Journal of Experimental Psychology
1972, Vol. 94, No. 1, 52–57

ON DOING TWO THINGS AT ONCE:

TIME SHARING AS A FUNCTION OF IDEOMOTOR COMPATIBILITY [1]

ANTHONY G. GREENWALD [2]

Ohio State University

A relationship between stimulus and response of "ideomotor compatibility" was defined as occurring to the extent that the stimulus resembles normally occurring sensory feedback from the response (e.g., saying a word in response to hearing it said). It was proposed that the stimulus of highly ideomotor-compatible combinations should effectively select the response without burdening limited-capacity decision processes of the central nervous system. Accordingly, (*a*) perfectly efficient time sharing of two simultaneous decision tasks was predicted when both tasks were highly ideomotor compatible, and (*b*) inefficient time sharing was expected when both tasks were not highly ideomotor compatible. Eight *S*s served in High and eight in Low Ideomotor Compatibility conditions that required rapid independent decision responses (spoken and manual) to two simultaneous stimuli (auditory and visual). The predicted effect of the ideomotor-compatibility variation on time-sharing efficiency was clearly confirmed.

Can two independent decision tasks be performed simultaneously with perfect efficiency, that is, with no loss of speed or accuracy for each relative to its performance in isolation? This should be possible only if the two tasks do not share in the use of any limited-capacity information-processing systems. Avoidance of common limited-capacity systems is evidently possible when neither of two simultaneous tasks requires a decision based on stimulus information (Adams, 1966, p. 190f.). However, when time sharing of *decisions* has been required, some residual inefficiency of simultaneous performance has generally been observed even when care has been taken to assure that the two tasks use different input modalities and output effectors (e.g., Schvaneveldt, 1969; see also the review by Welford, 1968, pp. 105–136). Accordingly, theorists have generally assumed the existence of a limited-capacity nervous system process, such as Broadbent's (1958) "P system" or Welford's (1968) "translation mechanism," that comes into play whenever a decision task is performed.

Some relatively fragmentary data reported by Gazzaniga and Sperry (1966) suggest that surgical bisection of the brain allows two independent decisions to be made simultaneously with no loss in efficiency. The present research sought to circumvent the limited-capacity decision process less drastically. The germinal idea for the experiment derived from ideomotor theory (Greenwald, 1970; James, 1890). Specifically, ideomotor theory proposes that responses are centrally coded by representations of their sensory feedback. Accordingly, it ought to be possible to select a response very directly, perhaps totally bypassing any limited-capacity process, by presenting a stimulus that closely resembles the response's sensory feedback. This should occur, for example, when a word is said in response to hearing it said. The dimension denoting the extent to which a stimulus corresponds to sensory feedback from its required response will be referred to as "ideomotor compatibility."

The ideomotor compatibility dimension

[1] This research was partially supported by Grants GS-1601 and GS-3050 from National Science Foundation and by Grant 1-R01-MH20527-01 from the United States Public Health Service. The author is grateful to Harvey G. Shulman for critically reading an earlier draft; to David D. S. Poor for substantial assistance in data analysis, part of which was accomplished using REACT, a program for sorting and reducing reaction time data written by David Poor and Thomas Crunkilton; and to Richard Prée for conducting the study.

[2] Requests for reprints should be sent to Anthony G. Greenwald, Department of Psychology, Ohio State University, 404C West 17th Avenue, Columbus, Ohio 43210.

overlaps with, but is not identical to, stimulus–response (S–R) compatibility. Thus it is not embarrassing to the present reasoning that previous studies have demonstrated both an increase in time-sharing efficiency with increasing S–R compatibility (Keele, 1967) as well as no change in efficiency with variations in S–R compatibility (Schvaneveldt, 1969). In a study by Noble, Trumbo, and Fowler (1967), performance at the task of tracking a visual target was found not to be impaired by the simultaneous (highly ideomotor-compatible) task of repeating the names of auditorily presented digits. The Noble et al. study fell short of assessing the limits of time-sharing capacity, however, in that rapid responses were not required for the digit-repeating task.

Method

Overview.—Each trial of the experiment consisted of presentation of two simultaneous stimuli, one an arrow pointing either left or right, presented on a television monitor, the other an auditorily presented word, either "left" or "right," heard through headphones. Two responses were required on each trial, one moving a switch left or right, using the preferred hand, the other saying the word left or right.

These stimuli and responses could be combined to yield a pair of low-ideomotor-compatible tasks or, alternately, a pair of high-ideomotor-compatible tasks. The low-ideomotor-compatible combinations —moving the switch left or right in response to the words left or right (respectively) and saying left or right dependent on the arrow direction—are tasks that would normally be considered to be S–R compatible, in that highly overlearned associations are involved. Nonetheless, in terms of the ideomotor analysis, correct response selection for these low-ideomotor-compatible combinations requires *S* to activate response representations not directly activated by the stimuli; further, a major component of the hypothesized code for the correct response in either of the low-ideomotor-compatible tasks is assumed to involve the same sense modality employed by the stimulus for the other task. Hence, substantial mutual interference between these two S–R compatible tasks when performed simultaneously is expected, in that they must compete for access to the hypothesized limited-capacity response selection mechanism. At the same time, the present formulation supposes no basis for mutual interference between the two simultaneous high-ideomotor-compatible combinations of the same stimuli and responses—that is, saying left or right in response to the auditory word stimuli and moving the switch left or right according to the arrow direction—because it is assumed that the limited-capacity response selection mechanism is bypassed for these combinations.

For purposes of comparison, *S*s performed at tasks requiring one decision or no decisions, in addition to the task requiring two simultaneous decisions. To equate these 0-, 1-, and 2-decision conditions for stimulus and response variables, *S*s were exposed to two simultaneous stimuli and made two simultaneous responses on each trial. The conditions were established by providing *S*s differing amounts of advance information about the stimuli to be presented on each trial. This information consisted of telling *S*s, in advance, that (*a*) both the auditory and visual stimuli would be randomly selected for a series of trials (2 decisions), or (*b*) only one of the two stimuli would vary randomly while the other was constant (1 decision), or (*c*) both stimuli would be constant over the series of trials (0 decisions). If one or both of the stimuli were to be constant, *S*s were also informed what the constant stimulus (or stimuli) would be.

Most of the *S*s also provided data for single stimulus-single response control conditions that were run shortly after completion of the experiment proper.

Subjects.—Sixteen volunteers, recruited from the student population of Ohio State University through various advertisements, were randomly assigned to the two conditions of High and Low Ideomotor Compatibility, with 4 males and 4 females in each condition. Each *S* provided data for four sessions, completed within a span of 5 days, and each received $1.25 per session plus bonuses of up to another $1.50 per session for speed and accuracy.

Apparatus.—Auditory stimuli consisting of the words left or right were first recorded in desired sequences at 4-sec. onset–onset intervals on an audiotape recorder. This audiotape was then played back through a voice-operated circuit that controlled onset of visual stimuli in a two-channel tachistoscope. The tachistoscope displayed either a right-pointing or left-pointing arrow for a .75-sec. duration, the onset of which was within a few milliseconds after auditory stimulus onset. These simultaneous auditory and visual stimuli were then recorded on videotape. Each session of the experiment was conducted by playing back a videotape for *S*, who sat in a chair equipped with a toggle switch (5.0 cm. handle) that could be moved comfortably to the right or left by the preferred hand. The *S* heard the auditory word stimuli through a headset equipped with a boom microphone used to detect spoken responses. Visual stimuli were viewed on a small television monitor mounted on a panel that *S* was facing, about 50 cm. distant and slightly lower than eye level. The left and right arrows, as seen on this monitor, were white on black background, .5 cm. thick and 2.3 cm. in horizontal extent. The arrows were displaced 3.0 cm. horizontally from center screen in the left and right directions, respectively. Auditory stimuli were heard at about 85 db., with background noise under 70 db. Latencies from stimulus to response onsets were automatically recorded for the simultaneous spoken and manual responses with .01-sec. accuracy.

Design and procedure.—Eight videotapes were prepared, for four sessions each of the low- and high-ideomotor-compatibility-task combinations. The order in which the four tapes for each condition were used was counterbalanced across *S*s. Within each session, three levels of decision difficulty were employed, with the tasks always proceeding from easiest level to most difficult as follows:

1. No-decision task. First were four eight-trial practice blocks, all eight trials within a block being identical, each block using a different one of the four possible combinations of right or left visual arrow stimulus and auditory word right or left. The same four blocks of trials were then repeated as test trials with reaction times recorded.

2. One-decision task for spoken responses. For the High Ideomotor Compatibility condition, this task consisted of two 16-trial practice blocks, one with all left arrow stimuli and the other with all right arrow stimuli, with word stimuli varying randomly, followed by two comparable 32-trial test blocks. The Low Ideomotor Compatibility condition differed in that the word stimuli were constant, either left or right, during these blocks, while the arrow stimuli varied randomly.

3. One-decision task for switch responses. Two 16-trial practice blocks, followed by two 32-trial test blocks, were constructed in a fashion parallel to the one-decision task for spoken responses.

4. Two-decision task. Two 32-trial practice blocks with the arrow and word stimuli independently randomized were followed by two 32-trial test blocks constructed in the same fashion.

For each of the four types of decision tasks, test data were obtained for equal numbers of trials using each of the four possible combinations of arrow and word stimuli. Trials occurred at a regular 4-sec. rate, with a maximum of 32 trials in a block. Each session lasted approximately 45 min.

Results

The data were examined initially by looking at the means of reaction times for each of the two simultaneous responses, classified by days, ideomotor-compatibility conditions, decision requirements, and absence versus presence of response conflict (conflict was considered to be present when a switch left and word right response, or a switch right and word left response, had to be made simultaneously). These detailed data are given, averaged over 4 days, in Table 1. (Data for the 4 days of the experiment differed only in that both error rates and reaction times decreased from Day 1 to Day 4; see Fig. 1.)

Inspection of Table 1 allows several immediate conclusions for which statistical analyses, although conducted, were super-

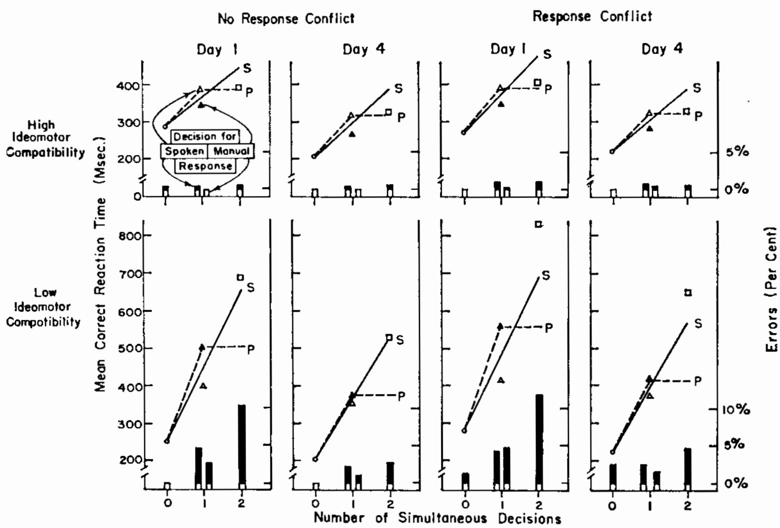

FIG. 1. Summary of reaction time and error data for Days 1 and 4. (Each data point is averaged for the two responses required on each trial. The two data points for the 1-decision condition give results separately as a function of whether the decision was required for the spoken or manual response. Curves labeled "P" and "S" indicate theoretical predictions for the 2-decision condition based, respectively, on parallel and serial decision-making models.)

fluous: (*a*) Reaction times were slower with Low Ideomotor Compatibility than with High Ideomotor Compatibility when one or two decisions were required; (*b*) spoken responses were generally slower than manual responses; (*c*) response conflict tended to increase reaction times; and (*d*) when it was necessary to make a decision to only one of the stimuli, the nondecision response was substantially slowed, sometimes by more than the decision response. This last observation suggested that *S*s might be grouping the two responses on each trial. As a consequence, the average of the two reaction times on each trial, to be referred to as "combined" reaction time, seemed to provide the most satisfactory datum for testing hypotheses concerning effects of the experimental variables.[3]

Figure 1 provides the data for combined reaction times for Days 1 and 4, classified by the experimental variables, and compared with theoretical curves for serial versus parallel decision processes. These theoretical curves were based on a subtractive method of computing combined "decision times." By the subtraction procedure, combined decision time is taken as the difference between mean combined reaction time in one of the decision conditions and that for the 0-decision condition at the same level of conflict and ideomotor compatibility. Curve S in each part of Fig. 1 is based on a *serial decision* assumption, that the combined decision time for the 2-decision task should consist of a simple addition of the combined decision times for the two 1-decision tasks. It may readily be seen by inspection of Fig. 1 that this model provided a good fit only for the No-Conflict trials in the Low Ideomotor Compatibility condition. The data for the Conflict trials in the Low Ideomotor Compatibility condition were discrepant from the serial decision assumption in the direction of requiring *greater* combined time for the two decisions than predicted by this assumption. In contrast,

[3] Table 1 can be used to ascertain that none of the conclusions to follow would be altered if hypotheses were tested against other dependent measures, such as just the spoken or just the manual response times.

TABLE 1

MEAN REACTION TIMES FOR SPOKEN AND MANUAL RESPONSES, AVERAGED OVER FOUR DAYS, AS A FUNCTION OF IDEOMOTOR COMPATIBILITY, DECISION REQUIREMENTS, AND RESPONSE CONFLICT (C)

Response	Cond.							
	0 decision		1 decision, spoken		1 decision, manual		2 decisions	
	No C	C	No C	C	No C	C	No C	C
Low Ideomotor Compatibility ($n = 8$ *S*s)								
Spoken	256	298	454	462	481	527	663	802
Manual	190	208	303	317	375	406	518	636
High Ideomotor Compatibility ($n = 8$ *S*s)								
Spoken	270	272	372	382	336	350	382	392
Manual	200	212	310	313	257	264	318	329

Note.—Each mean is based on a total of 1,024 observations (32 per *S* per day) except for the 0-decision condition in which only half as many observations were made. Reaction times are given in milliseconds.

the combined time required for two decisions in the High Ideomotor Compatibility condition was substantially less than predicted by the serial processing assumption. Theoretical Curve P, which provided quite a good fit for both the Conflict and No-Conflict data of the High Ideomotor Compatibility condition, is based on an assumption of *parallel decision making*, that two simultaneous decisions require no more combined time than that for the slower of the two 1-decision tasks. From Fig. 1, it may be seen that fit to the theoretical curves was not affected substantially by practice, although reaction times and errors were reduced from Day 1 to Day 4.

Data that can be used to assess in more detail the adequacy of the two theoretical models shown in Fig. 1 are presented in Table 2. The Table 2 data are averaged over Days 1–4 since, as noted above, the only effect of days was a decrease in reaction times that was proportional across the different decision conditions. The analyses presented in Table 2 indicated that the combined reaction time data for the High Ideomotor Compatibility condition were fitted quite well, regardless of the presence

TABLE 2

TIMES REQUIRED (IN MSEC.) FOR ONE OR TWO DECISIONS, WITH TESTS OF SERIAL VERSUS PARALLEL DECISION MODELS FOR LOW VERSUS HIGH IDEOMOTOR COMPATIBILITY AND PRESENCE VERSUS ABSENCE OF RESPONSE CONFLICT (C)

Cond. of response C	Averages, for two simultaneous responses, of:				Deviation of time for two decisions from:	
	Reaction time with 0 decision	Additional time required for:				
		1 decision: spoken	1 decision: manual	2 decisions	Serial model	Parallel model
Low Ideomotor Compatibility ($n = 8$)						
No C	223	155	205	367	7	162***
C	253	136	213	465	116*	252***
High Ideomotor Compatibility ($n = 8$)						
No C	235	106	62	115	−53**	9
C	242	106	65	119	−52**	13

Note.—Data averaged over four daily sessions.
* Significantly different from 0, $p < .05$.
** Significantly different from 0, $p < .01$.
*** Significantly different from 0, $p < .001$.

or absence of conflict, by the parallel decision assumption. The data for the Low Ideomotor Compatibility condition, in contrast, were fitted quite well by the serial decision assumption when conflict was absent, but not when conflict was present.

Single stimulus-single response control data.—To document the conclusion of perfect or near-perfect time sharing even more fully, it was judged desirable to obtain comparison data for the 1-decision tasks performed under single stimulus-single response conditions. Such comparison data were obtained from 13 of the 16 *S*s in a fifth session conducted shortly after completion of the experiment proper (3 of the *S*s could not be reached to schedule the fifth session). For the High Ideomotor Compatibility *S*s ($n = 7$), the average time for isolated spoken and manual decisions was only 10 msec. faster (*ns*) than for simultaneous decisions, while the same comparison for the Low Ideomotor Compatibility *S*s ($n = 6$) yielded a mean difference of 253 msec. These results indicated that the demonstration of very highly efficient time sharing in the experiment proper was in no way artifactually due to use of a control 1-decision task requiring two responses to two simultaneous stimuli.

DISCUSSION

Three major findings distinguished the Low Ideomotor Compatibility condition from the High Ideomotor Compatibility condition. First, highly efficient time sharing of two simultaneous decisions was found only in the High Ideomotor Compatibility condition. The obtained efficiency of time sharing was, as noted earlier, not significantly different from being perfect (see Table 2). Second, response conflict did not increase decision times for 2-decision tasks in the High Ideomotor Compatibility condition, although it increased them substantially in the Low Ideomotor Compatibility condition (see Table 2). Together, these two findings indicate that a common limited-capacity processing system was required for the two tasks in the Low Ideomotor Compatibility condition, but not in the High Ideomotor Compatibility condition.

The third important distinction between the two conditions was that decision times for 1-decision tasks were substantially faster in the High Ideomotor Compatibility condition. As may be seen in Table 2, the average 1-decision time for the High Ideomotor Compatibility condition was 85 msec., compared to 177 msec. in the Low Ideomotor Compatibility condition. The difference of over 90 msec. is quite compatible with the hypothesis that a process such as response selection was largely, if not entirely, bypassed in the former condition. The residual 85-msec. decision time for the High Ideomotor Compatibility condition presumably represented primarily the time required for stimulus identification.

The theorization underlying this experiment was based on an assumption that responses are coded centrally by representations of their sensory feedback. The findings have been fully consistent with this assumption. An interesting alternative, or perhaps supplementary, hypothesis can be formulated from the principle that verbal and noverbal functions are concentrated in different cerebral hemispheres.[4] In the High Ideomotor Compatibility condition, one task involved a verbal stimulus and a verbal response (e.g., hearing left, saying left) while the other involved a nonverbal stimulus and a nonverbal response (e.g., arrow pointing right, moving switch right). In the Low Ideomotor Compatibility condition, the tasks either combined a verbal stimulus with a nonverbal response (e.g., hearing left, moving switch left) or a nonverbal stimulus with a verbal response (e.g., arrow pointing right, saying right). The efficiency with which the two decisions were performed simultaneously may have depended in part on whether stimulus analysis and response selection functions could be isolated in separate hemispheres (High Ideomotor Compatibility) or required coordinated action of both hemispheres for each task (Low Ideomotor Compatibility). Because Schvaneveldt (1969), who also used a "pure" verbal task simultaneous with a pure nonverbal task, found relatively inefficient time sharing, this hypothesis may have more value in explaining the difficulty of time sharing in the Low Ideomotor Compatibility condition than in accounting for the efficiency of the High Ideomotor Compatibility condition.

A question that will need to be the target of future research concerns the minimum task requirements for producing highly efficient time sharing of decision processes. Must both tasks be ideomotor compatible or need only one be? Theoretically, it seems possible that the result of highly efficient time sharing could be obtained even if one of the two simultaneous tasks is not highly ideomotor compatible. That is, if ideomotor compatibility of one task results in that task placing no burden on a limited-capacity central process, then that limited-capacity process should be free for unhindered use by a second task, regardless of the latter's degree of ideomotor compatibility.

[4] This hypothesis occurred to the author when listening to a recent report concerning hemispheric differences in extracting verbal and nonverbal information from identical signals (Day, 1971).

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(Received October 1, 1971)