresponding words were presented for reading aloud.

Apparatus. The apparatus was the same as in Experiment 1.

Procedure. Subjects were tested individually in a dimly illuminated room. At the start of the session, the subjects were instructed to read the words aloud and to name pictures that appeared at position of the central fixation point in the display. The time interval between the disappearance of the fixation point and the presentation of the target stimulus varied randomly between 250 and 1500 msec. The subjects started with a practice series of 30 trials in which all stimuli were presented once in random order. Next, a series of 90 experimental trials was presented, that was preceded by four warm-up trials. In the experimental series each of the 30 stimuli (15 pictures and 15 words) was presented three times. The 90 stimuli were presented in random order. After the subject read the word or named the picture, or a time delay of 3000 msec, the stimulus disappeared from the screen. The Experimenter entered a code into the computer to indicate whether the response was correct or false. Inappropriate triggering of the voice-key apparatus was also registered. The complete session, including instruction and training, took about 20 min.

Results

The raw data were treated in the same way as in Experiment 1. The voice-key errors, the 3000 msec criterion, and the 2-S.D. criterion accounted for 2.2, 1.3, and 4.1% of the data, respectively, in the picture-naming task, and for 1.5, 0.8, and 4.1%, respectively, in the word-naming task. The data-trimming procedure resulted in roughly the same rejection rates in the three subject groups. The mean RTs and the percentages of errors of the three groups of subjects in the two tasks are shown in Table 4.

ANOVAs were performed on the word-reading times and the picture-naming times separately. The word-reading latencies differed significantly between groups of subjects, [F (2, 33) = 7.3, $P < 0.005$]. The Newmann–Keuls *post hoc* analysis showed that the control group differed significantly from each of the two patient groups ($P < 0.05$). In comparison with the control group, the LH group and the RH group showed increases in word-reading times of 155 and 134 msec, respectively. The difference between the two patient groups failed to reach significance. The picture-naming times showed a similar pattern. The three groups differed significantly [F (2, 33) = 8.5, $P < 0.005$], and the Newmann–Keuls analysis indicated a significant difference between the control group and each of the two patient groups ($P < 0.05$). In comparison with the control group, the LH groups and the RH group showed an increase in picture-naming latencies of 172 and 167 msec, respectively. The LH group made somewhat more naming errors than the other two groups, but this difference did not reach significance ($P > 0.05$).

In summary, the results of this experiment show that, in comparison with the control group, the two patient groups are significantly slower in both word reading and picture naming. The size of the increase in RT was comparable to the values obtained in the detection task in Experiment 1. LH patients were 155 msec slower in reading words, and 172 msec slower in naming pictures than the control subjects (the corresponding differences in the detection task were 195 and 190 msec, respectively). RH patients were 134 msec slower in reading words, and 167 msec slower in naming pictures than the control subjects (the corresponding differences in the detection task were 177 and 183 msec, respectively). So,

Table 4. Mean word-reading and picture-naming latencies in milliseconds (RTs) and percentages of errors (%E) in Experiment 2

	Word reading		Picture naming	
Group	(RT)	(%E)	(RT)	(%E)
Control	551	0.0	652	1.9
Left hemisphere	706	0.9	824	5.6
Right hemisphere	685	0.4	819	1.7

the increase in mean RT observed in the patient groups in comparison with the control group remains rather constant across a number of tasks that vary in complexity. The question whether this pattern changes when the target stimulus is accompanied by a distractor will be examined in Experiment 3.

Experiment 3: Stroop-like picture naming

In this experiment a standard picture–word interference task is used [2, 9], in which a to-be-named picture is accompanied by a to-be-ignored distractor word. Four distractor conditions are used: (a) the distractor word is semantically related to the target picture (e.g. the picture of a car accompanied by the word TRAIN), (b) the distractor word is unrelated to the target picture (e.g. the picture of a car accompanied by the word MOUSE), (c) the distractor is a series of nonletter characters (the control condition), and (d) the picture is presented in isolation. In this way, the overall Stroop-like interference effect (defined as the difference in mean RT between the semantically related and control conditions) can be decomposed into an effect that is due to the semantic similarity between target and distractor (the semantic interference effect) and an effect that is due to the presence of an unrelated word.

Method

Subjects. The same subjects participated in this experiment as in Experiment 1.

Stimuli. The 15 line drawings used in Experiments 1 and 2 were used as target pictures in this experiment: train, bicycle, car, piano, trumpet, guitar, hammer, saw, pincers, mouse, dog, duck, lamp, clock, and feather. The first 12 of these pictures belong to four different semantic categories: vehicles (train, bicycle, car), musical instruments (piano, guitar, hammer), tools (hammer, saw, pincers), and animals (mouse, dog, duck). The three remaining pictures do not belong to a single semantic category, and were only included because they were used in Experiments 1 and 2. However, the results obtained with these pictures were not included in the analyses. Four distractor conditions were used. In the semantically related condition, the 12 pictures that belong to the four semantic categories were accompanied by the name of the other two pictures in the same semantic category. For example, the picture of a bicycle was once accompanied by the word TRAIN and once with the word CAR. So, in this condition 24 different picture–word combinations were used. In the unrelated word condition, the 12 target pictures were accompanied by three words (picture names) from the other semantic categories (e.g. the picture of a bicycle was accompanied by the word PINCERS). Thus, the total number of unrelated picture–word stimuli amounted to 36. In the control condition all 12 pictures were presented twice in combination with the string ><><><, resulting in 24 stimuli. Finally, in the target-alone condition, the 12 pictures were presented twice in isolation, resulting in 24 stimuli. The to-be-named target picture was presented right above the central fixation point (contour–contour distance 3 mm). The distractor was presented at the same distance right below the central fixation point. In all further respects the stimuli were identical to those in Experiments 1 and 2.

Apparatus. The apparatus was the same as in Experiment 1.

Procedure. Subjects were tested individually in a dimly illuminated room. At the start of the session, the subjects were instructed to look at the central fixation point and to name as fast as possible the picture while ignoring the accompanying word. Subjects were shown the target pictures and were asked to name them. If necessary, the correct names were provided. Next, a practice series was run, containing all pictures in combination with randomly selected distractors. If necessary, this practice series was repeated. Each trial involved the following sequence. A fixation point was presented at the center of the display for 3000 msec, directly followed by target picture and distractor. In all further respects, the procedure was identical to that in Experiment 2. The experiment took about 25 min.

Results

The raw data were treated in the same way as in Experiment 1. The voice-key errors, the 3000 msec criterion, and the 2 S.D. criterion accounted for 2.7, 1.3, and 4.8% of the data, respectively. The data-trimming procedure resulted in roughly the same rejection rates in the three subject groups. The mean RTs and the percentages of errors of the three groups of subjects in the four distractor conditions are shown in Table 5.

First, an ANOVA was performed on the data of the picture-alone condition, to determine whether in this experiment too, the picture-naming latencies of the two patient groups differed from the control group. This analysis showed a significant effect of groups of subjects, [$F(2, 33) = 6.2$, $P < 0.01$]. The Newmann–Keuls *post hoc* analysis showed that the control group differed significantly from each of the two patient groups ($P < 0.05$). In comparison with the control group, the LH group and the RH group showed increases in picture-naming times of 170 and 143 msec, respectively. In Experiment 2, these values were 172 and 167 msec, respectively.

Table 5. Mean picture-naming latencies in milliseconds (RTs) and percentages of errors (%E) in the various distractor conditions of Experiment 3

Group	Picture alone (RT)	Picture alone (%E)	Control (RT)	Control (%E)	Unrelated (RT)	Unrelated (%E)	Semantically related (RT)	Semantically related (%E)
Control	677	2.4	700	1.5	744	1.8	770	6.8
Left hemisphere	847	3.1	906	3.7	949	8.5	965	10.3
Right hemisphere	820	0.6	849	0.3	936	1.7	1035	5.0

Next, separate ANOVAs were performed on three types of interference effects. First, the overall Stroop-like interference effect, defined as the difference in RT between the semantically related condition and the control condition (in which the series ><><>< was used as distractor). This interference effect differed significantly between groups of subjects, [F (2, 33) = 6.6, $P < 0.005$]. The Newmann–Keuls *post hoc* test revealed that the RH group showed a significantly larger amount of interference than both the control group and the LH group ($P < 0.05$). The latter two groups did not differ significantly. In two additional ANOVAs we examined whether this difference in interference between the RH patient group and the other two groups was due to an increase in semantic interference, an increase in interference due to the presence of an unrelated word, or both. An ANOVA performed on the semantic interference effects (defined as the difference between the interference induced by semantically related distractor words and unrelated distractor words), showed a significant difference between groups [F (2, 33) = 7.5, $P < 0.005$]. The Newmann–Keuls test indicated that the RH patients showed a larger semantic interference effect (99 msec) than both the control group (26 msec) and the LH patient group (16 msec; $P < 0.05$). The latter two groups of subjects did not differ significantly. To examine the reliability of the difference between the two patient groups we compared the eight LH patients with the eight RH patients that showed the smallest semantic interference effect in their group (consisting of 14 patients). This analysis showed that even in this conservative test, the semantic interference effect differed significantly between the two groups [F (1, 14) = 5.0, $P < 0.05$]. The semantic interference effects obtained with the eight LH and eight RH patients were 16 and 42 msec, respectively.

To determine whether the semantic interference effects in the three groups reached statistical significance, separate t-tests for correlated means were performed. These tests showed that the 26 msec semantic interference effect in the control group [t (13) = 2.96; $P < 0.05$] and the 99 msec semantic interference effect in the RH group [t (13) = 4.08; $P < 0.05$] reached significance. The 16 msec semantic interference effect in the LH group failed to reach significance [t (7) = 1.68; $P > 0.10$]. Finally, an ANOVA performed on the interference induced by unrelated words in comparison with the control characters showed no significant difference between groups of subjects ($P > 0.10$).

Similar ANOVAs were performed on the error percentages. The analysis on the data of the picture-alone condition showed that the three groups did not differ significantly ($P > 0.10$). Additional ANOVAs were performed on the increase in error percentages due to the presence of (a) a semantically related word in comparison with a string of control characters (the overall Stroop-like interference effect), (b) a semantically related word in comparison with an unrelated word, and (c) the presence of an unrelated word in comparison with a string of control characters. None of these analyses showed a significant difference between groups of subjects, indicating that the relatively large interference effect observed in the latency data of the RH patients cannot be attributed to a speed–accuracy trade-off.

The results of this experiment are clear. First, the results obtained in the picture-alone condition replicated the findings in Experiment 2. That is, both patient groups were significantly slower in the naming of pictures than the control group. Second, the LH patients did not show significantly larger interference effects than the control subjects. So, their performance can be interpreted as resulting from a general slowness in responding. The RH patients, however, did show a marked increase in interference, both in comparison with the control group and in comparison with the LH patients. In addition, the analyses show that this result is mainly due to an increase in semantic interference with the RH patients.

It could be argued that the difference between the RH and LH patients does not reflect a greater susceptibility of the RH patients for word distractors, but to a lower susceptibility of the LH patients for these words, due to impaired language functions. For two reasons this interpretation is highly unlikely. First, there is no evidence whatsoever for impaired language functions in the LH group in Experiment 2, in which the subjects were asked to read words and to name pictures. Second, the LH patients did not differ significantly from the control subjects in both the overall Stroop-like interference effect (59 and 70 msec, respectively) and the semantic interference effect (16 and 26 msec, respectively).

General discussion

To assess potential deficits in cognitive functioning, in particular disorders of attention, a clinical neuropsychologist may use a wide variety of tests. The Stroop color–word test is frequently used to assess selective attention. This task, however, was not designed to test selective attention. Stroop [18] described the remarkable phenomenon that it is more difficult to name a color when it is presented in the form of an incongruent color word than when it is presented in the form of a patch. This Stroop interference effect is a normal phenomenon in the sense that it is shown by almost all healthy subjects. Therefore, on the basis of the presence of an interference effect alone, one cannot conclude that a patient has problems with selective attention. It has to be demonstrated that the interference is different from that in healthy subjects. Moreover, even if larger interference effects are observed, this might not be due to specific attentional deficits, but may simply reflect a proportional increase in response latency in the control and incongruent conditions of the Stroop task.

The results of Experiments 1 and 2 showed that the mean response latency in the two patient groups increased with the complexity of the task: 612 msec in the detection task, 696 msec in the word-reading task, and 822 msec in the picture-naming task. However, the difference in mean RT between the patient groups and the control group was rather stable across the tasks: a difference of 186 msec in the detection task, 144 msec in the word-reading task, and 170 msec in the picture-naming task. Furthermore, the LH and RH patient groups produced rather similar results in these simple tasks. Given this pattern of results, the conclusion seems warranted that the slowness in picture naming exhibited by the patient groups in Experiment 2 is not due to specific processes that are involved in picture naming, like the visual recognition of the pictures or the process of name retrieval.

The results obtained in the picture–word interference task of Experiment 3 clearly differed for the two groups of patients. Despite longer picture-naming latencies in comparison with the control subjects, the LH patients did not show a larger interference effect. This was true for both the overall interference effect (the difference between semantically related words and the string of control characters) and for its two components: interference induced by unrelated words and the semantic interference effect. In contrast, in comparison to the control group, the RH patients did show an increase in interference. The overall interference effect was 186 msec (vs 70 msec in the control group), and this difference appeared to be mainly due to an increase in semantic interference (99 msec in the RH group vs 26 msec in the control group). Given the stable pattern of results across the various conditions in the three experiments and in view of the fact that in all other conditions the RH group was always slightly faster than the LH group (although this difference was not statistically significant), we believe that this finding reveals a specific interference effect in the RH group. The finding that this increase in interference is especially clear in the semantic component of the Stroop-like effect indicates that (a) it is not due to a general selective attention problem in the sense that these patients cannot distinguish between relevant and irrelevant information, and (b) it is not due to an increase in interference at a response output level. So, it is conceivable that the increased interference effect in the RH group (a) is due to problems in repressing irrelevant words, especially when they are primed by a semantic relation to the target picture [3, 6], or (b) is due to problems in the selective enhancement of the relevant information [11].*

*The fact that 5 out of the 14 RH patients showed signs of neglect at the time of neuropsychological examination does not offer an alternative account of the present findings. The semantic interference effect obtained with these patients was in fact smaller than the semantic interference effect observed with the RH patients without any signs of neglect (67 and 118 msec, respectively).

As the Stroop color–word test is used to assess attentional functions in patients presenting a wide variety of brain disorders, we did not have assumptions concerning the nature nor the site of the brain lesion that would be important in producing large interference effects. We decided to investigate a group of patients with clearly verifiable lesions and opted for patients with a single unilateral CVA. As we were interested in attentional problems we excluded patients with severe language problems or disorders of visual object recognition. Although the patients were slower than the control subjects, their error rates were quite low, indicating that they could perform these tasks quite well. Moreover, in the simple tasks of Experiments 1 and 2, no differences in terms of errors were found between the two groups. Nevertheless, one could argue that subtle language and perceptual problems contribute to the increase in response times. However, these effects then do not explain the surprisingly large semantic interference effect in the RH group. We do not see an obvious explanation for the fact that the right and not the left hemisphere patients appear to be sensitive to this interference effect.

In summary, the results of this study show that disproportional picture–word interference effects can be demonstrated in patients with right hemisphere lesions independent of a general decrease in speed of cognitive processing. These patients are not distracted by just any kind of distractor but semantic associations play a role and produce a significantly larger interference effect.

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