Two stages in postcategorical filtering and selection

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In a modified Stroop paradigm, Kahneman and Henik (1981) varied the spatial location of incompatible color words in relation to the position of the ink color to be named. A large effect on reaction time was found if the word was in the same position as the color, and a greatly reduced effect was found if it was in a different location. Kahneman and Henik concluded that (1) attention can be directed only to preattentively defined perceptual objects, (2) attention facilitates all the responses associated with properties or elements of the selected object, and (3) word reading is not automatic as proposed in unlimited capacity (UC) models. To evaluate these conclusions, the same paradigm was used in three experiments. The first two essentially replicated Kahneman and Henik's findings and supported the first two conclusions. The third experiment tested the capacity issue. The results provided no reason for rejecting the UC assumption. A theoretical analysis is outlined showing how a UC processing model with an object-selection stage and a subsequent dimension-selection stage can account for the results obtained. This model is an extended version of Van der Heijden's (1981) postcategorical filtering model.

Current theories of human attention and performance agree in postulating a number of distinct processing stages in which sensory information is analyzed and/or transformed prior to the emission of responses. Up to now, the theories have disagreed with respect to two basic issues: (1) the limited-capacity (LC) versus unlimited-capacity (UC) processing issue, and (2) the early versus late selection issue.

With respect to the capacity issue, two points of view have dominated the literature. The first suggests that all information registered is processed in parallel and without interference up to the stage of overt responding or storage in memory. This view argues that the assumption of UC is adequate for characterizing much of the processing in the human information processing system, at least up to late stages (e.g., Deutsch & Deutsch, 1963; Morton, 1969). The second view suggests that either the assumption of a structural bottleneck somewhere in the chain of processing stages (e.g., Broadbent, 1958) or the assumption that some or all stages require the expenditure of effort, of which there is a limited amount (e.g., Kahneman, 1973), that is, one or another assumption of LC processing, is necessary for adequately characterizing processing.

With respect to the selection issue, again two views have dominated the literature up to now. In the early selection view, it is maintained that a selection mechanism operating in a stage prior to the stages concerned with categorizing the information, that is, a mechanism that operates on a level containing unidentified information, has to be postulated in order to account for the selection aspect of

the human information processing system (e.g., Broadbent, 1958; Kahneman, 1973). Proponents of the late selection view argue that selection operates in a stage containing identified information (e.g., Deutsch & Deutsch, 1963; Norman, 1968).

The two possible points of view with respect to the capacity issue and the two possible points of view with respect to the selection issue (note that the latter issue is here defined in terms of the level upon which attention operates and not in terms of what is selected) can in principle lead to four overall theoretical proposals: (1) LC processing and early selection, (2) LC processing and late selection, (3) UC processing and early selection, and (4) UC processing and late selection. Up to now, only two of these four possibilities have been thoroughly considered; the other two possibilities have received only a minor amount of attention.

Broadbent (1958) introduced a LC processing-early selection model, the filter model. In this model, an early selection device, the filter, is postulated. It protects a subsequent serial (i.e., LC) processing stage from being overloaded. The filter admits stimuli after a rapid preliminary analysis of their physical attributes. Following Treisman (1960), Broadbent (1971) replaced this all-or-none filter by an attenuation filter. Furthermore, Broadbent (1970, 1971) added the LC processing-late selection possibility (i.e., response set) to his overall theoretical structure. Broadbent's LC processing-early selection model has been and still is very influential. Basically similar or closely related models have been proposed by, among others, Coltheart (1972), Estes and Taylor (1964, 1966), Kahneman and associates (Kahneman, 1973; Kahneman & Henik, 1981; Kahneman & Treisman, 1983), Neisser (1967), Rumelhart (1970), Sperling (1963). This type of model

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is very attractive because of its early selection aspect and not so much because of its LC aspect (see the next paragraph). Results obtained in a number of appropriately chosen experimental paradigms, for example, partial-report tasks and shadowing tasks, are easily explained in terms of an early selection mechanism and are very difficult or virtually impossible to explain in terms of late selection (see, e.g., Kahneman & Henik, 1981, Kahneman, Treisman, & Burkell, 1983, and Van der Heijden, 1981).

Deutsch and Deutsch (1963) proposed a UC processing-late selection model. The core of the model is a system containing a number of "central structures," or "classifying mechanisms" (nowadays generally called "logogens"). In the model, it is assumed that messages reach the same perceptual and discriminating mechanisms whether or not attention is paid to them (i.e., UC processing). Each central structure has a preset weighting of importance. The structure with the highest weighting of importance will switch in further processes, such as motor output, memory storage, etc. (i.e., late selection). Similar or closely related models have been proposed by, among others, Keele (1973), Morton (1969), Norman (1968), Posner (1978), Posner and Snyder (1975), and Shiffrin and Schneider (1977). This type of model is attractive because of its UC processing aspect and not, at least for a number of tasks, because of its late selection aspect (see the previous paragraph). Results obtained in a number of appropriately chosen experimental paradigms, for example, visual search tasks and varieties of the Stroop task, strongly suggest UC processing and fail to show a processing bottleneck or LC processing (see, e.g., Shiffrin & Schneider, 1977, Van der Heijden, 1981, and Van der Heijden, La Heij, & Boer, 1983; see especially Allport, 1980).

The above considerations are aptly summarized in Keele's (1973) paradox: "[I]f selectivity occurs at the level of physical characteristics of the message, why does the meaning of the ignored message affect response to the selected message? If, on the other hand, selectivity occurs at the level of activated memory, why do physical characteristics . . . affect selection?" (p. 151). These considerations led Van der Heijden (1981) to seriously consider the remaining overall theoretical position. He investigated the adequacy of a model combining UC processing and early selection to account for observed performance in a number of visual information processing tasks, especially whole-report and partial-report tasks and a variety of the Stroop task. In that model, the automatic, nonselective processing of information is accounted for by postulating a system of counters or logogens: transducers in which "programs of motor instructions" are activated by stimulus features. (See Van der Heijden, 1981, pp. 183-187, for a more elaborated version of the logogen concept.) The level of activation of a logogen is determined by "response readiness" or "response set" and by the momentary stimulation conditions. Upon presentation of a multielement stimulus array, a number of

logogens are activated; that is, sensory features and activated programs are simultaneously present in the system as linked or connected units (cf. McClelland & Rumelhart, 1981, for a similar logogen concept). An essential further assumption is that, shortly after exposure of the stimulus, the count of the logogens decreases according to an exponential decay function. Thus, unless further operations are performed, stimulation has only a transient effect in the logogen system.

Two further internal operations are distinguished in this model: (1) postcategorical filtering and (2) selection. In postcategorical filtering, it is assumed that the representations of the physical features of the stimulus are used for locating the relevant response. In terms of the logogen system, as defined above, this means that the input side of the logogens is used for locating the relevant logogen. It is further assumed that the "programs" can only be executed in the order of their level of activation. "Selection" can result in a reordering of the levels of activation. Because it is assumed that after stimulation the counts in the logogens automatically decrease, a selection mechanism capable of maintaining the count level of the relevant logogen until the count levels of the other logogens are sufficiently decreased can accomplish this.

For the tasks considered, the model appeared rather successful (cf. Van der Heijden, 1981, chap. 6 and 7). Furthermore, as will be clear, the model can easily incorporate new findings with regard to early selection or filtering (cf., e.g., Kahneman, Treisman, & Burkell, 1983; Treisman, Kahneman, & Burkell, 1983) and at the same time remain consistent with unequivocal new evidence in favor of UC processing (cf. Van der Heijden, La Heij, & Boer, 1983).

In an important study, Kahneman and Henik (1981), however, obtained evidence that strongly suggests that Van der Heijden's (1981) model (1) is at least incomplete with regard to its selection assumptions and (2) is possibly wrong with regard to its UC processing assumption (see Francolini & Egeth, 1980, for rather similar results). In the relevant part of their study, Kahneman and Henik (1981) used a variant of the Stroop task. In the original Stroop task, subjects have to name the colors of the inks in which incompatible color words are printed. Subjects face great difficulties in performing this task. Stroop (1935) found that color naming was slowed by about 75% in comparison with naming the colors of rectangular color patches. Klein (1964) showed that especially the color words used in naming the colors affect color naming, and not words in general; neutral words have virtually no effect. Rather similar results with color naming are observed when color word and color are spatially separated in short tachistoscopic presentations (cf., among others, Dyer, 1973; Gatti & Egeth, 1978; Kahneman & Chajczyk, 1983; Van der Heijden, 1981). This Stroop interference (the delaying effect of the irrelevant color word on color naming) is often taken as evidence in favor of the UC processing assumption (cf., among others, Keele, 1973; Morton & Chambers, 1973; Posner, 1978; Van der Heijden,

1981). In Van der Heijden's (1981) view, word(s) and color(s), if of sufficient intensity, are automatically processed, irrespective of their position and regardless of whether attention is involved or not. The simultaneous availability of processed information is thought to cause the Stroop interference.

Kahneman and Henik (1981) used a simple but powerful modification of the Stroop task. In a short tachistoscopic exposure, they presented two words simultaneously, one at the left and one at the right of a fixation point. In one of the experiments, one word was in color, the other black. The subjects were instructed to name the color of the colored word. Two trials illustrate the main experimental conditions: (1) the word RED is printed in green and the word MOST in black, and (2) the word RED is printed in black and the word MOST in green. In both trials, the correct response is green. At the present, UC processing models predict no differences between these two conditions: irrelevant words are automatically processed irrespective of their position and regardless of whether or not attention is involved (see, e.g., Van der Heijden, 1981). Contrary to this prediction, Kahneman and Henik (1981) found large and reliable differences between the two conditions. A color word delayed color naming appreciably when the color of its ink had to be named. Virtually no effect of the color word printed in black was observed.

In Kahneman and Henik's (1981) explanation of these results, three assumptions can be distinguished. (1) Attention can be directed only to preattentively defined perceptual objects. It is extremely difficult or impossible to restrict attention to the relevant properties of an object. (2) Attention facilitates all the responses associated with properties or elements of the selected object. (3) The focusing of attention on the relevant visual object prevents the involuntary reading of a distant color word; that is, word reading is not automatic as proposed in UC models (see also Kahneman & Chajczyk, 1983, p. 498).

It seems that the first two assumptions, in one or another form, are indeed needed for explaining the results. In Van der Heijden's (1981) model and, at the present, in all other UC processing models, neither a priority of objects over dimensions nor any facilitation of responses associated with irrelevant properties or elements of a selected object is recognized. In Van der Heijden's model, the relevant dimension is located or isolated and only the response associated with this dimension is "facilitated"; that is, selection prevents its decay. Kahneman and Henik's (1981) results strongly indicate that in this respect the model is incomplete and seem to force us to distinguish two stages: first, the relevant object is located and all responses associated with this object are prevented from decaying; then, the relevant dimension is isolated and only the response associated with that dimension is maintained.

But it furthermore seems that the first two assumptions are also sufficient for explaining Kahneman and Henik's (1981) results, and that the third assumption is not really

necessary. Instead of assuming that reading was prevented, it is also possible to assume that a distant color word is automatically read, and that initially the response is available. If during the time that the responses associated with the relevant object are facilitated (i.e., prevented from decaying) this response simply decays away, virtually no effect of this response on color naming is to be expected. Therefore, possibly Kahneman and Henik's (1981) paradigm, in the form they used it, is not sufficiently sensitive for deciding between LC and UC processing.

From the above considerations, it will be clear that Kahneman and Henik's (1981) paradigm is of fundamental importance and really can advance our understanding of human information processing. In this study, we report three experiments that used the same paradigm. In the first two experiments, we investigated whether it is necessary to assume that postcategorical filtering and selection is a two-stage process, as Kahneman and Henik strongly suggest. In the third experiment, we investigated whether it is indeed necessary to assume LC processing in this type of task, as Kahneman and Henik strongly suggest.

GENERAL METHOD

Apparatus

A Scientific-Prototype three-channel tachistoscope (Model 320 GB) was used to present the stimuli. Subjects initiated stimulus exposure by pressing a button inserted in the table surface. The tachistoscope was connected with an electronic timer that started counting when a stimulus card appeared and stopped when the subject spoke his or her response in a voice key. Latencies (reaction times, RT) were recorded accurate to 1 msec. The pre- and postexposure field consisted of a blank card with a black fixation cross in the center. The stimulus cards and the blank cards appeared at a luminance of about 50 cd/m². The exposure duration used for the stimuli was 150 msec.

Stimuli

In each experiment, a set of 36 stimulus cards was used. Each card contained two words, one above and one below the fixation cross. The distance between the center of a word and the fixation cross was .51° in visual angle. The height of the words was .22° in visual angle, and the length was between 1.06° and 1.37°. One of the words was printed either in red or in blue; the other word was always printed in dark brown (this color had about the same contrast with the background as red and blue). The words were written in lowercase.

Subjects

In each experiment, a different group of 12 students (6 males and 6 females) from the University of Leiden served as paid subjects. None of them had served in similar experiments before. All had normal or corrected-to-normal vision, and none of them was deficient in color vision.

Design

The set of 36 cards was presented five times to each subject. The first series was regarded as practice, and the data were not used in the analysis. The presentation of each series of 36 cards was in a different random order. For each subject and each condition, the number of errors was counted. Only the RTs on the correct trials were included in the analysis.

Procedure

The subjects were run individually in a normally illuminated room. They were instructed to initiate stimulus exposure when they clearly

saw the fixation cross. They were asked to name as fast as possible the color of the colored (i.e., red or blue) word and to neglect the dark-brown word. They were instructed to maintain accuracy. No information was given about RTs or correctness of response.

EXPERIMENT 1

This experiment was a partial replication, a slight modification, and an extension of Kahneman and Henik's (1981) Experiment 3. In the relevant part of that experiment, subjects were exposed to a pair of words, one on either side of the fixation point. One of the words was colored, and the other always black. Subjects had to name the color of the colored word. The two most relevant conditions had as stimuli (1) a colored incompatible color word and a neutral black word, and (2) a colored neutral word and a black incompatible color word. Thus, color and word content in the two conditions were exactly the same; only the combination of colors and words was changed. For this paradigm, Van der Heijden's (1981) model postulates that first the position of the color is located and then the color response is selected. Because of its UC processing assumption, the model predicts no effect of the positions of the simultaneously presented words. Kahneman and Henik (1981), however, found strong position effects indicating initial object selection instead of dimension selection. Because of the theoretical importance of this finding, replicating their experiment was worthwhile.

We slightly modified Kahneman and Henik's (1981) paradigm. They presented the words at the left and at the right of the fixation point. A number of studies have shown, however, that such configurations introduce additional effects possibly as a result of differential hemispheric specialization (see, e.g., Cohen & Martin, 1975, Schmit & Davis, 1974, and Van der Heijden, 1981, chap. 4, Experiment 2). We therefore placed the words above and below the fixation point. Furthermore, in order to assure equal identifiability, we used only two relevant colors instead of the four used by Kahneman and Henik (1981).

We also extended Kahneman and Henik's (1981) task. In the relevant part of their experiment, they used three different types of stimulus cards (i.e., three main experimental conditions were distinguished). In the present study, nine different types of stimulus cards were used (i.e., nine main experimental conditions were distinguished). As will become clear further on, this extension allowed us to investigate the effects of irrelevant distant words on color naming for three levels of mean RTs. The stimulus cards used and the main experimental conditions are described below.

Method

Two color words, "rood" (red) and "blauw" (blue), and one neutral word, "smal" (narrow), were used. Each word was printed three times in red and three times in blue above and below the fixation point, resulting in a total of 3 (words) $\times$ 2 (colors) $\times$ 2 (positions) $\times$ 3 (replications) = 36 stimulus cards. In the three replications, each of the three

words was used once and appeared in dark brown at the opposite side of the fixation point.

If we write the word containing the (red or blue) color in upper case and characterize the words with respect to their relation to the color to be named as congruent [the word "rood" ("blauw") if the color to be named is red (blue)], neutral (the word "smal") and incongruent [the word "rood" ("blauw") if the color to be named is blue (red)], the following nine main conditions can be distinguished: (1) CONGRUENT-congruent, (2) CONGRUENT-neutral, (3) CONGRUENT-incongruent; (4) NEUTRAL-congruent, (5) NEUTRAL-neutral, (6) NEUTRAL-incongruent; and (7) INCONGRUENT-congruent, (8) INCONGRUENT-neutral, (9) INCONGRUENT-incongruent. (In the following, we will use the words internal and external in combination with congruent, neutral, and incongruent for characterizing the colored word and the dark-brown word, respectively.)

In the relevant part of their experiment, Kahneman and Henik (1981) included only Conditions 5, 6, and 8.

Results

An analysis of variance was performed over the mean RTs per subject, with color to be named (red, blue), position of the color (above, below), internal color-word relation (congruent, neutral, incongruent), and external color-word relation (congruent, neutral, incongruent) as within-subject factors.

Color appeared to be significant [$F(1,11) = 11.26$, $p < .01$; the mean RTs for red and blue were 652 and 685 msec, respectively]. Position was not significant [$F(1,11) = 2.52$]. Internal color-word relation was highly significant [$F(2,22) = 40.85$; $p < .001$; the mean RTs for congruent, neutral, and incongruent were 614, 653, and 739 msec, respectively]. The effect of external color-word relation appeared to be just significant [$F(2,22) = 3.96$; $p < .05$; the mean RTs for congruent, neutral, and incongruent were 663, 662, and 680 msec, respectively]. The interaction between internal and external color-word relation was far from significant [$F(4,44) = 1.09$].

From the remaining interactions, two appeared significant. The first was the position $\times$ external color-word relation [$F(2,22) = 6.65$, $p < .01$]. Separate analyses of variance indicated a significant effect of external relation when the dark-brown word was below the fixation point [$F(2,22) = 7.20$, $p < .01$; mean RTs for congruent, neutral, and incongruent combinations were 658, 664, and 698 msec] and no effect when it was above the fixation point [$F(2,22) = .67$; mean RTs were 668, 660, and 661 msec, respectively]. The second was the color $\times$ internal color-word relation $\times$ external color-word relation [$F(4,44) = 3.66$; $p < .05$]. Table 1 presents this interaction.

The error rates were too low to allow a meaningful analysis. Generally, numbers of errors were positively related with RTs (see Table 1).

Discussion

As far as the main issue under investigation, that is, the difference between the effects of internal and external color-word relations, is concerned, the results of Experiment 1 are extremely clear: The effect of internal color-word relation is appreciably larger than the effect of external color-word relation. Although Table 1 sug-

Table 1
Mean RTs in Experiment 1 (in Milliseconds) and Numbers of Errors
(Within Parentheses) by Color of the Colored Word (Red or Blue)
for the Nine Combinations of Stimulus Elements

	Red				Blue			
	Ci	Ni	Ii	Mean	Ci	Ni	Ii	Mean
Ce	595(0)	623(0)	744(3)	654	610(1)	669(3)	740(7)	673
Ne	590(0)	641(0)	707(4)	646	620(0)	650(3)	766(1)	679
Ie	616(0)	641(0)	711(4)	656	653(2)	693(1)	764(5)	704
Mean	600	635	721		628	671	756	

Note—C = congruent; N = neutral; I = incongruent; e = external; i = internal.

gests a somewhat larger effect of external color-word relation for the conditions with the faster mean RTs (see the data for congruent and neutral internal color-word relations) than for the condition with the largest mean RTs (see the data for incongruent internal color-word relations), the analysis of variance showed that this trend (i.e., the internal $\times$ external color-word interaction) is far from significant. Furthermore, in none of the interactions involving external color-word relation were RT differences for this factor found to approach the size of the differences for internal color-word relation. In short, the results of Experiment 1 essentially replicate Kahneman and Henik's (1981) results.

These results force us to modify the selection assumptions in Van der Heijden's (1981) model. It appears that in the present paradigm, subjects are not able to start with locating and selecting the correct dimension. Instead, the results obtained are consistent with Kahneman and Henik's (1981) assumptions that subjects first choose the relevant object and that all responses associated with properties of that object are facilitated in one or another way. However, ultimately subjects have to choose the relevant dimension and to facilitate only the response belonging to that dimension. The latter assumption is needed to explain subjects' high-level (i.e., nearly errorless) performance. Thus, we have to assume that selection in this task is a two-stage process. First, the relevant object is located and all responses associated with this object are prevented from decaying. Then, the relevant dimension is isolated and only the response associated with that dimension is maintained. (See the general introduction.)

The analysis of variance revealed two significant interactions that are rather difficult to interpret. Instead of trying to interpret these interactions, we decided to run Experiment 2 to attempt to remove these interactions.

EXPERIMENT 2

In Experiment 1, two significant interactions were found. They were external color-word relation $\times$ position of relevant object and external color-word relation $\times$ internal color-word relation $\times$ to-be-named color. In general, these interactions indicate that the strength of the effect of external color-word relation changes from one

experimental condition to another. The details of these interactions are rather difficult to interpret. However, a general hypothesis about the causes of these interactions can be formulated and tested.

In Experiment 1, subjects had to name the color of the colored (i.e., red or blue) word and to neglect the irrelevant (dark-brown) word. Because there was no further information about which object was relevant, color had to be used to locate the relevant object. The three colors used—red, blue, and dark brown—are not so distinct that we have to assume that on all trials the relevant object is selected first. In other words, it is possible that on some subset of trials, subjects first select the irrelevant object and only then the relevant object. In Kahneman and Henik's (1981) view such selections result in the facilitation, and in Van der Heijden's (1981) model in the maintenance, of the responses associated with the irrelevant object. If these wrong selections are not distributed randomly, but are determined by color and position, for instance, then in both views interactions such as those observed are to be expected. (See also Kahneman & Chajczyk, 1983, on "capture.")

If this general hypothesis is correct, then experimental manipulations that prevent these wrong selections have to remove these interactions. Besides this, the same manipulations can have a further effect. The assumption of wrong selections on a subset of trials is sufficient to explain the just significant main effect of external color-word relation in Experiment 1. In other words, it is possible that with correct selections only, no effect of external color-word relation will be found. Thus, preventing wrong selections has to remove the interactions and can remove the main effect of external color-word relation.

In order to test this general hypothesis, in Experiment 2 the position of the relevant object was precued with barmarkers.

Method

The same 36 stimulus cards that were used in Experiment 1 were used here. A set of 36 barmarker cards was prepared, one for each stimulus card. Each barmarker card contained two horizontal black bars, $.88^\circ \times .04^\circ$ in visual angle. When shown simultaneously with the corresponding stimulus card, one barmarker appeared at the left and the other at the right of the colored (i.e., red or blue) word. The horizontal distance between the end of the barmarkers pointing at the word and the beginning or end of the word was about $.5^\circ$ in visual angle.

The subjects initiated barmarker and stimulus exposure by pressing a button. First, the barmarker card appeared for 50 msec, immediately followed by a 150-msec exposure of the stimulus card. The subjects were instructed to name as fast as possible the color of the word indicated by the barmarkers while maintaining accuracy.

Results

Table 2 gives the mean RTs for the nine main experimental conditions. An analysis of variance was performed over the mean RTs per subject with color to be named (red, blue), position of the color (above, below), internal color-word relation (congruent, neutral, incongruent), and external color-word relation (congruent, neutral, incongruent) as within-subject factors.

Table 2
Mean RTs in Experiment 2 (in Milliseconds) and Numbers of Errors
(Within Parentheses) for the Nine Combinations of Stimulus
Elements.

	Ci	Ni	Ii	Mean
Ce	656(3)	695(2)	784(18)	712(23)
Ne	652(1)	681(0)	772(10)	702(11)
Ie	657(0)	690(4)	786(7)	711(11)
Mean	655(4)	689(6)	781(35)	708

Note—See Table 1 for definitions.

Color appeared to be significant [$F(1,11) = 16.55$, $p < .01$; the mean RTs for red and blue were 686 and 730 msec, respectively]. Position was not significant [$F(1,11) = 1.66$]. Internal color-word relation was highly significant [$F(2,22) = 62.81$, $p < .001$; see Table 2]. The effect of external color-word relation was far from significant [$F(2,22) = .87$]. Neither the external color-word relation $\times$ internal color-word relation interaction presented in Table 2 [$F(4,44) = .11$] nor any of the other interactions appeared to be significant.

The error rates were too low to allow a meaningful analysis. Generally, numbers of errors were positively related with RTs (see Table 2).

Discussion

With regard to the issues under investigation, the outcome of this experiment is perfectly clear. First, precuing with barmarkers completely removes the interactions involving external color-word relation. It is therefore likely that the interactions observed in Experiment 1 indeed resulted from subjects' erroneously selecting the irrelevant dark-brown word on a subset of the trials before selecting the relevant object (see the introduction of Experiment 1).

Second, precuing with barmarkers also completely removed the main effect of external color-word relation. It is therefore likely that also this main effect observed in Experiment 1 resulted from subjects' erroneously selecting the dark-brown word on a subset of the trials before selecting the relevant object. The present result is of importance because it strongly suggests that the effect of external color-word relation observed in Kahneman and Henik (1981) and in our Experiment 1 is not the genuine, automatic, Stroop effect. The effect seems only to result from inappropriately controlling subjects' selection strategies.

In short, it appears that with correct selections only, a very simple pattern of results emerges in the present paradigm: a strong effect of internal color-word relation and no effect of external color-word relation. (The significant difference between red and blue is a nuisance factor of minor importance.) In line with Kahneman and Henik (1981), this pattern of results forces us to conclude that subjects first choose the relevant object and that all responses associated with that object are facilitated in one or another way.

To the problem of whether this pattern of results also forces us to assume that the irrelevant external color word

was not read (i.e., to assume LC processing), as Kahneman and Henik (1981) suggested, we return in Experiment 3.

EXPERIMENT 3

In Experiment 2, in which we used barmarkers to precue the position of the relevant object, no effect of external color-word relation was observed. Two interpretations of this result are possible, one involving the LC processing assumption and the other the UC assumption.

According to Kahneman and associates, data like these are inconsistent with the concept of automatic activation (i.e., UC processing) and support the LC processing assumption. In their view, results like these show that unattended objects lose most or all of their ability to evoke instrumental responses (Kahneman & Henik, 1981), or, in other words, show that the involuntary reading of a distant color word can be prevented by focusing attention on the relevant visual object (Kahneman & Chajczyk, 1983). Because the act of reading appears to depend on the allocation of attention, according to this view, reading cannot be strongly automatic (i.e., a UC process).

In the general introduction we already suggested an alternative interpretation involving the UC processing assumption. Instead of assuming that reading is prevented, it is also possible to assume that a distant color word is automatically read and that initially the response is available. If during postidentification central processing, that is, during the time that the responses associated with the relevant object are prevented from decaying and during the time that the resulting response conflict is solved, this response simply decays away, no effect on color naming is to be expected.

In summary, the LC view holds that no effects of external color words are observed because these words were not identified, and therefore not available as responses in the system. The UC view holds that the words were identified and therefore initially available as responses, but that no effects were observed because these responses simply decayed away during postidentification central processing. Experiment 3 was designed to decide between these two interpretations. The logic of Experiment 3 is rather simple.

From the UC view it follows that, if, by one or another means, postidentification central processing time is sufficiently reduced in the paradigm used in Experiment 2, a reliable genuine Stroop effect caused by the external incongruent color word should appear. This central processing time can be shortened by removing the internal color word conflict in this paradigm. This can be achieved by replacing the internal color words by, in all respects equivalent, neutral noncolor words (cf., e.g., Keele, 1972; Klein, 1964).

It will be clear that in Kahneman and Henik's (1981) LC view, no genuine external Stroop effect is to be expected in this changed paradigm. The barmarkers correctly direct selective attention to the relevant object, and the relevant

object again consists of a colored word. Therefore, it has to be assumed that the focusing of selective attention on this relevant visual object will prevent the involuntary reading of the distant color word as in Experiment 2.

Thus, a replication of Experiment 2, with the internal color words replaced by, in all further respects, equivalent neutral noncolor words can provide information for deciding between the LC and the UC view.

Method

A new set of 36 stimulus cards was prepared. The new cards were identical to those used in Experiments 1 and 2, with the only exception being that the internal, that is, colored, color words "rood" (red) and "blauw" (blue) were replaced by the neutral noncolor words "laat" (late) and "vroeg" (early), respectively.

In all further respects, the experiment was an exact replication of Experiment 2.

Results

In Table 3, the mean RTs for the nine main experimental conditions are presented. An analysis of variance was performed over the mean RTs per subject, with color to be named (red, blue), position of the color (above, below), internal color-word relation (neutral word 1, neutral word 2, neutral word 3), and external color-word relation (congruent, neutral, incongruent) as within-subject factors.

Color appeared to be significant [$F(1,11) = 11.85$, $p < .01$; the mean RTs for red and blue were 556 and 583 msec, respectively]. Position approached significance [$F(1,11) = 4.78$, $.05 < p < .10$]. The effect of internal color-word relation (i.e., the three different internal neutral conditions) was far from significant [$F(2,22) = 1.05$]. The effect of external color-word relation was highly significant [$F(2,22) = 10.93$, $p < .001$; see Table 3]. Neither the external color-word relation $\times$ internal color-word relation presented in Table 3 [$F(4,44) = .56$] nor any of the other interactions appeared to be significant.

The error rates were too low to allow a meaningful analysis. The number of errors was positively correlated with RTs (see Table 3).

In order to compare the results obtained in Experiments 2 and 3, two further analyses of variance were performed. In the first, all RTs of both experiments were included. From among the significant effects, two are especially relevant: (1) the difference between the overall mean RTs [$F(1,22) = 10.71$, $p < .01$; the mean RTs for Experi-

ments 2 and 3 were 708 and 560 msec, respectively] and (2) the interaction between experiments (Experiments 2 and 3) and external color-word relation [$F(2,44) = 5.42$, $p < .01$; the mean RTs for congruent, neutral, and incongruent were 712, 702, and 711 msec and 555, 560, and 594 msec for Experiments 2 and 3, respectively]. In the second analysis of variance, only the data for the common internal neutral conditions (i.e., the data for the 12 stimuli with "smal" as the internal neutral noncolor word) were included. Again, the same two relevant significant results appeared: (1) a difference in mean RTs for these stimuli in the two experiments [$F(1,22) = 7.51$, $p < .05$], and (2) a significant interaction between experiments (Experiments 2 and 3) and external color-word relation [$F(2,44) = 4.56$, $p < .05$]. Table 4 presents the relevant data.

Discussion

The two comparisons between Experiments 2 and 3 clearly show that we were successful in reducing the total processing time. Overall, subjects were 148 msec faster in Experiment 3 than in Experiment 2, and for the internal neutral condition, common to both experiments, a significant decrease of 115 msec was found. The (expected) complete absence of any internal color-word relation effect in Experiment 3 strongly suggests that this decrease in RTs was due entirely to removing the internal color-word conflict, that is, to a reduction in postidentification central processing time.

The important finding in the present experiment is that, with this reduced central processing time, a highly significant effect of external color-word relation (i.e., a reliable genuine Stroop effect) shows up. Of course, similar effects have been reported more often in the recent literature (see, e.g., Dyer, 1973, Gatti & Egeth, 1978, Kahneman & Chajczyk, 1983, and Van der Heijden, 1981). In principle, these results can be explained in terms of ineffectiveness of selection (as in our Experiment 1, in these experiments no barmarkers were used) and/or one or another form of identification load (in these experiments, color patches instead of colored words were used as relevant objects). Experiment 3, however, was, as far as identification and object selection is concerned, identical to Experiment 2, in which no effect at all of external color-word relation was found (see Table 2). Therefore, neither a difference in effectiveness of object selection (i.e., focusing of attention) nor a difference in identification load can account for the difference in effects of external color-word relation observed in Experiments 2 and 3.

In this way, the present results clearly fail to substantiate Kahneman and associates' LC interpretation, that unattended objects lose most or all of their ability to evoke responses, or that focusing attention on the relevant object can prevent the involuntary reading of a distant color word. If postidentification central processing time is reduced, it appears that these words were identified and cause interference. It is therefore parsimonious to assume

Table 3
Mean RTs in Experiment 3 and Numbers of Errors (Within Parentheses) for the Nine Combinations of Stimulus Elements

	Ni 1	Ni 2	Ni 3	Mean
Ce	557(4)	554(1)	554(3)	555(8)
Ne	550(3)	565(5)	564(4)	560(12)
Ie	587(11)	602(5)	593(2)	594(18)
Mean	565(18)	574(11)	570(9)	570(38)

Note—See Table 1 for definitions.

that these words are also identified in tasks involving longer central processing times, and that the words are initially available as responses. Because these responses do not remain in an activated state forever, long central processing times can cause their presence simply to go unnoticed. In the General Discussion, we elaborate this point of view, in combination with the notion of object selection, in further detail.

GENERAL DISCUSSION

This discussion is concerned primarily with explaining the present results, as well as those of Kahneman and Henik (1981), in terms of a UC processing model. In the first part of this discussion, we indicate which data have to be explained in detail. Then we start the explanation with a brief exposition of Van der Heijden's (1981) model; this model was devised explicitly to account for performance observed with incongruent color-word items in the Stroop task in terms of UC processing. It is then shown how these and the Kahneman and Henik data force us to change the original formulation of the model. It will be pointed out that only a change in the assumptions regarding the "further operations performed upon the processed information" is necessary. The data provide no reason to reject the UC processing assumption.

The present series of experiments makes explicit a problem for modeling tasks with RTs as the (main) dependent variable. This problem is summarized in Table 4. As described, Table 4 presents the mean RTs for exactly the same subset of stimulus cards for comparable groups of subjects under identical instructions in Experiments 2 and 3. Nevertheless, both the main effect of experiments as well as the interaction presented in Table 4 appeared to be significant. This shows that not only stimuli and instructions, but also the other experimental conditions of the total task in which the subtasks are embedded, determine performance. Similar results have been reported earlier in the literature. Eriksen and Eriksen (1979, Experiment 2) blocked (and mixed) different subtasks in two different ways. Appreciable differences between RTs for some subtasks were observed in the two different blocking conditions.

Logan (1978) provided a terminology to understand such results. In his view, the "stage structure" of a task, that is, the set of "processing modules" that have to oper-

ate either simultaneously or successively in a task, can be regarded as a temporary assembly of automatic, special-purpose processors, organized (by attention, in Logan's view) to deal with the task at hand. These task-relevant structures are organized and prepared before the stimulus appears. Stimulus presentation releases the automatic processes that the set comprises.

One important problem is that of what determines this stage structure for an experimental task, especially for composites of subtasks, as reported in this study. Another important problem is how such a stage structure affects the RTs in the different subtasks. Eriksen and Eriksen's (1979) results strongly suggest that the subtasks with the longest mean RTs, that is, the most difficult subtasks, primarily determine the stage structure of the total task. In other words, the stage structure appears to be optimal (i.e., adequate and efficient) for dealing with the most difficult subtasks or experimental conditions. Their results furthermore indicate that this stage structure can result in inefficient processing in the easier subtasks.

These considerations are sufficient for explaining the significant difference between the mean RTs presented in Table 4. In Experiment 2, the internal-neutral condition was mixed with the more difficult internal-incongruent condition. It was the latter condition that determined the stage structure. In Experiment 3, there were only three internal-neutral conditions, and therefore, this condition determined the stage structure. The difference in mean RTs shown in Table 4 clearly indicates that the optimal stage structure for the internal-incongruent conditions in Experiment 2 was nonoptimal for dealing with the internal-neutral conditions in that experiment.

These considerations also make clear why it is not worthwhile to try to model all subtasks in all experiments. If easier subtasks are mixed with more difficult subtasks requiring a more elaborate stage structure, as in our Experiments 1 and 2, the easier tasks are performed in a system switching in unnecessary, time-consuming, processing modules. For this reason, we restrict a detailed analysis to the two conditions for which we can be sure that they are dealt with in a system with an optimal stage structure: the internal incongruent-external incongruent condition in Experiment 2 (and Experiment 1) and the internal neutral-external incongruent condition in Experiment 3.

We start the discussion with a brief exposition of (1) the processing assumptions, and (2) the "further operations" assumptions of Van der Heijden's (1981) UC processing model. (For a global outline of this model, the reader is referred to the general introduction.)

Figure 1 presents a simplified summary of the processing assumptions. Two factors determine the activation levels of logogens. The first concerns the momentary stimulation conditions ("evidence" in Norman's, 1968, theory). The hypothetical effect of external activation is strong initially and decreases over time (for ease of exposition, we here use linear, instead of exponential, decay functions). In Figure 1, the lines labeled W_i and C_i

Table 4
Mean RTs (in Milliseconds) and Numbers of Errors (Within Parentheses) for the Common Internal Neutral Conditions in Experiments 2 and 3

	Ni	
	Experiment 2	Experiment 3
Ce	695(2)	554(1)
Ne	681(0)	565(5)
Ie	690(4)	602(5)
Mean	689(6)	574(11)

Note—See Table 1 for definitions.

Figure 1. Processing assumptions. Hypothetical time course of activation of four logogens. Activation level (A) in arbitrary units is plotted against time. Line P gives the pertinence level. W_i and C_i are the time courses for logogens triggered by neutral words and colors, W_r and $C_r (= W_i + P \text{ and } C_i + P)$ for logogens triggered by relevant words and colors.

represent the time courses of activation of logogens triggered by word information and color information, respectively.

The second factor concerns the effect of "response set" or "response readiness" (or "context"; "pertinence" in Norman's, 1968, theory). Its hypothetical effect is assumed to be constant over time. In Figure 1, this effect is represented by the dashed horizontal line, P.

Following Morton (1969, 1977), it is assumed that the two kinds of activation simply add (see also Van der Heijden, 1981, pp. 196-197). Therefore, in Figure 1, the lines labeled W_r and C_r represent the hypothetical time course of activation of logogens activated by words and colors whose names are members of the response set in use. (W_i and C_i give the corresponding time courses for logogens whose responses are not in this response set.) It will be clear that the above assumptions are essentially UC assumptions.

Figure 2 presents the further operations that, according to Van der Heijden (1981, pp. 161-166), have to be performed if the color of an incongruent color-word item in the Stroop task has to be named. Two further operations are distinguished. (1) The relevant logogen, that is, the logogen activated by the color information, is located on the basis of the representation of the physical features in the visual domain. In Figure 2, DL (dimension located) indicates the moment that the relevant logogen is located. (2) The count or level of activation of this logogen is maintained while the count of the logogen corresponding to the word decreases. In Figure 2, the count level is maintained during the interval of time DL-R. In this interval, the (internal) response conflict is solved. The response is initiated at the moment that the count of the relevant logogen is highest and exceeds the count of the next highest logogen (the logogen corresponding to the word) by a threshold amount δ . In Figure 2, this moment is reached at time R.

The assumptions described in the previous paragraphs suffice to account for the results presented in Van der Heijden (1981). Kahneman and Henik's (1981) results and our replication of their results in Experiments 1 and 2 force us, however, to incorporate one further assumption. The results show that internal color words and external color words are handled differently in the processing system. This finding can be dealt with in the model by assuming, following Kahneman and associates, that initially the relevant object (i.e., the colored word) is located and selected as a unit. Of course, in order to account for subjects' performance—they generally come up with the correct color name—it is necessary to assume that the object-selection stage is followed by dimension location and dimension selection, as proposed in Van der Heijden's model.

Figure 3 graphically shows the resulting model. At time OL, the relevant object (the color-word unit) is located. From then on until time DL, both the word count and the color count are maintained (i.e., the object is selected). At time DL, the correct dimension (i.e., the color) is located and selected and the activation level of the logogen triggered by the word decreases. At time R, the difference, δ , in count levels is reached and the response is initiated.

It is important to note that, in the way described in the previous paragraphs, not only Kahneman and Henik's (1981) primacy of object selection over dimension selection, but also their further suggestion that attention to an object "facilitates" all the responses associated with properties or elements of the selected object, is incorporated into the model. In Figure 3, both the color response and the word response are maintained together during the interval OL-DL, or, in other words, both responses are facilitated.

We now briefly indicate how the assumptions spelled out in the previous paragraphs suffice for explaining the

Figure 2. Van der Heijden's (1981) dimension selection assumptions for the Stroop task. At time DL, the logogen triggered by the color is located. Its activation level is maintained while the activation level of the word-logogen automatically decreases. The response is initiated at time R when a difference in activation levels of δ units is reached.

Figure 3. Modified selection assumptions for the Stroop task. At time OL, the "object" (i.e., the logogen corresponding to the color and the logogen corresponding to the word) is located. The activation levels are maintained until time DL, when the color dimension is isolated and only the activation level of the logogen triggered by the color is maintained.

absence of an external incongruency effect for the internal incongruent-external incongruent condition in Experiment 2 and the clear presence of such an effect for the internal neutral-external incongruent condition in Experiment 3. In other words, we will show that a further LC processing assumption is not really needed for explaining the results.

Figure 4 represents what, according to the model, happens with internal incongruent-external incongruent combinations in Experiment 2. Figure 4 (and its interpretation) is exactly the same as Figure 3, except that a further line, labeled 2 (crosses), is inserted. The line labeled 2 represents the time course of activation of the

Figure 4. Processing and selection assumptions for the internal incongruent-external incongruent conditions in Experiments 1 and 2. The figure is identical to Figure 3 except for the line labeled 2 (crosses). This line represents the time course of activation of the (nonselected) logogen triggered by the incongruent external color word.

nonselected logogen corresponding to the external incongruent color word. Figure 4 makes clear that, just because of the initial object-selection stage (interval OL-DL), the activation level of this logogen can decrease to such an extent that it cannot exert any effect in the interval during which the response conflict is solved (interval DL-R). In short, the external color word does not affect latencies in this subtask. Latencies are influenced only by a massive internal response conflict.

Figure 5 is the corresponding figure for the internal neutral-external incongruent combinations in Experiment 3. The only difference between Figures 4 and 5 is that the line labeled 3 is appreciably (i.e., P units; see Figure 1) lower in Figure 5 than in Figure 4. Now the line represents the time course of activation of a logogen having an evidence input but not a pertinence input, because it corresponds to a neutral word, that is, a word not in the response set in use. Figure 5 shows that with these combinations no internal color-word conflict has to be expected, and of course that is what generally is reported in the literature. But Figure 5 furthermore shows that now the activation level of the logogen corresponding to the external color word is of importance. Because no internal response conflict has to be solved, after time DL an effect of the external color word has to be expected.

This completes our detailed interpretation of what happens in the two most difficult subtasks in Experiments 2 and 3, respectively.¹ Given the further assumption that these two subtasks determine the stage structure (i.e., the overall strategy or overall criterion) in the respective experiments, a complete explanation of what happens in all subtasks in the two experiments can possibly be derived. For Experiment 2, it has to be assumed that on each trial a substage or processing component is switched in, set to deal with a massive internal response conflict, even if there is no such conflict. For Experiment 3, it has to be assumed that on each trial a (possibly the same) substage or processing component is switched in, set to deal with a mild external response conflict, even if there is no such conflict. Because on a number of subtasks these processing components are not really necessary, explanations based on a logical analysis of arbitrarily chosen isolated subtasks will not reveal what really happens.

One further implication of the present explanation is worth noticing. A comparison of Figures 4 and 5 indicates that more Stroop interference is predicted with integral combinations of words and colors than with spatially separate presentations of the word and color dimension. (Note the distance between DL and R in Figures 4 and 5.) The literature indeed supports this prediction. With integral combinations, values between 100 and 130 msec and up to 200 msec are reported. With separate presentations, the values do not exceed 70 msec (see, e.g., Glaser & Glaser, 1982, and Neumann, 1984, for a discussion of the relevant literature).

In conclusion, Kahneman and Henik's (1981) results and the present results strongly suggest that at least two stages have to be distinguished in the locating and select-

Figure 5. Processing and selection assumptions for the internal neutral-external incongruent condition in Experiment 3. The figure is identical to Figure 4 except for the line labeled 3. This line now represents the time course of activation of a logogen triggered by a neutral word, that is, a word not in the response set in use, and is therefore P units lower than the line labeled 3 in Figure 4.

ing of relevant information in a task such as that used in these experiments. It appears that first the relevant object is located (postcategorical filtering 1) and selected (selection 1) and that only then the relevant dimension is located and selected (postcategorical filtering 2 and selection 2). Our Experiment 3 and the analysis presented in this discussion also suggest, however, that Kahneman and Henik's further suggestion that processing is of limited capacity is not really necessary for explaining the results. In general, the UC versus LC processing issue can be better investigated with paradigms designed to investigate that issue, for instance, visual search tasks (see, e.g., Van der Heijden, La Heij, & Boer, 1983). Nevertheless, for certain aspects of this issue, Kahneman and Henik's (1981) elegant paradigm can be of great importance.

REFERENCES

- ALLPORT, D. A. (1980). Attention and performance. In G. Claxton (Ed.), *Cognitive psychology, new directions*. London: Routledge & Kegan Paul.
- BROADBENT, D. E. (1958). *Perception and communication*. London: Pergamon Press.
- BROADBENT, D. E. (1970). Stimulus set and response set: Two kinds of selective attention. In D. I. Mostofsky (Ed.), *Attention: Contemporary theories and analysis*. New York: Appleton-Century-Crofts.
- BROADBENT, D. E. (1971). *Decision and stress*. London: Academic Press.
- COHEN, G., & MARTIN, M. (1975). Hemisphere differences in an auditory Stroop test. *Perception & Psychophysics*, *17*, 79-83.
- COLTHEART, M. (1972). Visual information processing. In P. C. Dodwell (Ed.), *New horizons in psychology 2*. Harmondsworth, England: Penguin.
- DEUTSCH, J. A., & DEUTSCH, D. (1963). Attention: Some theoretical considerations. *Psychological Review*, *70*, 80-90.
- DYER, F. N. (1973). Interference and facilitation for color naming with separate bilateral presentations of the word and color. *Journal of Experimental Psychology*, *99*, 314-317.
- ERIKSEN, C. W., & ERIKSEN, B. (1979). Target redundancy in visual search: Do repetitions of the target within the display impair processing? *Perception & Psychophysics*, *26*, 195-205.
- ESTES, W. K., & TAYLOR, H. A. (1964). A detection method and probabilistic models for assessing information processing from brief visual displays. *Proceedings of the National Academy of Sciences*, *52*, 446-454.
- ESTES, W. K., & TAYLOR, H. A. (1966). Visual detection in relation to display size and redundancy of critical elements. *Perception & Psychophysics*, *1*, 9-16.
- FRANCOLINI, C. M., & EGETH, H. E. (1980). On the nonautomaticity of "automatic" activation: Evidence of selective seeing. *Perception & Psychophysics*, *27*, 331-342.
- GATTI, S. V., & EGETH, H. E. (1978). Failure of spatial selectivity in vision. *Bulletin of the Psychonomic Society*, *11*, 181-184.
- GLASER, M. O., & GLASER, W. R. (1982). Time course analysis of the Stroop phenomenon. *Journal of Experimental Psychology: Human Perception and Performance*, *8*, 875-894.
- KAHNEMAN, D. (1973). *Attention and effort*. Englewood Cliffs, NJ: Prentice Hall.
- KAHNEMAN, D., & CHAJCZYK, D. (1983). Tests of the automaticity of reading: Dilution of Stroop effects by color-irrelevant stimuli. *Journal of Experimental Psychology: Human Perception and Performance*, *9*, 497-509.
- KAHNEMAN, D., & HENIK, A. (1981). Perceptual organization and attention. In M. Kubovy & J. R. Pomerantz (Eds.), *Perceptual organization*. Hillsdale, NJ: Erlbaum.
- KAHNEMAN, D., & TREISMAN, A. (1983). Changing views of attention and automaticity. In R. Parasuraman & R. Davies (Eds.), *Varieties of attention*. New York: Academic Press.
- KAHNEMAN, D., TREISMAN, A., & BURKELL, J. (1983). The cost of visual filtering. *Journal of Experimental Psychology: Human Perception and Performance*, *4*, 510-522.
- KEELE, S. W. (1972). Attention demands of memory retrieval. *Journal of Experimental Psychology*, *93*, 245-248.
- KEELE, S. W. (1973). *Attention and human performance*. Pacific Palisades, CA: Goodyear.
- KLEIN, G. S. (1964). Semantic power measured through the interference of words with color-naming. *American Journal of Psychology*, *57*, 576-588.
- LOGAN, G. D. (1978). Attention in character-classification tasks: Evidence for the automaticity of component stages. *Journal of Experimental Psychology: General*, *107*, 32-63.
- MCCLELLAND, J. L., & RUMELHART, D. E. (1981). An interactive activation model of context effects in letter perception: Part I. An account of basic findings. *Psychological Review*, *88*, 375-407.
- MILLER, J. (1982). Divided attention: Evidence for coactivation with redundant signals. *Cognitive Psychology*, *14*, 247-279.
- MORTON, J. (1969). Interaction of information in word recognition. *Psychological Review*, *76*, 165-178.
- MORTON, J. (1977). Word recognition. In J. Morton & J. C. Marshall (Eds.), *Psycholinguistics series II*. London: Elek.
- MORTON, J., & CHAMBERS, S. M. (1973). Selective attention to words and colours. *Quarterly Journal of Experimental Psychology*, *25*, 387-397.
- NEISSER, U. (1967). *Cognitive psychology*. New York: Appleton-Century-Crofts.
- NEUMANN, O. (1984). Automatic processing: A review of recent findings, and a plea for an old theory. In W. Prinz & A. F. Sanders (Eds.), *Cognition and motor processes*. New York: Springer-Verlag.
- NORMAN, D. A. (1968). Towards a theory of memory and attention. *Psychological Review*, *75*, 522-536.
- POSNER, M. I. (1978). *Chronometric explorations of the mind*. Hillsdale, NJ: Erlbaum.
- POSNER, M. I., & SNYDER, C. R. R. (1975). Facilitation and inhibition in the processing of signals. In P. M. A. Rabbitt & S. Dornic (Eds.), *Attention and performance V*. New York: Academic Press.
- RUMELHART, D. E. (1970). A multicomponent theory of the perception of briefly exposed visual displays. *Journal of Mathematical Psychology*, *7*, 191-218.
- SCHMIT, V., & DAVIS, R. (1974). The role of hemispheric specialization.

- tion in the analysis of Stroop stimuli. *Acta Psychologica*, **38**, 149-158.
- SHIFFRIN, R. M., & SCHNEIDER, W. (1977). Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. *Psychological Review*, **84**, 127-190.
- SPELTING, G. (1963). A model for visual memory tasks. *Human Factors*, **5**, 19-31.
- STROOP, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, **18**, 643-662.
- TREISMAN, A. M. (1960). Contextual cues in selective listening. *Quarterly Journal of Experimental Psychology*, **12**, 242-248.
- TREISMAN, A. M., KAHNEMAN, D., & BURKELL, J. (1983). Perceptual objects and the cost of filtering. *Perception & Psychophysics*, **33**, 527-532.
- VAN DER HEIJDEN, A. H. C. (1981). *Short-term visual information forgetting*. London: Routledge & Kegan Paul.
- VAN DER HEIJDEN, A. H. C., LA HEIJ, W., & BOER, J. P. A. (1983). Parallel processing of redundant targets in simple visual search tasks. *Psychological Research*, **45**, 235-254.
- VAN DER HEIJDEN, A. H. C., SCHREUDER, R., MARIS, L., & NEERINCX, M. (in press). Some evidence for positively correlated separate activation in a simple letter-detection task. *Perception & Psychophysics*.

NOTE

1. In the analysis presented in the previous paragraphs, an important problem is left out of consideration: the separate activation versus coac-

tivation issue (see Miller, 1982, for a good introduction). In our experiments and also in Kahneman and Henik's (1981) experiments, on a number of trials two identical words or a word and a color having the same name were presented simultaneously. Separate activation models assume that activation from two or more channels remains separated in the processing system, so that each channel produces a response. It will be clear that the analysis we presented is based on this separate activation assumption. There is, however, an alternative set of models, the coactivation models, which assume that activation from separate channels can combine somewhere in the system. At the present, not very much can be said with regard to this alternative, because it consists mainly of a complex set of research questions concerned with problems such as: (1) whether coactivation can be demonstrated; (2) if so, in what types of tasks under what kinds of instructions it is found; (3) where in the system coactivation takes place (i.e., in what processing stage: recognition, decision, response); (4) at what level in a stage it occurs (i.e., if in the recognition stage, at the feature, letter, or word level); and (5) how activation combines (linear summation, weighted summation, summation after mutual reciprocal inhibition, etc.) In one of the few studies directly concerned with this issue, Miller (1982) stated that studies encouraging separate activation show that separate activation is possible. In a recent study (Van der Heijden, Schreuder, Maris, & Neerincx, in press), we found no evidence at all in favor of coactivation models in a simple letter search task. It therefore seems that our separate activation assumption is at least adequate as a starting point.

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