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The Flankers Task and Response Competition: A Useful Tool for Investigating a Variety of Cognitive Problems

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Research has shown that the reaction-time interference produced by the flankers task arises, at least in large part, from the incipient activation of competing responses. The response competition paradigm has made valuable contributions to evaluating continuous flow versus discrete stage models of information processing as well as understanding cortical evoked potentials. The paradigm has been used to map the visual attentional field as a function of task demands and has also been found useful in the study of memory. It offers promise in studies of cognitive categorization and has provided insights into the "fast same effect" on same–different judgements on comparison tasks. It is currently being applied to the study of disjunctive comparisons.

This presentation has several objectives: first of all, to give a brief history of the development of the response competition paradigm or, as it has sometimes been called, the "flankers" task; secondly, to mention briefly the research that clearly localized the effect in the activation of competing responses. The major emphasis, however, will be on reviewing how the paradigm has contributed to investigations in a number of different areas in the domain of cognitive psychology and, in so doing, on suggesting how the flankers task can be applied to new problems.

The development of the paradigm had an element of serendipity to it. I was studying the selective process in visual attention and had adapted a procedure used by Averbach and Coriell (1961) in their studies of iconic memory. Instead

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of iconic memory, I was interested in how the human subject selects one of a number of essentially equally potent visual stimuli for his/her response. The experimental procedure consisted of presenting a circular array of letters centred on a fixation point and requiring the subject to name the letter that was indicated by a conspicuous black bar. The displays were similar to those shown in Figure 1. Unlike Averbach and Corriel (1961), who presented the cue after the display in order to study iconic decay, I presented the bar cue at measured time intervals before the letter display occurred in order to determine the time course of the selection process. The results showed that the reaction time for naming the cued letter decreased in a monotonic function as the lead time or stimulus onset asynchrony (SOA) between the cue and the onset of the display increased, with the function becoming asymptotic in the region of 250 msec.

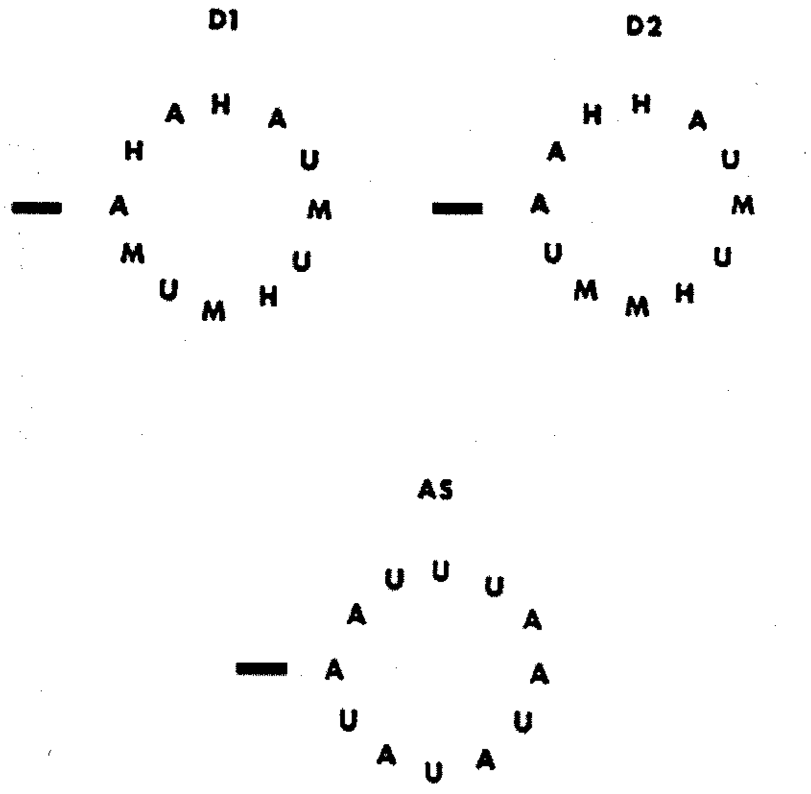

FIG. 1 Representative displays used for studying response competition. The D1 display shows a target letter in the nine-o'clock position, flanked by letters of the opposite response class. Similarly, D2 shows the response-competitive letters two display positions removed from the target letter. Display AS is a control display, where all letters are response-compatible with the target.

A most interesting finding was that the asymptotic level of performance, the response time (RT) in vocalizing the cued letter, depended upon the number of letters in the displays. Even when the cued location was available for over 500 msec before the display was presented, it still took approximately 50 msec longer for subjects to name the cued letter in a 12-letter display than in a 4-letter display, and 30 msec longer in an 8-letter display. This would not be surprising if subjects had to search the display for the target, but the target location was designated by the conspicuous cue for as long as a half-second beforehand. Even with ample time to process target location, the presence of surrounding letters slowed the vocalization time for the target.

Analysis of the errors found that they predominantly consisted of naming a letter adjacent to the designated target. Furthermore, subjects frequently reported that they knew that they were naming the wrong letter even as they were giving it as the response. This suggested to me that attention was not selective enough to eliminate the simultaneous processing of some of the other letters in the display and that even on correct trials the priming or partial activation of the names of the other letters was inhibiting and thus slowing the overt vocalization of the correct letter.

To test this possibility, Hoffman and I (Eriksen & Hoffman, 1973) devised an experiment to check on the possibility of response competition. Instead of having the subjects vocalize the target letter, a classification task was employed in which the subjects responded to the four target letters—*A*, *U*, *M*, and *H*—by moving a lever in one direction for *A* and *U* and in the other direction for *H* and *M*. Response time was measured, and speed was stressed. Circular displays of letters were again used, with the target letter in the display designated by the black bar cue. Examples of these displays are seen in Figure 1. The use of a classification task enabled us to manipulate the response compatibility of the noise letters in the display with the target letter as well as the perceptual heterogeneity of the display. For example, the entire 12-letter display might consist of letters that were response-compatible with the target letter (i.e. each letter in the display calls for the same direction of lever movement). Thus a compatible display would consist, for example, of *A* as the target, and the remaining 11 letters would be an assortment of *A*s and *U*s. An example of a response-incompatible display would be *A* as the target with *H*s and *M*s as the noise letters. Additional manipulations in this experiment were the distance in display positions between the cued target letter and response-incompatible distractor letters and the SOA by which the cue preceded the appearance of the display. (See Figure 1, where different display compatibilities are represented as well as different distances between target and response-incompatible distractor letters.)

The results were quite clear in showing that the response compatibility of the distractors was a potent determiner of target RT. If a response-incompatible distractor was in an adjacent position to the target, RT was appreciably increased. The amount of increase in target RT was less if the closest incompatible distractor was two display positions removed, but even then RT was appreciably and significantly greater than when the display contained only response-compatible distractors. However, if the incompatible distractor was four display positions from the target, RT was not significantly nor appreciably different from response-compatible displays. And it is important to note that these effects of target distractor compatibility persisted as the SOA by which the cue preceded the display increased from zero to 350 msec. In other words, even when the position of the target was made known as much as 350 msec ahead of time, response competition occurred.

In order to verify and extend these findings, my wife, Barbara, and I (B. A. Eriksen & C. W. Eriksen, 1974) simplified the task. We used displays in which the target always occurred in a known location immediately above the fixation point. Thus there was no location uncertainty regarding the target, and ample time was available for attentional direction. Task was again RT classification, with the target letters *H* and *K* requiring a lever movement response in one direction and the letters *S* and *C* in the other. There were three kinds of displays: compatible, incompatible, and neutral. In compatible displays, the target letter was flanked by letters that were either identical to the target or the other letter with the same response assignment as the target. Incompatible displays had the target letter flanked by letters of the opposite response assignment. In neutral displays, distractor letters were of two kinds: those sharing feature similarity with *S* and *C* and those sharing feature similarity with *H* and *K*. The distance between the target and the distractors varied between 0.06 and 1.0° of angle over trials.

The main findings were quite clear-cut. If the target was flanked by distractors from the other target class, RT was increased by as much as 80 msec over the RT obtained when the flanking distractors called for the same direction of lever movement as the target. The effect was greatest when the target-distractor separation was 0.06° of angle but was still present and appreciable when the distractors were 1° of angle in separation.

A most interesting suggestion in the data concerned the effect of neutral distractors (letters that did not have an experimentally defined response). If the neutral distractor letters shared feature similarity with the target letter, they tended to have little effect on RT. If, however, the neutral distractors showed feature similarity to the target letters in the other response class, they increased RT similarly to the opposite response class letters, although by a lesser amount. Although the finding regarding feature similarity to the target was only suggestive in this experiment, we have confirmed its existence in several other experiments (Eriksen & St. James, 1986; Yeh & Eriksen, 1984).

Instances of response competition had been known in psychology before our findings. The best-known example of a similar effect is the Stroop task (Stroop, 1935), where colour name words are printed in either congruent- or incongruent-coloured ink. When a subject is asked to name the colour of the ink, latency of response is increased if the colour name word is different from the colour of the ink in which it is printed. Our findings show that this response compatibility effect is much more general than had been assumed from experimentation with the Stroop task. The effect is not limited to conflict inherent within the stimulus itself; it can come from other objects in the visual field in proximity to the attended object. Furthermore, the findings show definite limitations on the spatial resolution of visual attention. It is a factor in the performance of visual search tasks and, as we shall see below, the pervasiveness of the phenomenon makes possible its use as a means of investigating a variety of problems in cognitive processing.

From our research thus far it seems clear that the effect of response compatibility is localized in the response system rather than in the perceptual or cognitive processing of the stimulus displays. The elevation in RTs in the presence of response-incompatible stimuli could readily be ascribed to reciprocal inhibition (Sherrington, 1906) arising from the incipient activation of the response associated with the incompatible distractors, which, in turn, would slow the execution of the correct response to the target. Similar explanations had been advanced for the Stroop effect. We were able to test this explanation directly by using electrophysiological measures of response activation.

Using the flanker displays of Eriksen and Eriksen (1974), an experiment was carried out (Eriksen, Coles, Morris, & O'Hara, 1985) in which subjects were instructed to make a squeeze response with one hand to the letter *H* and with the other hand to the letter *S*. Electromyographic recordings (EMGs) were taken from the forearms on each trial. We found that when the target was flanked by the other target letter, the EMGs associated with the incorrect response were greater and more frequent than when the target was flanked by response-compatible letters. This measure of incipient response activation was present even when the subject overtly executed the correct response. In a further, more extensive investigation (Coles, Gratton, Bashore, Eriksen, & Donchin, 1985), we replicated these findings and extended them to show that the squeeze response as measured by sensitive strain gauges was also activated at a low level by incompatible distractors. This study also measured cortical evoked potentials and found that incompatible distractors had a small slowing effect on the latency of the P300 wave.

A number of other studies were performed to determine to what extent response competition occurred in other experimental tasks. One task was semantic classification. Subjects were presented with the name of an animal and asked to classify the named animal as large or small as quickly as possible. In what the subject knew to be irrelevant display locations above or below the target word, other words would sometimes appear. In some cases these might be words unrelated to the task, but in the cases of interest the words *large* or *small* would occur. The results showed that when the words *large* or *small* occurred along with the target word, RT in classifying the animal's size was markedly affected if the distractor word was incompatible with the target word. For example, if the target word was *mouse* and the word *large* appeared at an irrelevant location in the display, RT to classifying *mouse* as "small" was increased relative to a neutral distractor word. If the distractor word was *small*, on the other hand, there was little or no effect upon the speed of classifying *mouse* as "small" compared to the neutral condition. Similarly, if the distractor word *lion* was presented with the target word *mouse*, RT was increased as compared with presenting a small-animal word distractor such as *worm*.

We thought that we might use this technique as a means of investigating cognitive classification or mental organization into what was relevant and irrelevant in terms of categorization. For example, if the subject's task is to classify the size of animals, we know that animal names in the same category (animals) will interfere if their size is incompatible with that of the target. But will distractor words from different categories interfere if the size of their referent is incompatible with that of the target? In other words, if the word *mountain* is presented with the target *mouse*, will the RT to classifying mouse as "small" be increased? Several experiments were carried out along this line of exploration, with the consistent result that distractor interference did not occur across categories. An incompatible distractor within the category of judgement produced marked interference in classification RT, as did also the direct response priming words *large* and *small*, but size-discrepant distractors from another category had little effect. (See Shafer & LaBerge, 1979, for additional work on classification using the competition paradigm.)

Matching Tasks: Same–Different Judgements

The response competition paradigm also turned out to be adaptable to the matching task or same–different judgements. Skelton and I (Skelton & Eriksen, 1976) had been using a matching task as a means of determining the speed with which visual attention could be switched from one location in the visual field to another location, and we found that distractors in the visual field markedly increased the latency of "same" judgements. Krueger (1970, 1973) had previously reported that extraneous stimuli presented with targets in a matching task influenced the latency both for "same" and for "different" judgements, depending upon the congruency of the extraneous stimuli and the targets. Based upon Krueger's results and our observations, my students at the time, Keren, O'Hara, and Skelton (1977), systematically explored the relation of distractors to the targets letters presented simultaneously for judgements of "same" and "different". In addition, they sought information as to the depth of processing of the distractors. It was evident from the previous research that we and others had carried out with the competition paradigm that the distractors were processed at least to the level of identification, but perhaps selective attention could screen out the effects of the irrelevant stimuli if further mental operations were required before a judgemental response.

To vary the level of processing required for a stimulus match, Keren et al. (1977) used Posner's (Posner & Mitchell, 1967) technique of having subjects match only for physical identity of the target letters, only for name identity, or only for conceptual identity (both matching stimuli vowels or consonants). Noise or distractor letters were presented in what the subject knew to be an ignored location between the two stimuli to be judged. The results showed that if the distractor was the same as the targets on "same" trials, little effect upon RT was found. But if the distractor was different from the targets on "same" trials, regardless of the level of the match, the latency of the "same" judgement was significantly and appreciably increased. Thus when the level of match was for physical identity, a distractor that was a different letter from the targets increased the latency for the "same" judgement. If the level of match was conceptual, the use of a consonant as a distractor increased the latency of judging that two vowel targets were the "same". The results were somewhat less consistent on "different" judgements, but in general a distractor that matched one of the targets resulted in longer RTs than were obtained when the distractor differed from both targets on the level that was to be matched.

Most recent models of how human subjects judge whether two stimuli are the same or different have taken as their point of departure the rather consistent finding that when the differences between a set of stimuli are not very great, the average reaction times of "same" judgements are faster than those of "different" judgements–the "fast same effect". C. W. Eriksen, O'Hara, and B. A. Eriksen (1982) have pointed out that the "fast same effect" may not reflect the speed with which cognitive operations are carried out but may, instead, be essentially an artifact arising from response competition. If so, the "fast same" effect cannot be taken as evidence that sameness can be processed faster than difference. These authors point out that the visual system is an integrative system over time and that as much as several hundred milliseconds may be required for a percept to develop maximum clarity. If the stimulus set is relatively homogeneous, the developing percepts of even different stimuli will have many features in common, and these common features are evident before the differences in features become discernable in the developing percept. If the sameness of features began to prime the response for "same", then by the time differences become detectable in the percepts, the overt signifying response for "same" has incipient activation that the response of "different" has to overcome before it can be executed. Consequently, the slower different responses or the "fast same" effect may result all or in part from a response system characteristic and may thus mask possible differences in the speed of cognitive operations underlying the perception of sameness or difference.

If the "fast same" effect is due at least in part to response competition, then one should expect to find evidence of incipient activation of the response system used for signifying "same" judgements when the stimuli to be judged are different but not grossly so. St. James and Eriksen (1992) found just such evidence in the form of minute double responses when slightly different stimuli were presented for matching. These investigators used a precision joystick coupled to a computer. Subjects were required to move the joystick in one direction for "same" judgements and in the other direction for "different" judgements. The stimuli were capital letters selected so that half of them were highly confusable with one another and the other half had very low confusability. On "*different*" *trials*, when the highly confusable letters were presented, there were more than twice as many abortive double responses on the joystick in the direction of a "same" judgement as were obtained on trials where the stimuli were the *same*. That double responses were not some artifact of "different" judgements was shown by the low number of double responses on "different" trials when the stimuli to be judged were from the set of letters with very low confusability. It will be recalled that the "fast same" effect does not occur reliably when the stimuli to be compared are easily discriminable, and, consistent with this, there was no significant difference in RT in this experiment between "same" judgements and the "different" judgements for the easily discriminated pairs. None of the current models of same–different judgement can accommodate these results other than the response competition model.

Our work with response compatibility and competition in the same–different task permitted Garner (1988) to resolve an anomaly in the research on integral and separable dimensions. The problem was consistent findings that stimulus dimensions that met the criteria for separability on classification tasks behaved like integral dimensions when a matching task was used. As an example, colour and form meet the criteria for separable dimensions on a classification task. But if a matching task is used and subjects are required to judge whether or not two stimuli have the same shape, presenting a red square and green circle as a stimulus pair results in an appreciably faster RT for the "different" judgement than if the stimulus pair consists of a red square and a red circle. In this case, where the stimuli differ in both shape and colour, there is a redundancy gain, a criterion for integral dimensions.

Garner (1988) was able to show that the inconsistency between the two paradigms resided at the response level. In the classification task there is no response incompatibility or competition, whereas on the matching task the red circle and red square stimuli lead to response conflict: The sameness of the stimuli in terms of colour primes the response for saying "same" which inhibits and slows the correct response "different".

Response competition on a matching task was used by O'Hara (1980) and O'Hara and Eriksen (1979) to study the differences in the way that words and anagrams were perceived and processed. The stimuli were capital letters presented in pairs, and the subject judged whether the letters were the same or different. On experimental trials short words or their anagram counterparts were presented as distractors along with the stimulus letters but in irrelevant locations in the display. The anagram distractors significantly increased the RT for "same" judgements of the letters, but the word distractors had little effect. The distractor *GDO*, for example, impaired "same" judgements of the target letters, but the same distractor letters arranged into the word *DOG* did not. Obviously the subjects were perceiving words as units rather than as collections of letters, but, most importantly, their minds were classifying the words as separate and not related to the matching comparison, whereas the group of letters was somehow entering into the comparison process. In this respect the results are similar to those I have reported above in connection with the judgement of animal size. The RTs for classifying animals as "large" or "small" were markedly increased if an incompatible-sized animal was presented as a distractor, but RTs were unaffected if the distractor was a non-animal object of discrepant size.

Measuring the Visual Attentional Field

There is diverse and substantial evidence that attention has a representation in the visual field and the matching task with the response competition modification can prove useful in measuring this representation. The technique was used by Pan and Eriksen (1993) to manipulate the extent of the relevant area of stimulation in the visual field (the attended area) by the amount of separation along the vertical or horizontal meridian between the two target letters on a matching task. The separation varied between 1 and 3° of visual angle. The distance of an incompatible distractor letter was varied orthogonally with the separation of the two target letters. Consistent with previous findings, the presence and location of a distractor letter identical to the targets had little or no effect upon the latency of "same" judgements. But a letter different from the targets markedly increased same RTs. However, the location of the incompatible distractor interacted with the separation of the targets. When the targets were 0.5° on either side of the fixation point, an incompatible distractor at 0.5° on the perpendicular meridian had maximum effect, but when it was located at 1.0° on this meridian, no measurable effect was obtained. As the separation of the targets increased, however, the distance at which an incompatible distractor impaired RT also increased. The attended area in the visual field, as assessed by this method, appeared to be elliptical in shape, with the principal axis determined by the location of the two letters to be matched.

Eriksen, Pan, and Botella (1993) used a variation on the flankers task to assess the attended area in the visual field. They combined a go/no-go task with a two-choice RT discrimination of line orientation. The stimuli they used are illustrated in Figure 2. The go/no-go task was used as a means of varying the extent of the attended area. If the ends of the form were the same—both (or both <)—it was a "go" trial, and the subject then discriminated the direction of

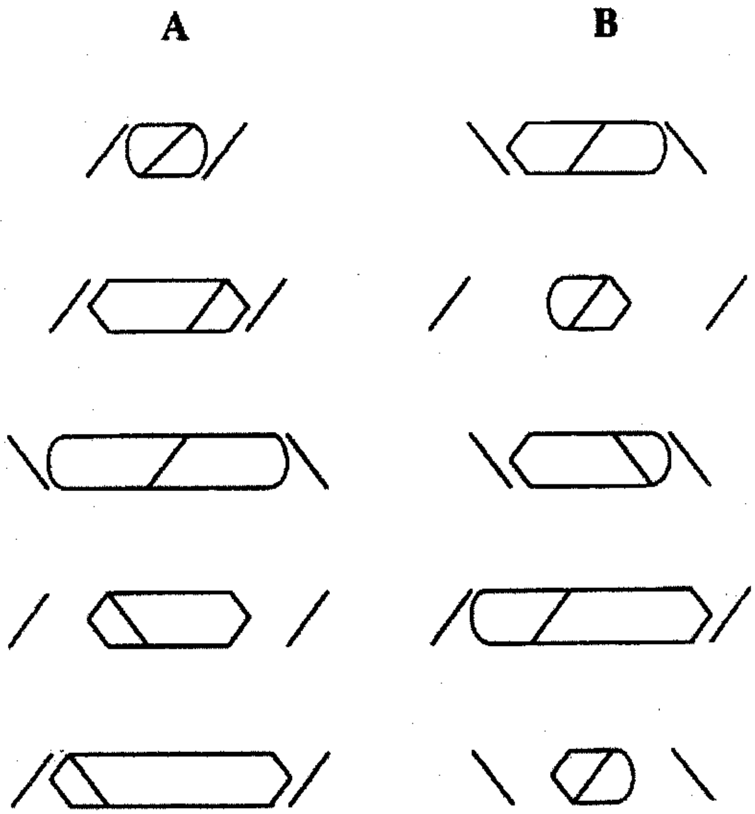

FIG. 2 Examples of the stimuli: Column A provides examples of "go" trials showing both compatible and incompatible distractors at different locations for different extents of attended area; variation in target position is also shown. Column B provides comparable examples of "no-go" trials.

line inclination by moving a lever either up or down. External to the form were line distractors that were either compatible or incompatible with the target line that occurred within the form. The horizontal extent of the form systematically varied, as did also the location of the distractors in terms of their distance from the edge of the form. The location of the target line within the form also varied from the centre of the figure to positions closer to one of the edges. By these experimental manipulations, it was possible across experimental conditions to vary the distance of the distractor from the target, holding constant the distance of the distractor from the edge of the form (attended area) and to vary the distance of the distractor from the edge of the attended area holding constant the distance from the target. The results clearly showed that the critical variable was the distance of the distractor from the edge of the attended area rather than the distance of the distractor from the line target. For example, if the attended area was only 1° of angle in extent and the target at zero degrees, an incompatible

distractor at 3° had little effect, but when the attended area was increased to 2.5°, an incompatible distractor at the same 3° eccentricity now had maximum interfering effect on target RT.

While we have succeeded in measuring the attended area in the visual field with response competition, the nature of this attended area is still unclear. It can be conceived as a variable-sized spotlight or a zoom lens, but we prefer an interpretation in terms of inhibition. Instead of the boundaries of the attended area representing the outer edges of a spotlight of enhanced processing, they represent the inner edges of a field of inhibition or attenuation of visual stimuli. Grice, Boroughs, and Canham (1984) and Flowers (1990) have noted that the presence of response competition requires that some inhibitory process exist to keep incipiently activated responses from overt occurrence, and the work on negative priming (e.g. Neill, 1977; Neill & Westberry, 1987; Tipper, MacQueen, & Brehaut, 1988) provides clear evidence of such inhibitory processes at work. Instead of a spotlight metaphor, Navon (1990) has suggested that the attentional field might be an aperture, and an aperture conception would be most compatible with a conception of the attended field as an inhibition-free area for stimulus processing.

How Selective Is Selective Attention?

The interference in RT produced by incompatible distractors has been interpreted by some (Yantis & Johnston, 1990) as failures of selective attention. However, Van der Heijden (1992) has perceptively pointed out that the response competition effect does not illustrate failures of attentional selectivity. Even in the presence of distractors, the to-be-attended target is responded to with a very high level of accuracy, and I might add that the increase in RT in the presence of incompatible distractors is typically only on the order of 10 to 20 msec. Furthermore, this increase in RT can be attributed to reciprocal inhibition in the response system and as such does not reflect the cognitive processes underlying stimulus selection. The target stimulus is correctly selected, and all that we have evidence for from the response competition is that some distractors have also been processed to the point of identification and incipient response activation. Selection has not failed, and it is quite possible that the cognitive side of the selective process is not impaired by the distractors. It is our RT measure of this selective process that is confounded or contaminated by response competition.

This view is entirely consistent with a late-selection theory of stimulus processing and selective attention. The evidence that we have been considering above seems amply clear in showing that identified stimuli result in some preparation of the appropriate responses. But response competition is not in itself a clear support for late-level theories. There is the consistent and troubling finding that there is a gradient around the spatial location of the attended target and only distractors within about 1.5° of the target elicit response competition. In other words, a distractor that is located on a retinal area with the same acuity as that of the target shows no response competition effects if it is 3° of visual angle from the target, but the same distractor at only 1° separation shows pronounced effects. Modification of late-selection theories is necessary to accommodate this gradient or spatial effect.

One solution is the concept of inhibition that I have mentioned above. Attention is not only selection of the relevant stimulus, but also the concurrent inhibition of the irrelevant or competing stimulation. If irrelevant stimuli are identified, they leak into the response system in terms of preparing the appropriate responses. Some inhibitory process would seem to be required to keep this response preparation from actually evoking responses.

Some investigators (e.g. Miller, 1991; Yantis & Johnston, 1990) have tried to make attention more selective by manipulating variables designed to eliminate or reduce the competition effect of response-incompatible distractors. This research might best be characterized as manipulating the intensity of attention (LaBerge, Brown, Carter, Bash, & Hartley, 1991). Most of us realize from observing our own behaviour that attention is not an all-or-none process. Our concentration or attention varies in intensity as a function of the task and its interest for us. In my case, if I am reading a *P & P* manuscript, I generally need to be called for dinner only once, but if I am reading a Tom Clancy novel, several calls are required before I "hear" or respond.

A concept of inhibition fits well with the variation of intensity of attention. As the intensity of attention increases, the attenuation or inhibition of stimuli irrelevant to the task increases. The work on the negative priming effect (e.g. Neill, 1977; Tipper et al., 1988) not only shows the existence of these inhibitory effects but also their central locus. The flankers task can be used as a measure of the inhibitory effect at the peripheral or motor level. The work of LaBerge et al. (1991) demonstrates that as the attentional demands of a task increase (increase in attentional intensity), the spatial region around the attended stimulus where response compatibility effects can be detected decreases. In this manner the flankers task can be used as a diagnostic of attentional intensity.

Continuous Flow and Discrete Stage Models of Information Processing

The flankers task and other response-compatibility paradigms have proven very useful when combined with psychophysiological and cortical event-related potential measures in the investigation of information-processing models. Discrete serial stage models of information processing have enjoyed a dominant role in cognitive theorizing motivated in part by the work of Sternberg (1969) and by Sanders (1990). These models assume that there are serially organized stages or operations in processing stimulus inputs and that each stage transmits its output in one discrete step. The next stage becomes active only after receiving

the input from the preceding stage. In the typical choice reaction-time task the decision stage transmits its output by activating the relevant response. Little or no attention is paid to the response process or how it is activated.

Continuous models, by contrast, assume parallel activation of the processing operations with the further assumption that these parallel operations communicate with one another during their operation so that they are constantly updating the other operations upon the status of the information analysis. Although not all continuous models concern themselves with how decisions are translated into responses (e.g. McClelland, 1979), the continuous flow model of Eriksen and Schultz (1979) and the variable criterion model of Grice, Nullmeyer, and Spiker (1977) make response activation an important focus in their models. Guided by the results from the flankers task and the other work from the response-compatibility paradigms, Eriksen and Shultz (1979) proposed that the results of partial information analysis is passed to the response system and serves initially to prepare relevant responses for activation or evocation.

The use of the flankers task, in conjunction with psychophysiological measures such as the electromyogram, evoked potentials such as the P300, and the lateralized readiness potential, has provided impressive support for the idea that partial incompletely processed information is transferred to the response system (e.g. Coles, Gratton, Bashore, Eriksen, & Donchin, 1985; Gratton, Coles, Sirevaag, Eriksen, & Donchin, 1988; Smid, Lamain, Hogeboom, Mulder, & Mulder, 1991). Not only has this body of research demonstrated the partial transfer of information through the processing operations, but it has, in addition, provided new and important information on how the response system is activated and the sequencing of the different components. Furthermore, the response competition paradigm has enabled the demonstration that the use of partial information by the human subject can be under strategic control (Gratton, Coles, & Donchin, 1992).

Conclusion and Some Implications

I have not tried to give a complete and/or exhaustive review of how response-compatibility paradigms have contributed and can contribute to research in psychology. Space does not permit it. I have focused mainly on the development of my ideas and the research of my students and my laboratory. I have had to ignore the work of numerous other investigators who have employed the flankers task and other variations of the response-competition paradigm in ingenious and fruitful ways on a variety of psychological problems. For example, Ste. Marie and Jacoby (in press) have used it in the study of memory, as have also B. A. Eriksen, C. W. Eriksen, and Hoffman (1986). Evans, Craig, and Rinker (1992) have used it in investigations of tactile discriminations, and recently Ridderinkhof (1993) has fruitfully employed the technique in developmental studies. But in closing I want to point out a general and what I consider an important implication of this body of research for experimentation in cognitive psychology. When choice reaction-time procedures are used in the study of cognitive processes, there is a serious risk that conclusions concerning cognitive processes can be confounded with characteristics of the response or motor system.

Many years ago, Guthrie criticized Tolman's cognitive theory of maze learning in the rat on the basis that Tolman's theory left the rat "buried in thought". Today many cognitive models are subject to the same criticism; they pay too little attention to how cognitive processing is translated or eventuates into behaviour. Perhaps this represents an unconscious over-reaction against the extreme behaviourism of the 1930s and the 1940s. All too often clever and elaborate models of cognitive processing end in a decision stage where a command is given and the appropriate response is emitted. But when the choice reaction-time procedures are used in the study of cognitive processing, there is a serious risk that conclusions concerning this processing can be confounded with characteristics of the response or motor system.

We have seen above that the incipient activation of responses due to the transfer of partial information to the response system can lead to response competition and the increase in RTs. Attempts to model the cognitive operations underlying same-different judgments on the basis of the finding that "same" judgments are faster than "different" judgments are precarious, as response competition may be an important component of the "fast same effect". Similarly, conclusions concerning the efficiency of selective attention based upon RT measures may reflect more response competition than the cognitive side of attentional selectivity. I will close with one further example.

Recently, Lisa Fournier and I (Fournier & Eriksen, submitted), while working on a problem on attentional load, found that our subjects could tell us that a stimulus object was a "small red S" faster than they could tell us that the object was "small" or "red" or an "S".

In these experiments there were 8 three-dimensional stimuli obtained from the possible combinations of two sizes (large and small), two shapes (S and C), and two colours (red and green). The values on these dimensions were so selected as to have the size discrimination the most difficult (in terms of a reaction-time criterion) and the colour discrimination the easiest or fastest. The nature of the subject's judgment varied from trial to trial. On one trial the subject might be asked, "Is the stimulus small?" On the next trial, a multidimensional judgment might be required, such as "Is the stimulus a large red S?" Subjects pressed response keys to signify their "yes" or "no" judgments.

Consistent with our expectations, size judgments were the slowest of the single-dimensional judgments, with colour the fastest, but the surprising result was that three-dimensional judgments were faster than any single-dimensional or two-dimensional judgments. Also, two-dimensional judgments involving colour or shape were faster than single-dimensional judgments of size alone.

Now there is no plausible serial or parallel model of processing that can account for this observation. After all, in order to tell that an object is a "small red S", subjects have to discriminate that it is "small", just as they have to do when the question they are asked concerns only size. In several experiments we varied the procedure, but the finding was quite robust: multidimensional discriminations were faster than some of the single-component dimensions.

Further experimentation resolved the puzzle. The subjects' RT measures were contaminated with a response-compatibility effect. Single-dimensional judgments were subject to response competition. If the dimensions were parallel-processed, the different dimensions finished processing in different orders. Thus, if the subject was to judge the size of the stimulus, on "same" trials information about shape and colour was frequently available earlier than size. This information primed the "no" response, much in the same way that an irrelevant dimension on a matching task increases the latency of "same" judgments. When the size dimension finished processing, the execution of the "yes" response had to overcome the inhibition resulting from the incipient activation of the "no" response. Multidimensional judgments were facilitated by positive response priming. When subjects were to judge on positive trials whether a stimulus was "red", "small", and "C", if the colour and shape information was available faster than the size, the positive answers for these two dimensions primed the "yes" response, so that when the final information on size was available, the "yes" response was executed with a shorter latency.

The cognitive operations to tell whether an object is "small", "red", and "C" probably do take longer than to determine only whether the object is small, but due to response-competition factors RT measures of the task can lead to the opposite result.

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Attentional Scanning in the Selection of Central Targets from Multi-symbol Strings

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Subjects responded to five-symbol strings consisting of a central target, one or two compatible or incompatible flankers, and neutral symbols in the remaining positions. Performance strongly depended on the position of compatible or incompatible flankers. With normal letters, left-side flankers had a much larger impact than right-side flankers. This left-side asymmetry of the flanker compatibility effect disappeared with strings composed of spaced letters or of tiny pictures and tended to turn into a right-side asymmetry with vertically mirrored letters. These results seem to indicate the operation of attentional scanning processes. Flankers may be scanned either automatically, due to a reading-like habit, or strategically, in attempting to localize the target.

The human ability to attend selectively to an object among others is rather limited. This is strikingly demonstrated in a task introduced by B. A. Eriksen and C. W. Eriksen (1974) that has become a very popular tool for investigating attentional mechanisms. Basically, the subject is presented with a target, say the letter *S* or *H*, to which a certain response is assigned, such as pressing a left- or right-hand key, respectively. The crucial manipulation is that the target is flanked by members of the target set, so that, in a given trial, target and flankers may be mapped onto either the same response (e.g. *SSSSS*) or onto different responses (e.g. *HHSHH*). Although subjects know the location of the target in advance and

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