

Early modulation of visual input: Constant versus varied cuing

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In a previous study, subjects were asked to decide if two lines presented to the left of fixation and two lines presented simultaneously to the right of fixation were, in each case, the same or different in length. In a block of trials, the subjects were to allocate 20%, 50%, or 80% of their attention to one pair of lines and the rest to the other. On every trial, the subjects judged both pairs. Performance, expressed as d'^2 , increased linearly with attention as predicted by Luce's (1977) sample-size model. The present experiments extended the previous findings, and showed that the model holds when allocation of attention is changed on every trial and also when 0% of attention is allotted to one task and 100% to the other one. They also suggest a difference in the mechanisms of attentive facilitation, depending on whether cuing is constant or varied. Moreover, the results suggest strongly that subjects use a sharing strategy in allocating attention and do not resort to a switching strategy.

In a previous study (Bonnel, Possamai, & Schmitt, 1987), we showed that subjects were able to allocate attention precisely within the visual field. In a concurrent task, subjects judged whether two lines presented to the left of fixation were the same or different in length and, simultaneously, whether two lines presented to the right of fixation were the same or different in length. The subjects were to allocate 20%, 50%, or 80% of their attention to one pair of lines and the rest to the other pair. The same allocation of attention was maintained throughout a 64-trial block. The results showed a linear relationship between the proportion of attention allocated and performance expressed as d'^2 . Such a relationship would follow from Luce's (1977) sample-size model, which defines the limited capacity of attentional resources as the number of observations available to the subject. A related conclusion was that subjects seemed to use a sharing strategy—that is, on every trial, they allocated to each task the required proportion of attention. However, switching was a possible alternative strategy (Kinchla, 1980; Sperling, 1984), according to which the subject would allocate 100% of his/her attention to one task (left or right) and 0% to the other during a proportion, p , of trials and reverse this allocation on the remaining trials. If the subject chose the value of p correctly, the amount of attention paid to each task would, at the end of the series, match that called for by the experimenter's instructions.

Although we have argued that a sharing strategy was most probably used, a switching strategy cannot be altogether dismissed. Indeed, given our blocked design, switching could be implemented readily on the basis of a single counter. Thus, for example, the subject could pay full attention to the "80%" task on four trials and to the "20%" task on a single trial, thereby matching the instructions. This strategy is so simple that it might even be used voluntarily. Now, if the required allocation of attention is changed from trial to trial, the voluntary use of a switching strategy becomes much more difficult. The subject would have to keep track of three counters—one for each type of allocation of attention 20%-80%, 50%-50%, and 80%-20%. Consequently, allocation of attentional resources should be less accurate and results should no longer fit Luce's model so nicely. The present experiment tested this line of reasoning by replicating the earlier one but using a varied design.

Furthermore, although it is generally held that blocked designs fail to produce facilitation in reaction time (RT) studies (Posner, Snyder, & Davidson, 1980), facilitation does show up in both accuracy (Bonnel et al., 1987) and event-related potentials (ERP; van Voorhis & Hillyard, 1977) experiments. Therefore, one might wonder whether the same mechanisms are in action with both designs. Within this framework, it was important to know whether our previous results could be replicated with a varied design.

EXPERIMENT 1

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The first experiment was a replication of the previous study, except that allocation of attention was varied from trial to trial. Only the main points and the differences with the previous experiment are noted in the method section.

Method

Apparatus and Stimuli. A PDP-12 computer presented the stimuli on a cathode ray tube and collected the responses. The experiment was conducted in a dimly lighted room. The distance between the subject's eyes and the screen was 0.65 m. The subject kept his/her fingers on the 10 keys that were used for responses. The subject used a footswitch to initiate each trial.

The five cues presented at fixation were explained to the subject: < (>) meant "allocate all your attention to the left (right) side" (left and right control conditions); ← (→) meant "allocate 80% of your attention to the left (right) side and 20% to the other side" (80-20 and 20-80 conditions); + meant "allocate the same amount of attention to each side" (50-50 condition).

The signals were two pairs of vertical lines, one pair presented to the left and the other to the right of fixation. The subject had to indicate, for each pair, whether or not the two lines were equal. The inner lines (standards) were presented at 2.8° from fixation; the outer lines were presented at 3.3°. The vertical extent of the standards subtended 4.4°. The outer lines were either equal to or longer than the standards on a .50-probability basis; the length of the longer lines was adjusted separately for each subject during a training session.

Design and Procedure. Eleven naive subjects served in three sessions. The first was devoted to training. The following two consisted of two control blocks of 64 trials each and two experimental blocks of 144 trials each. The control blocks were divided into two half-blocks, and the experimental blocks were divided into four quarter-blocks with 1 min of rest between subblocks and 10 min between blocks.

In an experimental block, a trial started with one of the 80-20, 50-50, or 20-80 cues. After 500 msec, the cue was replaced by a fixation point. At this time, the subject fixated this point and allocated his/her attention according to the cue. When ready, he/she pressed the footswitch. After 150 msec, the two pairs of lines came on for 50 msec. The subject responded by pressing either the key under his/her thumb or the key under his/her little finger to indicate that the corresponding lines were equal or different, respectively. Next, the subject reported his/her confidence by pressing the key under his/her forefinger, middle finger, or ring finger to indicate *quite sure*, *sure*, or *unsure*, respectively. The subjects responded to both pairs of lines, in whatever order they liked, using the left hand for the left pair and the right hand for the right pair. The intertrial interval was 3 sec.

The control single-task conditions were the same as in our previous study (Bonnel et al., 1987).¹ In a block of 64 trials, either the 100-0 cue or the 0-100 cue was presented consistently throughout. Both pairs of lines were presented, but the same/different and confidence responses were required only for the left pair (left control) or only for the right pair (right control).

The control blocks contained four independent stimulus combinations: equal-equal, equal-different, different-equal, and different-different. Each combination was presented 16 times in a block. The experimental blocks contained the same 4 stimulus combinations crossed with the 3 cues, to give 12 types of trial presented 12 times in a block. During the last two sessions, each subject performed each control task series once and the dual-task series twice. During the training session, short 16-trials blocks, using either the + or the < (>) cues, served to permit the adjustment of the outer line for 75% accuracy.

Results and Discussion

Because the slope differed slightly from unity, d'_e was taken as the value of d' (Egan & Clarke, 1966). The z statistic was used to test the differences between the ds . The ds in the 20%, 50%, 80%, and control tasks were .78, 1.48, 2.03, and 1.94, respectively. Compared with the 50% condition, performance was higher in the 80% condition and lower in the 20% condition ($p < .001$). Control and 80% tasks did not differ ($p = .184$).

Luce's (1977) sample-size model assumes that the resources allocated through the attentional mechanism are

proportional to the number of observations that the subject can make of the display. Therefore, the performance expressed as d'^2 should be 0 when no observation is made and should increase linearly with the percentage of attention (Bonnel et al., 1987). A straight line fitted to the data through the origin gives:

$$d'^2 = 4.85 \times p, \quad (1)$$

where 4.85 is the maximum performance when 100% of attention is devoted to the task and p is the proportion of attention allocated to the task ($0 \leq p \leq 1$). The eta-square, which is a measure of the goodness-of-fit, is .96.

The main difference from our previous study is that the slope of Equation 1 is steeper than that obtained with a blocked design (4.85 vs. 3.47). The 20% conditions yielded the same performance in both studies ($p = .18$), whereas the 50% and 80% conditions produced better performance with a varied than with a blocked design ($p = .002$ and $p < .001$). The value of the slope implies that, had the subjects devoted all their attention to one task and none to the other in the dual task, their performance would be $d' = 2.20$ (4.85 $^{1/2}$). Surprisingly, this value is higher than that measured in the single-task blocked condition. If this reflects a genuine difference between blocked and varied designs, it can be predicted that performance may sometimes be better in a dual task than in a single task; this should occur if a varied design is used in the dual task and a blocked design is used in the single task. The goal of the next experiment was to test empirically this prediction.

EXPERIMENT 2

The slope of the equation that relates the proportion of attention to d'^2 in our blocked-design study was 3.47. Consequently, we predicted that allocation of 100% of attention in a dual task should yield a score of $d'^2 = 3.47$. This predicted score was about 15% below that obtained in the single-task control. Taylor, Lindsay, and Forbes (1967) also found a 15% decrement in performance on a dual task relative to that on a single task. They attributed the decrement to the need for the subject to allocate capacity to the sharing mechanism. This implies that if, as appears to be the case, a varied design produces better performance than does a blocked one, the blocked-design control of Experiment 1 cannot be compared with the varied-design dual task. With respect to the hypotheses put forward thus far, several quantitative predictions are possible. If we ask a subject to allocate 100% of attention to one task in a dual-task situation, his/her performance expressed as d' should be $3.47^{1/2} = 1.86$ or $4.85^{1/2} = 2.20$, depending on whether a blocked or a varied design is used. In both cases, performance on the other task (0%) should be zero. Now, taking into account the 15% decrement of total capacity in dual tasks, performance on the single tasks should be $[3.47/(1 - .15)]^{1/2} = 2.02$ with a blocked design and $[4.85/(1 - .15)]^{1/2} = 2.39$ with a varied design. Experiment 2 was designed to test these predictions.

Method

Six subjects who had served in the blocked-design study (Bonnel et al., 1987) were recruited. No additional training was given. Only the 100-0 and 0-100 conditions were run.

The subjects were submitted to six 64-trial blocks during each session: two blocked-design, single-task blocks similar to the control blocks of Experiment 1; two blocked-design, dual-task blocks in which responses were required on both the left and the right; and two varied-design blocks in which the cue was varied on a trial-to-trial basis—in one block, the subject gave only the responses corresponding to the 100% task (single task), and in the other block he/she gave a response on both sides (dual task). In every other respect this experiment was the same as the first one.

Results and Discussion

The d' indices were obtained in the same way as in Experiment 1; statistical analyses were made in terms of confidence intervals (CI: .05 level).

With 0% of attention, performance was low (but somewhat higher than 0) both in the blocked ($d' = .68$; CI = .58/.78) and in the varied ($d' = .56$; CI = .41/.71) designs. The main prediction was for a dual task with 100% of attention. The predicted performance falls within the CI for both the blocked (expected, 1.86; observed, 1.9; CI = 1.72/2.05) and the varied (2.2; 2.27; 2.2/2.34) designs. In both cases, the performance is higher than the prediction, possibly because the subjects had several hours of practice after the length of the outer line was set for 75% accuracy.

In Figure 1, the d'^2 's are plotted against the proportion of attention. Also shown in Figure 1 are the best fits of the sample-size model to the data obtained with the blocked and the varied designs (the empty circles are from Bonnel et al., 1987). In both cases, the eta-square indicates a good fit (varied design, .98; blocked design, .97), and, as predicted by the model, the origins are very close to 0.

In contrast to the dual-task conditions, our predictions for the single tasks seem to be verified with a blocked

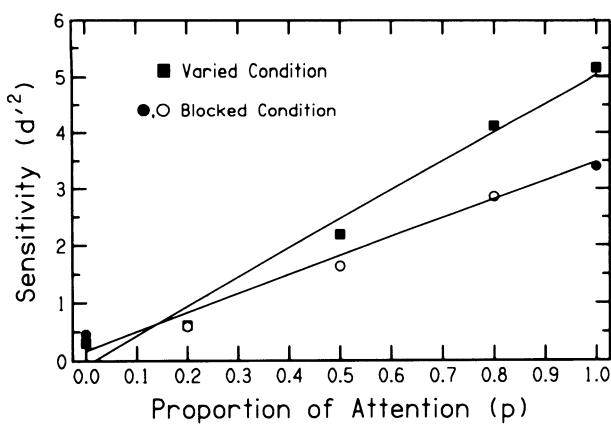


Figure 1. Relationship between the square of d' and the proportion of attention allocated to the task for the blocked- and varied-design situations. The data points at abscissas 0 and 1 are from Experiment 2, the middle filled squares are from Experiment 1, and the empty circles are from Bonnel et al. (1987). The solid lines are the best linear fits to data in both designs.

design (expected, 2.02; observed, 2.08; CI, 1.95/2.21) and not with a varied design (2.39; 2.08; 1.88/2.28). However, things are not that simple, because, for the first time, a significant difference between the left and right tasks shows up. With a blocked design, performance is higher than predicted for the left task ($d' = 2.3$, CI = 2.11/2.49) and lower for the right task (1.68, 1.5/1.86); also, performance with a varied design is higher for the left (2.35, 2.05/2.65) than for the right (1.49, 1.25/1.73) task.

One possible explanation for this is that the irrelevant stimulus, to which no response is made, disturbs the allocation of attention in single tasks, but did so differently for the left and the right stimuli. To check this possibility, we replicated this experiment using 5 naive subjects. The only differences were that the subjects were given a training session and that the irrelevant pair of lines was not presented. Two blocked-design blocks (left and right), in which both pairs of lines were presented, were also run. The results were as follows. First, left/right differences were no longer significant. Next, in the blocked-design two-pair control condition, d' was not different from those obtained in the previous experiments ($d' = 1.86$, CI = 1.64/2.32). Finally, when the irrelevant pair was removed, $d' = 1.97$ (CI = 1.76/2.20) with a blocked design and $d' = 2.13$ (CI = 1.69/2.57) with a varied design. Thus, the predicted values for a blocked design (2.02) and for a varied design (2.39) are within the CI of the observed values.

GENERAL DISCUSSION

These experiments provide further evidence that subjects are able to share their attention in the kind of dual task that we had previously used. At first, allocating a given percentage of attention to one task and the rest to another seems very odd to most subjects, and some of them think that the only way to cope with these instructions is to use a switching strategy. We argued, in the introduction, that this strategy was possible in the case of a blocked design but most improbable in the case of a varied design. Therefore, our finding that subjects can divide their attention with about the same precision in both designs supports the conclusion that they used a sharing strategy.

The second point regards the slope difference between the two types of designs. This slope represents the maximum performance (100% of attention) in a dual task. Since this slope is a d' value, it may increase for one or both of the following reasons: N , the total capacity, increases, and/or sigma, the internal noise which affects the coding process, decreases. Indeed, the blocked-design situation may appear as a duller task than the varied-design situation; hence, a greater N may stem from a higher interest in the task. If this is the case, factors that affect motivation, such as monetary incentives, should also affect the slope of the function relating performance to attention. Another possibility is that the varied design requires a stricter control of the allocation of attention and that this stricter control reduces internal noise (sigma).

Finally, let us consider a more general interpretation of the differences between the two types of design which could possibly account for the slope difference. One effect of attention is generally believed to yield a better and/or faster coding of the stimuli. It is possible that the enhancement that occurs—either better coding or faster coding—depends on the type of design. Suppose that allocation of attention in blocked design results in better encoding without (especially with simple tasks) shortening processing times. Such an effect can be revealed by greater accuracy (Bonnel et al., 1987) or by an enhanced N1 component of the ERP (van Voorhis & Hillyard, 1977), but it cannot be revealed by RT measures (Posner et al., 1980). Suppose further that,

with a varied design, attention allows both better and faster encoding of the stimulus. In this case, facilitation would become visible even in an RT study that is meant to measure the duration of the processes. Now, it seems reasonable to assume that a fast coding process operates on a stronger iconic trace than does a slow coding process, and thus to assume that the former provides a less noisy representation of the stimulus than the latter, which could explain the better performance with a varied, as opposed to blocked, design. Why the mechanisms are different with the two kinds of designs is not clear at the moment. Although highly speculative, this interpretation can be tested by combining time and accuracy measures (Pachella, 1974).

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NOTE

1. These control conditions were run in our previous study and in the two present experiments for purposes of comparison across experiments. The differences between these conditions were never statistically significant.

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Notices and Announcements

Royal Society International Discussion Meeting Auditory Processing of Complex Sounds London, England December 4-5, 1991

This meeting will consist of presentations by invited speakers, plus a limited number of contributed poster presentations. Invited speakers include: R. P. Carlyon (Sussex, U.K.), D. Deutsch (San Diego, U.S.A.), E. F. Evans (Keele, U.K.), J. W. Hall (North Carolina, U.S.A.), A. J. Houtsma (Eindhoven, The Netherlands), S. McAdams (Paris, France), B. C. J. Moore (Cambridge, U.K.), A. R. Palmer (Nottingham, U.K.), S. Rosen (London, U.K.), M. A. Ruggero (Minneapolis, U.S.A.), I. J. Russell (Sussex, U.K.), N. Suga (St. Louis, U.S.A.), A. Q. Summerfield (Nottingham, U.K.), E. D. Young (Baltimore, U.S.A.). The organizers are R. P. Carlyon, C. J. Darwin, and I. J. Russell.

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