

# Perceptual load as a major determinant of the locus of selection in visual attention

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In this paper, we propose that the debate concerning the locus of attentional selection can be resolved by specifying the conditions under which early selection is possible. In the first part, we present a theoretical discussion that integrates aspects from structural and capacity approaches to attention and suggest that perceptual load is a major factor in determining the locus of selection. In the second part, we present a literature review that examines the conditions influencing the processing of irrelevant information. This review supports the conclusion that a clear physical distinction between relevant and irrelevant information is not sufficient to prevent irrelevant processing; early selection also requires that the perceptual load of the task be sufficiently high to exceed the upper limit of available attentional resources.

Selection of information is the primary concern of attention research, yet the debate over the locus of selection in the flow of information processing remains unresolved. The locus of selection has been consistently debated ever since Broadbent (1958) laid the theoretical foundation of early perceptual selection, which was contested soon afterward by Deutsch and Deutsch's (1963) opposing theory of late response selection. The early-selection approach 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 that are used to distinguish between selected and nonselected stimuli. As a result, unattended stimuli are not fully perceived.

By contrast, the late-selection approach assumes that perception is an unlimited process that can be automatically performed in parallel, without need for selection. Selection according to this approach only occurs late in the process, after full perception, in order to provide the relevant response. The locus of selection has become a central question in attention theory, stimulating an abundance of studies over the past three decades but with lit-

tle resolution, and essentially just shifting the pendulum periodically from early to late selection.

Although the early-selection approach, especially as modified by Treisman (e.g., Treisman, 1969; Treisman & Geffen, 1967), initially gained most empirical support (e.g., Moray, 1959; Neisser, 1969; Neisser & Becklen, 1975; Snyder, 1972; Sperling, 1960; Treisman & Riley, 1969; Von Wright, 1970) from the late 1970s and early 1980s onward, there seems to have been a fundamental shift in interest. Automatic processes have become the focus of attention theories, consequently resulting in greater support for the late-selection position (e.g., B. A. Eriksen & C. W. Eriksen, 1974; LaBerge, 1975; Logan, 1988; Miller, 1987; Posner & Snyder, 1975). Regarding the locus of selection, this shift has resulted in a recasting of the question as to whether early selection is possible at all.

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. Early studies of attention were typically conducted within the "filtering paradigm," which is characterized by overloading the subjects with relevant and irrelevant stimuli and requiring complex responses. Classic examples of this paradigm are the shadowing task (e.g., Cherry, 1953) and the partial-report technique (Sperling, 1960). Later studies, conducted in the late 1970s and 1980s, belong to the "selective set paradigm," typified by requiring a simple detection or identification response to a discretely presented stimulus appearing alone or with just a few irrelevant stimuli. Typical examples of this paradigm include studies of spatial

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(Jonides, 1981; Posner, 1980; Posner, Nissen, & Ogden, 1978; Posner, Snyder, & Davidson, 1980) and semantic priming (Keele & Neill, 1978; Neely, 1977), and visual search experiments (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Kahneman and Treisman (1984) argued that the marked differences between the two paradigms may entail the operation of different attentional mechanisms, thus precluding any meaningful generalization regarding the locus of selection from one paradigm to the other.

The proposition put forward in the present paper further explicates Kahneman and Treisman's conclusions by focusing on the perceptual load of the task as the major factor distinguishing the two paradigms. We will first elaborate on the role of perceptual load in attentional selection and then present a selective review of the literature, beginning at the late 1970s from the perspective of perceptual load, while also examining previous claims that the physical distinction between relevant and irrelevant stimuli is the primary influence on the locus of selection.

The debate concerning the locus of selection has essentially been an empirical one (e.g., Johnston & Dark, 1982; Miller, 1987, 1991; Pashler, 1984). In the last two decades, most research has attempted to show that early selection is either possible (e.g., Yantis & Johnston, 1990) or impossible (e.g., Miller, 1991), with little consideration of the *causes* for early perceptual selection. Obviously, the need for selection arises because of some processing limitation. However, even though Broadbent's (1958) filter model was based on the assumption of attention as a limited-capacity channel (see also Moray, 1967), the emphasis in subsequent research on selective attention has been primarily on the role of physical distinction between relevant and irrelevant stimuli rather than on information load (e.g., Duncan, 1981, 1984; Humphreys, 1981; Nissen, 1985; Snyder, 1972; Tsal & Lavie, 1988, 1993).

The clear physical distinctiveness of relevant information, however, has proved to be insufficient for early selective processing (e.g., Gatti & Egeth, 1978; Hagenaar & van der Heijden, 1986). We argue that although this factor is important in maintaining processing priority and thus in enabling the selection of relevant information, it cannot in itself prevent processing of irrelevant information. Selective processing is dictated by capacity limitations. Irrelevant processing is only prevented when the perceptual load of relevant information is sufficiently high to demand all the available resources.

### THE PROPOSED MODEL FOR SELECTIVE ATTENTION

We propose to incorporate the factors of physical distinctiveness and perceptual load within a single mechanism by applying the capacity approach, traditionally applied to relevant processing in dual-task situations (e.g., Kahneman, 1973; Navon & Gopher, 1979; Nor-

man & Bobrow, 1975; Wickens, 1980), to explain irrelevant processing in selective attention tasks as well. In the present account, early selection is the direct consequence of the process of allocating resources from a limited pool (e.g., Kahneman, 1973; Navon & Gopher, 1979; Wickens, 1980). Resources have been conceptualized as an internal input, essential for processing but available in limited quantities, that can be shared within or between tasks (e.g., Navon & Gopher, 1979; Wickens, 1980). The latter principle reflects the domain of the phenomena that this approach was developed to explain, namely, tasks of divided attention rather than of focused attention. Focused attention is uniquely characterized by attempting to ignore some stimuli or aspects of stimuli defined as irrelevant, while concentrating on relevant processing. As previously formulated, the capacity approach cannot give a satisfactory answer to whether irrelevant stimuli can be successfully ignored in such tasks, since in the traditional formulation of the resources approach the only constraint that limits the allocation of resources is the upper limit of the amount of resources that are momentarily available (e.g., Kahneman, 1973; Navon & Gopher, 1979). All resource theories assume that attentional capacity is limited, but this limitation is considered quantitative and flexible. In other words, it is not related to a fixed locus in the flow of information processing, but rather changes with the temporal state of alertness, the momentary availability of resources, and the structural constraints imposed by subject-task parameters (e.g., Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975).

Navon and Gopher (1979) provided an explicit rule that specifies the amount of resources allocated to a given task. According to their proposed economy of the processing system, "The system will supply resources to meet the demand of the internal level of performance to the extent that they are available; that is, the supply equals either that demand or the limit on available resources, *RI*, whichever is smaller" (p. 216). This constraint implies that one cannot allocate more than the total available resources to the performance of a given task. However, the relevant question for selective processing in resource terms is whether one can allocate *less* than the available capacity. That is, when the demand of processing is *below* the upper limit of available resources, can the perceiver withhold the allocation of the spare resources left by relevant (primary) processing to the low-priority irrelevant processing? Since traditional capacity theory assumes that the perceiver enjoys a flexible control over the allocation policy within the upper limit for available capacity (see Gopher, 1992, for recent evidence), it cannot explain results showing failure of selective processing.

In order to extend Navon and Gopher's rule to explain selective as well as divided processing, we propose an additional constraint on the allocation of attentional resources, namely, that attentional control is constrained by a lower limit of allocation as well as the upper limit

previously suggested. Our further premise is that one cannot allocate *less* than the total capacity available at a given time. Thus, according to our conception, perceptual processing is a limited resource, but it proceeds automatically until it runs out of capacity.

The present view proposes a compromise between the early- and late-selection approaches by integrating the (early-selection) assumption that perception is a limited process with the (late-selection) assumption that perception is an automatic process (i.e., not subject to voluntary control; e.g., Jonides, 1981; Posner & Snyder, 1975). Thus, the perceiver can only determine the priority of allocation or regulate the direction of attention to relevant stimuli, provided they are sufficiently distinguished from irrelevant ones (e.g., Bundesen, 1987, 1990; Yantis & Johnson, 1990; Yantis & Jones, 1991). Irrelevant information will be excluded from processing only if the prioritized relevant processing exhausts all of the available capacity.

## LITERATURE REVIEW

Our emphasis on perceptual load rescues previous structural approaches, which treat selective attention as a fixed mechanism located at a fixed place in the flow of information processing, from the absurd consequence of treating processing limitations in qualitative all-or-none terms, so that, for instance, the processing of just *one* irrelevant stimulus indicates unlimited perception. A quantitative account of such results would suggest instead that perceptual capacity is limited, but at the same time may accommodate more than one item at a time (see also Broadbent, 1971). Similar accounts have been presented by Fisher (1982), McLeod (1977), and Yantis and Johnson (1990). We propose that the quantitative distinction between high and low perceptual load can provide the means for settling the debate between early and late selection by showing that results supporting early selection have been obtained under conditions of high perceptual load, whereas results consistent with late selection have typically been obtained with low perceptual load.

Obviously, the concept of perceptual load is difficult to operationalize. It necessarily includes two components that are not easily defined—the number of units in the display and the nature of processing required for each unit. In the present discussion we consider units as those items appearing in the display with different identities, in light of the customary use of redundant displays with repetition of identical items (e.g., B. A. Eriksen & C. W. Eriksen, 1974; Flowers & Wilcox, 1982; Gathercole & Broadbent, 1987; Miller, 1987). Note that by the term *unit* we do not refer to basic perceptual units, but rather to items that serve as different alternatives for the relevant responses in the task. Consequently, a string of letters, for example, can serve as one unit (word) or as several units (letters), depending on the required re-

sponse. The number of units, so defined, provides the level of perceptual load. We chose to focus primarily on display size, since it is a generally accepted index of perceptual load (e.g., Duncan 1980; Johnsen & Briggs, 1973; Kerr, 1973; Miller, 1991; Navon, 1989), and it permits relatively easy comparisons across studies. However, perceptual load also correlates with the amount of information required to process each unit in order to produce the required response (Kantowitz, 1985). For example, counting relevant items in a given display certainly ought to be considered a less demanding task than the identification of these same items.

In order to maximize uniformity in our analysis of perceptual load for previous studies, we focus primarily on comparisons among studies that measured the same process, namely, identification of items at various display sizes. In the final section of the literature review, we broaden our analysis from just set size to include the nature of perceptual operations required for a given stimulus. It is important to note that in this final section we do not make any claims regarding the absolute level of load in each study, but rather examine the effects of manipulating relative processing demands for the same stimuli within each study.

The following literature review is also organized according to the level of physical distinctiveness between relevant and irrelevant items, which has traditionally been treated as the major factor determining the efficiency of selection. Although perceptual segregation can be facilitated by various physical features (e.g., color; Harms & Bundesen, 1983; Humphreys, 1981), we chose to focus on the most commonly accepted dimension of physical distinctiveness, namely, location. The majority of studies classified as low load show the insufficiency of mere physical separation between target and distractor for eliminating the processing of the latter, with only a few exceptions. The review of the studies classified as high load allow us to examine the notion that a clear physical distinction is necessary, if insufficient, for selection, and we provide some support for this claim.

The following review is not intended to be an exhaustive survey of the literature on visual attention. It is rather selective, focusing on a representative set of findings and including several influential studies in the field. The review excludes research that is relevant to the issue of locus of selection, but does not directly address the question of whether early selection is possible. This research lacks the requirement to ignore a prespecified set of stimuli that are defined as irrelevant. Hence, we do not discuss visual search studies (e.g., Duncan, 1980; C. W. Eriksen, Webb, & Fournier, 1990; Jonides & Gleitman, 1972; Schneider & Shiffrin, 1977; Treisman & Gelade, 1980) or studies investigating the phenomenon of redundancy gain (e.g., C. W. Eriksen, Goettl, St. James, & Fournier, 1989; Grice, Canham, & Gwynne, 1984; Miller, 1982).

**STUDIES WITH LOW PERCEPTUAL LOAD  
AND POOR PHYSICAL DISTINCTION  
BETWEEN RELEVANT AND  
IRRELEVANT STIMULI  
Support for Late Selection**

The most extreme case of poor physical distinction between relevant and irrelevant stimuli is when both occupy the same location, comprising different dimensions of the same object. A classical example of this is the Stroop task (Stroop, 1935), which clearly demonstrates that when subjects have to respond to the color of a word, they cannot avoid processing its meaning; when the word is a color name printed in an incongruent color, reaction time to respond to the color of the print is substantially elevated relative to a baseline of either responding to a color patch or responding to the color of a noncolor word. Stroop-like interference has been extended beyond the color and word dimensions (e.g., for position, size, numerosity, and global and local components of letter processing). The interference is typically asymmetric—that is, values on one dimension influence the other dimension more than vice versa (e.g., words interfere with color naming, whereas colors usually do not interfere with word reading in the conventional Stroop task). The Stroop effect has generally been interpreted as an indication of parallel processing of the relevant and irrelevant dimensions. The asymmetry in interference has been explained by differences in either processing speed or stimulus–response compatibility (SRC) relationships for the two dimensions (see Dyer, 1973; MacLeod, 1991, for extensive reviews).

Logan (1980) has shown that this asymmetric interference can be modulated or even reversed by manipulating expectancy. He varied the probability of trials in which either dimension, when irrelevant, was congruent or incongruent, and found that rare incongruency (20% of trials) was more disruptive. This applied whether the dominant dimension was irrelevant and the nondominant was relevant, or vice versa. For the purposes of the present review, the important point is that since Logan's (1980) effects depend on the frequency of various relations between relevant and irrelevant dimensions, they imply that both dimensions are processed in all cases.

The Stroop task is characterized by an especially low level of perceptual load, as well as poor physical distinction, since the display typically contains a single stimulus requiring an identification response. Thus, it is difficult to attribute the observed failures of early selection in these tasks uniquely to either the poor physical distinction or the low perceptual load. This question is addressed more directly in the next section by examining the results of several variations on the Stroop task.

One such variation is a paradigm developed by the Eriksens (e.g., B. A. Eriksen & C. W. Eriksen, 1974). In the Eriksen paradigm there is one central target flanked by distractors, which are usually identical (e.g., AUA or AAUAA). Thus, the display typically contains items with only two different shapes (e.g., U and A). The phys-

ical distinction between target and distractors is usually in terms of distances that are no more than 1° and usually about 0.3° of visual angle. Subjects are instructed to ignore the distractors and respond as quickly as possible to one of two possible response categories to which the central target belongs. The major finding is that when the distractors are from the response category that is opposite that of the target, reaction times increase. This finding indicates that the irrelevant distractor is identified, consequently activating the alternative response and slowing down the correct one.

In a subsequent study, C. W. Eriksen and Schultz (1979) showed that prolonging the processing of the target (by reducing its size or its contrast) increases the interfering effects of the distractors. Miller (1987) developed a variation of the Eriksen paradigm, but unlike Eriksen's studies, the distractors did not share a response category with the target. Instead, by varying the frequency of co-occurrence for particular targets and distractors, some distractors were associated with a particular target more than others. Responses to the target were facilitated when they were predicted by associated distractors. Thus, the distractors were processed even when they did not belong to one of the target response categories, and therefore they could not be primed in this way. Miller therefore concluded that such priming is not a necessary condition for late selection.

Although we agree with this specific conclusion, Miller's account of irrelevant processing is inconsistent with our proposed model of selective attention. We argue that under conditions of low load, the irrelevant stimuli are processed because of the involuntary allocation of spare *attentional* capacity to these stimuli. Miller, on the other hand, contended that the distractors were processed automatically, without consuming any attentional capacity. His conclusion was based on results showing that the distractors were processed even when their correlation with a certain target response was not expected (as they were part of a set in which only some of the distractors were correlated with some of the targets), and also when memory at the end of the experiment did not differ for distractors from the different correlational sets. However, these observations do not warrant Miller's conclusion that attentional processing has no role in identifying the distractors. First, the fact that expectations did not influence distractor processing says little about the involvement of attentional processes. Various studies have demonstrated attentional effects that are completely independent of expectations (e.g., Jonides, 1981; Posner et al., 1980). Second, a null effect in postexperiment measures of memory does not establish that attention was never involved, as it is a retrospective measure and thus potentially insensitive.

A more sensitive measure of attentional processing in this task was employed by Paquet and Lortie (1990). They found that the associated-flanker effect in Miller's paradigm was attenuated when target location was precued by a fixation point, thus showing that the flanker effect obtained by Miller is, in fact, sensitive to manip-

ulations of attention. Presumably, the spatial precue helped to separate the target from the irrelevant flankers. Note, however, that although this better separation improved selection, it was not sufficient to completely eliminate the distractor effect, but merely reduced it.

The above studies are characterized by low perceptual load, since the displays consisted of only two different letters as well as by a lack of clear physical distinction; in all these studies the target and distractors occupied nearby locations within an area of about  $1^\circ$ . Thus, low perceptual load and poor physical distinction lead to failures in early selection.

### **STUDIES WITH LOW PERCEPTUAL LOAD AND CLEAR PHYSICAL DISTINCTIVENESS BETWEEN RELEVANT AND IRRELEVANT INFORMATION Further Support for Late Selection**

In one of their experiments, B. A. Eriksen and C. W. Eriksen (1974) increased the contour-to-contour distance between the target and distractors to  $1^\circ$  of visual angle. Although the interference of the distractor was somewhat reduced, it still remained significant. Thus, it seems that a clear physical distinction between relevant and irrelevant items was not sufficient to produce early selection. Miller (1987) also increased the distance between the target and distractors, essentially producing results that were similar to those of the Eriksens.

Keren, O'Hara, and Skelton (1977) found that in a *same-different* matching task, the interference produced by two identical distractors (appearing in the center of the display) depended on the level of processing for the flanking targets. For example, when a physical match was required between A and A, the distractors "aa" produced interference that was identical to that produced by "mm," whereas the pair of "AA" distractors did not interfere. However, when a name match was required between the same "AA" targets, the distractors "aa" produced no interference—similar to that for the "AA" distractors. Keren et al. concluded that the distractors were processed to the level required for matching the targets. Thus, in the physical match, the distractors produced interference because "aa" is physically different from "AA." No such interference was observed in the name match, because these targets and distractors shared the same semantic category.

Keren et al.'s conclusion is partly inconsistent with the present proposal in suggesting that early selection is possible even with low load (few distinct identities within a display) when the task is performed at the physical level. However, the reasoning behind Keren et al.'s conclusion seems faulty. The fact that "aa" distractors produced interference with an "AA" target pair under physical matching does not indicate that the distractors were only processed to the physical level and not to the semantic or name level. It simply shows that they interfered because of their physical dissimilarity to the tar-

gets. Obviously, subsequent and congruent semantic processing cannot eliminate the interfering effects of this earlier physical mismatch, especially given the serial aspects of the model that originated from the physical/name-matching paradigm (e.g., Posner & Mitchel, 1967).

B. A. Eriksen, C. W. Eriksen, and Hoffman (1986) conducted an experiment that provides indirect support for late selection in displays of low perceptual load. They used Sternberg's (1969) memory-scanning paradigm, adding two identical distractors to the target (at a separation of approximately  $1^\circ$  from the target). The distractors could be either compatible with the target (i.e., the target and distractor were both members of the memory set or neither were members of the memory set, so that they belonged to the same response category) or incompatible (i.e., one was a member and one was not a member of the memory set, so that they belonged to different response categories). The results indicated that both compatible and incompatible distractors increased the intercept of the memory-scanning function, and that the latter produced the stronger effect. To produce this effect, the distractor must have been processed to a sufficiently high level for the system to recognize whether or not it belonged to the memory set.

One of the strongest sources of support for the late-selection position has been provided in a series of studies by Tipper and his associates. They have demonstrated the phenomenon of negative priming (NP), expressed by delays in responding to a target that served as a distractor on a preceding trial (e.g., Allport, Tipper, & Chmiel, 1985; Tipper, 1985). It should be noted that in all of these studies the displays consisted of only two items. NP occurred even between letters with the same identity but different shapes (Tipper & Cranston, 1985), and also between pictures and names of objects sharing a semantic category (Tipper & Driver, 1988), suggesting that the distractor was processed to the semantic level. Although many of the experiments reporting NP used displays in which the target and distractor were distinguished only by color (e.g., Tipper, 1985; Tipper & Cranston, 1985) or occupied nearby locations (e.g., Tipper, MacQueen, & Brehaut, 1988), Allport et al. showed that NP was evident even when the locations of the target and distractor were separated by  $1.8^\circ$  of visual angle. It therefore seems that, with low perceptual load, even a clear physical distinction between relevant and irrelevant items cannot preclude irrelevant processing.

Although the NP phenomenon appears to provide a sensitive measure for detecting traces of irrelevant processing under certain circumstances, one should be cautious in interpreting these effects as unequivocal support for the late-selection position. NP may be at least partially due to retroactive priming caused by the target processing in the subsequent trial. Thus, a relatively "raw" trace of the distractor on trial  $n$  may be primed by the higher-level processing of the target on trial  $n + 1$ .

Alternatively, the attentional mechanism may set processing priorities so that distractor interference is de-

layed until relevant processing is completed. If so, distractor processing would be expected to influence trial  $n+1$ , but not trial  $n$ . Thus, the level of representation of the distractor during processing of the simultaneous target cannot be directly assessed by the method of negative priming.

Interference effects obtained in the Stroop task, in which the relevant and irrelevant aspects of the stimulus are physically well separated, also provide support for the late-selection position. All of these effects were obtained in low-load tasks using displays with only two different identities. Gatti and Egeth (1978) presented a central, relevant, colored patch, vertically flanked by two identical irrelevant color names. The words appeared 1°, 3°, or 5° away from the color spot. They found that naming the color of the patch was substantially faster when the color names were compatible with the patch than when they were incompatible. Although this effect was weaker when the word was farther away from the target, it was never eliminated.

Merkle and Gorewich (1979), in a similar Stroop task, manipulated the size of the distractor (either 0.24° or 0.57°) and the distance between the distractor and the target (either 0.5° or 2.5° of center-to-center distance). They found that the incompatible distractor had an interfering effect in all conditions, except when it was small and far from the target. However, the lack of interference in the latter condition could be attributed to a reduction in visual acuity for the peripheral distractor.

Hagenaar and van der Heijden (1986) argued that the Stroop paradigms used by Gatti and Egeth (1978) and Merkle and Gorewich (1979) were inadequate for studying the effect of spatial separation on distractor processing, since they confounded spacing with retinal acuity. To overcome this problem, Hagenaar and van der Heijden presented the color patch and either the neutral or incompatible color word in two of four possible positions on an imaginary circle that was 2.19° in diameter, centered at fixation. The word was placed either 1.09° or 1.89° from the target color patch. Hagenaar and van der Heijden found only a main effect for compatibility; color-naming latencies were 16 msec slower in the incompatible condition. Distance did not have a main effect, nor did it interact with compatibility. This result was replicated in a situation in which the target location was precued, and there was an even greater separation (2.19°) between the target and the distractor. Thus, once again, a clear spatial separation seems insufficient for early selection under conditions of low load.

In a further variation on the Stroop task, Kahneman and Henik (1981) presented two remote color words (separated by 4.8°), one on either side of fixation, with one enclosed in a square and the other enclosed in a circle. Subjects were instructed to name the color of a word enclosed in a specified shape (square or circle). A larger Stroop effect was found from incongruent color words appearing within the specified shape. The effect was reduced for incongruent color words appearing in the ir-

relevant shape, but it remained significant. In a subsequent study, van der Heijden, Hagenaar, and Bloem (1984) used Kahneman and Henik's procedure and showed that, although precuing the relevant location eliminated the interference of an incompatible irrelevant word when the target itself was an incompatible color name, this effect recovered when the relevant word was neutral. They concluded that the irrelevant word was processed under both conditions, but that interference from a distant and uncued object could be swamped by the more substantial interference found when incongruent information was present in the target object itself. This late-selection interpretation accords with our proposal, since the display set size was small (and thus perceptual load was low) in both cases, and so distractor processing would be expected.

Several recent studies have investigated the joint effect of physical separation between target and distractor and the temporal conditions of their presentation. Murphy and C. W. Eriksen (1987) presented a target and a distractor in two of six possible positions at 1°, 2°, or 3° to the right or left of fixation. Target location was marked by a cue either appearing together with the target or preceding it by a variable interval ranging from 25 to 175 msec. Compatibility effects were obtained under all conditions, supporting our proposal of late selection with low perceptual load even in cases of clear separation. The distance between the target and the distractor had an effect only when the target was precued by 175 msec. Under this condition, compatibility had a stronger effect when the target and distractor occupied the same side of fixation relative to when they appeared on opposite sides of fixation.

In Flowers and Wilcox's (1982) study, the target and distractor were separated by either 1.1° or 3.3°, and the distractor preceded the target by a variable interval ranging from 600 to 0 msec. They found a smaller compatibility effect when the target and distractor were more remote in space, and a progressive attenuation of the compatibility effect as the interval separating the distractor from the target presentation was lengthened. These effects also produced a complex interaction, resulting from the fact that the incompatible distractor produced a stronger effect at the shorter distance and intervals, whereas the compatible distractor produced a stronger effect for the longer interval at both distances—both relative to the case of a neutral distractor. It is important to note that compatibility effects were still obtained when the distractor preceded the target by as much as 600 msec and when the target and distractor occupied remote locations. Once again, clear physical distinction between target and distractor was alone insufficient to produce early selection when perceptual load was low.

Gathercole and Broadbent (1987) compared compatibility effects for a target and distractor that were separated by either 0.6° or 1.9°. The distractor either preceded the target by 20 or 40 msec, appeared simultaneously

with it, or succeeded it by 20 or 40 msec. They found that the nature of distractor interference strongly depended on the temporal separation between the target and the distractor. When the distractor preceded the target, the same interference was obtained for the short and long distances. When the target and distractor appeared simultaneously, the distractor interfered only for the short distance. When the distractor succeeded the display, no interference was observed.

The studies reviewed above suggest that, in addition to perceptual load, there are several other important variables influencing distractor processing, such as distance from the target, eccentricity, relative onset time, and so on. In most of the cases described above, these variables often influenced the *magnitude* of interference from distractors, but they did not completely *prevent* its occurrence. Thus, in cases of low perceptual load, the distractor is usually processed even when it is small, peripheral, distant from the target, and asynchronous with the target.

#### **Data Limitations and Locus of Selection Under Situations of Low Load**

The factors reviewed above may hint at the boundaries of our load hypothesis. Obviously, factors such as the eccentricity of the distractor should restrict distractor processing, even under situations of low load. At this point it seems useful to bear in mind the distinction drawn within the framework of capacity theories between data (and/or structural) and resource limitations (Kahneman, 1973; Norman & Bobrow, 1975). Data limitations restrict the range in which resources can have their effects and, thus, set up the boundaries for the effectiveness of resource allocation.

Navon and Gopher (1979) extended the concept of data limitations to incorporate interactions between the subject and environment (under the heading of "subject-task-parameters"). Thus, factors such as the stimulus-response compatibility (SRC) relationships in the task, or amount of practice, can restrict resource effectiveness in addition to the sensory or "data" quality of the stimulus itself (e.g., Greenwald, 1970, 1972; Wickens, Sandry, & Vidulich, 1983). Studies of SRC (e.g., Beller, 1975; Flowers, Warner, & Polansky, 1979; McClain, 1983; Zakay & Glicksohn, 1985) indeed seem to show reduced interference when the irrelevant stimuli are less compatible with the response. These effects may be independent of load and therefore constrain the present discussion. Thus, manipulating data limitations, or subject-task-parameters, for the distractor in a task may decrease or increase its effects, irrespective of the task load. To sum up, a degraded distractor, or one that is weakly associated with the relevant response, or one that appears after the response has been generated (see discussion of relative onset for target and distractor in the previous section), usually will not interfere with response to the target, even under situations of low load.

#### **Effects of Increasing Segregation of Target From Distractors by Inducing Perceptual Grouping in the Task**

Throughout this paper we focus primarily on the spatial separation between relevant and irrelevant stimuli as the major dimension determining physical distinction. It is important to note, however, that several recent studies (e.g., Baylis & Driver, 1992; Driver & Baylis, 1989; Kramer & Jacobson, 1991) have shown that, under certain conditions, embedding the target and distractors in different perceptual groups may produce even more efficient selection than their mere spatial separation. These studies were characterized by an intermediate level of perceptual load, as they used display sizes of three different items (i.e., a target, two instances of the same neutral distractor, and two instances of the same incompatible or compatible distractor). Therefore, our load hypothesis cannot unequivocally predict the extent of processing of incompatible distractors. The results of these studies do demonstrate the importance of perceptual grouping. Distractors that were embedded in the same object and/or shared the same color or movement as the target tended to produce greater interference than distractors belonging to a perceptual group that was different from the target's. Note that although Baylis and Driver found some interference from both types of distractors (i.e., those adjacent to the target but not grouped with it, *and* those distant but belonging to the target's group), Kramer and Jacobson found that only distractors that were grouped with the target interfered. The tasks employed in these two studies were quite different from one another (Kramer & Jacobson used dotted vs. dashed lines for targets and distractors, and Baylis & Driver used letters). Such differences complicate a direct comparison of their effects. Nevertheless, the somewhat ambivalent pattern of interference found across these two studies is perhaps to be expected on our load perspective, given the intermediate loads that were involved.

In sum, the vast majority of studies with high physical distinction but low load have shown that distractor interference is not completely eliminated by clear physical distinction, although it can be reduced. In the course of our review, we have identified a number of factors that may modulate the *extent* of interference, but we have clearly established that physical distinction alone is an insufficient condition for perfect early selection.

#### **STUDIES WITH HIGH PERCEPTUAL LOAD Support for Early Selection**

Studies of visual attention from the last two decades are characterized by attempts to formulate simple paradigms, enabling the isolation of elementary components of attention (see Kahneman & Treisman, 1984). This paradigmatic shift has resulted in relatively few studies investigating selection in displays of high perceptual load.

Pashler (1984) devised a variation of the bar-probe technique (Averbach & Coriell, 1961). He used eight-



item displays, with three stimulus onset asynchronies (SOAs) between display and probe. This task is characterized by a high level of perceptual load; the display contained four possible shapes and the task required the conjunction of shape and location, essentially resulting in eight different combinations. He found that physical factors (target-background contrast, target size, and physical dissimilarity between target and distractors) influenced identification times, even when the probe succeeded the display by as much as 300 msec. Furthermore, there was no interaction between these effects and SOA. These findings question the late-selection position in showing that selection occurred at the perceptual stage even when the display was exposed for 300 msec prior to the probe.

C. W. Eriksen and Hoffman (1972, 1973) used a paradigm similar to that of B. A. Eriksen and C. W. Eriksen (1974), but instead of a string containing a target and one or two identical distractors, they presented circular displays subtending 2° in diameter and containing 12 letters of four different shapes—that is, perceptual load was then high. The subjects were instructed to respond as quickly as possible with one hand to either the letter A or U and with the other to either M or H. The location of the relevant letter was marked by an arrow appearing either simultaneously or preceding the display by a variable interval. C. W. Eriksen and Hoffman found that when the display contained distractors from the response category that was opposite that of the target (e.g., target-A, distractor-M), response latencies were longer than when the target and distractors were from the same response category. Most importantly, however, this effect occurred only when the interfering distractor was within 1° of visual angle from the target. For more remote distances, the identity of the distractor had no effect on reaction times. Furthermore, the interfering effects of the near distractors remained, even when the indicator precuing the location of the relevant letter preceded the display by as much as 350 msec.

These findings and others (e.g., Posner, 1980; Posner et al., 1980) have led to the metaphor of attentional spotlight, according to which attention can “illuminate” a small designated area—that is, facilitate the processing of any stimulus appearing within it—relative to stimuli that appear outside that attended region. In fact, the spotlight notion suggests very early selection, since it implies that location is processed even earlier than other physical properties whose processing can be modulated by selective attention to their locations (see Tsal & Lavie, 1988, 1993).

Yantis and Johnston (1990) investigated the possibility of early selection, combining the Eriksen and the cuing (e.g., Posner, 1980; Posner et al., 1980) paradigms in a high-load situation. They presented circular displays of eight different letters with either a central or a peripheral cue directed at one of the letters. They examined the effect of an irrelevant redundant target (Experiments 1 and 2) and an incompatible distractor (belong-

ing to the opposite response category—Experiments 3 and 4) on reaction times. Redundancy gain was not obtained when the cue was valid, only when it was neutral or invalid. Incompatible distractors produced interference only when they were either adjacent to the target or separated by one item. No such interference was observed for more remote distances. Moreover, the interference effect was found to be much smaller than that observed in previous studies (7.6 vs. 20–60 msec).

Several studies reviewed in this section have shown that adjacent distractors tend to be processed, even under conditions of high load. Hence, although physical distinctiveness is not a sufficient condition for early selection, it may be a necessary one. That is, although high perceptual load inevitably leads to selective processing, a sufficient distinction must exist between relevant and irrelevant information for this selection to be the appropriate one. Otherwise, the irrelevant information may be processed instead. Irrelevant items that are either adjacent or grouped with relevant ones (see previous section) may not be sufficiently distinct to enable their exclusion from further processing. We should note, however, that the evidence regarding the effects of “pure” spatial separation is mostly inconclusive. In the studies by C. W. Eriksen and Hoffman (1972, 1973) and Yantis and Johnston (1990), for instance, spatial separation usually covaried with the number of intervening items between the target and incompatible distractors. More neutral items may, therefore, have been processed in addition to the target “on the way” to the more distant distractor, consuming capacity and thus reducing processing of the critical distant distractor. Thus, many putatively spatial effects might also succumb to a load explanation. Yantis and Johnston (1990, Experiment 4) did carry out a manipulation of distance that was unconfounded with the number of intervening items. They simply varied the radius of the circle of letters and found that it had no effect. Distractors separated from the target by at least one item never interfered, regardless of their spatial separation. On the other hand, adjacent distractors always interfered, even in this study, suggesting perhaps that any spare capacity was likely to spill over to them first.

The conclusion that may be derived from the above studies is that high load necessitates selection, whereas separation from the target (defined by number of intervening items) determines which items will be selected.

The zoom-lens metaphor proposed by C. W. Eriksen and his associates (C. W. Eriksen & St. James, 1986; C. W. Eriksen & Yeh, 1985) to account for the conjoint role of load and physical separation is generally consistent with this conclusion. These studies emphasize the importance of capacity limitations in the processing of equidistant items. C. W. Eriksen and St. James showed a reduction in distractor interference with increased distance from the target (defined by the number of intervening items). However, they also found that equidistant distractors produced more interference when they were within rather than outside the cued area. Thus, allocat-



ing attention to or away from distractors influenced the extent of their processing. We should add that our proposed load hypothesis predicts a greater decline in distractor interference with distance when more items are precued, since fewer spare resources should then remain, and consequently they should be distributed over a smaller area. C. W. Eriksen and St. James, however, obtained a constant "fringe" of the zoom, rather than the interaction predicted above.

### **STUDIES MANIPULATING DISPLAY SIZE** **Further Support for Early Selection** **With High Load**

The studies reviewed thus far suggest that perceptual load is indeed the major factor determining the locus of selection; studies using displays with few items support late selection, and those using more items usually support early selection. However, cross-study comparisons may be problematic to a certain extent, since the various studies employ different presentation conditions. The studies reviewed below overcome this problem since they have actually manipulated perceptual load, thus allowing for within-study comparisons and therefore providing clearer evidence that early selection is found only under conditions of high perceptual load.

Navon (1989) examined the possibility of early selection among all possible combinations of physical and semantic properties for selection sets and response sets. The two physical properties were color and size of a pointer, and the semantic property was the category of the relevant item, either a letter or a digit. Subjects were required to press one of two buttons as quickly as possible to each of two values for a given property. Experiment 4 of Navon's study is most relevant here, since perceptual load was directly manipulated by comparing selection effects for two- and four-item displays. The items were letters and digits; the low-load display contained a target and a distractor, and the high-load display contained a target and three distractors. In the latter condition, the four items were positioned in the vertices of an imaginary square with a contour-to-contour distance of  $.7^\circ$  between adjacent items. The subjects responded as quickly as possible to one of two possible sizes of a pointer that appeared at  $.1^\circ$  to the right or left of the target. The selection property was either color (i.e., respond to the pointer of the red/green item) or category (i.e., respond to the pointer of the letter/digit). A distractor could be compatible with the target (i.e., a pointer adjacent to another letter of the same size as the relevant pointer), incompatible (i.e., the irrelevant pointer was of the size associated with the opposite response category), or neutral (i.e., an irrelevant pointer whose size was different from both response categories).

The results indicated that when selection was made on the basis of color, there was no effect of display size nor of distractor compatibility. When selection was made on the basis of category, the display-size effect interacted

with the distractor compatibility effect. That is, for the two-item displays, responses were slower when the distractor was incompatible than when it was neutral or compatible. However, for the four-item displays, there was no effect of distractor compatibility. The findings for selection by category are consistent with the proposition that early selection is dependent on load, as distractor interference was reduced within the same task when load was *relatively* high. It is not clear, however, why there was no distractor effect for the color selection set. This null result is somewhat curious in light of the results obtained in Experiment 1 of the same study (Navon, 1989), in which interference from incompatible distractors was found with color selection for a display size of two, under the same conditions as in Experiment 4. Perhaps Experiment 4 was simply less powerful, since it included fewer subjects than Experiment 1.

Kahneman and Chajczyk (1983) manipulated perceptual load in a variation of the Stroop task. They measured reaction times for naming the color of a central patch appearing together with a black word directly above or below it. They found that when the word spelled a compatible color, naming responses were substantially faster than when it spelled a color that was incompatible to the patch. This compatibility effect was markedly reduced when either a second neutral word or an array of Xs was added to the display. Kahneman and Chajczyk concluded that the addition of an irrelevant neutral stimulus reduced the attentional resources available for capture by the incompatible distracting stimulus.

This interpretation is consistent with our proposition that attentional resources are involuntarily allocated to irrelevant stimuli only when relevant processing is not sufficiently demanding. However, the present view is not necessarily committed to the specific attention-capture hypothesis of Kahneman and Chajczyk, which argues that this dilution effect is due to a serial allocation of attention to the items in the display, resulting in the processing of the color bar and only one of the distractor words on any given trial. Indeed, Yee and Hunt (1991) recently showed that this attention-capture hypothesis cannot account for the dilution effect when the individual data are inspected. Instead, their data could support the assumption that both irrelevant items were processed, but with different weights assigned to their identity by different individuals. Thus, the reduction of available resources by the additional processing of irrelevant items could apply to parallel as well as to successive operations. This conclusion is consistent with those from several investigators (e.g., McLeod, 1977; Townsend, 1971, 1974; Yantis & Johnson, 1990), who argued that the notion of limited capacity does not necessitate the serial assumption.

In further support of the present proposition, two recent studies have shown that increasing display size reduces or eliminates priming from irrelevant items. Neumann and DeSchepper (1992) found that a single distractor produced a negative priming effect on re-

sponses to a subsequent target, but produced no such effect when the prime and probe displays contained three distractors.<sup>1</sup> Dark, Johnston, Myles-Worsley, and Farah (1985) presented a matrix of four possible relevant locations and four irrelevant ones. They found that an irrelevant word produced a higher level of recognition memory as well as semantic priming when it appeared by itself relative to when it was accompanied by a relevant word. In fact, specific comparisons indicated that semantic priming disappeared in the latter condition. Thus, increasing display size produced more effective selective processing.

Yee (1991) compared priming effects for irrelevant distractor words under conditions of single- versus double-distractor presentations. She reported that the double-distractor condition produced both suppression and facilitation (at short and long intervals, respectively) of reaction times in a lexical decision task on the following trial. However, no such effect was observed in the single-distractor condition. This study is the only one reviewed in the present paper that is inconsistent with our proposition. However, several considerations should be noted in interpreting these findings. First, these results are clearly in contrast with those of Dark et al. (1985) and Kahneman and Chajczyk (1983), described previously, as well as with those of Neumann and DeSchepper (1992), who have shown that suppression actually decreases as the number of items in the display increases. Moreover, Yee's results are puzzling in the context of previous investigations of inhibitory mechanisms, which have typically observed suppression effects with only a single distractor (e.g., Lowe, 1985; Neill, 1977; Neill & Westberry, 1987)—the very condition that showed no effects in Yee's study.

In a recent study, Miller (1991) investigated the influence of perceptual load on the flanker compatibility effect. Subjects responded with different hands to two randomly selected consonants. Display size served as a manipulation of load; a target letter appeared in the center of the display with one, three, or seven other relevant letters positioned around an imaginary circle. Two identical flankers were placed at about 3.3° to the right or left of the circle. The compatibility effect produced by the flankers was found to vary as a function of display size; as display size increased, the effect of flanker compatibility decreased. In fact, this effect was reliable only for a display size of two.

Since overall RT increased with display size, Miller suspected that the elimination of the flanker compatibility effect in the large displays did not necessarily indicate that the flankers were not identified. Instead, the interference effects could have dissipated in larger display sizes, perhaps before the target was even found. Miller examined this possibility in three additional experiments, and found that facilitating target processing in the large displays (Experiment 8), or retarding the perception of distractors by delaying their presentation by 250, 350, or 450 msec following the target with ei-

ther onset (Experiment 9) or offset (Experiment 10) distractors, reinstated the flanker compatibility effects for the larger set sizes. Miller therefore concluded that perceptual load is not a major factor for early selection.

However, this conclusion is not warranted in light of several possible confounding effects produced by Miller's (1991) manipulations. First, the definition of load in Experiment 8 does not seem adequate. In order to expedite the processing of the target in the large displays, Miller used displays consisting of four identical targets and four irrelevant letters. However, the redundancy gain of the four identical relevant targets can certainly diminish the processing load of the display. The redundant targets minimize search requirements and are therefore not strictly comparable to the other displays with only one relevant target. Thus, obtaining compatibility effects in this experiment may, in fact, suggest the inability to ignore irrelevant information under conditions of low perceptual load—in this case caused by redundancy. Second, in Experiments 9 and 10, the SOA manipulation that was intended to retard the processing of the flanker was confounded with the abrupt onset or offset of the flanker on its own. Thus, the processing of the flanker could have resulted from the automatic allocation of attention to the distractor's location because of the abrupt change (Jonides & Yantis, 1988; Kahneman, Treisman, & Burkell, 1983; Yantis & Jonides, 1984, 1990).

Lavie (1992, *in press*) directly addressed whether high perceptual load is a prerequisite for early selection; a version of the Eriksen paradigm was used. Subjects performed choice responses to a target letter located at a central location, possibly embedded among other central items relevant to the target task. A critical distractor, which could be compatible, neutral, or incompatible with response to the current target, appeared above or below it. This distractor was separated from the target by 1.3°–2.9°. That is, there was always an adequate physical distinction between target and critical distractor. Several manipulations of load converged to show that compatibility effects from the irrelevant distractor were dependent on the relevant information load. Compatibility effects from the remote distractor were found only when the load on target perception was low. The manipulations of load included set size for the relevant elements in the display. The target letter could appear alone with a single critical distractor (low load), or embedded in a row with five additional letters, requiring search for the target (high load). Compatibility effects were found only in the former case. In this experiment, Lavie also examined the relationship between the effect of relevant load and the effect of data degradation for the target (in the form of reduced retinal acuity for more peripheral targets). The results showed that peripheral targets were more prone to distractor interference, replicating C. W. Eriksen and Schultz's (1979) findings. However, the effects of target data quality did not interact with load. For every target position, distractor processing was reduced by the load manipulation.

In another of Lavie's (1992, *in press*) studies, set size was held constant while the load of the central search task was reduced by inducing pop-out for targets with a unique color or shape. An additional technique manipulated load, without involving any change in display appearance, by varying the processing requirements for identical displays. In these studies, an additional shape appeared near the central target letter, and subjects were required to either respond or withhold response for the target letter according to various rules applied to the additional shape. By varying these rules, the load of the target task could be manipulated. For example, detecting the presence of the additional shape before making a response imposed only a low load, whereas discriminating its precise size and position produced a high load. Compatibility effects from the irrelevant distractor were only found under the low-load detection task. Similar results were found in a study that manipulated load by requiring feature detection or feature conjunction for the additional shape. Under the low-load condition, the target go/no-go task was contingent on the color of the additional shape, whereas its conjunction of shape and color was critical under the high-load condition. Even though the displays were identical in these two cases, once again, compatibility effects were found only with the low-load target task. The variety of manipulations in these studies allowed the effects of load to be generalized across possible confounding factors, such as overall RT or the perceptual saliency of the distractor.

The studies reviewed above seem most supportive of the contention that high perceptual load is a prerequisite for early selection. In the majority of these studies, increasing the set size of the display resulted in substantially reducing or totally removing irrelevant interference. Since the comparisons between the different display sizes were conducted within studies, changes in the selectivity of processing can be confidently attributed to the effects of perceptual load only.

### STUDIES MANIPULATING ALTERNATIVE PARAMETERS OF PERCEPTUAL LOAD

In the following section, we deviate from the strict definition of perceptual load as indexed by display size and examine studies that have manipulated processing difficulty for the same type of stimuli. We do not make any claims regarding the absolute level of load in these studies, but only assume that perceptual load increases with higher processing demands of a given stimulus.

In a study conducted by LaBerge, Brown, Carter, Bash, and Hartley (1991), subjects made a choice response to a target letter belonging to one of two categories that was flanked by eight identical items on each side. The flankers were compatible, neutral, or incompatible with the target. The subjects were instructed to respond only when a preceding display contained the digit 7 at the center. The digit was flanked by eight alternating Ts and Zs on either side. The duration of the

digit display was varied from 67 to 600 msec. The major finding was a reduction in flanker compatibility effects on choice RT to the second display, with shorter exposures of the preceding digit displays. LaBerge et al. concluded that the short durations demanded a narrower focus of attention on the central target.

Our account seems to be consistent with this conclusion and may further explicate it. Why would short exposure durations produce a narrow focus of attention? We propose that the shorter durations of the digit displays increased task load by demanding greater resources for the identification of the digit, and perhaps also by loading the subsequent letter processing with the ongoing processing of the immediately preceding digit display at very short interstimulus intervals. Thus, fewer spare resources would be available for irrelevant letter identification when the preceding digit display was very brief and recent. The significant increase in the overall RTs with short digit exposure seems consistent with this load explanation.

Weisgerber and Johnson (1989) presented a central target flanked by two identical distractors. The distance between the target and each distractor was  $0.34^\circ$  of visual angle. The distractors were either compatible or incompatible with the response to the target and appeared either simultaneously with the target or preceded it by either 100 or 300 msec. The subjects were instructed to press one button if the target was familiar (i.e., one of four possible English letters) and press another button if it was an unfamiliar symbol (i.e., one of four unfamiliar letters, two Hebrew and two Arabic). The results showed a clear interference effect on response time to the target when the target was familiar and the distractors were unfamiliar, but no such effect when the target was unfamiliar and the distractors were familiar. Additional experiments indicated that this asymmetrical effect was not entirely due to the unfamiliarity of the symbols *per se*, since similar results were obtained when the Hebrew and Arabic letters were replaced by familiar symbols (3, 7, #, and an arrow), although they were smaller in magnitude when compared with the interfering effect of the unfamiliar symbols. Nor were the results due to the greater cohesiveness of the familiar-letter response set, since the same results were obtained when the two categories were intermixed and the subjects had to respond with one hand to the symbols ?, F, H, and #, and with the other hand to the symbols S, R, &, and an arrow. It seems that the best interpretation of these results is in terms of perceptual load. The symbols, especially the unfamiliar ones, required attentional resources for their processing, leaving no spare resources for the unintentional processing of the distractors, thus eliminating distractor interference. The English letters, on the other hand, were easily processed, requiring minimal resources for their identification, and hence leaving sufficient resources for the processing of the distractors to produce interference.

Allport et al. (1985) showed that negative priming was more pronounced when the selection between the

target and distractors was made easier. In their study, for the easy-selection condition, the target always appeared at the center and the distractor appeared at one of four surrounding locations. In the difficult-selection condition, the target and the distractor appeared at two of the four surrounding locations, unknown to the subjects in advance. A significant NP effect was obtained in the easy-selection condition, whereas the effect in the difficult-selection condition did not reach significance. These findings are consistent with our present contention, as they suggest that the lack of preknowledge of target location may have increased perceptual load, consequently reducing the processing of the distractor.

### POSSIBLE EXTENSION TO OTHER MODALITIES

Although the present paper focuses on the locus of selection in *visual* attention, there have been several investigations of attention in the auditory modality, with results bearing on the issues discussed here.

Zelniker (1971) asked subjects to shadow a list of digits while ignoring the feedback of their own voices, which was delayed by 0.2 sec. This delayed feedback is very disruptive, often interfering with the response and sometimes causing stuttering. Zelniker found that the delayed feedback was more difficult to ignore and caused more stuttering when the shadowing was relatively easy—that is, repeating just the first group of four digits twice throughout while listening to the subsequent second and third groups. Interference was markedly reduced when the task became more difficult—repeating the first group of digits while listening to the second and repeating the second group while listening to the third.

This finding is only generally supportive of the claim put forward in the present discussion. Certainly it indicates that as the resources required for the performance of a given task increase, the interference produced by distracting elements decreases. However, this finding need not relate to early perceptual selection, as it could possibly reflect resource competition in a later response stage.

Barr and Kapadnis (1986) investigated whether manipulating the difficulty of the relevant task affects the ability to ignore an irrelevant auditory message. They found that in a standard shadowing task, native speakers of English noticed more changes (i.e., speech interruptions and reduction in voice intensity) in the unattended channel than nonnative speakers did, and also that these changes caused greater interference in shadowing for native than for nonnative speakers. This result seems generally consistent with our proposition, since it suggests that the extra attentional resources required for shadowing an unfamiliar language reduce available resources for processing the competing irrelevant message. However, as in Zelniker (1971), it is not clear whether this finding reflects perceptual interference or response interference.

Physiological studies of auditory selective attention using measures of event related potentials (ERPs) seem to show that a difference in the physiological response to attended and unattended stimuli is more pronounced under conditions of loaded presentation of relevant stimuli (manipulated by fast presentation rate) that are easily discriminable from the irrelevant ones (see Hansen & Woldorff, 1991, for a review of ERP studies). Hansen and Woldorff conclude that: "Early attention related ERP differences are elicited only when easily discriminable classes of stimuli are presented at a rapid rate, implying that early selection occurs only when it is both necessary and possible" (p. 5).

### SUMMARY AND CONCLUSIONS

The literature review presented here supports the notion that early selection is possible only when the perceptual load of processing the relevant information is sufficiently high to approach or exceed the upper limit of the total available resources. If this condition is not met, spare capacity will be unintentionally allocated for irrelevant processing, thus preventing early selection. Thus, it may be that:

The nervous system is forced to use whatever discriminative systems it has available, *unless* these are already fully occupied with other tests or inputs, so that we tend to use our perceptual capacity to the full on whatever sense data reach the receptors. (Treisman, 1969, p. 296)

The role of physical distinctiveness between relevant and irrelevant information is less clear cut. Clearly, it is not a sufficient condition for early selection, as studies of low perceptual load have shown interference from distractors, even when the relevant and irrelevant items occupied very remote locations in the display. Regarding the necessity of this condition, it seems obvious that some level of distinction between relevant and irrelevant items ought to be maintained for available resources to be prioritized appropriately. Several studies reviewed in the present paper (Navon, 1989; Pashler, 1984; Weisgerber & Johnson, 1989) have demonstrated early selection in cluttered displays, even when the target and distractors occupied nearby locations within 1° of visual angle. More importantly, however, other researchers, using cluttered displays and actually manipulating the distance between target and distractors (C. W. Eriksen & Hoffman, 1972, 1973; Yantis & Johnston, 1990), have found that adjacent but not remote distractors produced interference, hinting that the presence of intervening items that consume spare capacity may be critical.

In sum, it seems that high load is necessary for selective processing, whereas the separation of the irrelevant item from the target (perhaps in terms of how many items are between them) determines whether the selection will be the appropriate one, so that the relevant items exhaust the available capacity rather than the irrelevant ones. Thus, although the exact nature of the in-

teraction between perceptual load and physical distinctiveness required for early selection is not yet clear, it appears that both variables are fundamental components of effective attentional selection. To quote Yantis and Johnston: "Effective focused attention may be carried out only when task demands make it desirable and visual conditions make it possible" (1990, p. 146). We propose that what makes early selection "desirable" is high perceptual load, which forces selection by exhausting capacity. What makes early selection "possible," given a high load, is a clear physical distinction between relevant and irrelevant stimuli.

We contend that the notion of perceptual limitation can serve as a useful theoretical construct by integrating the quantified treatment of the capacity approach with the structural metaphor of attentional selection. The proposed approach suggests a resolution to the early- versus late-selection debate by postulating that perceptual load is the necessary condition for early selection. Our review of recent literature in visual attention reveals that support for either early or late selection is dependent on the two conditions of perceptual load and physical distinctiveness. The present analysis also suggests that future research concerned with the issue of locus of selection ought to pay special attention to the joint manipulation of these two variables.

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## NOTE

1. Neumann and DeSchepper (1992) suggested inhibition as a means for selection. According to this view, the finding of a "fan effect" for inhibition under high load may demonstrate a failure of selection rather than its success. It is only under our proposal that this result should be interpreted as showing better filtering with load.

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