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Perceptual Load as a Necessary Condition for Selective Attention

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The early and late selection debate may be resolved if perceptual load of relevant information determines the selective processing of irrelevant information. This hypothesis was tested in 3 studies; all used a variation of the response competition paradigm to measure irrelevant processing when load in the relevant processing was varied. Perceptual load was manipulated by relevant display set size or by different processing requirements for identical displays. These included the requirement to process conjunctions versus isolated features and the requirement to perform simple detection of a character's presence versus difficult identification of its size and position. Distractors' interference was found only under low-load conditions. Because the distractor was usually clearly distinct from the target, it is concluded that physical separation is not a sufficient condition for selective perception; overloading perception is also required. This allows a compromise between early and late selection views and resolves apparent discrepancies in previous work.

While no one disputes the importance of selective mechanisms in mental processing, the locus of selection in the sequence of processing from perception to action remains to be resolved (see, for example, Francolini & Egeth, 1980; Johnston & Dark, 1982; Lambert, 1985; Pashler, 1984). The early selection approach, originally proposed by Broadbent (1958) and developed further by Treisman (1969; Treisman & Geffen, 1967), claims that perception is a limited process that requires selective attention to proceed. Consequently, attentional selection occurs early, after the rudimentary analysis of physical features, which are used to distinguish between selected and nonselected stimuli. As a result, unattended stimuli are not fully perceived. By contrast, the late selection approach advanced by Deutch and Deutch (1963, 1967) and Norman (1968) assumes that perception is an unlimited process, which can be performed in an automatic parallel fashion without need for selection. Selection according to this approach occurs only late in the process, after full perception, in order to provide the relevant response.

Although the debate on the locus of selection has stimulated a great deal of empirical work, this research has succeeded only in moving the pendulum of the debate from one side to the other. While initial studies offered support for the early selection approach (see, for example, Neisser, 1969; Snyder, 1972; Sperling, 1960; Treisman & Riley, 1969; Von Wright, 1970), from the late seventies onward the consensus shifted toward the late selection view (e.g., Keele & Neill, 1978; LaBerge, 1975; Logan, 1988; Miller, 1987; Posner & Snyder, 1975). As a result, the question of the locus of selection came to be restated as whether early selection was possible at all (e.g., Miller, 1991; Yantis & Johnston, 1990).

Kahneman and Treisman (1984) suggested that this change in emphasis from early to late selection was the result of a paradigmatic shift within the field of attention. They claimed that the experimental situations that characterized the pioneering studies of attention (e.g., Cherry, 1953; Sperling, 1960; Treisman & Geffen, 1967) were typically more complex than those of modern research (e.g., Keele & Neill, 1978; Neely, 1977; Posner, 1980; Posner, Snyder, & Davidson, 1980; Posner, Nissen, & Ogden, 1978; Schneider & Shiffrin, 1977). They presented a list of differences between the *filtering paradigm* (characterizing the early research) and the *selective set paradigm* (characterizing the modern research) and argued that the marked differences between these two paradigms may lead to the operation of different attentional mechanisms, thus, precluding any meaningful generalization regarding the locus of selection from one paradigm to the other.

In this article I examine further Kahneman and Treisman's (1984) suggestions by considering the role of perceptual load in selective attention tasks. I suggest that perceptual load is the major determinant of the occurrence of early or late selection and that consideration of this factor can resolve the apparent discrepancies between previous studies of the locus of selection.

Perceptual Load as a Determinant of the Locus of Selection

The assumption of some limitation or "bottleneck" in processing is crucial in the early and late selection approaches, as it is this limitation that is thought to produce the requirement for selection. The dispute is over the locus of this bottleneck in the sequence of information processing. However, even though Broadbent's (1958) classic filter model had a limited capacity channel as its central construct, the emphasis in subsequent research has tended to be

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on the role of physical distinctions between relevant and irrelevant information rather than on information load (e.g., Duncan, 1981, 1984; Humphreys, 1981; Nissen, 1985; Snyder, 1972; Tsal & Lavie, 1988, 1993). Clear physical distinction, however, proved to be insufficient for selective processing as there were numerous demonstrations of semantic effects from distractors that were clearly distinct from the target by means of location, color, or size, or a combination of these attributes (e.g., Eriksen & Schultz, 1979; Gatti & Egeth, 1978; Hagenaar & van der Heijden, 1986).

Accordingly, I suggest that physical distinction is a necessary but not a sufficient condition for selective processing. Clear physical distinctions allow relevant stimuli to be readily differentiated from irrelevant stimuli so that only the former are *responded* to. However, this differentiation does not in itself entail that the irrelevant items will be excluded from full perceptual *processing*. The cause for such exclusion is not physical distinction per se but overload of the perceptual system. Once the capacity limit is exceeded, selection of the information to be processed will be required.[1]

I suggest that it is only if the latter condition is met that selective processing will occur. Thus, according to this account, early selection is both the inevitable outcome of allocating attention from a limited pool (e.g., Kahneman, 1973; Navon & Gopher, 1979) and impossible to achieve when the capacity is not exceeded. When the relevant stimuli do not demand all of the available attentional capacity, irrelevant stimuli will unintentionally capture spare capacity, consequently enabling their processing. Hence, a substantial relevant information load constitutes a necessary condition for early selection.

This view proposes a compromise between the early and late selection approaches because it combines the assumption (of the early selection approach) that perception is a limited process with the assumption (of the late selection approach) that perception is an automatic process to the extent that there remains available capacity. Perception is automatic in this approach not in the sense that it does not require attention but in the sense that it is not subject to complete voluntary control (e.g., Jonides, 1981; Logan, 1988; Posner & Snyder, 1975). Perceptual processing is limited, but it proceeds automatically until the mechanism runs out of capacity. Hence, selection on this view is the natural consequence of allocating attention. To account for selective attention, we may just assume that voluntary control is restricted to determining priorities in the allocation of attention between relevant and irrelevant information (Bundesen, 1987, 1990; Yantis & Johnson, 1990; Yantis & Jones, 1991). However, any spare capacity beyond that taken by the high-priority relevant stimuli is automatically allocated to the irrelevant stimuli. Perceivers cannot reduce the amount of attention paid by inhibiting the allocation of attention. Such active inhibition may be restricted to processes that are later than perception[2] (e.g., Lowe, 1985; Neely, 1977; Neill, 1977; Neill & Westberry, 1987; Tipper, 1985; Tipper, MacQueen, & Brehaut, 1988).

This proposal allows more predictability for selective attention tasks: Conditions of load will determine whether perceptual processing will be selective or not, only loaded processes will be selective. Conditions of clear physical distinction between the relevant and irrelevant stimuli will determine only whether the selection will be the appropriate one.

Previous Research Reconsidered in Terms of Perceptual Load

The approach developed above explains why most research conducted since the late seventies has supported the late selection view; the reason is that the experimental situations involved low perceptual load, as defined by small display set size. By using variations of the Stroop task, Eriksen and Eriksen (1974), Gatti and Egeth (1978), Hagenaar and van der Heijden (1986), Kahneman and Henik (1981), Keren, O'Hara, and Skelton (1977), Miller (1987), Paquet and Lortie (1990), and others have found that irrelevant flankers are often identified. These studies used displays with usually no more than two different items: a target and a distractor. Research into the negative priming phenomenon has been conducted under analogous conditions (e.g., Allport, Tipper, & Chmiel, 1985; Tipper, 1985; Tipper & Cranston, 1985) and established similar results. The present claim is that all of these studies showed failure of early selection because they were conducted in situations of low load, which did not require early selection. As discussed previously, selection does not occur until capacity is exceeded. A more detailed account and analysis of contemporary results in the light of perceptual load is given in another article (Lavie & Tsal, 1994).

Manipulation of Perceptual Load in Selective Attention Tasks

A similar proposal to the present one was made by Treisman (1969). She suggested that the nervous system is forced to use whatever discriminative systems it has available, unless these are already fully occupied with other tests or

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[1] Note that the phrase *exceeding the capacity limit* need not imply that perceptual selection operates on the basis of a threshold point of transition from early to late selection. A gradual dilution in the distractor processing may be characteristic of load effects instead. The present study was not designed to investigate this issue but rather to establish initially that there is strong dependence between load of relevant information and selective perception of irrelevant information. Thus, I focused only on low and high levels of load and did not include levels that seemed intermediate.

[2] Perhaps it should be clarified at this point that *perception* as used here follows the conventional usage in the early versus late selection debate, namely referring to processes that lead to stimulus identification. Elaborative semantic activation, memory, response selection, and response execution are conceived as post-perceptual processes from this perspective. See Pashler (1989) and Pashler and Johnston (1989) for discussion of distinctions between perception, in this sense, and later processes.

inputs "so we tend to use our perceptual capacity to the full on whatever sense data reach the receptors" (Treisman, 1969, p. 296).

However, few attempts have been made to manipulate perceptual load in focused-attention tasks in connection with the question of early selection. One exception is a paper by Kahneman and Chajczyk (1983), who varied perceptual load in a version of the Stroop color task. They found that the compatibility effect of an irrelevant word was markedly reduced when either a second neutral word or even an array of *x*s was added to the display. Kahneman and Chajczyk concluded that the addition of an irrelevant neutral item reduced the resources available for processing of the incompatible distractor. This conclusion reflects theoretical reasoning similar to the present account, namely that irrelevant processing is limited and load dependent. However, the interpretation of their findings in terms of perceptual load is not unequivocal. In the displays used in Kahneman and Chajczyk experiments, the addition of a neutral irrelevant object not only increased perceptual load but may also have reduced the perceptual saliency of the irrelevant distractor. A single distractor in the periphery may have more power to attract attention than one of two peripheral distractors (Jonides, 1981). Similar results established under similar conditions were found by Dark, Johnston, Myles-Worsley, and Farah (1985).

Two recent studies searched for the optimal situation for the occurrence of early selection. The first manipulated the distinctiveness of the relevant stimuli by using the cuing paradigm. Yantis and Johnston (1990) measured identity effects of irrelevant items between valid and invalid cues that indicated target position in circular arrays loaded with eight different letters. When the target was validly cued, early selection was indeed obtained, as defined by the minimal effects from the identity of other letters in the display. However, it is difficult to reach firm conclusions on the role of perceptual load in this study as load was not varied; rather, a single high-load condition was used. In a further study, Johnston and Yantis (1990) manipulated the perceptual load of the display in a similar cuing paradigm to the study described above. They demonstrated that cuing the position of a target eliminated compatibility effects for irrelevant letters only under the condition of high load (circular array of eight letters); under the low-load condition (array of two letters), the cue was not effective in reducing the processing of the distractor. They concluded that "cluttered" displays were important for selection. This conclusion is in accordance with the load hypothesis advanced here. However, it remains possible that embedding the critical distractor letter in a compact circle with many others primarily had the effect of reducing its perceptual saliency or "orienting pull."

Miller (1991) more directly investigated the effect of perceptual load by comparing the compatibility effects of flanking distractors on response to a central target embedded in displays of two, four, or eight items. Miller found that the compatibility of the flanker affected response times only under conditions of low perceptual load, with a display size of two items. The elimination of the flanker compatibility effect cannot be attributed in this study to its reduced perceptual saliency with large display sizes because the letters were added only in a central circular array comprising the target and additional nontargets used to manipulate load, while the critical flanker appeared outside this circle and was very large.

All of these previously mentioned studies manipulated perceptual load by increasing display size. As a result, they usually involved substantial changes in the appearance of the displays, leading to difficulty in interpretation. The purpose of the present study was to achieve a more general and clearer conclusion concerning the role of perceptual load in the processing of irrelevant information.

General Method

In the interest of generality, in the following experiments I used several different manipulations of load, with the anticipation that they would all result in the elimination of distractor interference in high-load displays, thus providing converging evidence for the influence of perceptual load on irrelevant processing. In all of the experiments I used the Eriksen paradigm (e.g., Eriksen & Eriksen, 1974), which has been accepted as diagnostic of early or late selection, with the innovation that load in the relevant processing was manipulated. The participants were required to make a choice response to the identity of a target letter. This target always appeared in the central region of the display. A critical distractor that could be incompatible, neutral, or compatible in relation to the target response was located far from the target, above or below the center. Reaction times (RTs) to the target were measured as a function of the nature of the critical distractor and the load of the relevant processing in the task.

All the manipulations of load used in the present study changed the nature of the task in the center, without "touching" the peripheral distractor. The aim was to show that load in the processing of the relevant information determines the degree of processing of the irrelevant information and that this determination is not dependent on any change in the perceptual saliency of the irrelevant information (see earlier discussion in the Manipulation of Perceptual Load in Selective Attention Tasks section.

The critical distractor was always located relatively far from the target letter to allow a test of my claim that clear physical distinctions between relevant and irrelevant information are not sufficient alone for early selection to occur. This claim implies that even when a clear distinction between target and distractor exists, whether or not early selection takes place will depend mainly on the perceptual load of the task and will obtain only when load is high.

Operationalizing Perceptual Load

Perceptual load, though a term often used in attention research, is an abstract, if not vague, concept. The aim of the present research was not to investigate any specific formulation of load but to rely on conventional operational definitions. Because with the current hypothesis early selection requires load in *perceptual* processing, it seemed important to choose operational definitions that were more likely to load perceptual routines rather than postperceptual ones.[3] Thus, in Experiment 1, the relevant display set size of items among which the target appeared was manipulated (i.e., the number of items among which the target appeared). In Experiments 2A, 2B, and 3, I kept the high- and low-load displays physically the same but varied the processing that was required. All of the displays in the latter studies contained an additional shape situated near the target letter in the center, and the choice response to the letter was dependent on different requirements for the perceptual processing of this additional shape's properties. In Experiments 2A and 2B, the shape was colored, and load was manipulated in accordance with the feature integration theory of attention (e.g., Treisman & Gelade, 1980; Treisman & Sato, 1990; Treisman & Schmidt, 1982). Either the conjunction of this shape's color and form or just its color had to be processed in addition to the target letter to decide which response should be made to the target. In Experiment 2B I tested the hypothesis that physical distinction is a necessary albeit not sufficient condition for selective processing by comparing the effect of a near distractor (within 1° with the target) and a far distractor (more than 1° of separation from the target) under high and low relevant loads.

In Experiment 3 I tested the load hypothesis by using the traditional distinction between detection and identification as an additional load manipulation (e.g, Bonnel, Possamamai, & Schmitt, 1987; Bonnel, Stein, & Bertucci, 1992; Graham, 1989; Sagi & Julesz, 1985; Uttal, 1987). Participants were required to detect the presence of either a circle or a bar shape under the low-load condition and to identify the size and exact position of the circle and the bar shape under the high-load condition.

In all of these experiments I tested the hypothesis that the compatibility effects from the critical distractor would vary as a function of the perceptual load conditions of the relevant processing in each task. The prediction was that the identity of the critical distractor would affect the RTs to the relevant target only under conditions of low load in the central task; namely under conditions of small display size, simple detection, and single-feature processing rather than high display size, fine discrimination, and conjunction processing. Under the low-load conditions, the clear physical distinction between target and critical distractor should not suffice for selective processing, which should only be observed when there was also a high load in relevant processing.

In all cases, the processing of the distractor was measured by comparing conditions in which its identity was compatible, incompatible, or neutral with respect to the appropriate response for the current target letter. Incompatible distractors would be expected to produce interference relative to the neutral baseline when they are identified because of response competition. The predictions for compatible distractors were less clear. Because our compatible distractors *were always identical to the target*, their identification could be based on an early and presemantic detection of the physical match to the target. This stage of processing may not require full identification and may not, therefore, indicate true late selection. Moreover, it is unclear what effects on RTs should be predicted when the distractor is identical to the target. Matching of the physical features may cause both interference because of feature-specific inhibition (cf. Bjork & Murray, 1977; Estes, 1972; Santee & Egeth, 1982) and facilitation because of redundancy gain effects on signal activation, response selection, or both (e.g., Eriksen & Eriksen, 1979; Eriksen, Gottel, St. James, & Fournier, 1989; Flowers & Wilcox, 1982; Grice, Canham, & Gwynne 1984; Miller, 1982; Santee & Egeth, 1982). Fortunately, these problems of interpretation do not apply to the incompatible conditions in which interference as a result of distractor identification can unambiguously be predicted. Accordingly, my conclusions are primarily based on the effects of incompatible distractors as compared with neutral distractors. Compatible distractors had to be included to prevent any predictable relation between distractors from the response set and the particular target shown because any such correlations are known to affect performance (Miller, 1987).

Experiment 1

The traditional way to increase task load is by having larger display sizes (see Duncan, 1980; Johnsen & Briggs, 1973; Kerr, 1973; Navon, 1989). Displays with a larger number of items involve a direct increase in the amount of the information presented. The purpose of Experiment 1 was to investigate the effect of an irrelevant distractor in a version of the Eriksen paradigm (Eriksen & Eriksen, 1974) that involved manipulation of the display set size for the target task. Each display contained a target and a critical irrelevant distractor. The distractor could be compatible, incompatible, or neutral in relation to the target response, and it was physically distinct from the target by being larger in size and situated in remote and irrelevant positions. The variable of perceptual load had two levels: low perceptual load consisted of relevant display size one (Condition S1), and high perceptual load consisted of relevant display size six (Condition S6). In Condition S1, the target appeared in one out of six possible positions, whereas the other five positions were empty. In Condition S6, the five other positions were occupied by five neutral letter nontargets (with

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[3] Manipulations of memory load, and of number of alternatives for response, were not chosen for this reason. It is possible to advance a more general version of the load hypothesis that would also apply to processes that are considered to be later than perception. For example, the extent of semantic activation and of memory for irrelevant information may also depend on load in relevant processing at these levels. It seemed, however, more relevant for the early versus late selection debate to establish first the load hypothesis for the process of shape identification. Note also that a load manipulation such as increasing the number of alternatives might weaken the stimulus–response associations in the task and thus reduce distractor compatibility effects without necessarily affecting distractor perception.

no associated response in the experiment). Examples of the displays are given in Figure 1.

The hypothesis of this experiment was that the load in the relevant task would determine the ability to ignore the irrelevant distractor. Under Condition S1, the processing of the target should leave spare capacity, which will be unintentionally allocated for the processing of the irrelevant distractor. Under Condition S6, searching for the target among five nontargets should load attentional capacity and leave no spare capacity for the irrelevant processing. Therefore, interference from the critical distractor was expected under S1 and was not expected under S6.

Method

Participants. The participants were 14 undergraduates from the University of California, Berkeley, who participated to fulfill a course requirement. All had normal or corrected-to-normal vision.

Apparatus and stimuli. An IBM PC compatible computer attached to a VGA color monitor presented the stimuli and recorded the response latencies. The software used for creating and running the experiments was Micro Experimental Laboratory (MEL), sold by Psychology Software Tools, Inc. (Schneider, 1988).

A target letter, which could be either *x* or *z*, appeared randomly and equiprobable at one of six positions arranged in a row, located at the center of the display. The target letter appeared alone in Condition S1 or was accompanied by five nontarget letters (*k, s, m, v,* and *n*) in Condition S6. These five nontargets occupied the other positions in the central row equally often in a random order. The target and nontarget letters were presented in lowercase, and at a viewing distance of 60 cm, they subtended a visual angle of 0.70° vertically and 0.4° horizontally and were separated by 0.65° from nearest edge to edge. A critical distractor of a larger size, subtending a visual angle of 0.96° vertically and 0.48° horizontally, appeared randomly and equiprobable either above or below the center. The distance between the distractor edge and the fixation point was 1.9° so that the separation between the distractor and the central row letters (from edge to edge) varied from 1.40° of distance for the two central letters to 2.10° and 2.90° of separation for the two intermediate and two end letters, respectively. All of the letters were presented in a light grey color (No. 7 in the MEL color palette) on a black background. The critical distractor was equally likely to be incompatible (the capital letter *X* when the target letter was *z*, or vice versa), compatible (the capital letter *Z* when the target letter was *z*, or likewise for *x*), or it could be neutral in relation to the targets (the capital letter *P*, which had no defined response in the experiment). Each of the distractor categories appeared equally often with each of the target positions. Seventy-two displays were created according to these specifications.

Procedure. Before each display, a light grey fixation dot appeared at the center of the display for 1 s. This was immediately replaced by the target display, which appeared for approximately 50 ms. Participants used the numerical keys on the right-hand side of the computer keyboard for their responses. They were required to press the zero key with their thumb for the target letter *z* and the number two key with their index finger for the target letter *x* as fast as they could while avoiding errors. Feedback on errors was given by a 500-ms computer tone. Participants were also emphatically instructed to ignore the irrelevant distractor and were informed about the occasional presence of incompatible distractors and their

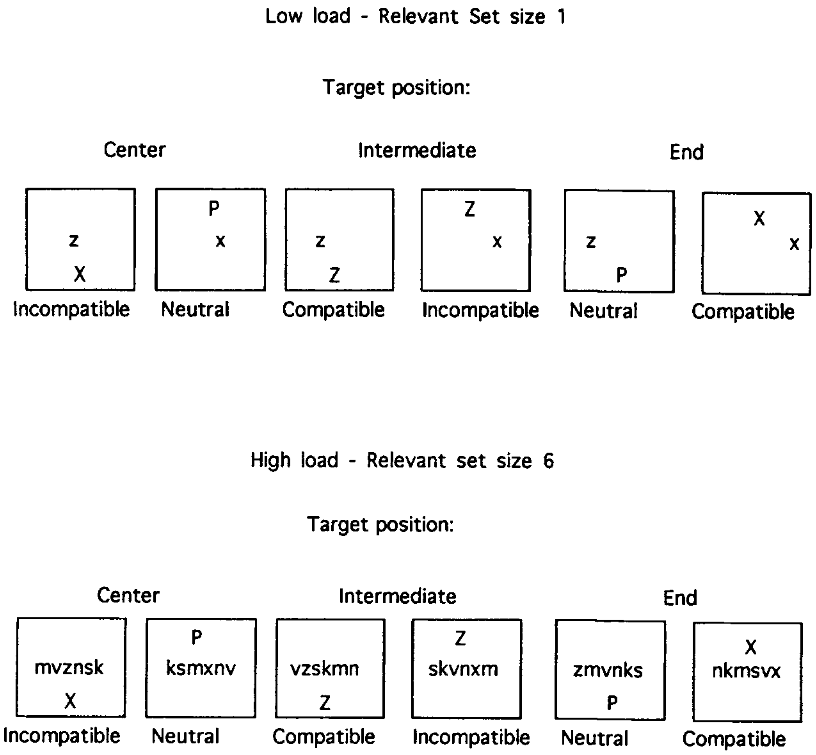

Figure 1. Examples of stimuli used in Experiment 1.

possible detrimental effect on performance if they were not ignored. The S1 and S6 conditions appeared in separate blocks in alternate fashion. Half of the participants got the S1–S6 order, and half of the participants got the reverse S6–S1 order. Each participant passed through 10 blocks of 72 trials each. The first 2 blocks were discarded as practice and their results were excluded from analysis. An intermission of 5 min was given after the first 6 blocks. The participants initiated each block by pressing the space bar. The order of the trials within blocks was randomized with no repetitions.

Results and Discussion

Median RTs were computed for each participant as a function of the display set size and the nature of the critical distractor (compatible, neutral, or incompatible). Response latencies longer than 2 s were excluded from analysis. The averages across participants are presented in Table 1 together with the associated error rates.

A two-way within-subject analysis of variance (ANOVA; Set Size × Distractor Type) on the RT data showed a main effect of the set size, $F(1, 13) = 144, p < .001$, confirming that perceptual load was effectively manipulated. To reveal the possible interference and facilitation effects of the distractor identity, I conducted pairwise comparisons of incompatible with neutral distractors and compatible with neutral distractors by an ANOVA. As noted previously, my main concern was with the possible interference effects of incompatible distractors relative to the neutral condition because only these unambiguously specify the level of processing of the distractor.

In the analysis of incompatible versus neutral conditions, set size interacted significantly with the type of distractor, $F(1, 13) = 5.93, p < .03$, in accordance with the load hypothesis. The interference effect from the incompatible distractor was significant only under the low-load condition of S1, $F(1, 13) = 7.62, p < .02$ ($F < 1$, in the S6 condition).

In the separate comparison of identical distractors with the neutral baseline, the identical distractor produced only a main effect of facilitation, $F(1, 13) = 7.38, p < .02$, which did not interact with the set size ($F < 1$). However, the facilitation effect was more consistently obtained under the S1 condition, as it was only significant for this, $F(1, 13) = 8.68, p < .01$, ($p > .10$, under S6).

Table 1
The Intersubject Means of Reaction Times (in Milliseconds), Standard Errors, and Percentage of Errors as a Function of Distractor Compatibility and Task Load

Task load	Distractor identity				
	I	N	I − N	C	N − C
Low					
M	501	461	40[a]	452	9[a]
SE	22	13		11	
%E	4.1[a]	1.9		1.5	
High					
M	613	609	4	594	15
SE	19	22		17	
%E	5.4	2.9		4.4	

Note. I = incompatible; N = neutral; C = compatible; %E = percentage of error.
[a] Indicates significant effects of the pairwise comparisons with the neutral conditions.

Analysis of errors. A two-way ANOVA (Set Size × Distractor Type) showed a main effect of load on the number of errors, $F(1, 13) = 10.52, p < .006$.

Pairwise comparisons of the incompatible and of the compatible distractor with the neutral baseline showed that the interference effect from incompatible distractors on the percentage of errors was obtained only under the low-load condition, $F(1, 13) = 9.66, p < .01$. There were no other significant effects in the analysis of errors ($p > .10$ in all of the other comparisons).

Effect of target positions on distractor processing. The target letter could appear in six different positions. There were two central positions: two end positions and two intermediate positions. The central targets were situated 0.53° from fixation, the intermediate and end targets were 1.6° and 2.65°, respectively, from fixation. The variable of target positions also involved a difference in separation between target and distractor, which varied from 1.3°, 2.1°, and 2.9° from edge to edge for the central, intermediate, and end positions, respectively. A three-way ANOVA was conducted on the variables of target position, load, and distractor type for incompatible versus neutral distractors.[4] The three-way interaction between the variables of target position, load, and distractor type did not reach significance ($p > .10$), which is why the results of the load effect on distractor processing were reported pooled across the target positions. However, target position did have a main effect on the overall RTs $F(2, 12) = 19.94, p < .001$, which tend to increase as the foveality of the target decreased. The overall RTs were 511, 552, and 606 for the central, intermediate, and end positions, respectively. Table 2 presents the distractor interference effects as a function of the target position.

A significant two-way interaction was found between the target position and the distractor effect, $F(2, 12) = 17.36$, $p < .001$. As can be seen from Table 2, the irrelevant distractor tended to produce more interference in the case of more peripheral targets.

Thus, the results of the position analyses seem to be in agreement with Eriksen and Schultz's (1979) conclusion that distractor effects tend to be stronger for degraded targets. They showed that reducing the target size or contrast increased the interfering effects of irrelevant distractors. The present results are important in showing the contrast between the effects of relevant information load and data quality. Loading the perceptual system with more information enabled participants to avoid irrelevant processing in the present study. However, the reduction in retinal

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[4] A similar three-way ANOVA (Target Position × Load × Distractor) was also conducted on the compatible distractor versus the neutral baseline. Only the main effect of facilitation and the interaction of position and load were significant in this analysis ($p > .10$ in all the other comparisons).

Table 2
Distractor Interference on Reaction Times (in Milliseconds) as a Function of Load and Target Positions

	Low load			High load		
Position	I	N	I − N	I	N	I − N
Center						
M	475	453	22	555	562	−7
SE	19	15		20	20	
Intermediate						
M	504	464	40	626	614	12
SE	23	14		21	27	
Edge						
M	558	476	82	705	684	21
SE	31	15		29	32	

Note. I = incompatible; N = neutral.

acuity of more peripheral targets made them more prone to irrelevant interference. Because more peripheral targets took a longer time to be processed, it may be that the prolonging of the relevant processing increased the chance of distractor intrusion during the accumulated time (e.g., Eriksen & Schultz, 1979; Navon, 1989).

The fact that the significant increase in overall RTs because of target eccentricity had an independent effect that was the reverse of the load effect in the present study seems to be in clear contrast with a claim by Miller (1991). He claimed that it is the higher overall RT, which is typically confounded with increases in the display size, rather than the higher load itself that causes the elimination of distractor effects because of a dissipation of the effect in time. Miller showed that when the distractors' appearance was delayed, they were processed under high-load conditions. However, his stimulus onset asynchrony manipulation, intended to retard the processing of the flanker, was confounded with its abrupt onset or offset, which has been shown to capture attention (Jonides & Yantis, 1988; Kahneman, Treisman, & Burkell, 1983; Yantis & Jonides, 1984, 1990). Thus, the processing of the flanker could have resulted from the automatic allocation of attention to its location.

In this study, the increase in overall RTs with more peripheral target locations did not involve any change in the appearance of the distractor. Under these conditions a significant increase in the overall RTs actually increased the distractor effect rather than eliminating it, as long as an increase in load was not involved.

The target-to-distractor distance was confounded with retinal acuity in this study, preventing any clear conclusion about its influence on the distractor processing. However, the present results do demonstrate that clear physical distinction between target and distractor (defined by their spatial separation and size) is not sufficient in itself to eliminate distractor processing. The distractor was processed under all conditions of target-to-distractor separation in the low-load displays. Note that the nearest target-to-distractor separation was still "far" in spotlight terms (e.g., Eriksen & Hoffman, 1972, 1973). The spotlight results were usually obtained in crowded displays equivalent to the high-load conditions of the present study. The results obtained under the low-load condition of the present study seem to be in accordance with the studies of Murphy and Eriksen (1987), Hagenaar and van der Heijden (1986), and Merikle and Gorewich (1979), which showed no effect of target-to-distractor separation on the distractor effect. Note that all of these studies were characterized by low-load situations.

In summary, the pattern of results of the present study gave clear support to the hypothesis that the load involved in target processing determines the extent of processing for an irrelevant distractor. This conclusion was found to be independent of target-to-distractor separation, the stimulus quality of the target, and the overall RTs.

Experiments 2A and 2B

The following experiments further tested the load hypothesis by using load manipulations that did not involve any change in the appearance of the displays. In Experiment 1, the manipulation of the relevant set size did involve a change in the appearance of the displays. This change should not have had any effect on the saliency of the peripheral distractor given its distance from the central target region. However, some confounding variables may still have been involved. One might say, for example, that the perceptual difference between the target and the irrelevant distractor was more pronounced in S6. The neutral nontargets accompanying the target in the center of the S6 displays might be grouped perceptually with the target by proximity and similarity in size, resulting in a stronger perceptual segregation between the target and the critical distractor (see Driver & Baylis, 1989; Kahneman & Henik, 1977; Prinzmetal, 1981; Prinzmetal & Banks, 1977).

In the following experiments I manipulated the processing demands for displays that were identical in their appearance. This was intended to emphasize the role of processing load in resource terms, with no effect on the data conditions of the stimuli. The manipulation of load was adapted from feature integration theory (Treisman & Gelade, 1980; Treisman & Sato, 1990). According to feature integration theory, perception of features is load free, and it is only their conjunctions that require the focusing of attention and therefore impose perceptual load. Treisman has used several converging operations that provide support for this claim: The phenomenon of illusory conjunctions (Treisman & Paterson, 1984; Treisman & Schmidt, 1982) and studies of visual search (Treisman, 1991; Treisman & Gormican, 1988; Treisman & Gelade, 1980) have generated the most widespread and persuasive examples. Although it has been sometimes disputed (e.g., Navon, 1990; Tsal, 1989; Wolfe, Cave, & Franzel, 1989), feature integration theory seems currently the best explanation for a wide range of selective attention studies. Thus, manipulating the requirement to process features versus conjunctions has the advantage of implementing a well-established operational formulation of perceptual load.

I manipulated the perceptual load in the present experiment by requiring two different forms of processing for an additional shape presented next to the target letter while maintaining an identical display. The target appeared in the center of the display with to its right or left side a colored shape that could either be a circle or a square, with either a blue or a red color. As in Experiment 1, the participants made a choice response to the target letter. An irrelevant critical distractor that could be compatible, neutral, or incompatible in relation to the target response appeared above or below the center, as before. However, in this experiment the response to the target was also dependent on the color feature of the closely flanking shape (in the condition of feature demand) or on the conjunction of its shape and color features (in the conjunction demand condition). In the feature demand condition participants had to make their choice response to the target letter when the color of the additional shape was blue and to withhold response when it was red, no matter whether the shape was a circle or a square; that is, a go/no-go procedure contingent on the additional item determined whether the choice response should be made to the target letter. On 25% of the trials, randomly intermixed with the other trials, the no-go color appeared. In the conjunction demand condition, either a blue square or a red circle had to be present for a response to be appropriate, and participants had to withhold response to the opposite conjunctions (i.e., a blue circle or a red square). Thus, participants now had to process the specific conjunction of color and shape for the additional item rather than simply its color. On 25% of the trials, the no-go conjunctions appeared (see Figure 2).

I predicted that the level of perceptual load manipulated by the demand of the task would determine the degree of processing of the irrelevant distractor. While the understanding of the mechanisms of feature integration and of why it poses such a demand on attention may not be clear, few would dispute that the conjunctive processing of two features in addition to the target letter should be more demanding than processing a single color feature. Thus, in the feature demand condition, the color feature should be detected with little or no increase in the load of relevant processing, leaving spare capacity to spill over automatically to the critical distractor. Under the conjunction demand condition, the task of recognizing the appropriate conjunctions in the very same displays should impose much more of a demand on attentional capacity, leaving considerably less for the irrelevant distractor and hence reducing interference effects.

Experiment 2A

Method

Participants. The participants were 14 undergraduates from Tel-Aviv University who participated to fulfill a course requirement. All had normal or corrected-to-normal vision.

Apparatus and stimuli. The stimuli were presented by a four-field Gerbrands tachistoscope. A colored shape and a black target letter were situated in the center of each display, with 0.70° of contour-to-contour separation between them. Each of these stimuli appeared with equal probability and in random arrangement either

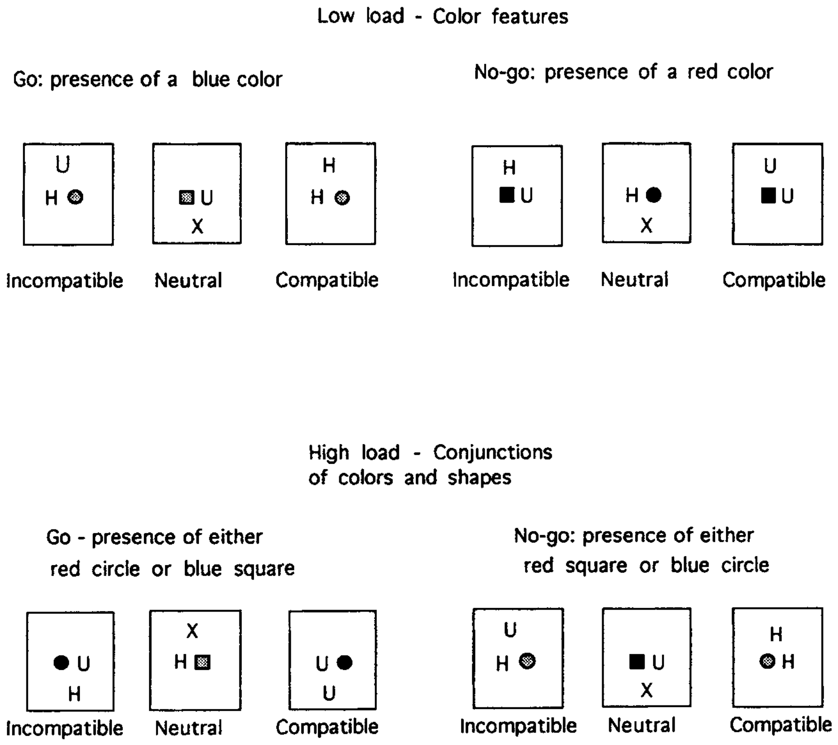

Figure 2. Examples of stimuli used in Experiment 2A. Black = red; dotted texture = blue.

to the left or to the right side of fixation. The target letter was either the capital letter *H* or *U*, and it subtended a visual angle of 0.36° vertically and 0.25° horizontally. An irrelevant distractor of a larger size, subtending a visual angle of 0.50° vertically and 0.36° horizontally, appeared randomly and equiprobably either above or below the center, separated by 1.30° of visual angle from the nearest contour of the central stimuli. The distractor letter was equally likely to be incompatible (the letter *U* when the target letter was *H*, or vice versa), compatible (the letter *H* when the target letter was *H*, or likewise for *U*s), or it could be neutral in relation to the targets (the letter *X*, which had no defined response in the experiment). In the feature demand condition, the color of the shape was blue on 75% of the trials or red on 25% of the trials. For each of the colors, the shape could equally probably be a square or a circle. In the conjunction demand condition, either a blue square or a red circle appeared on 75% of the trials, and either a red square or a blue circle appeared on 25% of the trials. The order of the colors, shapes, their locations, and each of their combinations was random with the constraint that none was repeated more than three consecutive times.

Procedure. Before each display a black fixation point appeared at the center of the display for 1 s. This was immediately replaced by the target display that appeared for 100 ms. The participants were required to press one of two buttons as fast as they could on go trials while avoiding errors. Half of the participants were asked to respond with their dominant hand to the target letter *H* and with the nondominant hand to the target letter *U* (the other half received the opposite instruction). Participants were also emphatically instructed to ignore the irrelevant distractor. The conditions of task demand were arranged in blocks consisting of 48 display cards. Each condition was run in one session consisting of three repetitions of the condition block. An intermission of 5 min separated the two sessions. The order of the sessions was counterbalanced between subjects. In addition to the choice RT instructions, participants were requested to pay attention to the color of the shape (in the feature demand condition) or to the relevant conjunctions of color and shape (in the conjunction demand condition) and to respond to the target only when the appropriate feature or conjunctions appeared. This instruction was emphasized and participants received feedback on their errors. Each session began with 24 practice trials, except for the participants who got the conjunction demand condition in the first session, for which they received 48 practice trials.

Results and Discussion

The results of Experiment 2A are discussed with the results of Experiment 2B.

Experiment 2B

In Experiment 2B I tested whether selective processing under high-load conditions is dependent on the spatial separation between the target and distractor and can only be obtained with far distractors. Spotlight studies have found that selective perception did not occur for items that were within an area of 1° from the target (e.g., Eriksen & Hoffman, 1972, 1973). These results were obtained under situations of high load as defined by set size. Thus, it may be that a minimal physical separation is required for elimination of distractor interference in addition to high load. In other words, it may be that physical separation between stimuli is a necessary condition for selective attention to occur, even though it is not sufficient without high load in the relevant processing.

If adequate distractor separation is a necessary condition for selective processing, then a very near distractor should be processed even when the processing load is high.

Method

Participants. Eighteen new participants from the same pool as Experiment 2A were tested in Experiment 2B. (None of these participants participated in Experiment 2A.)

Stimuli and procedure. The stimuli and procedure were identical to those of Experiment 2A, except for the following changes. In Experiment 2B I reversed the role of go and no-go attributes, thus participants were required to respond to the red color under the feature demand condition and to either a red square or a blue circle under the conjunction demand condition.

Half of the displays included a very near distractor that was placed above or below fixation and was separated by 0.7° of visual angle from the nearest contour of the central stimuli and subtended 0.43° vertically and 0.29° horizontally. These displays were randomly mixed with the original displays from Experiment 2A.

Each participant passed through four blocks of 48 trials for each task. Half the participants performed the feature task in the first session, whereas half began with the conjunction task.

Results and Discussion

The means of the RTs were computed for each participant of Experiment 2A as a function of the task demand (feature demand or conjunction demand), distractor identity, and presentation order, which was a between-subjects variable according to whether the function demand session or the conjunction demand session was first.[5] A three-way mixed ANOVA conducted on these variables showed no effect of the presentation order and no interaction involving this variable ($p > .10$ in all cases). Thus, the presentation orders were pooled for further analyses. Table 3 shows the averages of RTs and error rates across participants and orders.

To increase the statistical power, I included in the current analyses the conditions with the far distractor for both feature demand and conjunction demand tasks of Experiment 2B, which were equivalent to those of Experiment 2A. A two-way ANOVA (Task Demand × Distractor Type) of the RT data showed a main effect of the task demand, $F(1, 31) = 507.7, p < .001$, demonstrating that perceptual load was effectively manipulated.

In the analysis of the incompatible distractors versus the neutral baseline, there was an interaction between task demand and the distractor type, $F(1, 31) = 3.94, p < .056$. In accordance with the predictions of the load hypothesis, the interference effect was significant only under the low-load

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[5] In the following experiments I used the mean RTs for each participant rather than the medians, as the increase in number of go/no-go errors under the high-load conditions resulted in a different number of responses in between conditions (see Miller, 1988).

Table 3
Mean Reaction Times (in Milliseconds), Standard Errors, and Percentage of Errors as a Function of Distractor Compatibility and Task Load in Experiments 2A and 2B

	Distractor identity				
Task load	I	N	I − N	C	N − C
Low					
M	633	617	16[a]	612	5
SE	15	15		14	
%E	1.6	0.7		1.3	
High					
M	959	966	−7	994	−28[a]
SE	25	25		27	
%E	2.6	2.8		1.9	

Note. $n = 32$. I = incompatible; N = neutral; C = compatible; %E = percentage of error.
[a] Indicates significant effects of the pairwise comparisons with the neutral conditions.

condition of feature demand, $F(1, 31) = 6.8, p < .01$, ($F < 1$, under conjunction demand condition).

A comparison of the compatible distractors with the neutral baseline also showed an interaction between the task and the distractor type, $F(1, 31) = 7.21, p < .01$. This interaction seems to reflect the opposite trends of compatible distractors under the different load conditions (see Table 3). The compatible distractors produced interference in RTs in the high-load conjunction demand condition, $F(1, 31) = 7.93, p < .008$, and the facilitation trend observed under the low-load condition did not reach significance ($F < 1$). The present RT cost for compatible distractors is not discussed as there was an opposing trend in the analysis of errors (described below), making the relative performance in compatible and neutral conditions difficult to assess unambiguously. However, as noted previously, compatible effects are difficult to interpret in terms of the level of processing for the distractors, as they were physically identical to the target, so any effect they might produce could arise at the level of physical features. Indeed Bjork and Murray (1977) have previously argued that compatible distractors produce interference at such level.

Analysis of errors. Both pairwise comparisons of the incompatible and of the compatible distractor with the neutral baseline showed a significant load effect on the percentage of errors ($p < .01$). The analysis of the incompatible distractor interference on the percentage of errors showed that a decrease in the accuracy of the choice responses with incompatible distractors was obtained only under the low-load condition of feature demand. Although this result was only marginally significant, $F(1, 31) = 3.49, p < .07$, it is of course consistent with the RT data on interference from incompatible distractors. Pairwise analysis of the error data for the compatible versus neutral distractors showed an interaction between the load and distractor facilitation effect, $F(1, 31) = 6.82, p < .01$, which seemed to reflect the opposite trends from those obtained with the RTs analysis (see Table 3). Thus, it may be that the distractors identical to the target caused some trade-off between speed and accuracy. A full consideration of the effects of compatible distractors is presented in the *Discussion of the identical distractors' effect* section after the experiments that follow.

The analysis of errors in the go/no-go task (i.e., failing to respond to the relevant feature or to the relevant conjunctions or responding to the wrong feature or to the wrong conjunctions) replicated the difficulty of the conjunction demand condition. The accuracy of the go/no-go in the conjunction demand task was 93%, and the corresponding accuracy of the FD-go/no-go task was 99%.

Effect of target–distractor separation. A three-way ANOVA analysis on the incompatible distractor interference for the RTs of Experiment 2B was conducted. The distance variable neither interacted with the interference effect nor interacted with the variables of load plus distractor interference ($F < 1$, in both cases). Only the two-way interaction of load and interference effect was significant, $F(1, 17) = 4.24, p < .055$.

Thus, it seems that the distractor-to-target-distance did not change the effect of load on incompatible distractor processing. (The interference effects for the incompatible distractors of Experiment 2B under the low and high loads, respectively, were 12 ms and −5 ms for the far distractors and 7 ms and −8 ms for the near distractors.) However, a definitive conclusion as to whether physical separation is a necessary condition, albeit insufficient, for selection cannot be obtained from the present study, as the analysis of the compatible distractor effects did show an interaction of distance with the load plus distractor variables, $F(1, 17) = 6.96, p < .02$. This interaction showed that the distractor-to-target distance mattered for the compatible distractor effect only under the high-load conditions. Under the low-load conditions there was no difference between far and near compatible distractors ($F < 1$), which had 10 ms of facilitation effect on average. However, under the conditions of high load, the effect of compatible distractors interacted with distance from target, $F(1, 17) = 8.57, p < .01$, and simple effects analysis of the high-load conditions revealed a significant 58 ms facilitation in RTs with very near compatible distractors. (The far distractors had the reverse effect of interference as noted earlier.)

Pairwise analyses of the error data for the compatible versus neutral distractors in Experiment 2B did not show an interaction of the distractor effects with distance from the target ($p > .10$, in all analyses).

The facilitation of RTs by near compatible distractors may indicate that the amount of resource left under the conjunction demand condition was sufficient only for a more raw processing of the very near distractor shape. This interpretation is more congruous with the zoom lens rather than spotlight description for spatial attention (i.e., Eriksen & St. James, 1986; Eriksen & Yeh, 1985), as it seems to demonstrate the flexibility in both size and power of the attentional lens. A loading demand caused attentional resources to spread over a smaller distance, in which only crude irrelevant processing was allowed. However, this suggestion is tentative given the inconsistency of compatible distractor effects observed under the present studies.

The conclusion from Experiments 2A and 2B is more definitive with regard to the effects of the far distractors. The present studies showed that load in the processing of relevant information determines the interference produced by incompatible irrelevant information. The latter was found only under the low-load conditions. It seems that a demand to process just the color feature left extra capacity that spilled over to the irrelevant processing. This irrelevant processing was only excluded when the task demanded processing of conjunctions of features. Note that this result was found with a manipulation of load that did not involve any change at all in the appearance of the displays. The results of this experiment cannot therefore be attributed to any change in the data quality of the target or the distractor (e.g., their physical distinctiveness) or the distinction between their perceptual groups. Thus, manipulating selective attention by instruction alone can load the relevant information processing sufficiently for the elimination of irrelevant distraction, without any change in the stimuli.

Experiment 3

The purpose of Experiment 3 was to provide another operational characterization of load that does not involve any change in the appearance of the stimuli. One of the classic distinctions in the literature on perception is between detection and identification (see Graham, 1989, for an extensive review of the two paradigms). Simple detection of stimulus presence has been found to be a very simple task indeed and usually shows flat RT functions with set size (see, e.g., Bonnel et al., 1992; Sagi & Julesz, 1985; Treisman & Gelade, 1980). Identification, on the other hand, can be more demanding (e.g., Bonnel et al., 1987; Bonnel et al., 1992), and be made very difficult as the similarity between the possible identities increases (see Duncan & Humphreys, 1989).

In Experiment 3 I used a go/no-go task, similar to that of Experiments 2A and 2B. The target letter appeared flanked by an additional character in the center of the display, and an irrelevant distractor letter appeared above or below the center. The additional character could either be a circle or a short line. Participants made a choice response to the target letter by pressing one of two keys with their right hand and were asked to ignore the irrelevant distractor letter. This choice response was sometimes to be withheld, depending on certain properties of the flanking character. Load was manipulated by different instructions for the go/no-go task. Under the condition of low load, a simple detection of the character's presence was required. Participants were asked to respond to the target letter only when it was flanked by the circle or line. On some trials neither additional characters appeared, and the participants were required to withhold response to the target letter on those trials and press the space bar with their left hand instead. Under the high-load condition, participants were required to judge the size of the line or the exact position of the circle. On the positive go trials, the line or circle had the size and position that it had under the low-load condition, that is, the displays were identical. Only the negative no-go trials differed. On these trials the line was slightly longer than the usual size, and the circle was positioned slightly more to the right or left from the regular position of both characters (see Figure 3). Thus, participants had to monitor the position and size of the characters to maintain correct performance under the high-load task. Note that the load manipulation in this task again changed only the processing requirements for identical displays.

Method

Participants. Eighteen undergraduates from the University of California, Berkeley, served as paid participants. All had normal or corrected-to-normal vision. Participants who did not exceed 50% accuracy in the go/no-go identification task were excluded from analysis and replaced with new participants. Only one such participant was replaced.

Apparatus and stimuli. Stimuli and apparatus were similar to those used in Experiment 1, except for the following changes. The target letters could be either *X* or *N,* and the distractor letters could be *X, N,* or *P* (for the neutral condition). All of the letters used were capital letters, and at a viewing distance of 60 cm they subtended a visual angle of 0.96° vertically and 0.48° horizontally. The distance between the nearest distractor edge and fixation point was 1.80° (resulting in 1.32° separation from the nearest edge of the target letter). On the positive trials for both detection and identification go/no-go tasks, a small circle with diameter of 0.30 cm (subtending about 0.29°) or a small line subtending the same length appeared on the right side of the target separated by a 0.80 cm from the letter edge. The line and circle characters did not appear in the negative trials of the detection task (which were identical otherwise to those of the positive trials). On the negative trials of the identification task, either the line subtended 45 mm or the circle appeared at an unusual location, equiprobably 6 mm from the nearest edge of target letter or 10 mm. Seventy-two displays were created for each task according to these specifications.

Procedure. The procedure was similar to the procedure of Experiment 1, except for the following changes. The load conditions were blocked and run in separate sessions with an intermission of 5 min in between them. The order of the load sessions was counterbalanced between participants. Each session consisted of four experimental blocks of 72 trials each. Two thirds of trials in each block were positive go trials, and one third were of no-go trials. The types of distractor appeared equally often in a random order with all of the possible combinations of character identity. Participants started each session with a practice block of 48 trials. In addition to the instructions for the choice responses to the target letter, participants were requested to pay attention to the presence–absence of the additional characters in the detection task or to the size and position of the characters in the identification task. They were asked to respond to the target only when the positive attributes of the characters appeared. This instruction was emphasized and participants got feedback on their errors throughout the experiment, in both the go/no-go and choice response tasks, by using a 500-ms computer tone.

Results and Discussion

The means of the RTs were computed for each participant as a function of the task demand and the distractor type. Response latencies longer than 3 s were excluded from

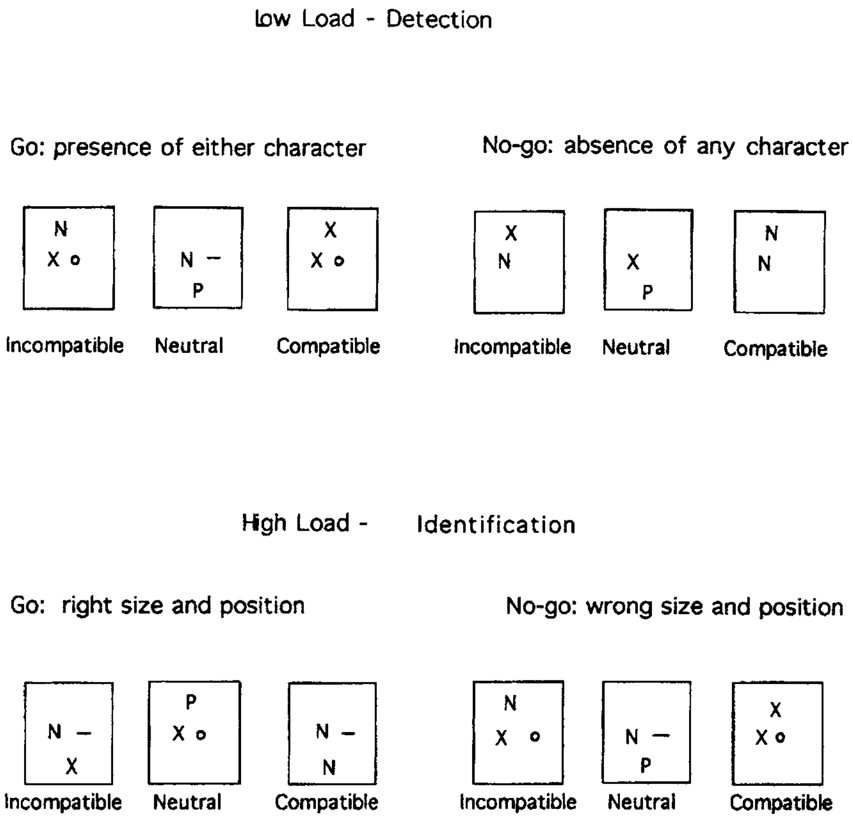

Figure 3. Examples of stimuli used in Experiment 3.

analysis. The averages of RTs and error rates across participants are presented in Table 4.

A three-way mixed ANOVA (Task Demand × Distractor Type × Tasks presentation order) showed no effect or any interaction involving the presentation order variable ($p > .10$ in all of the comparisons), thus, the presentation orders were pooled for further analyses. A two-way ANOVA on the RT data showed a main effect of task demand, $F(1, 17) = 162.75$, $p < .001$. Pairwise analyses showed a significant interaction between the task demand and the incompatible distractor interference, $F(1, 31) = 4.55$, $p < .048$. The interference effect was significant only in the low-load detection task, $F(1, 17) = 19.39$, $p < .001$, ($F < 1$, in the discrimination task). This result clearly supports the load hypothesis.

The compatible distractor did not have any significant effects under any of the load conditions ($p > .10$). However, the opposed direction of the trends under the two load conditions (i.e., facilitation under the high load and interference under low load) was significant, $F(1, 17) = 5.03$, $p < .04$. Further inspection of the individual data revealed that the trend of facilitation under the high load was largely due to the slowest participants of the pool. Three participants were slower by more than 230 ms relative to the average RT, which was 924 ms (they were at 1.6–1.7 standard deviations from the mean). Their overall RTs were 1,181, 1,178, and 1,163 ms. Exclusion of these participants from analysis eliminated completely the facilitation effect of the identical distractor, under the high load (from 31 ms to 2 ms), and did not change the strength of the interference effect of the incompatible distractor (which was 30 ms without these slowest participants).

Table 4
Mean Reaction Times (in Milliseconds), Standard Errors, and Percentage of Errors as a Function of Distractor Compatibility and Task Load in Experiment 3

	Distractor identity				
Task load	I	N	I − N	C	N − C
			Detection		
Low					
M	737	705	32[a]	720	−15
SE	34	32		33	
%E	3.1	2.6		2.8	
			Identification		
High					
M	1,157	1,153	4	1,122	31
SE	49	52		39	
%E	8.5	9.3		8.8	

Note. I = incompatible; N = neutral; C = compatible; %E = percentage of error.
[a] Indicates significant effects of the pairwise comparisons with the neutral conditions.

Thus, the facilitation effect of compatible distractors in the high-load task does not seem to be a robust effect in the present study. The somewhat erratic effects of compatible distractors are discussed further below. As in the previous experiments, no such difficulties of interpretation apply to the interference effects from incompatible distractors.

Analyses of errors. A three-way mixed ANOVA (Task Demand × Distractor Type × Order) showed a main effect of load on the number of errors, $F(1, 13) = 10.52, p < .006$. There were no other effects in the analysis of the choice response errors.

The analysis of errors in the go/no-go task (i.e., failure to respond to the presence of the character in the low-load condition or to its appropriate position or size in the high-load conditions, plus false-alarm responses in the absence of the appropriate character) demonstrated the difficulty of the identification task. The average accuracy for the go/no-go task requiring detection was 98%, and the corresponding accuracy of the identification task dropped to 71%. This suggests that the identification task overloaded capacity.

Inspection of the individual data did not show any differences in the pattern of performance for the identification task between participants whose overall go/no-go performance was relatively accurate or inaccurate. As a result, the only criterion I applied to go/no-go performance was to replace participants that were less than 50% accurate in this task.

Discussion of the identical distractors' effect. The identical distractors in the far locations seemed to have minor and inconsistent effects on the performance in the present studies (the near distractors are discussed separately). The rather strange trends observed under the last two experiments are not without precedent. Previous studies have shown that identical distractors can sometimes interfere with performance rather than facilitate it, presumably because of early feature-specific inhibition (cf. Bjork & Murray, 1977; Estes, 1972). Other studies have shown facilitation effects (e.g., Eriksen & Eriksen, 1979; Flowers & Wilcox, 1982; Santee & Egeth, 1982) or no effects at all for identical distractors (e.g., Miller, 1991; Flowers & Wilcox, 1982). This inconsistency can be explained by the assumption that identical distractors may have two opposing effects of both interference and facilitation (perhaps at different levels of processing, namely an early interference effect at the feature extraction level and later facilitation effects on signal, response activation, or both). These components may be emphasized differently in different situations (e.g., with different exposure times, stimulus onset asynchronies, and relative emphases on accuracy versus speed; see Flowers & Wilcox, 1982; Santee & Egeth, 1982). The current data shed little real light on these previous discrepancies. They merely show that information load does not seem to be an important variable in their explanation.

Load effects on the processing of incompatible distractors as compared with the neutral ones are easier to interpret because previous research has shown consistent interference effects (see Driver & Baylis, 1989; Eriksen & Eriksen, 1974; Eriksen & Hoffman, 1972; Miller, 1991). Note also that measuring the effect of load on distractor interference tests a more surprising and counterintuitive prediction, namely, that easy tasks are more prone to interference from irrelevant information than are more difficult ones.

General Discussion

The results of the present study suggest that perceptual load plays a causal role in determining the efficiency of selective attention. The different manipulations of load converged to show that interference from irrelevant distractors was found only under conditions of low perceptual load in the relevant processing and was eliminated under conditions of high load. This pattern of results was observed with three different manipulations of load in the target task: relevant display set size of one versus six items, a demand to process color alone versus conjunctions of color and shape, and simple detection of characters' presence rather than identification of their exact position and size. Hence, the results provide converging evidence for the concept of perceptual load and show that the ability to ignore irrelevant information is directly related to the load in the processing of the relevant information.

These conclusions derive further support from previous work, discussed earlier, showing a decrease in flanker effects in more loaded situations (Dark et al., 1985; Johnston & Yantis, 1990; Kahneman & Chajczyk, 1983; Miller, 1991; Yantis & Johnston, 1990). All of these studies showed a reduction in the flanker effect with an increase in display set size. The present study generalized these findings by manipulating load without affecting the data quality or salience of distracting stimuli and by relating manipulations in display set size to other manipulations of load.

The variety of manipulations used allows us to generalize the conclusion on the role of perceptual load in selective attention across different levels of overall RT and across the accompanying differences in variance. Note that the overall RT for the low-load conditions in Experiments 2 and 3 (621 ms and 721 ms, respectively) were actually higher than the overall RTs of the high-load condition in Experiment 1 (605 ms). Moreover, the variance of the low-load condition of Experiment 3 ($SE = 33$) was higher than the variance of the high-load conditions of Experiments 1 and 2 ($SE = 19$ and $SE = 26$, respectively). Thus, taken together, the results of the present experiments show that the degree of interference from incompatible distractors was more consistently associated with manipulations of load than with either overall RTs or statistical variance.

This point is further underlined by the detailed pattern of results in Experiment 1, which deconfounded load from overall RT by means of target eccentricity. The processing delay caused by the reduced acuity for eccentric targets actually had an opposite effect on distractor processing to increases in load, even though both produced longer RTs. Distractor interference was greater for peripheral versus central targets but was reduced by higher load for each of the target positions. This pattern of results clarifies the relation between the load hypothesis and the overall RT in a particular task. On the one hand, in the absence of strictly quantitative definitions of perceptual load, the increase in overall RTs typically found under high-load conditions (as here) serves to verify that a task indeed became more difficult. On the other hand, the theoretical meaning of load encompasses more than just delayed RT or increased difficulty. The concept of load implies that the system must carry out further operations or must apply operations to additional units. It is these additional demands on capacity, rather than mere delay in processing, that should block low-priority, irrelevant items from consuming scarce capacity.

By contrast, the mere prolonging of relevant processing (e.g., by acuity limits), without imposing additional operations or items, should actually increase rather than decrease susceptibility to irrelevant distraction. Stimulus evidence for the distractor may gradually accumulate over time (Eriksen & Schultz, 1979), and the statistical chance for intrusion from irrelevant stimuli (at any particular point in time) is inevitably greater with an increased time window (see Navon, 1989). The pattern of results in Experiment 1 is consistent with these analyses. When relevant processing was prolonged by degrading the data quality for the target (i.e., by eccentricity), distractor interference increased. By contrast, loading the relevant processing eliminated this interference for targets at every position.

The Nature of Capacity Limits That Determine Selective Processing

In the present framework I have used a very general concept of perceptual capacity limits to explain when selective processing occurs. However, previous attempts to account for divided attention (rather than selective attention, as here) in terms of general capacity limits have ultimately had to incorporate various structural (or content-specific) constraints as well (e.g., Allport, 1980; Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1980). Thus, multiple resources, and specific cross-talk conflicts within hypothetical network implementations, have been proposed to explain a range of content-specific effects in dual-task performance (see, for example, Navon, 1984).

How do such proposals relate to the present hypothesis, which concerns the role of capacity limitations in selective rather than divided-attention tasks? It seems that the notion of limitation used in the present study might be consistent with any of the above accounts, as they all predict increased limitation with an increase in the load of processing (e.g., cross talk in pathways is more likely to arise when more information is transmitted in them). Hence, the prediction for the effect of load on irrelevant processing remains essentially the same for all perspectives (i.e., reduced irrelevant processing with greater load).

Note, however, that from the specific-resource or cross-talk perspectives the load hypothesis might only apply when relevant and irrelevant processes share a common routine. *Thus, to exclude irrelevant* stimuli from particular perceptual operations, one might have to load these very same operations with the relevant stimuli. In the present experiments, the load manipulations were all directed at identification processes, which were presumed to be involved in both the relevant and the irrelevant processing. It might possibly be argued for an even greater specificity of load, namely, in shape discrimination. Thus, in Experiment 1, more different shapes had to be coded for relevant stimuli in the high-load condition. In Experiment 2, high load meant that the shape and the color of the go/no-go stimulus had to be coded. Finally, in Experiment 3, the shape, location, and size of the go versus no-go stimulus rather than its mere presence had to be processed in the high-load condition. Thus, the present results are at least consistent with a rather specific process, namely shape discrimination, being subject to capacity limits that lead to selective processing under high load.

Alternatively, it might be argued that both specific and general limitations apply for each routine. Human attention has recently been described as a multiple system, consisting of both specialized processing routines and a central executive controller that sets up and coordinates priorities and goals (see Carr, 1992; Posner & Petersen, 1990, for recent neuropsychological evidence). On the present hypothesis, selective processing might in principle be achieved by loading either specific subsystems or a general-purpose executive control system. The present study was not designed to distinguish these possibilities but rather to establish a general principle for selective processing that can be explored in future research. At this juncture, it might be speculated that my first experiment specifically loaded the perceptual process of search, whereas the second and third study may have loaded executive processes, by means of a more complex decision rule in the high-load condition, in addition to any lower level changes in perceptual processing. Further experiments designed to manipulate load in one component of processing versus another are required to decide such issues.

The Relation Between Load and Physical Separation in Selective Processing

In the present study I proposed a resolution to discrepancies in previous findings concerning the role of target–distractor spatial separation in selective processing. Studies conducted in the framework of the spotlight metaphor have suggested that irrelevant items that are separated by more than 1° of visual angle from the target are not processed (e.g., Eriksen & Hoffman, 1972, 1973). However, studies conducted in the framework of the late selection approach (e.g., Gatti & Egeth, 1978; Hagenaar & van der Heijden, 1986; Merikle & Gorewich, 1979) have found that distractors separated by considerably more than 1° from the target were processed.

In the present set of experiments, results that accord with spotlight claims were obtained under the high-load conditions, whereas results supporting late selection claims were obtained under the low-load conditions. Moreover, previous spotlight studies have typically used high-load displays, consisting of 8 to 12 items, whereas results favoring late selection have typically been obtained under low-load conditions. (A more detailed review of task load in various contemporary studies appears in Lavie and Tsal, 1994.) Thus, previous apparent discrepancies may now be attributed to variations in perceptual load.

Furthermore, the load hypothesis may allow a clearer characterization for the role of physical distinctions between relevant and irrelevant stimuli in determining whether processing is selective. The specific suggestion is that such distinctions will be more effective in ensuring the appropriate allocation of attention under situations of high load. Note that in the low-load conditions of the present experiments, the distractor was processed in spite of its clear separation from the target in terms of location (and in size as well for some studies). Traditional late selection approaches would take such results as evidence that perception is not a selective process, supporting the unlimited capacity view. However, with the present account, the processing of a clearly distinct distractor under low-load conditions leads to the conclusion that physical distinction alone is not sufficient to ensure selective processing. High load in the relevant processing is also required.

The facilitation effect from the very near compatible distractor under the high-load condition of Experiment 2B lends some support to the suggestion that physical separation plays a necessary if not a sufficient role in allowing selective processing. However, interpretation of these results is complicated by the inconsistency of the compatible distractor effects when they were presented far from the target. It should also be noted that in Experiment 2B I used only one manipulation of the physical distinction between target and distractor (namely, their location), which may not have been the strongest means for linking the distractor with the target items (see, for example, Driver & Baylis, 1989; Kramer & Jacobson, 1991). A more definitive conclusion as to whether clear physical separation is a necessary condition for selection under conditions of high load should await more extensive study of the interaction between these variables.

Elimination of Interference and the Locus of Selection

The present study suggests a compromise between traditional early and late selection models because it showed that late selection results are found under the conditions of low load and early selection results under conditions of high load. In the present view both results are produced by the same attentional mechanism, which allocates resources for the processing of information until it runs out of capacity. Thus, the suggested resolution combines the assumption of the early selection approach that perception is a limited-resource process with the assumption of the late selection approach that perception is an automatic process (i.e., cannot voluntarily be prevented) to the extent that there remains available capacity.

The current model can therefore explain selective processing without requiring any active mechanism (e.g., inhibition) for rejecting irrelevant information (see Neisser, 1976, for a similar view). On the present account, distractors are simply not processed when relevant processing consumes full perceptual capacity. No specific mechanism is required for this early selectivity beyond the intrinsic capacity limitations of perception. These limitations will necessarily result in selective processing whenever the relevant information exhausts available capacity.

How would this view accommodate the evidence that inhibitory mechanisms can be involved in attention, such as the various phenomena of negative priming (e.g., Tipper, 1985)? Perhaps active inhibition of distractor information is only necessary when the intrinsic means of selection (i.e., by means of capacity limits) fail to prevent distractor processing. On this view, negative priming should only be found under conditions of low load (because spare capacity will spill over to distractors) rather than under high load (because selectivity will emerge naturally from resource limits). The characteristically small stimulus set size (i.e., low load) used in typical negative priming paradigms seems consistent with this suggestion (see Lavie & Tsal, 1994, for a more detailed review).

Note that the prediction derived above from the load hypothesis, namely for more negative priming under low-load conditions, is the opposite to what would follow from conventional accounts of negative priming that posit inhibition as the primary means of selection. Consider the present experiments, which found greater selectivity (i.e., less distractor interference) under high-load conditions. If inhibition were the means of this selectivity, there should be more negative priming under high load, corresponding to the greater selectivity. Such a finding would imply that the reduction in interference I have observed under high load was caused by a later selectivity than the one I have argued for. It would show that the noninterfering irrelevant distractor was actually processed under high load and then inhibited (see Driver & Tipper, 1989). More definitive conclusions on the exact nature of selection await further indexes of processing (e.g., priming in addition to interference measures).

For the moment, I can conclude that high task load plays a role in selective attention by prohibiting interference that would otherwise arise. This seems to be an important conclusion in itself, from both theoretical and practical aspects. Obviously, the practical implications of finding the conditions for avoiding distraction from irrelevant information are important. Paradoxically, my data suggest that more difficult tasks (i.e., those with high load) can be performed better in this sense (i.e., show less interference). Theoretically, the load hypothesis combines tasks of focused and divided attention under the same explanation. On the present view, performance under focused-attention tasks is not essentially different from performance under divided-attention tasks (i.e., spare capacity from the primary relevant perception task was allocated to the secondary irrelevant perception task). The focused-attention tasks of the present study differed from divided-attention tasks only in that participants were strongly requested to ignore the irrelevant stimuli. Yet, they succeeded in rejecting irrelevant information only when the relevant task load was high. Thus, it seems that perceivers can only regulate order of priority in the allocation of attention (Yantis & Johnson, 1990; Yantis & Jones, 1991). However, from this point on, processing is entirely determinate. Whether selective processing will occur is at the mercy of the perceptual load imposed by external events.

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