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ON DOING TWO THINGS AT ONCE:
II. ELIMINATION OF THE PSYCHOLOGICAL REFRACTORY PERIOD EFFECT[1]

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The psychological refractory period (PRP) effect of interference between 2 choice reaction time tasks at short intertask intervals was eliminated when both of the tasks were ideomotor compatible. The PRP effect was, however, obtained when either or both of these tasks were replaced by stimulus–response compatible tasks that were not ideomotor compatible. It was concluded that a major source of the PRP effect is a limited capacity mechanism that (*a*) translates between an encoded stimulus and a response code, and (*b*) is not needed when a task is ideomotor compatible.

The psychological refractory period (PRP) effect occurs as a slowing of reaction time to the second of 2 rapidly successive signals, an effect that decreases with increasing intervals between signal onsets (see reviews by Herman & Kantowitz, 1970; Reynolds, 1964; Smith, 1967). The present research deals with the PRP effect as it occurs in a task involving response uncertainty that must be resolved on the basis of a decoding of each signal.[3]

The attempt to eliminate the PRP effect from a situation involving response uncertainty was suggested by the ideomotor (IM) theory interpretation (Greenwald, 1970; James, 1890, Ch. 26) of the response selection process. This formulation holds that an action is encoded, for the purpose of performance control, in the form of an image of its sensory feedback. This may be restated so as to avoid the (distasteful to some) term "image" by hypothesizing an entity to be called a "response code," this being the precise form in which information must occur to enable selection of a given response. In terms of IM theory, the response code is directly activated by signals that closely resemble sensory feedback from the response. A relationship between stimulus and response of IM compatibility is defined, then, as one in which the stimulus resembles sensory feedback from the response. "Stimulus–response (S–R) compatibility" is a term that is also important to the present research, but is less clearly defined. Stimulus–response combinations are said to be S–R compatible when "natural" or highly learned associations are involved (see, e.g., Welford, 1968, pp. 180–189).

The response selection process involves a translation by the nervous system from stimulus information to response information—from the encoded stimulus to the response code. It follows from the IM formulation that this translation process is especially simple when S–R relationships are characterized by IM compatibility; i.e., it is simple because the encoded stimu-

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[3] A PRP effect that probably does not involve response selection processes (i.e., it is found when there is response certainty) occurs when there is uncertainty about the temporal interval between signal onsets. This effect is avoided in the present research, as in most recent PRP research, by varying signal onset intervals only between blocks of trials, not within.

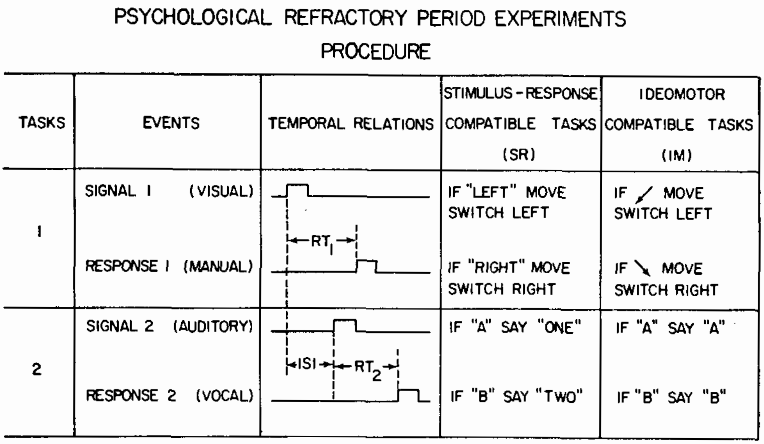

FIG. 1. Tasks and procedures. (RT = reaction time; ISI = interstimulus interval.)

lus and the response code are very similar. On the further assumption that the PRP effect is due at least in part to an overburdening of this translation process, it was predicted that the PRP effect would be (*a*) reduced by the use of an IM compatible task as 1 of the 2 tasks in the PRP paradigm, and (*b*) perhaps eliminated when both tasks were IM compatible. It has already been demonstrated (Greenwald, 1972) that time sharing of 2 simultaneous decision tasks proceeds without mutual interference when both tasks are IM compatible. Prediction *b* was, then, an extrapolation of this finding to asynchronous tasks.

The basic design of the 2 experiments reported here was a between-*S*s 2 × 2 factorial, with compatibility conditions for Task 1 and Task 2 in a PRP paradigm varied orthogonally. Each task could occur in either an S–R compatible version that was also IM compatible or an S–R compatible version that was not IM compatible. These 2 task versions will henceforth be referred to more simply as IM compatible and S–R compatible, respectively. Interstimulus interval (ISI) was a within-*S*s factor, with stimulus onsets for the 2 tasks separated by intervals ranging from 0 to 1,000 msec. Single-task control conditions (Task 1 and Task 2 alone) were employed only in Experiment II. The S–R combinations for each task are given in Figure 1. These were the same for both experiments.

EXPERIMENT I

Method

Subjects. Respondents to an advertisement for *S*s in the Ohio State University campus newspaper were employed. They were paid $1.25 per session plus a bonus of up to $1.00 per session for fast and accurate performance. Data were analyzed for the first 20 male and 20 female volunteers who had normal hearing, vision, and (English) speech. Five males and 5 females were assigned randomly to each of the 4 cells of the design. The sex factor produced only nonsignificant main effects (males faster than females) and is not considered in the analyses presented below.

Procedure. The apparatus for presenting televised visual signals and recorded audio signals on each trial, and for recording reaction times to manual and vocal responses, has been described in an earlier report (Greenwald, 1972). Auditory stimuli were generated onto magnetic audiotape by a PDP-1 computer, which equated rise times, amplitudes, and durations of the stimuli.

All *S*s participated in 2 sessions on successive days, the first session being regarded as practice. Each session consisted of 18 blocks of 20 trials, with blocks separated by 30 sec. and trials occurring at a fixed rate of 1 every 4 sec. Interstimulus intervals, which were constant within blocks, varied over the 6 values of 0, 100, 200, 300, 500, and 1,000 msec., with onset of the visual signal for Task 1 always preceding onset of the auditory signal for Task 2 except, of course, when the two were simultaneous. Within each of 3 subsets of 6 blocks of trials in each session, the 6 ISI conditions each appeared once, in different arbitrary orders. Within each block, each

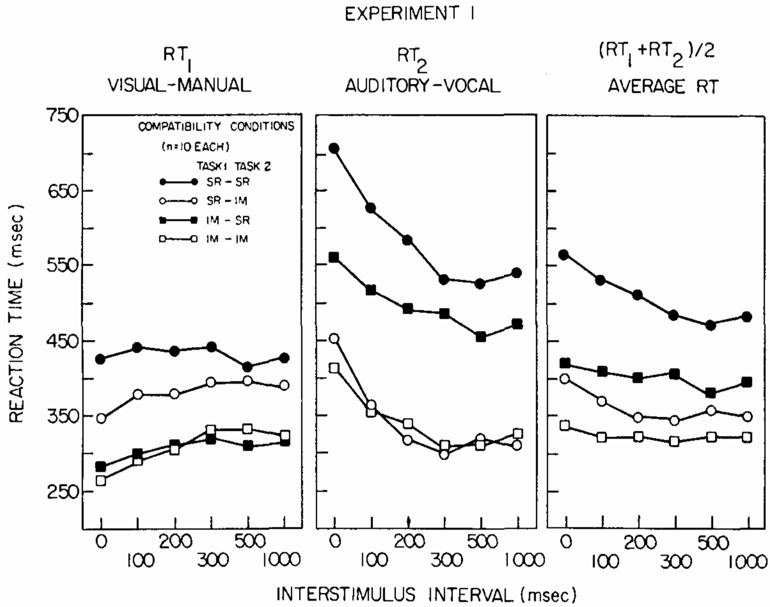

FIG. 2. Results of Experiment I. (Mean reaction times, RTs, are based on correct trials only. SR = stimulus–response; IM = ideomotor.)

of the 4 possible stimulus combinations (i.e., of the 2 visual and 2 auditory signals) appeared equally often, in a different random order for each block.

Results

Errors occurred on fewer than 1% of the responses—a frequency too low to warrant analysis. Reaction times for correct responses, presented separately for Tasks 1 and 2, are given in the first 2 panels of Figure 2. The PRP effect is typically sought in the data for Task 2, and it may be seen that an effect with the characteristics of the PRP effect was obtained for all conditions in the Task 2 data. Task 2 reaction times were strongly affected by the compatibility conditions, with latencies being reliably shorter for IM compatible tasks than for S–R compatible tasks, $F(1, 36) = 24.46$, $p < .001$. The magnitude of the PRP effect, as indexed by the effect of the ISI factor, was, contrary to predictions, not significantly affected by Task 2 compatibility—for the Task 2 Compatibility × ISI interaction, $F(5, 160) = 2.20$, $p > .05$—although it was strongly affected by Task 1 compatibility, $F(5, 160) = 7.07$, $p < .001$. The overall pattern of results was somewhat surprising because, in part, it constituted a failure to replicate an earlier finding (Greenwald, 1972) of nearly perfect time sharing of 2 simultaneous IM compatible tasks. In the present data, this result should have been manifested as no difference between the 0-msec. and 1,000-msec. conditions for the group of *S*s performing with both tasks IM compatible. This difference was, in fact, significant at the .001 level, $F(1, 32) = 19.83$.

In an attempt to interpret these data further, results for Task 1 were examined (first panel of Figure 2). These showed, unexpectedly, that reaction times for Task 1 increased significantly with increasing ISIs, $F(5, 160) = 14.47$, $p < .001$, a reversal of the usual PRP effect. Further, the ISI effect for Task 1 was significantly affected by the compatibility factors for both Task 1 and Task 2, interaction Fs $(5, 160) = 4.97$ and 2.32, ps $< .001$ and $< .05$, respectively. The juxtaposition of results for Tasks 1 and 2 suggested that *S*s might have been trading off processing capacity between the 2 tasks such that, as ISIs increased, Task 2 received relatively more capacity and Task 1 less. If this were the case, it would be misleading to test, with data from either task alone, any hypothesis concerned with allocations of processing capacity as a function of ISI. Accordingly, the data were combined for Tasks 1 and 2 by averaging reaction times for the 2 tasks on each trial, as shown in the third panel of Figure 2. These combined results more closely resembled the predicted effects, with the PRP effect being nearly absent when both tasks were IM compatible, and most strongly present when neither task was IM compatible. In the analysis of these combined reaction time data, all main effects were significant. The Fs (1, 32) for Task 1 compatibility and Task 2 compatibility were, respectively, 16.32, $p < .001$, and 6.75, $p = .01$, while for ISI, F (5, 160) = 27.83, $p < .001$. The compatibility factors for each task had significant impact on the ISI effect: Task 1 Compatibility × ISI interaction, F (5, 160) = 4.59, $p < .001$, and Task 2 Compatibility × ISI interaction, F (5, 160) = 7.24, $p < .001$.

Discussion

The results of this experiment did not allow firm conclusions regarding the initial hypotheses of the study. It was obvious that the compatibility variations were related in the predicted manner to magnitude of the observed PRP effect when this effect was assessed by examining the average of reaction times for the 2 tasks on each trial. However, 2 aspects of the data were disturbing. First, the predicted results were far from apparent when only Task 2 was considered. Second, the data for the condition with both tasks IM compatible provided a less-than-satisfactory replication of Greenwald's (1972) earlier finding of perfect time sharing. Even when averaged for the 2 tasks, reaction times at the 0-msec. interval for this condition averaged 18 msec. slower than for the 1,000-msec. control condition. This difference, although not statistically reliable, F (1, 32) = 1.64, $p < .20$, seemed large in light of the no-difference prediction.

Experiment II

In the instructions given to *S*s for Experiment I, it was stressed that Task 2 always followed Task 1—*S* was not informed that some blocks of trials involved simultaneous signals for the 2 tasks. It was conceivable that this aspect of the instructions caused *S*s to impose a constant input processing order on the signals or a constant output ordering on the responses—first Task 1 and then Task 2. Consequently, there may have been an unnecessary delay in reaction time for Task 2 when, because the signals for the 2 tasks were simultaneous, these orderings were inappropriate. A second experiment was conducted as a replication, modifying only those aspects of the procedure required to examine this possibility.

Method

Subjects. The same population used for Experiment I was sampled in a different academic term. Again, 20 males and 20 females participated, 5 of each sex in each of the 4 cells of the design.

Procedure. The major change from Experiment I was in instructions. The *S*s were informed that most often the 2 signals on each trial would be simultaneous and were not given any expectation that one signal might reliably precede the other. In order to appear consistent with these instructions, the sampling of ISIs used was changed. The 6 within-*S*s conditions included 4 ISIs—0, 100, 200, and 1,000 msec.—and 2 control conditions involving only Task 1 (visual signal, manual response) or only Task 2 (auditory signal, vocal response). It was felt that concentration of conditions at relatively short ISIs would appear consistent with the instructions that the tasks were most often simultaneous. A final change of procedure was the use of only a single session. Since *S*s had little difficulty learning the tasks in Experiment I, it was judged that first-session data should be sufficiently reliable and error free to provide adequate hypothesis tests.

Results

In the 2-task conditions, a trial was scored as an error if either response was incorrect. Overall, errors were quite infrequent, occurring on fewer than 1.5% of trials. The highest error rate was 3.5% in the 0-msec. condition for the group with both tasks S–R compatible. Since (*a*) errors were affected by conditions in essentially the same manner as were reaction times, and (*b*) the error data were less sensitive to design effects, the error data will not be detailed further.

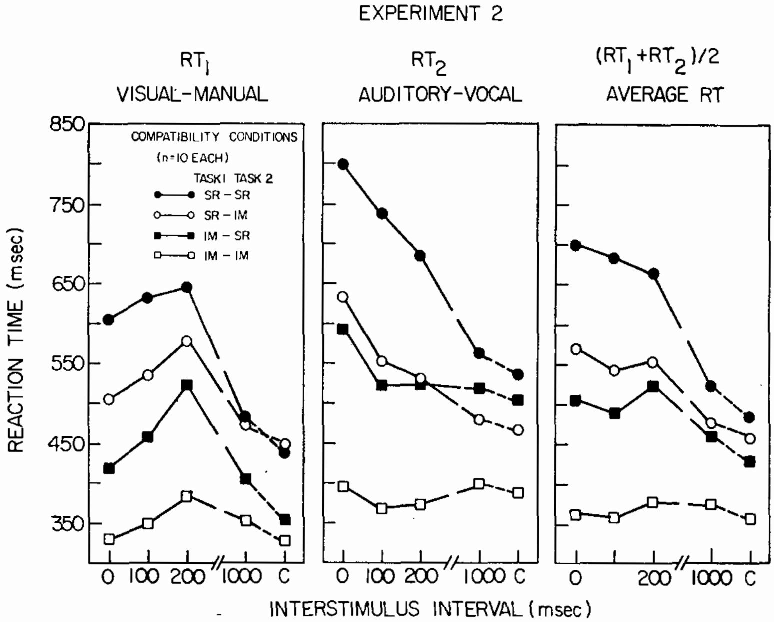

Fig. 3. Results of Experiment II. (Mean reaction times, RTs, are based on correct trials only. S–R = stimulus–response; IM = ideomotor; C = single-task control.

The reaction time data, presented in Figure 3, conformed very closely to the initial predictions. Apparently the change of instructions was important, as evidenced by the absence of a PRP effect for either task with both tasks IM compatible. The Task 1 data, as in Experiment I, showed for all groups a trend opposite to that which traditionally characterizes the PRP effect. Statistical analyses confirmed that, for all effects shown in Figure 3, the main effects of Task 1 and Task 2 compatibility and of ISI were highly reliable, and that interactions of ISI with the compatibility factor for each task were reliable (all but 1 of 15 ps $< .001$). The 3-way interaction effects and the 2-way interactions of compatibility conditions for Task 1 and Task 2 were nonsignificant (6 Fs < 1).

The data for the critical condition involving IM compatibility for both tasks are shown in detail for both experiments in Figure 4. In comparing the 2 experiments, it may be seen that the details of results for each task taken separately differed substantially between the experiments. However, for the measure of reaction time combined over the 2 tasks (right-hand panels of Figure 4), the results for the 2 experiments appeared more similar. In Experiment II, the reaction times for the 0-msec. and 100-msec. conditions were actually slightly faster than those for the 200-msec. and 1,000-msec. conditions, and were almost indistinguishable from the averaged control data for the 2 tasks performed in isolation. These latter findings provided a clear replication of the earlier finding (Greenwald, 1972) of essentially perfect time sharing of 2 simultaneous IM compatible tasks.

General Discussion

The results of the 2 experiments, and of Experiment II particularly, show that it is possible to eliminate the PRP effect that often occurs with 2 rapidly successive decision tasks. The PRP effect occurs quite strongly with 2 S–R compatible tasks if these tasks are not also IM compatible. When the task for either the first or second response is IM compatible the PRP effect is reduced, and the PRP effect is eliminated when both tasks are IM compatible.

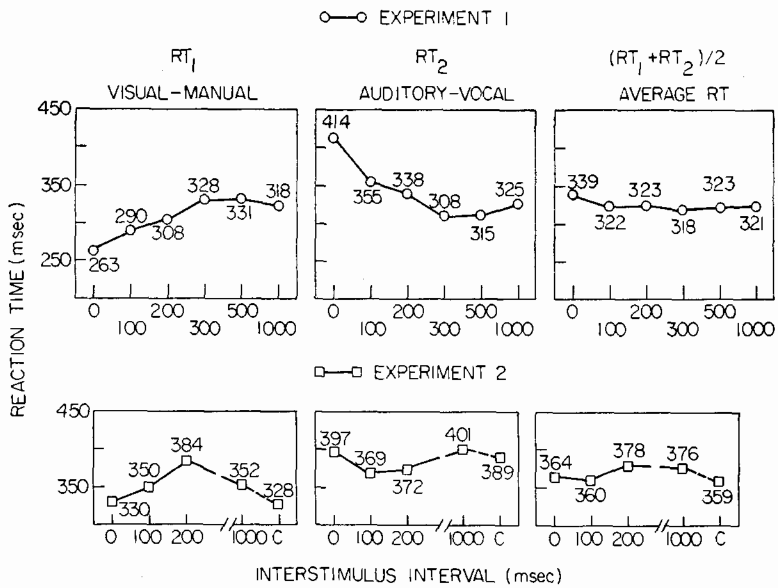

FIG. 4. Detailed results for the condition with both tasks ideomotor (IM) compatible. (Mean reaction times, RTs, are based on correct trials only. C = single-task control.)

These findings must be interpreted as supporting the 2 assumptions on which this study was based. Accordingly, it is concluded that (*a*) the PRP effect, when it occurs in tasks involving response uncertainty, is the consequence of limited capacity in a process that involves translation from an encoded stimulus to a response code; and (*b*) the capacity required for this translation process is minimized by employment of IM compatible relations of stimuli to responses, presumably because in this arrangement the response code closely resembles the encoded version of the stimulus.

The present results, and Greenwald's (1972) earlier time-sharing findings, are consistent with the idea that stimulus encoding mechanisms generally have sufficient capacity to permit perfect time sharing of encoding 2 independent signals in different modalities. The suggestion that encoding is not the locus of a limited capacity process is also supported by the analysis of attention presented by Posner and Boies (1971). However, it remains possible that encoding processes are altered by the IM compatibility arrangement such that (*a*) a different output of the encoding process is produced, and (*b*) this difference permits bypassing of encoding processes that are otherwise too limited in capacity to permit perfect time sharing. This possibility, although clearly less parsimonious than an interpretation appealing only to operations of stimulus code–response code translation processes, cannot be ruled out by the present findings.

These studies turned up some effects that have not been noted in previous PRP studies, and these are worth some comment. First was the reversal of the PRP effect in the data for responses to the first task. Herman and Kantowitz (1970) reported that Task 1 data frequently show the same PRP effect shown in Task 2 data. However, most of the studies on which their conclusion was based differed from the present research by using temporal uncertainty in addition to response uncertainty. That is, although the ISI between 2 tasks was constant within blocks of trials, *S*s did not know which of 2 signal sources would occur first. In the present research, when temporal uncertainty was totally eliminated, the data for Task 1 showed a reversal of the PRP effect which, however, typically was of smaller magnitude than the "proper" PRP effect shown in the Task 2 data. This was interpreted as indicating that *S*s were trading off processing capacity between the 2 tasks, with the relative proportion of capacity devoted to Task 2 increasing directly as a function of ISI.

The second unusual finding emerged from a comparison of the present Experiments I and II. It appeared possible that a small PRP effect in the condition with both tasks IM compatible in Experiment I might have been an artifact due to *S*s imposing an input or output ordering on 2 tasks when the experimental context stressed a reliable sequential ordering of the tasks. Although no direct confirmation of this ordering hypothesis was obtained, the effect in question was eliminated when instructions and context were redesigned to avoid stressing the sequential ordering of tasks.

Problems in the Definition of Ideomotor Compatibility

The notion of IM compatibility has a potential advantage over that of S-R compatibility because of the existence of a conceptual definition for the former (as resemblance between a stimulus and feedback from its required response) but not for the latter. This conceptual superiority is somewhat compromised by problems that remain in the operational definition of IM compatibility. In the present research IM compatibility was operationalized as (*a*) repeating (speaking) a heard word, or (*b*) giving a spatial (switch movement) response to a spatial visual cue (positioned arrow). Task *a* clearly conforms to the conceptual definition of IM compatibility but, in the case of task *b*, it is necessary to assume that spatiality of a visual positional cue "resembles" the spatial component of kinesthetic and visual feedback from movement. The reader probably shares the somewhat uncomfortable feeling of the authors that, had the results not turned out as expected, it might have been more convenient to criticize this resemblance assumption than to criticize the conception of IM compatibility. Accordingly, it must be acknowledged that the operational definition of IM compatibility has limitations that will remain until clarifications are achieved through further research. The operational definition is, however, adequate to identify S-R combinations—e.g., moving a switch left in response to an unpositioned stimulus such as hearing or reading the word LEFT—that are commonly thought of as S-R compatible but are certainly not IM compatible. It is this level of operationalization on which the present experiments have rested and with respect to which the results can be fairly clearly interpreted.

REFERENCES

Greenwald, A. G. Sensory feedback mechanisms in performance control: With special reference to the ideo-motor mechanism. *Psychological Review*, 1970, **77**, 73-99.

Greenwald, A. G. On doing two things at once: Time sharing as a function of ideomotor compatibility. *Journal of Experimental Psychology*, 1972, **94**, 52-57.

Herman, L. M., & Kantowitz, B. H. The psychological refractory period effect: Only half the double-stimulation story? *Psychological Bulletin*, 1970, **73**, 74-88.

James, W. *Principles of psychology*. Vol. 2. New York: Holt, 1890.

Posner, M. I., & Boies, S. J. Components of attention. *Psychological Review*, 1971, **78**, 391-408.

Reynolds, D. Effects of double stimulation: Temporary inhibition of response. *Psychological Bulletin*, 1964, **62**, 333-347.

Smith, M. C. Theories of the psychological refractory period. *Psychological Bulletin*, 1967, **67**, 202-213.

Welford, A. T. *Fundamentals of skill*. London: Methuen, 1968.

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