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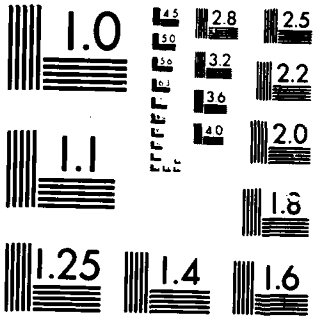

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THE ROLE OF OUTCOME CONFLICT IN DUAL-TASK INTERFERENCE

David Navon and Jeff Miller

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The traditional explanation for dual-task interference is that tasks compete for scarce processing resources. Another possible explanation is that the outcome of the processing required for one task conflicts with the processing required for the other task (e.g., cross-talk). To explore the contribution of outcome conflict to task interference, we manipulated the relatedness of the tasks. In Experiment 1, subjects searched concurrently for names of boys in one channel and names of cities in another channel. Responses were significantly delayed when a nontarget on one channel belonged to, or was even just related to, the category designated as the target for the other channel. No comparable effects were found when the tasks were performed in isolation. Thus, the difficulty of the individual tasks is not the only determinant of how much they will interfere when combined, and there must be substantial interactions between processes carrying out the two tasks. In Experiment 2 subjects searched one channel for specific target letters and another channel for specific target digits. The nontargets in a channel were either from the same alphanumeric category as the targets for that channel, or from the opposite category (i.e., the category of the —

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targets for the other channel). It was found that although between-category search was more efficient than within-category search in single tasks, it was less efficient in dual tasks. Thus, there appear to be significant task interactions due to the confusability emerging when the nontargets of one task belong to the same category as the targets of the concurrent task. In addition, the congruence of target presence or absence on the two channels was found to have a sizeable effect. We suggest four potential sources of outcome conflict that may contribute to dual-task interference and argue that a great deal of the residual interference might result from other sorts of outcome conflict.

Contents

The Role of Outcome Conflict in Dual-Task Interference

DAVID NAVON and JEFF MILLER

When two tasks are attempted at the same time, the typical result is some cost. The cost may be manifested in two ways. First, a deficit may be observed in the performance of either or both tasks with respect to the single-task performance level. Second, task performance may exhibit trade-off so that the performance of one task can be improved only at the expense of performance on the other task.

A prevalent explanation for dual-task interference effects is that the two tasks are carried out using processing resources drawn from a common limited pool (e.g., Kahneman, 1973; Kerr, 1973; Norman & Bobrow, 1975) or a number of pools (e.g., Navon & Gopher, 1979; Sanders, 1979; Wickens, 1980). When the demand for a limited resource exceeds the supply, processes carrying out the two tasks must compete for what both need, and interference results.

An obvious case of competition arises when two tasks require incompatible uses of a single sensory mechanism or effector; for example, a person cannot simultaneously look or reach the right hand in two different directions. However, many instances of dual-task interference cannot be attributed to competition for such peripheral structures. The concept of competition has nonetheless been extended to these instances of *central* interference, even without independent evidence for the existence of limited central mechanisms (e.g., Norman & Bobrow, 1975). Usually these central mechanisms have been thought of as coming in units that can be distributed among concurrent processes, and referred to as *resources* (see Navon, 1984, 1985). In any case, the common feature of all these explanations is that they attribute task interference to the competition of tasks for the use of some scarce entities—call them resources, mechanisms, or structures.

However, tasks could hypothetically interfere not only because they compete for the same input or enabling mechanism, but also because each produces outputs, throughputs, or side-effects that are harmful to the processing of the other one, in that they change the state of some variable that is relevant for the performance of the concurrent task. Such effects have been termed by one of us (Navon, 1985) as *outcome conflicts*. To take a physical analogy, simultaneous telephone calls will interfere even when their number does not exceed the number of available lines, if there is some cross talk among parallel lines due to electrical induction. A psychological example may be one in which the pattern of activations driven by the processing of one task (say, reading a word; see McClelland & Rumelhart, 1981) inhibits activation that is essential for the accomplishment of the concurrent task (say, comprehending an auditorily presented word). Some more examples, as well as a tentative taxonomy, are presented in Navon (1985). Outcome conflicts may either degrade the performance of tasks that are processed in parallel or call for serial processing to avoid such degradation. In neither case is task interference due to scarcity—an inability of the processing system to furnish the concurrent tasks with the provisions each would have when performed in isolation.

The hypothesis that task interference may be due to outcome conflict has been put forward. How can it be tested? As argued elsewhere (Navon, 1984), at the present state of the art it is almost impossible to diagnose for any given instance of interference between tasks whether it arises from competition for resources or from outcome conflict. However, it *is* possible to examine the extent to which task interference is sensitive to variables that are thought to affect the likelihood of outcome conflict without affecting the complexity of each task performed alone. Since such variables do not change the resource demands of the individual tasks, any effect on task interference must be ascribed to some interaction between the tasks other than their competition for common resources.

EXPERIMENT 1

In this experiment, subjects performed two independent visual search tasks concurrently. The main objective of the experiment was to examine whether there is outcome conflict between simultaneous tasks, and, if so, how sizeable its effects are. Performance in the dual-task condition was compared to performance in single-task conditions with equivalent displays. . the latter conditions, subjects were required to perform only one of the search tasks at a time (i.e., focused attention).

The display consisted of four words in a cross pattern. The two words on the horizontal limb (i.e., left and right words) were defined as the input channel for one task, and the two words on the vertical limb (top and bottom words) were defined as the input channel for the other task. One task was to indicate whether or not any boy's name appeared on one channel, and the other task was to indicate whether or not any name of a city appeared on the other channel.

Two independent variables were manipulated, with the intention of varying separately the difficulty of the two single tasks in isolation and the amount of outcome conflict between tasks. One variable was display size: There were one or two words presented on each channel. This manipulation was expected to influence the difficulty of each single task in isolation, based on the standard result that search time increases with the number of items to be searched (e.g., Atkinson, Holmgren, & Juola, 1969).

The second independent variable was the semantic relatedness of the nontarget words to the target categories. Specifically, there were four kinds of nontargets: (a) *Associate*—a word from a category semantically related to the target category for the *same* channel on which the word appeared (e.g., a girl's name presented in the channel searched for boys' names); (b) *Off-Channel Target*—a word from the category defined as the target for the *other* channel (e.g., a city name presented in the channel searched for boys' names); (c) *Off-Channel Associate*—a word from a category semantically related to the category defined as the target for the *other* channel (e.g., a state name presented in the channel searched for boys' names); (d) *Neutral*—a word from a category semantically unrelated to both target categories, used to establish a baseline for determining the effects of the three types of semantic relations.

Associates were expected to increase single-task difficulty relative to neutral nontargets. Typically, it is harder to search through nontargets that are more similar to targets, and this effect is found for semantic as well as visual similarity (e.g., Graboi, 1974; Henderson & Chard, 1978). On the other hand, off-channel targets and off-channel associates were expected to produce outcome conflict without affecting single-task difficulty. Single-task difficulty should not be affected because these sorts of nontargets are equivalent to neutral nontargets with respect to the channel searched: They are unrelated to the target category. In the dual-task condition, however, the semantic relatedness of such nontargets to the targets sought on the other channel creates conditions amenable to outcome conflict. If word identification occurs within a common lexicon, and categorization processes use activated lexical entries to reach a decision, then the activations produced by words from one channel could easily interfere with the categorization process working on the other channel. This outcome conflict should slow responses on trials with such nontargets, relative to trials with neutral nontargets.

Note that resource models do not predict that off-channel targets or off-channel associates will be more effective distractors than neutral nontargets. If the only interaction between tasks is their use of a common resource, then such relatedness should have no bearing on performance on either channel. If off-channel relatedness is found to have some effect, the effect must be interpreted as evidence for the existence of outcome conflict between processes *sharing* the same mechanism. That is, an effect of off-channel relatedness must be interpreted as evidence against the sufficiency of capacity models of dual-task decrement.

In summary, one can derive several quite different predictions for this experiment from different hypotheses about the interaction between processes carrying out the two search tasks. If the tasks are processed in a totally independent fashion, the only factors that should affect performance on a given channel are the number of words on that channel and the relatedness of a nontarget in the channel to the target category for the channel itself. If performance on one task is also affected by the *difficulty* of the concurrent task on the other channel, that would be a typical manifestation of task interference that could be interpreted in several ways (Navon, 1984, 1985), including, of course, competition for resources. However, if performance is also affected by the *relatedness* between a nontarget on one task and the target category of the other task, then we must conclude that there is outcome conflict between processes *sharing* the same mechanism.

Method

Subjects and apparatus. Forty-two undergraduates at the University of California, San Diego, served as subjects in partial fulfillment of a course requirement. Each subject was tested in a single session lasting about 45 min. Stimuli were presented and responses and their latencies recorded by an Apple II+ microcomputer. Four keys on the bottom row of the computer keyboard were used as response keys, and subjects pressed these keys with the index and middle fingers of the left and right hands.

Stimuli and tasks. The display consisted of four words arranged in a cross pattern. The vertical limb of the stimulus display consisted of two words appearing 1.2° above and below fixation. The horizontal limb consisted of two words centered 3.33° to the left and right of fixation. Stimulus words were presented in the standard computer font of upper case letters, which were about 0.31° wide and 0.46° high.

One task was to indicate whether any boy's name was present in one limb of the display (hereafter called the "Boy channel"), and the other task was to indicate whether any city name was present in the other limb of the display ("City channel"). The two responses associated with each task (present/absent) were assigned to the index and middle fingers of a single hand, with finger assignments counterbalanced across subjects. The assignments of tasks to limbs of the display and to response hands were also counterbalanced across subjects.

The same set of 1,517 words was used for each subject, though they were randomly assigned to trials and display types (described next) separately for each subject. There were 836 filler words, and the rest were approximately equally divided between boys' names, girls' names, city names, and state or country names. Words varied in length from 3 to 14 letters, with an average length of 7 letters.

Regardless of the task, the two limbs of the stimulus display varied independently in both the number and the type of words present. A limb was equally likely to have words in both positions (display size 2), or a word in one position and a row of five asterisks in the other (display size 1). A limb could contain a target word, an associate, an off-channel target, an off-channel associate, or a neutral filler word, as defined above. One-third of the limbs contained neutral words, and the other two-thirds were equally likely to contain a word of one of the other four types. When display size was two, at most one of the words was a target or any of the semantically related types of nontarget, the second word on the limb always being neutral. Positions of the two stimuli on each limb were randomized.

Design and procedure. Each subject served in six blocks of trials: three practice blocks followed by three experimental blocks. The first two practice blocks were the two single-task conditions, with 36 trials per block. The order of practicing the two single-task search tasks was counterbalanced across subjects. The third block was a dual-task practice block of 72 trials. The three experimental blocks repeated the same three conditions as the practice blocks, though with twice as many trials per block. The order of experimental blocks was usually different from that of the practice blocks. Half of the subjects were tested first in the dual-task experimental block, then in the two single-task blocks (in counterbalanced order). The other half of the subjects were tested in the two single-task blocks first, then in the dual-task block.

Because there were more possible display conditions than trials in most blocks, not all of the possible display conditions could be tested in every block. All combinations of word types on the two limbs were tested in every block. In the practice blocks, display size was simply randomized. In the single-task experimental conditions, display size of the relevant limb was factorially crossed with the word type combinations, but display size of the irrelevant limb was randomized. In the dual-task experimental conditions, all possible display conditions were tested.

Instructions were given separately before each block of trials. Subjects were shown the two-limbed stimulus display, and they were instructed that they would be presented with one or two words on each limb. In the single-task blocks they were told that they should look only at the words on the appropriate limb of the display, ignoring the words on the other limb. They were instructed to press one response key as quickly as possible if a word of the target category (city name or boy's name) was present in either of the two relevant positions, and to press the other response key as quickly as possible if no such word was present. The dual-task blocks were described as a combination of the two tasks they had done previously, and subjects were asked to make both of the two responses appropriate for the two limbs. They were told that they could make the two responses in either order or at the same time and that their goal was to make both of the responses as quickly as possible.

Each trial began with the presentation of a fixation point for 500 msec, and the display remained blank for 1 sec after its offset. Then the two-limbed stimulus display appeared, and it remained in view until the subject responded (one response in the single-task blocks; two, in the dual-task blocks). Separate accuracy feedback for each task was presented for 1 sec after the response, and the next trial began about 1 sec later.

Results and Discussion

Individual subject means were obtained in each of the conditions excluding error trials and trials on which RT was less than 50 msec or more than 10 sec. All analyses were collapsed across the two channels, maintaining a distinction between the channel to which the response was made ("response channel") and the other channel present in the display at the same time ("other channel"). In the dual-task blocks, this meant that each display was classified in two potentially different ways—once with respect to each response. For example, suppose a display had one word on the Boy channel and two words on the City channel. Then, with respect to the response to the Boy channel, the display would be classified as having display size one on the response channel and display size two on the other channel. With respect to the response to the City channel, however, the display would be classified as having display size two on the response channel and display size one on the other channel. For the single-task conditions, of course, each display was only classified once, with respect to the single response that was made. After responses were thus classified, the corresponding RTs were averaged across channels within these categories (e.g., Tables 1 and 2).

Since display size was not completely crossed with stimulus type within each subject, these two factors were analyzed separately. For the analysis of display size, average reaction time (RT) and percentage of correct responses (PC) were computed separately for each subject, task, and display size combination, and means of these values across subjects are shown in Table 1. It is clear that responses took much longer in the dual task than in the single tasks, and display size on both the response channel and the other channel also influenced RT. It can also be seen that both types of display size had much larger effects in dual tasks than in single tasks.

To confirm the statistical reliability of these effects, the individual subject values were analyzed by repeated-measures analyses of variance (ANOVAs) with factors of response-channel display size, other-channel display size, and task (single vs. dual). In the analysis of RT, significant effects were obtained for all three main effects and both two-way interactions of task with display size factors: response-channel display size, $F(1,41) = 169$, $p < .01$, $MS_e = 21{,}478$; other-channel display size, $F(1,41) = 92$, $p < .01$, $MS_e = 16{,}951$; task, $F(1,41) = 208$, $p < .01$, $MS_e = 447{,}215$; the interaction of task with

TABLE 1

Experiment 1: RT (PC) as Functions of Display Size and Task

Other-Channel Display Size	Response-Channel Display Size 1	2
Single Task		
1	978 (93)	1136 (93)
2	1012 (94)	1182 (94)
Dual Task		
1	1880 (93)	2146 (93)
2	2127 (93)	2365 (93)

TABLE 2

Experiment 1: RT (PC) as Functions of Stimulus Type and Task

Other Channel Stimulus	Response Channel Stimulus: Target	Associate	O-C Target	O-C Assoc.	Neutral
Single Task					
Target	1193 (74)	1190 (91)	1069 (99)	984 (99)	988 (99)
Associate	1377 (80)	1273 (89)	1003 (99)	974 (99)	990 (98)
O-C Target	1395 (76)	1199 (89)	1069 (98)	978 (98)	955 (98)
O-C Associate	1318 (76)	1195 (88)	1080 (96)	1051 (98)	968 (99)
Neutral	1240 (78)	1247 (92)	1069 (97)	1011 (99)	969 (99)
Average	1305 (77)	1221 (90)	1058 (98)	1000 (99)	974 (98)
Other Channel Averages:	1085 (93)	1123 (93)	1119 (92)	1122 (91)	1107 (93)
Dual Task					
Target	2686 (74)	2550 (90)	2574 (99)	2383 (98)	2238 (98)
Associate	2584 (75)	2247 (92)	2273 (98)	2118 (99)	2040 (99)
O-C Target	2609 (70)	2205 (93)	2249 (98)	2148 (98)	1975 (98)
O-C Associate	2504 (72)	2028 (92)	2086 (99)	2002 (98)	1930 (98)
Neutral	2371 (74)	2042 (93)	1995 (98)	1930 (99)	1784 (99)
Average	2550 (73)	2214 (92)	2236 (98)	2116 (98)	1993 (98)
Other Channel Averages:	2486 (92)	2252 (93)	2237 (91)	2110 (92)	2025 (93)

Note: "O-C" is an abbreviation for "Off-Channel"

response-channel display size, $F(1,41) = 14$, $p < .01$, $MS_e = 11{,}081$; and the interaction of task with other-channel display size, $F(1,41) = 72$, $p < .01$, $MS_e = 10{,}819$. No sources of variance were significant in the analysis of PC.

The overall analysis of stimulus type was conducted similarly, and means are shown in Table 2. Again, responses were much slower for dual tasks than single tasks. Furthermore, the semantic properties of the distractors also influenced RT. Response-channel distractors had a large effect in both single and dual tasks, whereas other-channel distractors only had a large effect in dual tasks.

In an ANOVA on RT with factors of response-channel stimulus, other-channel stimulus, and task, all of the main effects and two-way interactions were significant: response-channel stimulus, $F(4,164) = 63$, $p < .01$, $MS_e = 194{,}305$; other-channel stimulus, $F(4,164) = 27.5$, $p < .01$, $MS_e = 104{,}460$; task, $F(1,41) = 227$, $p < .01$, $MS_e = 2{,}845{,}610$; response-channel stimulus by other-channel stimulus, $F(16,656) = 1.77$, $p < .05$, $MS_e = 93{,}549$; response-channel stimulus by task, $F(4,164) = 9.48$, $p < .01$, $MS_e = 124{,}029$; and other-channel stimulus by task, $F(4,164) = 37$, $p < .01$, $MS_e = 97{,}169$. The three-way interaction did not approach significance, $F(16,656) < 1$. In an overall ANOVA on PC, the only significant sources of variance were the main effect of response-channel stimulus, $F(4,164) = 138$, $p < .01$, $MS_e = 30{,}987$; and the interaction of task and response-channel stimulus, $F(4,164) = 3.6$, $p < .01$, $MS_e = 16{,}334$. Stimulus conditions with higher accuracy tended to have smaller average RTs, so differences among these conditions are not attributable to a speed-accuracy tradeoff.

Table 3 shows the results in terms of effect sizes of the different experimental manipulations. The display size effect was computed by comparing performance in display size 1 with performance in display size 2. The effects of the three different types of nontargets were computed with comparisons against the neutral condition. Each effect was calculated separately for conditions in which the stimuli appeared on the response channel and conditions in which the stimuli appeared on the other channel. Furthermore, each effect was calculated separately for the single-task condition, the dual-task condition, and the difference between single- and dual-task conditions (i.e., the dual-task decrement).

As expected, off-channel targets (i.e., words that belonged to the category designated as the target for the other channel) interfered with performance in the dual-task condition. For example, when a word like *CHICAGO* appeared in the Boy channel, response latencies to both channels were longer than when a neutral word like *TABLE* appeared there (response channel: $F(1,41) = 105$; other channel: $F(1,41) = 60$). The increase in RT caused by an off-channel target was more than 200 msec—about the same as the increase caused by the larger display size or an associate on the response channel. The effect of off-channel associates was also clearly present in the dual-task conditions (response channel: $F(1,41) = 19$; other channel: $F(1,41) = 14$), though the effect was about half that of off-channel targets. The existence of both of these effects shows that outcome conflict is a potent factor.

TABLE 3

Experiment 1: Effects of Experimental Manipulations on RT as Functions of Channel and Task, and Associated Significance Levels

	Effect on		
Manipulation	Single Task	Dual Task	Decrement
Response Channel			
Display Size	164**	252**	88**
Nontarget Relatedness:			
Associate	247**	221**	-26 (n.s.)
O-C Target	84**	243**	159**
O-C Associate	26 (n.s.)	123**	97**
Other Channel			
Display Size	40 (n.s.)	233**	193**
Nontarget Relatedness:			
Associate	16 (n.s.)	227**	211**
O-C Target	12 (n.s.)	212**	200**
O-C Associates	15 (n.s.)	85**	70**

Note: "O-C" is an abbreviation for "Off-Channel"
n.s.: p > .05. ** : p < .01.

Furthermore, the effects of off-channel targets and off-channel associates on dual-task performance were much larger than their effects on single-task performance, supporting the notion that outcome conflict is a determinant of dual-task decrement. For off-channel associates in particular, there was a 104 msec effect on dual tasks, with virtually none on single tasks.

Considering the results from the point of view of resource theory, we find that associates in the response channel had a surprisingly small effect on the dual-task decrement. Resource theory assumes that the rate of processing of one task is reduced by the requirement to perform another task concurrently. When that is the case, difficulty manipulations should have larger effects on latency in dual-task conditions than in single-task conditions (Navon, 1984, pp. 224-225). A *post-hoc* explanation for the absence of the expected increase, in terms of resource theory, might be that there are criterion shifts causing subjects to allocate additional resources to the more difficult conditions. However, we doubt that criterion shifts influenced our results; because we collapsed across the two tasks, the tasks were very comparable to begin with, and difficulty varied randomly within blocks. Whatever the correct explanation is, it probably assumes some weakening of the associative relationship in the dual-task condition. Such weakening is not predicted *a priori* from resource theory.

Performance was also affected by the difficulty of the concurrent task on the *other* channel (namely. by its display size and the relatedness of the nontarget to the target category). This result is compatible with any theory of task interference, including resource theory.

In summary, while we have direct evidence that outcome conflict contributes to dual-task decrement, we have no direct evidence of competition for resources. Furthermore, the lack of an effect of a response-channel associate on the dual-task decrement for that channel is unexpected, given resource models. This leads us to conclude that dual-task interference is generated to a great extent by outcome conflict.

It may be concluded in view of these findings that a major source of task interference is the inability of subjects to separate completely the lines of processing for the two tasks. Therefore, the tasks interact much more than they would if they could have been processed in separate, "sealed" channels. That sort of interference looks like conflict between processes that share the same processing environment rather than competition for a limited pool of resources or queueing for a common mechanism. It is perhaps an outcome conflict of the type termed elsewhere (Navon, 1985) as difficulty in making nonhabitual transitions—namely, the difficulty in transferring control and throughput between successive modules of processing when two or more modules operate in parallel. For example, in this case there might have been some problem with the correct addressing of the outputs of the processes functioning as Boy and City detectors to the appropriate effector units. Putting it differently, the mapping of stimuli to responses should have been channel-dependent, yet the contingencies were probably not kept sufficiently apart. For example, the inhibition of a "yes" response to a city name presented in the Boy channel might have somewhat or sometimes spread to the City channel as well.

The finding that the presence of an off-channel target inhibited responses to both channels indicates that outcome conflict occurs on at least two levels. There appears to be confusion over assigning a stimulus to its spatial origin, resulting in a tendency to respond to an off-channel target as if it were a target appearing in the response channel. Let this be termed *perceptual conflict*. It is demonstrated by the effect of off-channel targets appearing in the other channel. There also seems to be confusion over the stimulus-response mapping in a given channel, resulting in a tendency to respond to an off-channel target as if it were a target in the response channel. Let this be termed *S-R mapping conflict*. It is evident from the effect of off-channel targets appearing in the response channel.

There might also be other sources of conflict that are responsible for some or all of the residual task interference that was not accounted for by the factors we manipulated. For example, there might be some confusion over relaying the internal responses that are output from successful stimulus-response mapping to the appropriate hands. That could result in a tendency to respond to a target presented on a given channel with the finger assigned for a target on the other channel, and the same *mutatis mutandis* for a nontarget. It is obvious why such conflict, that may be termed *channel-effector mapping conflict*, is impossible to be substantiated definitely in our design, as well as in most other dual-task paradigms: It may occur in all conditions.

A putative contention might be that although a considerable outcome conflict was certainly demonstrated, it still does not account for the large single- to dual-task decrement that has been observed here. It is, of course, possible to answer that since task interference exists in dual-task paradigms regardless of whether a direct manipulation of outcome conflict is attempted, some amount of task interference is from the outset expected not to be accounted for by the manipulation. Is the residual variance due to competition for resources? It is hard to tell, for reasons discussed by Navon (1984). However, there is some indication that this is not the case, or at least not the whole story. Resource theory predicts that a manipulation of the difficulty (or complexity) of a task will affect the performance of that task more than the performance of the concurrent task (see Navon & Gopher, 1979, pp. 219-220). In this experiment, however, for each of the factors manipulated, its effects on the two tasks were about equal. That could also have resulted from a response grouping strategy in which both responses are emitted at once (cf. Pashler, 1984), but an analysis of inter-response intervals shows that this interval was greater than 100 msec on about half the trials. Thus, there was ample opportunity for differential effects on the two tasks to have been observed.

Nevertheless, we suspected that perhaps the cause of the unusually large dual-task deficit obtained here was that subjects adopted a partly sequential strategy to avoid potential outcome conflicts. If so, an experimental attempt to demonstrate outcome conflict in a within-blocks comparison may defeat its own purpose. This suggests that the best way to observe outcome conflict is, somewhat paradoxically, to make it tolerable enough so that subjects are not be forced into a sequential strategy. Another way is to manipulate outcome conflict as a between-subjects variable. Experiment 2 was meant to attain both objectives.

EXPERIMENT 2

The arrangements of the display and response keys in this experiment were the same as in Experiment 1, but the stimuli were different. The targets for one of the channels were two specific letters, and the targets for the other channel were two specific digits. Two characters appeared in each channel. One was always a member of the same category as the targets for that channel, though it was not necessarily one of the targets. For subjects in the *pure-homogeneous* group, the other was always a nontarget of the same category. For subjects in the *mixed* group, the second character was a nontarget that either belonged to the same category as the target, on *homogeneous* trials, or to the other category, on *heterogeneous* trials. On heterogeneous trials the nontarget belonged to the same category as the targets searched for on the other channel, but it was never one of the two specific items designated as targets. For example, when the target letters were D and G, a nontarget letter presented on the digit channel in the heterogenous condition could be any letter other than D and G. Thus, there were no off-channel targets in this experiment as there were in Experiment 1. We hoped that this feature would make the two tasks more amenable to parallel processing, thereby enabling us to observe the hypothesized by-product of parallel processing, namely, outcome conflict. As in Experiment 1, single-task conditions were administered in which equivalent displays were presented but the subject was required to perform only one of the search tasks.

The main interest was in the way the homogeneity factor would interact with the dual-task requirement. We expected that for any individual task in itself, search in the heterogeneous condition would be superior to search in the homogeneous condition, since subjects could capitalize on the category distinction to reject some of the nontargets (e.g., Jonides & Gleitman, 1976). If competition for resources is the source of dual-task interference, then the largest amount of interference should be observed when the two more difficult conditions—by expectation, the homogeneous ones—are conjoined. However, according to an outcome conflict view, the channels can be better separated when distinguished by category in addition to location. Thus, the likelihood of conflict is greater when a nontarget on one channel is from the same category as the targets of the other channel. By outcome conflict considerations, then, dual-task performance of subjects in the mixed group should be better with homogeneous displays on both channels than with heterogeneous ones, even though single-task performance should be better with heterogeneous displays. For the same reason, dual-task performance of the pure-homogeneous subjects should be better than that of the mixed subjects, even though the mixed subjects should perform better in the single tasks. Thus, the two prominent theoretical alternatives for explaining dual-task interference make conflicting predictions in this case.

Method

This experiment was conducted using the same apparatus as the previous one, and 120 new subjects were drawn from the same pool. The general procedure was the same as in the previous experiment, with some changes due to the alteration of stimulus materials, as noted below.

The two-limbed stimulus display was again used, but stimuli were single alphanumeric characters appearing 1.2° above and below the fixation point, and 1.3° to the left and right of it. One task was to indicate whether either of two specific target letters was present in one limb of the display, and the other task was to indicate whether either of two specific target digits was present in the other limb of the display. The letters *A-J* were used, excluding *I*, and the digits 1-9 were used.

The contents of the two limbs of the display varied independently. For one group of 80 subjects (heterogeneous displays), a limb could contain a target character plus a distractor character of the same alphanumeric class, a target character plus a distractor character of the opposite class, two distractors of the same class as the target, or one distractor of the same class as the target and one of the opposite class. Each of the 16 combinations (four compositions of each limb) was presented three times in each practice block, and six times in each experimental block. For another group of 40 subjects (homogeneous displays), a limb contained only characters of the same alphanumeric class as the targets for that limb: either a target plus a distractor or else two distractors. Each of the four possible combinations (two compositions of each limb) was presented 12 times in each practice block and 24 times in each experimental block.

Results and Discussion

As in Experiment 1, mean RTs and PCs were computed separately for each subject and each condition. Means of these values across subjects and channels are shown in Tables 4 and 5, again maintaining the distinction between the response channel and the other channel. Separate ANOVAs were performed on the results of the mixed and pure-homogeneous groups.

TABLE 4

Experiment 2, Pure-Homogeneous Group:
RT (PC) as Functions of Task and Target Presence/Absence

Other Channel Target	Response Channel Target: Present	Response Channel Target: Absent
Single Task		
Present	686 (97)	805 (98)
Absent	695 (97)	776 (98)
Dual Task		
Present	1504 (96)	1838 (97)
Absent	1786 (96)	1620 (98)

TABLE 5

Experiment 2, Mixed Group:
RT (PC) as Functions of Task and Display Condition

	Response Channel			
	Target Present		Target Absent	
Other Channel	Nontarget Same Category	Nontarget Different Category	Nontarget Same Category	Nontarget Different Category
	Single Task			
Target Present				
Nontarget Same Category	701 (95)	687 (97)	784 (98)	797 (96
Nontarget Differennt Category	707 (95)	682 (96)	790 (95)	784 (98)
Target Absent				
Nontarget Same Category	695 (94)	693 (97)	758 (97)	793 (97)
Nontarget Different Category	708 (94)	696 (96)	765 (98)	771 (97)
	Dual Task			
Target Present				
Nontarget Same Category	1564 (95)	1639 (97)	2071 (8)	2087 (96)
Nontarget Different Category	1611 (95)	1633 (96)	2060 (95)	2106 (98)
Target Absent				
Nontarget Same Category	2019 (94)	1974 (94)	1726 (97)	178 (97)
Nontarget Different Category	2047 (91)	2067 (93)	1756 (97)	1838 (95)

Analyses of mixed group. For the mixed group, the ANOVA included the five factors of task (single vs. dual), response-channel nontarget category (same as target vs. different), response-channel target status (present vs. absent), other-channel nontarget category (same vs. different), and other-channel target status (present vs. absent). In the analysis of RT, significant main effects were obtained were obtained for all five factors: task, $F(1,79) = 414$, $p < .001$, $MS_e = 1{,}993{,}060$; response-channel nontarget category, $F(1,79) = 4.85$, $p < .05$, $MS_e = 38{,}603$; response-channel target status, $F(1,79) = 62$, $p < .001$, $MS_e = 96{,}318$; other-channel nontarget category, $F(1,79) = 4.15$, $p < .05$, $MS_e = 35{,}320$; and other-channel target status, $F(1,79) = 4.44$, $p < .05$, $MS_e = 86{,}524$.

The effect of major interest was that responses were faster when nontargets on a channel belonged to the same category as the targets for that channel—just the opposite of the usual category effect in visual search (cf. Jonides & Gleitman, 1976). For the response channel, the advantage for same-category nontargets was 35 msec in the dual task, but −1 msec in the single task, leading to a significant interaction of task and response-channel nontarget category, $F(1,79) = 5.7$, $p < .025$, $MS_e = 35{,}305$. For the other channel, the advantage for same-category nontargets was also larger in the dual task than in the single task (41 vs. −1 msec), though this interaction did not quite reach statistical significance, $F(1,79) = 3.679$, $p < .06$, $MS_e = 42{,}832$.

Overall, responses were about 100 msec faster when targets were present than when they were absent on the response channel, with the same effect being about 25 msec on the other channel. The advantage for target-present trials on the response channel was about the same for single and dual tasks, but the advantage on the other channel was larger in the dual task than the single (56 msec vs. −7 msec), $F(1,79) = 7.9$, $p < .01$, $MS_e = 79{,}322$. In addition, the congruence of the two channels with respect to the presence or absence of a target was potent. Overall, responses were 185 msec faster when targets were present on both channels or neither than when a target was present on one channel but not the other, producing an interaction of target presence/absence on the two channels, $F(1,79) = 87$, $p < .001$, $MS_e = 249{,}702$. The interaction was larger in the dual task (359 msec) than in the single task (11 msec), $F(1,79) = 84$, $p < .001$, $MS_e = 229{,}321$.

The results of the parallel analysis of PC showed that subjects missed targets more often than they made false alarms and that the size of this effect depended on both display properties and, in the dual-task condition, congruence of target presence or absence. Overall, response accuracy was higher when targets were absent on the response channel (96.1%) than when they were present (94.8%), $F(1,79) = 13$, $p < .01$, $MS_e = 8{,}697$. However, the higher accuracy for target-absent trials depended on the category of nontarget appearing in both the response channel, $F(1,79) = 12$, $p < .01$, $MS_e = 4{,}270$, and the other channel, $F(1,79) = 4.33$, $p < .05$, $MS_e = 2{,}789$. Both of these interactions can be summarized by saying that subjects were more likely to miss a target the more items from the target category were present in the display. Averaging across single and dual tasks, the higher accuracy for target-absent trials was obtained only when the target was absent on the other channel, not when it was present, $F(1,79) = 15$, $p < .001$, $MS_e = 8{,}424$. However, the pattern of this two-way interaction depended on task, $F(1,79) = 10$, $p < .01$, $MS_e = 4{,}635$. In the dual-task condition, target congruence was an additional factor: Accuracies were higher when targets were present on both channels or neither channel than when a target was present on one channel but not the other. Finally, responses were more accurate in the single task than the dual task (96.2% vs. 94.7%), $F(1,79) = 10$, $p < .01$, $MS_e = 14{,}087$, and there was an interaction of task with response-channel nontarget category, $F(1,79) = 6.6$, $p < .02$, $MS_e = 4{,}873$. In single tasks, responses were less accurate when nontargets on the response channel were from the same category as the target sought on that channel (95.6%) as opposed to the opposite category (96.8%), but no difference was found in dual tasks.

Analyses of pure-homogeneous group. The ANOVAs included factors of task, response-channel target status, and other-channel target status. In the analysis of RT, these factors had effects much like those obtained in the mixed group. Overall, responses were 92 msec faster when targets were present on the response channel than when they were absent, $F(1,39) = 32$, $p < .001$, $MS_e = 20{,}662$, and responses were 947 msec faster in single tasks than dual tasks, $F(1,39) = 399$, $p < .001$, $MS_e = 179{,}232$. There was a 134 msec advantage for trials on which targets were present on both channels or neither channel as compared with trials on which a target was present on only one channel, $F(1,39) = 31$, $p < .01$, $MS_e = 45{,}823$. This congruence effect was larger in dual tasks (250 msec) than in single tasks (19 msec), $F(1,39) = 38$, $p < .001$, $MS_e = 28{,}012$. In the corresponding analysis of PC, the only significant source of variance was the effect of response-channel status, $F(1,39) = 7.62$, $p < .01$, $MS_e = 2{,}265$, with responses being less accurate when targets were present (96.3%) than when they were absent (97.8%).

Comparisons of mixed and pure-homogeneous groups. It was expected that between-category search would be easier than within-category search in single tasks, but that the reverse would be true in dual tasks. Accordingly, subjects in the pure-homogeneous group should show smaller dual-task decrements than subjects in the mixed group. To test this prediction, the dual-task decrement score was computed separately for each subject: the mean of all RTs obtained in dual tasks minus the mean of all RTs obtained in single tasks. Dual-task decrements were significantly larger in the mixed group (1136 msec) than in the pure-homogeneous group (947 msec), $F(1,118) = 4.87$, $p < .05$, $MS_e = 196{,}411$.

Discussion. Dual-task performance was worse under the heterogeneous conditions than under the homogeneous ones. As expected, this effect was stronger when the combination of only heterogeneous conditions in both channels was compared with the combination of only homogeneous conditions. The effects seem to exist in performance scores for both channels (although the effect of homogeneity on the latency to respond to the concurrent channel was just marginally significant). The effects were not large, but their existence corroborates the conclusions suggested by the findings of Experiment 1; namely, outcome conflict seems to be unavoidable on at least two levels, perceptual and S-R mapping (and perhaps even at the channel-effector mapping, even though we do not have evidence for it), and it takes part in determining task interference. The prediction from resource theory, namely that dual-task interference will be decided by the difficulty of the tasks when performed in isolation, was not borne out, although the test is not conclusive simply because category homogeneity had a very weak effect on performance in single-task conditions.

We failed to demonstrate a larger effect of what is presumed to be the manipulation of outcome conflict. The reason is probably that even though we have used much simpler search tasks than in the previous experiment, and even though we have not included any off-channel targets, there were nevertheless enough sources of outcome conflict in the paradigm to induce subjects to adopt a partly sequential strategy. Indeed, when those sources were eliminated, namely in the design used for the pure-homogeneous group, dual-task performance improved considerably (mean latency was about 190 msec shorter). This result suggests that in addition to the effects of the actual presence of off-channel associates that was discussed before, there is a cost to their *potential* presence in the situation. That cost is presumably due to a shift in strategy that is devised to forestall possible outcome conflicts.

So far we have identified two loci of task interference that may be attributed to the effects of outcome conflict. We incidentally learned about a third one. The congruence of target presence/absence on the two channels was impressively effective. Since the effect was observed only in dual-task conditions and not in the single-task ones, it is reasonable to conclude that its locus is the processes of decision or response preparation. It appears that responses are facilitated when the same decision is reached for both channels, or are inhibited when the decisions diverge: a case of outcome conflict par excellence. We label this a *cross-response conflict*. We can rule out the possibility that it results from some problem in motor coordination (see Duncan, 1979), since assignments of responses to fingers were counterbalanced. A similar pattern was not observed in Experiment 1. It is conceivable that the discrepancy stems from the different levels of difficulty of the two experiments. In Experiment 2 the tasks themselves were quite easy (738 msec and less then 4% errors in the single-task conditions), so that subjects could perhaps configure their responses in the following manner: (a) targets on both channels, (b) no target in any channel, and (c) one target detected in which case it has to be figured out which of the hands is to report the detection. This could not be done in Experiment 1, first because the tasks were more difficult, and second because of the occasional presence of off-channel targets that precluded any attempt to configure the tasks.

Earlier we suggested that subjects might tend to perform two tasks sequentially rather than simultaneously if outcome conflicts were severe. We had in mind effects on the strategy with which the subject approached the dual tasks. However, even holding strategy constant, it is possible that outcome conflict would act to desynchronize processing on the two channels, and there is a suggestion of this effect in the present data. For subjects in the mixed group, we measured the time between the two responses that had to be emitted in the dual task conditions: inter-response time (IRT). Using this as the dependent variable in an ANOVA parallel to that performed on the RT data for this group (omitting the task factor), we found a significant interaction corresponding to the congruity effect noted above in RT and PC, $F(1,79) = 30$, $p < .001$, $MS_e = 55{,}624$. When the two channels had congruent target status, both present or both absent, the mean IRT was 192 msec. When the two channels were incongruent, however, the corresponding mean was 265 msec. Thus, it is likely that the outcome conflict resulting from incongruent channels interfered with simultaneous processing of the two channels and caused them to be handled more sequentially.

GENERAL DISCUSSION

We have demonstrated four different effects that can be attributed to outcome conflict: The effects of off-channel targets and off-channel associates on responses to the other channel, effects we ascribed to some perceptual conflict; the effects of these items on the response to the channel on which they appeared, effects we called S-R mapping conflict; an effect on the strategy subjects use when they anticipate possible outcome conflict; and an effect of target presence/absence congruence, which we denoted a cross-response conflict. Taken together, those effects account for a large part of the extra difficulty of dual-task performance. This in itself suggests that outcome conflict is a potent determinant of task interference.

A resource theorist must try to explain the task interactions demonstrated here by appealing to certain limited capacity mechanisms. For example, the explanation of Experiment 1 would probably rely on a single lexicon in which word recognition takes place. The tasks would interact because both try to make incompatible use of a single structure: the lexicon.

Our reply is that this argument concedes our position. No doubt the tasks interact because they both make use of a common lexicon, but they do not *compete* for it. The lexical activations produced in the single tasks are not stronger or more elaborated than those produced in dual tasks, as would be expected from the notion of a limited capacity system. Rather, each set of lexical activations reaches full strength, but the existence of one set interferes with analysis of the other. We feel that this effect is much more similar to a case of cross-talk between conversations over two telephone lines than to queueing for a single line.

The findings reported here add to existing empirical results more congenial to the notion of outcome conflict than that of limited resources. For example, tasks usually interfere more the more similar they are or the closer their processing loci are in cerebral space (Kinsbourne, 1981, 1982). The proposal to regard the two hemispheres as two separate resource pools (e.g., Friedman & Polson, 1981; Friedman, Polson, Dafoe, & Gaskill, 1982) does not seem convincing, mainly in view of the fact that between-hemisphere interference does exist and that task interference seems to be a continuous function of cerebral distance between processing loci (see Kinsbourne & Hicks, 1978). It is more plausible that the decrease in interference with greater cerebral distance is due to reduced outcome conflict between distant processing loci.

Other data that are quite naturally explained in terms of outcome conflict are findings of specific interferencce between similar tasks. Especially compelling is the demonstration of two pairs of tasks that manifest large within-pair interference but very little between-pair interference. For example, Brooks (1968) found that vocal responses interfered more than spatial responses with recall of a sentence but less than spatial responses with recall of a line diagram. Such a result is clearly incompatible with the view that the amount of interference between tasks is related to their demand for resources from a single pool. This and similar results (e.g., Allport, Antonis, & Reynolds, 1972; Baddeley, Grant, Wight, & Thomson, 1975; Treisman & Davies, 1973) were interpreted as evidence for the existence of multiple pools of resources (see Navon & Gopher, 1979; Sanders, 1979; Wickens, 1980). Indeed, it is usually easy to define the common attributes of interfering tasks as another pool of resources. However, the merit of such an approach is doubtful. First, as pointed out elsewhere, there is rarely any evidence that the hypothesized structure in which interference supposedly takes place is really a pool of resources in the interesting sense of the term (Navon, 1984, 1985). Furthermore, it is neither parsimonious nor intuitively compelling to add a resource pool, or even a structure, for every source of task interference that may be found. For example, the semantic similarity between city names and state names that contributed to the task interference in Experiment 1 does not seem to justify postulating a separate memory for geographical names. It seems more reasonable to interpret this effect as resulting from the priming of the concept of city names by activation spreading from any state name—a clear case of outcome conflict.

Finally, dual-task interference that seems unavoidable is much reduced or even eliminated with extensive practice (e.g., Hirst, Spelke, Reaves, Caharack, & Neisser, 1980; Spelke, Hirst, & Neisser, 1976; Underwood, 1974). To accomodate such findings, resource theory would have to assume that the same tasks demand less resources as the dual task is practiced. While this might seem plausible if any of the tasks needed practicing in isolation, it is clearly implausible when the tasks are as individually well-practiced as reading and taking dictation. In addition, Hirst et al. (1980) showed that the tasks were not performed automatically even at the end of practice. What is being learned is presumably not how to optimize the tasks in terms of resource consumption but rather how to avoid the interaction between the processes comprising the tasks, namely, how to reduce outcome conflict. These experiments converge with ours in showing that single-task difficulty is not the critical determinant of dual-task interference, since interference disappeared even though the single tasks had not been automated.

Do the results of this study shed any new light on the possible sources of the residual task interference or task interference observed in situations that do not appear to invite as much outcome conflict? Granted, it would have been quite impressive (and not only from a theoretical point of view!) if we had managed to eliminate all task interference with some clever manipulation that could reasonably be believed to affect only task interaction. Of course, we did not do that, though others may have uncovered such situations (e.g. Hirst et al., 1980; Spelke et al., 1976). Task interference is a robust phenomenon that we may be able to modulate but we cannot control, nor can, so we suspect, any experimental manipulation derived from any theoretical approach. The issue is what is now a reasonable conjecture about the sources of task interference beyond that which was accounted for. We propose that we have just scratched the surface in identifying the forms that outcome conflict might assume. For example, we pointed out the possible existence of channel-effector mapping conflicts that could be operating in every dual-task situation which involves two response sets. Presumably, just as we reduced dual-task interference in Experiment 2 considerably by assigning subjects to a purely homogeneous design, future experiments may find ways to control other sources of outcome conflict. The predictions of rescurce theory—about the relative impact of task difficulty variables on the task being manipulated and on the concurrent task—were not borne out. Thus, we are in a position to propose that task interference may be largely due either to outcome conflict or to the attempt to avoid it by retreating to sequential access to some processing mechanisms.

It should be added that the sorts of outcome conflict demonstrated here in so-called divided attention paradigms seem to have much in common with factors that are often thought to induce failures of selective attention. Indeed, even in the focused attention conditions that served here to measure single-task performance, there was some disruptive effect of the appearance of an off-channel target in the relevant channel. It seems that whatever impedes selection of one out of many processes must hamper as well, and presumably even more, the separation among multiple ongoing processes.

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