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Competition for Left [illegible] Right Hemisphere [illegible] Verbal Information [illegible]

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In this paper, we present a direct test of a multiple-resources approach to resource allocation in information processing, in which the two cerebral hemispheres are assumed to have separate, limited-capacity pools of undifferentiated resources. Five right-handed men were selected on the basis of having manifested a RVF-LH superiority for processing the stimuli used in each of two tasks that were to be performed concurrently in the main experiment. We then measured both single and dual-task performance on the tasks, which were a centrally-presented verbal memory load, and a nonsense syllable naming

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task in which the syllables were presented to either visual field. Subjects were paid according to their accuracy during both single and dual-task trials; on the latter, the payoff ratios were varied, to induce them to allocate more attention to either the memory task, the visual field naming task, or to both equally. In our approach, the two types of visual field trials are treated as two different dual-task situations. Right and left visual field trials of the naming task combined with the verbal memory load constitute, respectively, cases of complete or partial overlap in demand for left hemisphere resources. Therefore, on RVF dual-task trials, left hemisphere resources should be more scarce than on LVF trials. Under moderate to heavy memory loads, subjects who had shown large RVF single-task performance advantages for naming nonsense words showed larger performance decrements on RVF trials than on LVF trials in the dual-task situation, such that both naming task and memory performance was now superior when the naming task stimuli were presented to the left visual field. In addition, the payoff manipulation produced a reliable Task X Task Emphasis interaction, indicating that performance tradeoffs between tasks were occurring on both types of visual field trials, and thus providing the necessary evidence for overlap in demand. The experiment is illustrative of the prescribed methodology for testing models of limited-capacity processing, and the data support the idea that there are at least two types of resource supplies, which are associated with processing in the left and right hemispheres.

Competition for Left Hemisphere Resources: Right Hemisphere Superiority at Abstract Verbal Information Processing

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Technical Report No. 2

June 1981

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In an earlier paper (Friedman & Polson, 1981), we introduced a theory of resource allocation in information processing based upon the idea that each cerebral hemisphere has access to its own independent supply of undifferentiated resources, which it can allocate to the processing of any task. In addition, we proposed that while the left and right hemispheres have equivalent amounts of supplies, they may not directly "borrow" resources from one another. Thus, the hemispheres together comprise a limited-capacity, multiple-resources information processing system.

Although we demonstrated how this framework accommodates a range of data from experiments employing diverse methodologies and measures, the data we previously addressed were not obtained in a fashion that enables some of the more subtle predictions of a multiple-resources model to be rigorously tested. This is primarily because those cases we discussed from the cerebral specialization literature that used dual-task conditions did not meet the requisite methdological criteria. That is, they either did not require subjects to vary their attention systematically between tasks, or did not use within-subjects designs, or did not take measures of single-task performance baselines (e.g., Hellige & Cox, 1976; Hellige, Cox, & Litvak, 1979; Kinsbourne & Cook, 1971; Smith, Chu, & Edmonston, 1977). Further, those cases we discussed from the divided attention literature that did meet these methodological criteria did not, of course, take into account the handedness or potential degree of "lateralization" of their subjects, nor the degree to which the tasks that were used might demand resources from one or the other hemisphere (e.g., Rollins & Thibadeau, 1977; Sperling & Melchner, 1978). Thus, while the weight of the existing data supports many of our assumptions, a more explicit and rigorous test is clearly necessary

In the present paper, therefore, we will present evidence to support our contention that there are at least two types of resource supplies available to the human information processing system, which are independently under the control of each cerebral hemisphere. Further, we will show that each resource supply behaves as a single-capacity system by itself, which places constraints on the kinds of performance tradeoffs that can happen in any particular concurrent-task situation.

More specifically, we will show that performance is a function of the degree of overlap between the resources demanded in a given task environment, and those available, for a particular subject, to be allocated by either hemisphere. In so doing, we will demonstrate that a single-capacity system can no longer be considered viable. We also hope to show that the framework we are proposing can be valuable for understanding the role played by cerebral specialization in information processing. For example, it allows us to predict the conditions under which subjects who have been selected on the basis of their "left hemisphere language dominance" perform better when unfamiliar, abstract, verbal information is presented to their *right* hemispheres.

Our theory developed as an effort to understand cerebral specialization within a framework that evolved from years of work in the field of divided attention (Kantowitz & Knight, 1976; Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975, 1976). In reviewing this research (Navon & Gopher, 1979), it became reasonably clear that its underlying assumption--that the information processing system draws on a single, limited-capacity pool of supplies--is likely to be too simplistic, on both logical and empirical grounds. It is much more plausible that several types of resources exist that are different in kind, and that therefore may not necessarily be substituted for one another, even when a supply shortage exists and it would be advantageous to do so.

However, if different types of resources are permitted to coexist in the system, then certain findings from dual-task experiments take on a very different interpretation from what they typically are taken to imply within a single-capacity system. For example, the presence or absence of interference effects that differ between sets of tasks as a function of either the types of tasks involved, the increasing difficulty of one of the tasks, or prolonged practice, may not necessarily indicate that the task combinations differ in difficulty, or that processing on one of the tasks has become automatic (e.g., Logan 1979; Posner & Snyder, 1975). Rather, such effects might occur because the tasks in question each require resources of different types (Friedman & Polson, 1981; Navon & Gopher, 1979, 1980; Wickens, 1980).

Thus, an idea that is generally basic to a multiple-resources approach is that performance is related to the types of resources demanded by a task, the amount of each type available to be allocated, and their relative efficiency. An implication that follows from our implementation of this more general model is that in order to determine, *a priori*, how performance will be affected when two tasks are combined, it is necessary to know the relative amounts of resources they demand from each hemisphere for the particular individuals tested.

For example, due to the independence of the hemisphere's resource supplies, we believe that when unilateral stimulus input or response modes are used (e.g., when items are presented to different visual fields, or subjects respond with different hands), it is necessary to consider each condition as a different task, for which the supplies demanded from each hemisphere may potentially differ. This means that each type of visual field trial, hand of response, etc., may or may not cause competition for the type of resource required by any other concurrently performed task. Further, these considerations may apply even when such unilateral techniques are not employed.

There will be some tasks, for example, that can be performed with either of two different resource compositions, each requiring supplies from primarily one or the other hemisphere. This means that both hemispheres would be able to do the processing required for such tasks by using primarily their own strategies, mechanisms, and resources, which in combination may or may not be differentially effective with respect to performance. The range of individual differences typically observed in the cerebral specialization literature, and the variety of strategies that allow some measure of success on most tasks, suggests that this situation may be the most frequent, although there probably are some tasks that require a hemisphere-specific resource (*Footnote 1*) Moreover, the relative performance of each hemisphere on any task can depend, among other things, less on the relative efficiency of its resources than on the existing concurrent demands for those resources.

The implications of this approach are best tested using dual-task methodology with tasks whose underlying resource compositions are reasonably well understood. Navon and Gopher (1979, 1980), who first suggested that observing dual-task performance across sets of carefully chosen task pairs can provide evidence for the independence of resource supplies, have performed several experiments using this methodology, as have several others (Brickner & Gopher, Note 1; Gopher, Brickner, & Navon, in press; Gopher & North, 1977; Hoffman & Nelson, Note 2, Note 3; Hoffman, Nelson & Laubach, Note 4). However, the main difficulty with Navon and Gopher's framework is that they have no reliable means of specifying in advance whether a particular set of tasks might demand qualitatively different resources, or why. Indeed, we believe a theory that restricts the number of possible resource types is preferable to Navon and Gopher's for a variety of reasons. A more restricted theory is simpler, more tractable, and is possible to disprove, whereas it is not entirely clear how or whether one could disprove theirs (see also Wickens, 1980). In addition, we are able to use the cerebral specialization literature as a rough guideline for making *a priori* statements regarding the types of overlap to expect between tasks for different individuals, whereas Navon and Gopher's approach is somewhat more *ad hoc* in this regard.

In general, if resource supplies are independent, then the type(s) of resources demanded by a particular task (i.e., its resource composition) may overlap with those demanded by another either completely, partially, or not at all. This has implications for the kinds of interference effects and tradeoffs that may or may not be observed when such tasks are combined in a dual-task situation. It therefore also has implications for the relative performance of the two hemispheres.

For example, if two tasks draw resources from primarily the same hemisphere, and if they each can be performed using only that particular resource composition, then their resource demands completely overlap. In this situation, we make the same predictions as a single-capacity model (see Friedman & Polson, 1981). Thus, in the complete overlap case, several things can be expected to occur when resources are scarce. In general, there should be an overall performance decrement for both tasks in the dual as compared to the single-task situation. Yet a decrement from single-task performance is only partial evidence that the tasks have overlapping hemispheric resource requirements, since these decrements can also arise from concurrence costs accruing to joint performance *per se.(Footnote 2)* Thus, to insure that resource demands overlap, it is necessary to show that when subjects are induced to pay more attention to one task through the use of a payoff scheme that rewards them for doing so, performance on it improves and a concomitant decrement is observed on the other task (Friedman & Polson, 1981; Navon & Gopher, 1979, 1980; Wickens, 1980). In other words, we should be able to observe complementarity of supplies between tasks.

A contrasting case is one in which a task requiring resources from primarily one hemisphere is combined with a task requiring resources from the other. In such a case of no overlap in demand, there may be an overall decrement from single to dual-task performance due to concurrence costs of a managerial nature, yet mutual *tradeoffs* in performance could not be observed, because resources released from one task would be irrelevant to the other. This situation could not occur if there were only one type of resource to be shared among tasks.

Finally, the partial overlap situation is of interest because the effects here can be much more subtle, particularly when the overlap pertains to stimulus presentations involving one visual field but not the other. In general, performance decrements and tradeoffs can be observed in this situation only when there is a scarcity of the *overlapped* resource. In the experiment below, we will be comparing the performance of the right and left hemispheres in two situations in which the resource compositions of the tasks entail either complete or only partial overlap in their requirements for left hemisphere resources as a function of the visual field to which the stimuli are presented.

We have repeatedly emphasized that in testing this approach, it is necessary to make assumptions about the resource requirements of the tasks being used for the particular subjects at hand. This can be determined either *a priori*, from independent experiments that have used other subjects, or preferably, empirically, by gathering single-task baseline measures on the same subjects who will perform in the concurrent task situation. That is, in order to test whether the resources of each hemisphere are independent, it is necessary to select tasks whose hemispheric resource demands and information processing requirements are reasonably clear. Therefore, it is important to choose tasks that either logically or empirically admit as few strategies as possible. It is equally important to select subjects on the basis of some independent assessment of their degree of lateralization, and to measure single-task performance under conditions in which these subjects are attempting to perform at the maximum levels possible. Otherwise, you can neither assume that all the resources available were being applied in the single-task situations, nor that your *a priori* assumptions about the resource requirements of the tasks were true for the particular individuals involved.(*Footnote 3*) Finally, the tasks are combined in a dual-task situation, and subjects are induced to vary the proportion of resources allocated to each, in order to see whether or not resources freed from one can be used to improve performance on the other.

Since the strategic assumptions we made about our tasks entailed that they primarily or partially demanded left hemisphere resources, we screened our subjects to insure that they would be drawn from a population in which it could be assumed that verbal processing was lateralized in the left hemisphere. Thus, we first selected right-handed men whose self-reports indicated no family history of left-handedness and who wrote with a noninverted writing posture (Hardyck & Petrinovich, 1977; Levy & Reid, 1976, 1978). Second, to further insure that they were strongly right-handed, we administered several manual tests and selected individuals whose performance was in fact superior when using their right hands.

At this point, we were confident we had a group of subjects who, according to the wisdom in the cerebral specialization literature, would be strongly "left-hemisphere language dominant." Yet according to our approach, it was still necessary to insure that these individuals were "lateralized" as expected for the specific stimulus and single-task parameters we used. Therefore, although we were using tasks and materials that should have, *a priori*, demanded primarily left hemisphere resources, we selected only those men who manifested a healthy right visual field superiority on both of our tasks when performed individually, so that we could make our dual task predictions with some assurance regarding resource requirements.

The tasks we chose to combine were a centrally-presented verbal memory load task and a nonsense syllable naming task in which the stimuli were briefly presented to either visual field. These will be referred to as the load and target tasks, respectively. We believed that right vs. left visual field naming trials combined with a verbal memory load task would constitute two different dual-task situations for our subjects, and need to discuss, therefore, our assumptions about their likely information processing requirements and the differences between them in hemispheric resource demands.

The verbal load task involved remembering either two, three, or four pronounceable nonsense words (CVCVCs) that were centrally-presented for relatively long durations. The task itself involved reading the words aloud, holding them in memory for a specified time, and then recalling them. Although the stimuli in this task are nominally available to both hemispheres, we initially assumed, as have several others (e.g., Hellige & Cox, 1976; Hellige, Cox, & Litvak, 1978), that the task utilizes primarily left hemisphere resources for certain right-handed individuals, and attempted to back this up with our screening procedure.

Of course, it was not possible to screen subjects for their lateralization on this particular task in its centrally-presented form. However, we used subjects who manifested a large RVF-LH superiority when required to process, remember, and name CVCVCs presented one at a time, briefly, to each visual field. Thus, we felt we had taken what precautions we could to insure that primarily left hemisphere resources would be required when a memory component and several more of these stimuli were added to the task.

The second task we used involved brief presentations of pronounceable nonsense syllables (CVCs) to either visual field. At the very least, this requires that the CVCs be processed to some level of representation that includes a phonemic code or a motor program for generating such a code, and that the motor program then be executed. Thus, for simplicity, we assume there are two major processes involved in naming a briefly-presented syllable or word: perceptual decoding (which may actually involve several subprocesses) and verbal output.

The bulk of available evidence suggests that both hemispheres are capable of perceptually decoding verbal information, but the left is normally more efficient for right-handed individuals (Day, 1977; Moscovitch, 1976; Sperry, 1974). However, there are good reasons to believe that for many right handed individuals, the right hemisphere is incapable of speech production *per se* (e.g., Broca, 1861, 1865; Sperry, 1974). Consequently, when a word to be named is presented to the left hemisphere, resources exist in that hemisphere that are entirely sufficient for performing the perceptual decoding and verbal output components involved in the task. Conversely, when a word is presented to the *right hemisphere* for naming, then because of the verbal output component, these trials constitute a *task* whose resource composition must include supplies from *both* hemispheres.

Accordingly, when our laterally-presented naming task is conjoined with the verbal memory load task, the amount of overlap in resource demands will not be the same for left and right visual field presentations. The differences are represented schematically in Figure 1. On right visual field-left hemisphere trials, there will be complete overlap in the resource compositions of the load and target tasks, insofar as only left hemisphere resources are demanded by each. Therefore, in the dual-task situation, we expect a performance decrement for both tasks as soon as the resources *required exceeded* the supply available in the left hemisphere. In addition, when this stage is reached, a payoff manipulation that rewards subjects for memory performance will result in load task *increments* and naming task *decrements*; conversely, rewarding subjects for naming task accuracy on right visual field trials should result in improved naming accuracy at the expense of memory performance.

Insert Figure 1 about here

In contrast to right visual field trials, if our analysis is correct, then on left visual field-right hemisphere naming trials, there will be only partial overlap in the *resource demands* of the two tasks. Left hemisphere resources would still be entirely sufficient for the memory task, but the naming task would now require supplies from both hemispheres. This could be advantageous, however, because while the right hemisphere performed the necessary perceptual decoding of the target CVC, the left would only have to do the processing associated with its verbal output. Therefore, on left visual field naming trials, there should be more resources available in the left hemisphere for either the memory task or the verbal output component of the naming task than there would be on right visual field trials. This means that there should be a smaller overall decrement from the single-task performance levels of both tasks on LVF trials than on RVF trials. Note, however, that since left hemisphere resources are still required for the memory task and part of the naming task, it should still be possible to observe performance tradeoffs between the two. That is, since there is still demand for a common resource on LVF trials, tradeoffs should occur as soon as the supply is scarce.(*Footnote 4*)

What is interesting about the partial overlap situation is the potential for reversing a single-task left hemisphere advantage for CVC-naming in the dual-task situation. In other words, despite the fact that we are using unfamiliar verbal stimuli and subjects who were selected to have a RVF single-task performance advantage for processing these stimuli, in the dual-task situation, the theoretical difference in left hemisphere resource demand between RVF (complete overlap) and LVF (partial overlap) trials may suffice to reverse the absolute visual field advantage in the latter case.

As mentioned earlier, a drop in performance of one task when conjoined with another may be construed as being due to either a genuine concurrence cost or to the fact that both tasks require resources from the same pool, and joint demand exceeds available supply. Thus, in order to obtain conclusive evidence that both our memory and naming tasks require resources from the left hemisphere, it is not sufficient to only observe single-to-dual task decrements; we must also observe mutual performance tradeoffs between tasks as subjects are induced to pay more attention to one or the other. If such tradeoffs are obtained, then at least part of the drop from single-task performance would be due an overlap in demand. We could at that point say that decrements which differed as a function of the two types of visual field trials reflected differences in degree of overlap--the greater the drop, the more that the resources of a particular hemisphere are demanded by the two tasks In contrast if the hemispheres could truly share resources, or if there were only one resource supply that they both had access to, there would be no reason to expect that performance decrements would differ as a function of visual field.

From our point of view, if performance tradeoffs between tasks on the two types of dual-task visual field trials are equal--that is, if the increments in naming performance on both RVF and LVF trials produce equal decrements on the memory task and vice versa--then we will argue that the resources of the left hemisphere are either undifferentiated or else are equally substitutive between tasks. In other words, though there should be extra supplies available in the left hemisphere on LVF trials, due to the right hemisphere's sharing part of the processing, the efficiency of those left hemisphere resources as they are applied to either the memory task or the verbal output portion of the naming task should be the same as it is on RVF trials. If it were not, that is, if the supplies released in the left hemisphere from the visual field task were of a qualitatively different kind than those necessary to perform the memory task, we would not expect the *same degree of performance changes between* tasks when the target task was presented to different visual fields.

In summary, if the single to dual-task drops in performance are unequal for the two visual fields, we can argue that there are more resources available to perform the two tasks in the visual field condition that produces the smaller drop. With our tasks and *screened subjects*, this should be the case on LVF trials if the right hemisphere can take over some of the target task stimulus processing (i.e., perceptual decoding). The left hemisphere, in this case, should have more resources available for the memory task and the verbal output portion of the naming task. But since the overlap on both types of visual field trials is still confined to one hemisphere--the left--the relative performance changes with task emphasis should be the same in both dual-task situations.

METHOD

There were two screening sessions, one practice session, and six experimental sessions. In the experimental sessions, we measured single and dual-task performance levels on a verbal memory task of three different levels of difficulty (2, 3 or 4 nonsense words to remember), and a nonsense syllable naming task in which the syllables were presented briefly to either visual field. Subjects were paid for their single-task performance, in order to insure we were obtaining their maximum performance levels. In the dual-task conditions, subjects performed the memory task conjointly with the naming task, under payoff conditions in which they were induced to pay more attention to one or the other task, or else to pay attention to both equally. The three levels of memory task difficulty were used in the dual-task conditions as well as the single-task conditions.

Experimental Design

All experimental conditions could be fit into two days of testing, in which there were two blocks per day. Since there were six experimental sessions, all conditions in the experiment were replicated three times for each subject. Thus, there were four types of trial blocks within a replication, each repeated three times.

The first block in a replication was always a single-task block, in which performance was measured on the CVC naming task as well as all three levels of the memory task. The subject first received 12 CVC-naming trials as practice, and then 48 experimental trials, 24 to each visual field. In every block of 12 naming trials, half the trials were randomly presented to each visual field, with no more than four trials in a row to the left or the right.

The single-task naming trials were always followed by the single-task memory load trials. Subjects first received 12 practice trials, 4 at each load level (i.e., 2, 3, or 4 CVCVCs to remember), and then 48 experimental trials, 16 at each load level. During both the single and dual-task blocks, the memory task was always blocked by increasing level of difficulty; i.e., the 2-word condition first, followed by the three and then the 4-word conditions.

The remaining three blocks in a replication were dual-task blocks, in which subjects performed the memory task conjointly with the visual field naming task. Each of these blocks was run under a particular task emphasis condition, with subjects instructed and paid for emphasizing either their memory performance more, their naming task performance more, or both tasks equally. Across the three replications for each subject, the target, load, and equal emphasis conditions each occurred once as the first, second, or third dual-task block, and the order of the dual-task emphasis conditions was counterbalanced across subjects and replications.

The dual-task blocks each consisted of 12 practice trials, 4 at each memory load level, followed by 48 experimental trials, 16 at each load level. Half the CVC-naming stimuli at each load level during both the practice and experimental trials were presented to each visual field. In any session in which there were two dual-task blocks (i.e., the second day of each replication), the practice trials were omitted for the second block.

To summarize, subjects received four blocks of trials every two days: a single-task block in which the naming and memory tasks were performed by themselves, and three dual-task blocks, in which the tasks were conjoined on each trial. A single-task block consisted of 96 trials altogether; 48 CVC-naming trials, 24 to each visual field, and 48 memory load trials, 16 at each load level. The three dual-task blocks each consisted of 48 trials, 16 at each load level, with 8 of the CVC-naming trials within a load level presented to each visual field. Thus, the dual-task blocks were distinguished from one another by the task emphasis payoff contingency that was in effect for those 48 trials: target, equal, or load emphasis. These four types of blocks were replicated three times for each subject, and the single-task block within each replication served as the baseline for dual-task performance during the dual-task blocks. Note that if there are within-day practice effects for these tasks, the sequence of block orders and load levels we used are biased against obtaining decrements from single-task performance, or decrements that increase as a function of load level.

Emphasis manipulation

In order to induce subjects to vary the amount of resources allocated to each task on the dual-task trials, and to insure to the extent possible that they were operating at their data-limited levels on the single-task trials, we paid the men the basis of their trial-by-trial performance during the experimental sessions. On single-task naming trials, the subjects were paid 10 cents for each CVC they named correctly. On single-task memory trials, they were paid 10 cents for each trial on which all the words in a set were correctly recalled, disregarding order of recall. Thus, for purposes of payment, memory performance was paid only if all of the words were recalled correctly. For purposes of scoring the data, however, recall accuracy was defined as the number of load words recalled on each type of visual field trial, divided by the total presented. The subjects were given feedback at the end of each task as to how much they had earned.

On dual-task trials, payment was divided between tasks in three different proportions, but the same criteria for getting paid on each task were used. On each trial, subjects were either paid 8 cents for one task and 2 cents for the other (in the target and load emphasis conditions), or 5 cents for each (in the equal emphasis condition). The subjects were given feedback concerning how much they had earned on each task after every eight trials, so they could determine if they were properly dividing their attention. Subjects earned approximately $70.00 in the experiment.

Stimulus Materials

For the memory load task, a pool of two-syllable nonsense words (CVCVCs) was created using a computer program, and screened for pronounceability and any obviously high associations. From this pool, 2,532 different words were selected; no word was ever used more than once in the experiment. We used nonsense words to minimize the possibility that subjects could associate the words within each set to each other, and unique words on each trial of the experiment to minimize familiarity with the stimuli. Both measures were taken to assure that the effective memory load level would be constant on each trial for each load level, task emphasis, and visual field condition.

For the target task, 360 different one-syllable pronouncable nonsense words were drawn from a list of rated nonsense syllables (Noble, 1961). The CVCs were selected such that their association values were equated across conditions. The mean association value across conditions was 24.7, with a standard deviation of .1. Each CVC appeared only twice in the experiment; once in each visual field within a given load level condition, but never twice within the same block.

The target and load stimuli were both drawn on microfilm, with white letters on a black background, using computer graphics routines. The target task stimuli were printed vertically and centered 3 degrees from a central fixation point. They subtended a vertical visual angle of 2.3 degrees. The load words were centered horizontally on the slide, one above the other, subtending a horizontal visual angle of 3.5 degrees and vertical angles of from 1.5 degrees, to 3.2 degrees, depending on the memory condition.

Apparatus

The subject sat at a booth with a headrest, in order to maintain a fixed viewing distance from a rear projection screen. In front of him was a button panel, which could be lit to indicate that the next trial could be initiated. Two Kodak random access projectors fitted with Gerbrands shutters were used to project the stimuli onto the back of the screen. A Southwest Technical Products 6809 microprocessor controlled the projectors and shutters, and was used to store the data. The experimenter sat at a terminal in the room with the subject and recorded whether he was correct or incorrect on the target task, as well as how many of the load task stimuli were recalled on each trial. The experimenter was positioned so that he was unable to observe which visual field the stimuli were presented to.

Subjects and General Procedures

Subject Screening. Five right-handed men from the University of Colorado who met all our selection critera participated in the main experiment. None of them had any familial history of left-handedness, and all used a noninverted writing posture

(Levy & Reid, 1976, 1978). All selected subjects had either normal or corrected to normal vision, and spoke English as their native language.

We selected our subjects in stages; those who did not meet our criteria at each successive stage did not participate further. A version of a behaviorally-validated handedness questionnaire consisting of 15 questions about preference for performing certain manual tasks (Raczowski, Kalat, & Nebes, 1974) was used as an initial screening device. The response choices were right, left, or both hands preferred, which were scored +1 for a right-hand preference, −1 for a left-hand preference, or 0 for both hands equally. Thus, a score of 15 represented a right-hand preference for all tasks.

The questionnaires were filled out at the same time that a group of right-handed men who were potential subjects signed up to participate in the experiment. From these questionnaires, we selected 12 men who had a score of 12 or higher for the questionnaire and no left-handed first degree relatives.

***Session 1:* Motor tests for handedness.** At the beginning of this session, subjects read and signed an informed consent form, at which point we confirmed that they wrote with their right hands, using a noninverted posture. They then performed a series of five behavioral tasks which, scored as a group, have been shown to be sensitive to degrees of handedness (Thomas & Campos, 1978). Each task was performed twice with each hand, and the subject was told to start with the hand he thought would be better able to do it. The subject was scored +1 or −1, depending on which hand he chose to use first, and an additional +1 or −1, depending on which hand performed better (taken as the average performance on both trials). If neither hand was better for a particular task, the performance score for that task was zero. Thus, 10 points was the maximum right-handed score.

The tasks performed were (1) squeezing a dynamometer, (2) using the index finger to tap a counter as many times as possible in a 30 second period, (3) using tweezers to pick up small pins and place them in holes on a board (scored as the number of pins successfully placed in a 30 second time period), (4) screwing six nuts onto a bolt (scored as time elapsed), and (5) balancing a 90 cm rod in a vertical position on the tip of the index finger (scored as time elapsed). The handedness session lasted about 30 minutes.

Between the questionnaire and the behavioral tasks, it was possible to receive a "dominance score" ranging from −25 to +25 (i.e., from extremely left-handed to extremely right-handed). Of the 12 men who were administered the handedness tests, 10 achieved our criterion score of 20.

Session 2: Visual Field Tests. We screened the subjects to insure they had a RVF superiority for processing the particular stimuli we used within the single-task procedures employed in the main part of the experiment. For the CVC naming task, the screening procedure was therefore identical to that used in the main experiment, but for the memory load task, of course, it could not be. Thus, what we screened for on the memory task was a RVF superiority for naming a single CVCVC presented to either visual field. We felt that if subjects displayed a RVF advantage in accuracy when called upon to name a CVCVC presented for a brief interval to either visual field, then when they had to read, remember, and subsequently recall several of those same stimuli, the task would require primarily left hemisphere resources.

The subjects performed 96 trials of CVCVC naming, broken down into two blocks of 48 trials each, followed by 48 trials of CVC naming. For each task, an equal number of stimuli were presented to either visual field within each block of 12 trials, and no more than 5 in a row were presented to one visual field. All the nonsense words for both tasks appeared once during the first half of the trials and once during the second half, with each presentation to a different visual field. The procedures used were similar to the single-task target task procedure described below. The CVCVCs used in the screening were drawn from the Toglia and Battig (1978) norms, and were rated to be low in imagery and association value. They were centered vertically 3 degrees from fixation, and subtended a vertical visual angle of 3.8 degrees. The CVCs were drawn from the list of rated nonsense syllables (Noble, 1961), and except for the particular letter combinations used, were physically identical to those used in the main experiment.

The exposure duration was individually determined for each subject for both types of stimuli so that overall performance was approximately 60% correct. Our maximum exposure duration was 180 msec, in order to preclude eye movements. For the 5 subjects who were eventually selected to participate in the remainder of the experiment, the mean exposure duration for the CVC task was 25 msec, with a range between 15 and 40 msec. Their mean exposure duration for the CVCVC naming task was 106 msec, with a range between 75 and 180 msec.

We chose subjects who manifested a RVF superiority on both tasks to participate in the remainder of the expeiiment. Of the 10 men brought for visual field task screening, seven met our criterion, but two of these dropped out of the experiment due to personal time constraints, leaving five subjects who participated in all experimental sessions. For these five men, the mean percent correct for LVF and RVF trials of the CVC-naming task, respectively, was 53.3% and 76.7%, $F(1,4) = 196.00$, $MSe = .0007$, and the different in accuracy between visual fields ranged between 20.8% and 29.2%. Their mean percent correct for LVF and RVF trials of the CVCVC task was 34.6% and 60.8%, respectively, $F(1,4) = 12.64$, $MSe = .0273$, with visual field differences ranging between 6.3% and 47.9%.

Practice Session. In a third session, subjects were given a block of 48 single-task target trials, 24 to each visual field, a block of 48 single-task memory trials, 16 at each load level, and a block of 48 dual-task trials, 16 at each load level, in order to familiarize them with the tasks and procedures, and to stablize their performance. Session 3 and the remaining 6 experimental session were each about one and one half hours long. Subjects were paid $12.50 for the two and one half hours of screening and practice. Any subjects who were eliminated earlier were paid at the rate of $5.00 per hour.

Experimental Sessions. The trials were subject-paced. When the subject was ready to begin, he fixated a central point projected on a screen and pushed a start button. The fixation point remained on for 500 msec after the button was pushed. On single-task target trials, when the fixation point went off, the CVC appeared for a brief period in either the right or left visual field, then the fixation point reappeared. After a 2,000 msec delay, an auditory signal was given to the subject to name the nonsense syllable aloud. The experimenter scored the trial and the start button was lit to indicate to the subject that the next trial could begin.

The same general procedure was used for the single-task memory trials. After the subject initiated a trial and the fixation point went off, the load words were presented. If it was the 2-word condition, the words remained on for 3 seconds. The 3 and 4-word memory loads remained on for 9 and 18 seconds, respectively. The subject was instructed to pronounce the words aloud and study them. When the memory words went off, the fixation point reappeared, and after a 1 second delay, an auditory signal was given for the subject to recall the words. The experimenter scored the number of words correctly recalled.

On the dual-task trials, when the subject initiated a trial, the fixation point remained on for 750 msec, then the memory words appeared for either 3, 9, or 18 seconds, depending on the condition. When the memory words went off, the fixation point reappeared for 500 msec, then the target CVC appeared in either visual field for that subject's predetermined exposure time. The subject was given an auditory signal to recall the load words 700 msec after the target word went off. When the subject finished recalling the load words, he named the target stimulus and the experimenter scored his responses.

RESULTS AND DISCUSSION

The target task data were scored separately for each visual field by dividing the number of correctly named nonsense syllables by the total number of trials presented to that visual field in each memory condition in that block. The memory data were also scored separately for each visual field and load level as the total number recalled divided by the total number of words presented. These proportions were used in the analyses below, and hence are reflected in the *MSe*'s reported. However, for convenience, we will discuss the data in terms of percents.

We will discuss three basic analyses. The first involves single-task performance on both the memory and target tasks, and serves as a baseline against which to compare the absolute levels of dual-task performance. The second set of analyses used data from only the dual-task conditions, and compared our major variables of interest in terms of absolute performance measures (i.e., proportion correct). Finally, we wished to determine whether there were differential decrements from single-task performance levels in the two hemispheres, but equivalent tradeoff effects between tasks. Accordingly, each subject's dual-task performance was subtracted from the appropriate single-task control block, and these difference scores were analyzed.

This third analysis addresses different points for the target and load tasks. For the target task, it was necessary to determine whether any differences in the dual-task conditions between the two visual fields were due to differential decrements from single-task performance. This would be the first support for arguing that there were different amounts of overlap between the target and load tasks when the former was presented to different visual fields. For the load task, besides addressing the issue of differential decrements, the same difference score analysis addresses the question of whether any apparent differences in memory performance in the dual-task conditions as a function of increasing load are due to differences in the absolute performance levels for each load level in the single-task situation.

Single-Task Performance

Memory load task. Subjects received a total of three blocks of 48 memory task trials, in which there were 16 trials each of remembering either two, three, or four nonsense words. These data were subjected to a Load Level x Replication x Subjects analysis of variance. Note that visual field is not a relevant variable for *single-task memory trials.*

Only the main effect of load level was reliable, $F(2,8) = 92.84$, $MSe = .002$, indicating that memory performance declined with increasing loads. The means for the two, three, and four word conditions were 99.2%, 86.5%, and 75.6%, respectively. There was no reliable improvement across replications; the means for the first through third replications were 86.4%, 87.3%, and 87.7%.

Generally, we can conclude that the load task requires increasing amounts of resources across levels, and that performance is relatively stable. These data by themselves, however, do not indicate which hemisphere's resources are more heavily demanded by the memory task. What we can assume is that when this task is combined with another, if there is any overlap in demand between the two, then the overlapped resource will become increasingly scarce as the memory load is increased. In addition, since there seems to be no effect of practice, we can assume that the load level remained reasonably constant across conditions.

Target task. Subjects also received a total of three blocks of 48 target task trials, in which there were 24 trials presented to each visual field. These data were analyzed in a Visual Field x Replication x Subjects ANOVA. Note that load level is not a relevant variable for single-task CVC-naming trials.

The main effect of Visual Field was reliable, $F(1,4) = 28.49$, $MSe = .007$, and was due to a large performance advantage on right visual field-left hemisphere trials compared to left visual field-right hemisphere trials (84.2% vs. 68.1%, respectively). Indeed, in 14 of the 15 possible cases (5 subjects x 3 single-task blocks), there was a left hemisphere advantage for CVC naming that ranged from 4.2% to 33.3%, with an average difference of 17.3% for the 14 cases. Of course, these data are not surprising, insofar as we selected subjects who showed a RVF advantage on this task to begin with. However, it is important to note that in the absence of having to maintain a verbal memory load, our subjects remained consistently superior at naming nonsense syllables presented to their left hemispheres.

Dual-Task Performance

Across replications in the dual-task conditions, each subject received three blocks of 48 trials for each task emphasis condition. Within each of these blocks, 16 trials had a 2-word memory load, 16 trials had a 3-word load, and 16 had a 4-word load, and within each memory load level, 8 target task trials were presented to each visual field. The target and load task data were analyzed in separate ANOVAs in which the factors were task emphasis (target, equal, or load emphasis), memory load (2, 3, or 4 words), visual field (left or right), and replication (first, second, or third). The data were then combined in a third analysis in which task (target or load) was a factor.

The effect of task emphasis was reliable in both the individual analyses, $F(2,8) = 23.87$, $MSe = .0455$ for the target task, and $F(2,8) = 5.56$, $MSe = .0074$ for the load task, and importantly, the Task X Emphasis interaction was reliable in the analysis that combined the two tasks, $F(2,8) = 23.12$, $MSe = .0322$. Thus, performance did change for each task as a function of how subjects were allocating their attention, and these changes were in opposite directions, indicating that resources freed from one task were beneficially applied to the other.

Our subjects had all reported that the target task was easier for them than the load task. Their intuitions were confirmed by the difference in relative performance changes between tasks as a function of emphasis. As Navon and Gopher (1979) point out, when joint demand exceeds the supply available, the largest performance changes with task emphasis will occur on the task which was easier to begin with (i.e., for the task in which the function relating performance to resources has the steeper slope). For our subjects, the largest change in performance as a function of emphasis occurred on the target task; as subjects shifted their attention from the target to the memory task, memory performance increased by 3.6% while target task performance decreased by 21.9%.

There were also strong main effects of load level for each task in the dual-task situation, $F(2,8) = 60.52$, $MSe = .0341$ for the target task, and $F(2,8) = 172.98$, $MSe = .009$ for the load task, such that performance on both tasks decreased with increasing memory loads. Performance declined from 98.0% to 71.7% for the memory task, and from 75.4% to 47.4% for the target task. However, these performance decrements as a function of increasing resource scarcity were not the same for each type of visual field trial, as indicated by the reliable Load Level X Visual Field interactions in the individual task analyses, $F(2,8) = 8.58$, $MSe = .0204$ for the target task, and $F(2,8) = 6.07$, $MSe = .0089$ for the load task. The means for these interactions are shown separately for each task in Table 1. Essentially, the effect of increasing memory load was much less severe on LVF trials than on RVF trials. For the memory task, performance decreased 21.4% on LVF trials and 31.2% on RVF trials in going from a 2 to a 4-word load, while on the target task, performance decreased 20.6% on LVF trials and 35.6% on RVF trials with increasing loads.

Insert Table 1 about here

Not surprisingly, in the individual analysis of the memory data, the main effect of visual field was reliable, $F(1,4) = 61.49$, $MSe = .0026$. This shows that *memory* performance was reliably better when the target task stimulus was presented to the right hemisphere than when it was presented to the left hemisphere (87.5% vs. 82.6%, respectively). This is notable because the memory task stimuli, being centrally-presented for a relatively long period of time, were nominally available to both hemispheres, yet performance was worse in the situation of complete overlap, i.e., on RVF-LH target task trials. Further, as indicated by the Load Level X Visual Field interaction mentioned above, the effects of increasing memory load, and thus left hemisphere resource demands, was more detrimental to memory performance when the target task stimulus was presented to the right visual field. For example, in the 2-word condition, there was essentially no difference in memory performance as a function of visual field, whereas recall was 9.6% better on LVF trials than on RVF trials in the 4-word condition (see Table 1).

Thus, when the right hemisphere was able to partially process the target task stimulus, the resources freed in the left hemisphere were beneficially applied to remembering the nonsense words, and this was particularly useful in the situation when left hemisphere resources were scarce; i.e., during the 3 and 4-word load conditions. These data indicate that with increasing resource demands of the load task, there was a larger amount of resources demanded from the left hemisphere than from the right, and this is in accord with our expectations regarding the resource compositions of the two tasks.

These results are echoed by the analysis of the dual-task target data. There was *no* main effect of visual field in the target task data, which stands in direct contrast to the strong and consistent left hemisphere superiority on this task when it was performed alone. The reason for this is best seen in Load Level X Visual Field interaction, the means for which are shown on the right side of Table 1. The original left hemisphere advantage of 16.1% for the naming task in the single-task condition was reduced to 7.5% with a concurrent 2-word memory load and actually *reversed itself* in the 3 and 4-word conditions, such that better performance was seen when the stimuli were presented to the *right* hemisphere (there were 8.1% and 7.5% differences in favor of the left visual field in the 3 and 4 word conditions, respectively).

In the analysis that combined dual-task performance on both tasks, we were primarily interested in the interactions with the task factor, particularly the Task X Emphasis interaction that has already been discussed. There were, however, reliable main effects of task, $F(1,4) = 211.46$, $MSe = .0464$, emphasis, $F(2,8) = 18.46$, $MSe = .0207$, and load level, $F(2,8) = 108.47$, $MSe = .0318$. These showed that performance on the memory task was generally better than performance on the target task (85.1% vs. 58.1%), that the overall performance levels for each payoff condition were slightly but reliably different (75.9%, 72.0%, and 66.8% for the target, equal, and load emphasis conditions), and that increasing the memory load generally resulted in poorer overall performance (the means for the 2, 3, and 4-word conditions were 86.7%, 68.5%, and 59.5%).

The Task X Load Level interaction, $F(2,8) = 14.93$, $MSe = .0113$, showed that while increasing the memory load from 2 to 4 words decreased target task performance about as much as load task performance (28.0% vs. 26.3% decrements, respectively), the pattern of decrement differed for the two tasks. Memory performance decreased about as much in going from a two to a three word load (12.5%) as it did in going from a three to a four word load (13.8%). In contrast, the largest decrement in target task performance (23.9%) was between the two and three word memory conditions, with an additional 4.1% decrement in the four word condition.

As expected from the individual analyses, the Load Level x Visual Field interaction was reliable in the overall analysis, $F(2,8) = 10.55$, $MSe = .0189$, indicating that increasing the memory load affected overall performance on RVF trials more than it affected performance on LVF trials. Across tasks, performance on LVF trials dropped from 84.8% in the 2-word condition to 63.8% in the 4-word condition--a decrease of 21.0%. In contrast, dual-task performance on the RVF trials dropped from 88.6% to 55.2%, representing an overall decrement of 33.4%.

Of even more interest in this interaction are the differences in performance levels between visual fields. With a 2-word memory load, there was an overall 3.8% performance advantage (across both tasks) in favor of the left hemisphere. However, LVF performance actually became 6.4% better than RVF performance with a 3-word load, and this superiority increased to 8.6% in the 4-word condition.

The significance of these results can be seen in Figure 2, which shows the data from the Task x Emphasis x Load Level interaction, which approached reliability, $F(4,16) = 2.92$, $MSe = .0181$, $p < .06$. The data are plotted separately for each visual field, with the single-task performance levels included for comparison.

Insert Figure 2 about here

Overall, the data from the individual and combined analyses show that the nature of the changes in performance observed between tasks as a function of load level depends upon the degree of overlap in their resource compositions. The changes in performance with different emphasis instructions indicate that there was at least partial overlap in the resource requirements of both tasks during both LVF and RVF trials. The larger effects of increasing load difficulty on RVF trials than on LVF trials indicates that left hemisphere resources were becoming increasingly scarce as the demands of the memory task increased, and that the larger concurrent task demand for those resources occurred on RVF trials.

Thus, while the payoff emphasis affected performance on both RVF and LVF trials, since we had a situation of complete overlap on RVF trials and partial overlap on LVF trials, the increasing memory load was more largely detrimental on trials when the target task stimulus was presented to the left hemisphere. In the heavier memory load conditions, performance on the target task was best in the target emphasis condition and worst in the load emphasis condition, yet in all three payoff conditions, the left hemisphere's target task performance was worse than the right hemisphere's performance. Similarly, memory task performance was better in the load emphasis condition than the target emphasis condition, but with the heavier memory loads, memory performance on RVF target task trials was below that on LVF trials.

Single-to-Dual Task Decrements

There are several senses in which the most interesting data in this experiment are those in which the effects of task emphasis and increasing memory load in the dual-task conditions are viewed as decrements from performance in each of the single-task conditions. This is because the only sense in which the left hemisphere may borrow right hemisphere resources is in the partial overlap situation, when by virtue of the tasks' resource compositions, the right hemisphere can do some of the processing on the target task. Thus, we expect to see much larger decrements from single-task memory and CVC-naming performance on RVF-LH trials than on LVF-RH trials. In contrast, if the two hemispheres could truly exchange resources with each other, we would expect to see equal decrements in going from single-to-dual task performance, regardless of the visual field of presentation.

Accordingly, to test these ideas, we subtracted the dual-task performance in each condition from the relevant single-task baselines, to find the percent decrement (and in some cases, percent increment) in performance. For the target task, this means the dual-task performance for each visual field in the various emphasis and load level conditions was subtracted from two different constants (i.e., single-task RVF and LVF performance means). For the load task, dual-task performance for each visual field, load level, and emphasis condition was subtracted from three constants--the single-task performance levels for each of the three load level conditions. These data were analyzed in separate Task Emphasis X Memory Load X Visual Field X Replication ANOVAs, as well as a combined ANOVA in which Task was a factor.

For the target and load task analyses, respectively, the primary effects of interest are main effects of visual field and load level, while for the combined analysis, the effects of interest are the interaction of these factors with each other and with the task factor. All other main effects and interactions are redundant with those of the previous analyses, although some of the means will be discussed for illustrative purposes.

In contrast to the percent correct data, in the decrement data, the main effect of visual field was highly reliable for the target task, $F(1,4) = 55.58$, $MSe = .0429$, indicating that the decrements in CVC naming performance were indeed less severe on LVF than on RVF trials (the mean percent decrements were 8.6% vs. 27.4%, respectively). The visual field effect was, of course, also reliable in memory data, $F(1,4) = 61.49$, $MSe = .0026$, since the same single-task memory constants were used on both types of visual field trials. Performance on the load task was essentially not different from single-task performance on LVF trials (it was actually .4% above the single-task level), but there was a 4.5% decrement in recall accuracy on RVF trials. The Task X Visual Field interaction was also reliable, $F(1,4) = 38.74$, $MSe = .0168$, and as the means above suggest, this was because the left hemisphere was more severely affected by the dual-task demands, and much more so on the target than the load task.

For the memory task, since the single-task constant used for each visual field condition differs across load levels, the difference score analysis tells us whether there were different decrements from single-task memory performance for each load level condition that therefore might be attributable to something beyond the fact that the performance levels on this task were different to begin with. Since there was no reliable main effect of load level, the relative decrements in memory performance between the single and dual-task conditions were the same for each load level. Thus, the decrements from single-task memory performance were entirely due to the addition of the target task, which presumably demanded a constant "chunk" of left hemisphere resources across all three load level conditions. The size of the "chunk" depended on both the emphasis condition and the visual field of presentation; it was largest with target emphasis and RVF presentations, and smallest with load emphasis and LVF presentations.

In contrast, the effect of increasing memory loads left over fewer and fewer resources for the target task, as indicated by the reliable main effect of load level in the combined analysis, $F(2,8) = 32.89$, $MSe = .0356$, and by the Task X Load level interaction, $F(2,8) = 65.95$, $MSe = .0139$. While the single-to-dual task decrements from the two-word condition to the four-word condition were only 1.2% and 3.9%, respectively, for the load task, they went from .7% to 28.8% for the target task. Thus, the addition of the target task put a roughly equivalent demand on left hemisphere resources at all three load levels, while the addition of increasing memory loads had an increasingly deleterious effect on target task performance. This can be seen in Figure 3, which shows the effects of increasing the difficulty of the memory task on both memory and naming task performance, separately for each visual field and emphasis condition.

Insert Figure 3 about here

As before, the Load Level X Visual Field interaction was reliable in the combined analysis, $F(2,8) = 10.55$, $MSe = .0189$, and is shown separately for each task in Table 2. Across tasks, the effect of increasing memory loads increased the difference in performance decrements between visual fields, with much greater dual-task decrements occurring on RVF trials. For example, in the 2-word condition, performance was essentially the same as single-task levels for both types of trials, actually increasing by 1.2% on LVF trials and decreasing by only 3.1% on RVF trials. In the 4-word condition, however, performance decrements on RVF trials were three times as large as they were on LVF trials (24.7% vs. 8.0%, respectively).

Insert Table 2 about here

The data above indicate that in the dual-task situation, the demand for left hemisphere resources was much greater on RVF trials than on LVF trials, which supports the view that the two types of trials are cases of complete vs. partial overlap, respectively. In further support of this contention, and against the idea that the single to dual-task decrements reflect different concurrence costs on RVF and LVF trials, is the reliable Task X Emphasis interaction, $F(2,8) = 23.12$, $MSe = .0322$, and the *absence* of a reliable Task X Emphasis X Visual Field interaction. Performance on the load task was decremented by only .9% under load emphasis conditions but by 4.5% under target emphasis conditions. Similarly, target task performance was only decremented 6.8% from single-task levels under target emphasis conditions, but by a full 28.8% when subjects were paying more attention to the load task. Clearly, there were mutual tradeoffs between tasks, such that resources freed from one were used to improve performance on the other. And equally clearly, as can be seen from Figure 4, the slopes of the tradeoff functions were nearly identical on both types of visual field trials for both tasks. The differential decrements between RVF and LVF trials indicate that resources were scarcer on RVF trials; the tradeoffs between tasks on LVF trials indicate that some left hemisphere resources were required on these trials as well as on RVF trials; and the equality of slopes for the two types of trials is an indication that the overlapped *resources--those from the left hemisphere--are undifferentiated, insofar as* they could be applied to both tasks on both types of visual field trials.

Insert Figure 4 about here

GENERAL DISCUSSION

The basic findings of the present study can be summarized very simply. First, as left nemisphere resources became scarce because of increasing memory loads, subjects who had maintained a consistent RVF-LH superiority for naming nonsense words when that task was performed alone had larger decrements from both single-task memory and naming performance during the dual-task trials on which the CVCs were presented to their left hemispheres. So much so, in fact, that the visual field advantage on the naming task was reversed, and subjects became more accurate at naming CVCs presented to their right hemispheres. These differential performance decrements as a function of visual field imply that whatever else may have been going on here, resources for both tasks were scarcer on RVF trials. Thus, either the concurrence costs were greater or the resource requirements of the tasks overlapped more on RVF trials than they did on LVF trials. It should be noted that the RVF superiority for naming CVCs did *not* reverse during the easiest dual-task condition (i.e., with a 2-word load). This suggests that there was nothing peculiar to the dual-task circumstances *per se* that caused the tasks to differ qualitatively from the single-task conditions, either in terms of processing requirements or resource demands.

Second, performance tradeoffs were observed between the two tasks. As subjects shifted attention away from the memory task, memory performance declined and naming performance improved. The reverse relationship held as they shifted attention away from the naming task. Importantly, the relative amounts of improvements and decrements between tasks were equivalent on both types of visual field trials, although, of course, performance was generally better on LVF trials. The equivalent tradeoffs in performance between tasks for the two types of visual field trials argue that left hemisphere resources were required on both types of trials; the greater decrements from single-task performance on RVF trials indicate that this task combination entailed more competition for those left hemisphere resources than did the LVF dual-task combination. Together, the results are exactly what would be expected if RVF vs. LVF naming trials combined with the memory task represented complete vs. partial overlap in demand for a particular type of resource, and provide strong support for our main theoretical assumption regarding the existence of at least two types of supplies. The data also suggest that these supplies are independent since, had the left and right hemispheres been able to share resources, there is little reason to have expected decrements from single-task performance to have differed as a function of visual field.

Although a single-capacity model cannot easily account for these findings, there is one possibility. The claim would have to be made that rather than reflecting the difference between complete and partial overlap in the amount of a particular type of resource required, the differential decrements from single-task performance as a function of visual field were entirely due to a more severe concurrence cost on RVF trials, which increased with increasing load levels. Were this the case, and were there only one resource supply, then there would in fact have been reason to expect that tradeoffs between tasks would be equal, but dual-task decrements would differ, for each type of visual field trial. Yet, although the assumption of different concurrence costs could explain a finding of different decrements and equal tradeoffs, it is not intuitively appealing, both because the tasks to be performed did not change as a function of visual field, and because it implies that the costs were somehow greater on the type of trials that produced more efficient performance in the first place (i.e., in the single-task situation). While this does not seem likely, we must acknowledge the possibility.

Further, although our data do seem more likely to support the existence of two different resource supplies, since we have only compared conditions of complete and partial overlap, the data can suggest, but not conclusively prove, that these supplies are independent. The suggestion arises, once again, from the different performance decrements and from the different effects of increasing memory loads as a function of visual field. But some sort of semi-independence between types of supplies could also produce such data, (Moscovitch & Klein, 1980; Wickens, 1980). Conclusive support for our independence assumption must therefore wait for a comparison between complete vs. no overlap in demand for a particular hemisphere's supplies. Like the present experiment, we would expect differential decrements from single-task performance, with more severe decrements again occurring in the complete overlap conditions. Yet unlike the present case, rather than finding equivalent tradeoffs between tasks on both kinds of visual field trials, we should not obtain tradeoffs when the resource requirements of the tasks do not overlap.

There is another theoretical assumption that is not rigorously addressed by the current experiment, and it, too, needs to be tested before our model can be presumed to have widespread applicability. This is our assumption that the resources of each hemisphere are either undifferentiated, or else are mutually substitutive between tasks. The present data are again more suggestive than conclusive in this regard, since both tasks required some sort of verbal information processing. A more definitive test would require, for example, that one task involve verbal information processing while the other involve primarily a motor response. If performance tradeoffs could be observed when two tasks with such different information processing components were combined, and both demanded the resources of the same hemisphere, it would be strong evidence that those resources were in fact undifferentiated.

Despite the caveats above, the data we have presented can speak to several issues. First, it would appear that any experiments using dual-task methodology to test either single or multiple-resource models of information processing may need to address, or at least consider, which hemisphere's supplies are required by the tasks that are to be combined, as well as the degree to which the particular subjects involved may or may not be "lateralized" for those tasks. For example, we have shown that the same stimulus materials presented to different visual fields for the purpose of being named *comprise a task which certain individuals can perform with* two different resource compositions, one of which requires left hemisphere supplies exclusively, and the other, supplies from both hemispheres. Thus, the predictions one makes for dual-task performance when this task is combined with any other differ in each case, and will also depend on the hemispheric resource demands of the other task.

This same reasoning applies when tasks are responded to with different hands, or stimuli are presented to different ears, etc. In many cases, responding hand has not even been reported in a dual-task experiment (e.g., Kantowitz & Knight, 1976), and most studies that do report responding hand do not take this variable into account when analyzing the possible reasons for the particular patterns of interference observed (e.g., Gopher, Brickner & Navon, in press). In our view, when either the input or response made is unilateral, these types of conditions entail the distinct possibility that the task may not have the same resource composition in each case.

Further, it may be important to consider a task's hemispheric resource requirements even in situations that do not involve visual field techniques or other procedures designed to promote lateral reception of or response to stimuli (e.g., Moscovitch & Klein, 1980). For example, we found that performance on the memory task we used, in which the stimuli were nominally available to both hemispheres, was affected differently as a function of the visual field to which the naming task stimuli were presented. Indeed, it is just such data, aside from our initial screening procedures, that allow us to assert that the memory task demanded primarily left hemisphere resources from our subjects. Thus, one of the reasons it is important to consider that there may be at least two supplies of resources that can be drawn on for information processing, each under the control of one of the two hemispheres, is that the *absence* of decrements from single-task performance as a function of increasing the difficulty of a second task might otherwise be erroneously interpreted (see Friedman & Polson, 1981; Navon & Gopher, 1979, 1980; Wickens, 1980).

The second set of issues we can address with the present study pertain to cerebral specialization *per se*, and they are both methodological and theoretical. On the methodological side, it should be apparent that in using dual-task procedures to test any particular approach to cerebral specialization, demonstrations of different decrements from single-task performance as a function of visual field are only preliminary evidence regarding which hemisphere is primarily responsible for processing any particular task or combination of tasks. Conclusive evidence requires observing mutual tradeoffs between tasks as subjects shift their attention from one to the other. Then, different decrements from single-task performance can be used to infer the degree to which tasks have overlapping resource requirements, and the particular type(s) of hemispheric supplies that are necessary. Further, single-task baseline measures need to be acquired from the same subjects who are to perform in the dual-task situation, under circumstances in which they are motivated to perform as well as possible. Otherwise, it is not obvious how to interpret performance changes that may ensue when subjects enter the dual-task situation, (e.g., Hellige, Cox, & Litvak, 1978; Kinsbourne & Cook, 1971; Lomas, 1980; Wexler & Heizinger, 1980).

On the theoretical side, it is clear that other current models of cerebral specialization (e.g., Kinsbourne, 1970; 1973; Kinsbourne & Hicks, 1978) simply do not have the scope to accommodate the data from the present study. For example, on the basis of our screening data alone, in which we found that only 58.3% of the right-handed men who had passed a self-report criterion also displayed a RVF-LH superiority on both of our verbal information processing tasks, it should be obvious that to regard the left hemisphere as verbal and the right as mute, and the handedness of a subject as sacrosanct insurance of this, is far too simplistic. Further, even for those subjects who were "lateralized" for our particular tasks when they were performed individually, the performance obtained on LVF dual-task trials makes it obvious that the *right* hemispheres of these subjects were capable of at least partially processing abstract, unfamiliar, verbal information. Had it been necessary to "send" the left hemisphere the right hemisphere's data representation of the target task stimulus on LVF trials, then according to conventional wisdom, dual-task performance should have been worse on these trials than on RVF trials, due to degradation of the information as it crossed the callosum. Yet it was not. Thus, any model of cerebral specialization in which it is assumed that functional asymmetries exist because information that is incompatible with a hemisphere's specialization must be sent to the opposite side of the brain is not supported by the current data.

In summary, for the most part, we are not committing ourselves to statements about the types of stimuli, tasks, or processes which belong to the domain of either hemisphere, as it is likely that individual differences in this regard will typically outweigh any similarities. Further, as we have shown, the relative capabilities of the hemispheres in performing any task may depend more on the current supply and demand situation than they do on any other single factor. Thus, the cerebral specialization literature can, at best, be used as a rough guideline for choosing tasks that might require left or right hemisphere resources for certain individuals, and then subjects can be drawn from that particular population and screened to ascertain that this is so, before proceeding to a dual-task procedure. Conceivably, after many such experiments, we may indeed find subpopulations of individuals who display similar patterns of lateralization across several sorts of tasks and materials, and thus acquire a rigour of prediction that has so long eluded the field.

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FOOTNOTES

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1. Even for tasks and subject populations in which there is good reason to believe that performance requires a hemisphere-specific resource (e.g., simple motor tasks or those requiring speech production; see Friedman & Polson, 1981), it is still necessary to assume that there are two relevant functions relating performance to resource allocation. It would simply be the case that the function for the "irrelevant" resource pool/hemisphere would appear flat across all levels of allocation (i.e., in Norman and Bobrow's (1975) terminology, it would be data-limited at zero performance).

2. Concurrence costs and benefits in dual-task situations may arise when the joint demand for supplies by two tasks bears a nonadditive relationship to the single-task demands. That is, joint demand may be greater or less than the sum of the individual demands. Concurrence costs can emerge from such things as the need for extra resources to coordinate the processes of two tasks, while benefits can arise if, for example, both tasks require the product of the same process, such that it only need be executed once.

3. For any particular intended level of performance, we assume there are equal amounts of supplies available in both hemispheres. Therefore, when subjects increase their overall attention, for whatever reason, there will be an equivalent supply increase in both hemispheres, which may or may not result in equal increases in performance. We have previously discussed why the simple addition of a second task is likely to produce such an overall increase in arousal and hence, in allocated resources (Friedman & Polson, 1981). Thus, when subjects are not performing at the

maximum levels possible during single-task conditions, it is not clear how to interpret either decrements or increments from single-task performance, because it is unlikely that all available resources were being allocated to the tasks during the single-task conditions.

4. The exact patterns of interference that are manifested in a dual-task situation with these particular tasks will depend on the way in which they are combined. Since it is physically impossible to recall the memory task words and name the target word at the same time, the verbal output of both tasks is of necessity serial. Thus, the order in which the tasks are performed affects whether there is a memory component for each task. Take the situation in which a subject is first given the memory load words to study, followed by a briefly presented target word. If the memory words must be recalled before the target word is named, which is the procedure we used, we would expect relatively small decrements in memory performance and larger decrements in naming task performance. However, if the target stimulus is seen and pronounced immediately, followed by recall of the words in memory, then we expect smaller decrements in target task performance with relatively larger decrements in load task performance. We would, however, expect to be able to observe tradeoffs between tasks in either case.

Table 1

Percent Correct for Dual-Task Trials as a Function of Task, Visual Field, and Memory Load Level

	CVCVC Memory Task			CVC Naming Task		
	2-word	3-word	4-word	2-word	3-word	4-word
LVF Trials	97.9	88.1	76.5	71.7	55.6	51.1
RVF Trials	98.1	82.9	66.9	79.2	47.5	43.6

Table 2

Percent Decrement from Single-Task Performance as a Function of Task, Visual Field, and Memory Load Level

	CVCVC Memory Task			CVC Naming Task		
	2-word	3-word	4-word	2-word	3-word	4-word
LVF Trials	1.3	-1.5[1]	-0.9	-3.6	12.5	16.9
RVF Trials	1.1	3.7	8.8	5.0	36.7	40.6

1. Negative numbers represent an increase in performance from the single to the dual-task conditions, zero represents no change, and positive numbers are percent decrement scores.

FIGURE CAPTIONS

Figure 1. Schematic representation of processing by the two hemispheres in two different dual-task situations formed when CVC target stimuli are presented to different visual fields.

Figure 2. Percent correct in the dual-task situation for each task emphasis condition, plotted as a function of the memory load condition and the visual field to which the CVC target stimulus was presented. The darkened points on the left side of the figure represent single-task memory performance for 2, 3, and 4 nonsense words, and the horizontal lines on the right side of the figure represent single-task CVC naming accuracy.

Figure 3. Percent decrements from single-task performance for each level of memory load, plotted as a function of the task emphasis instructions and the visual field to which the CVC target stimulus was presented. Zero is plotted at the top of the ordinate, so that points that are lower on the figure represent decrements that are more severe.

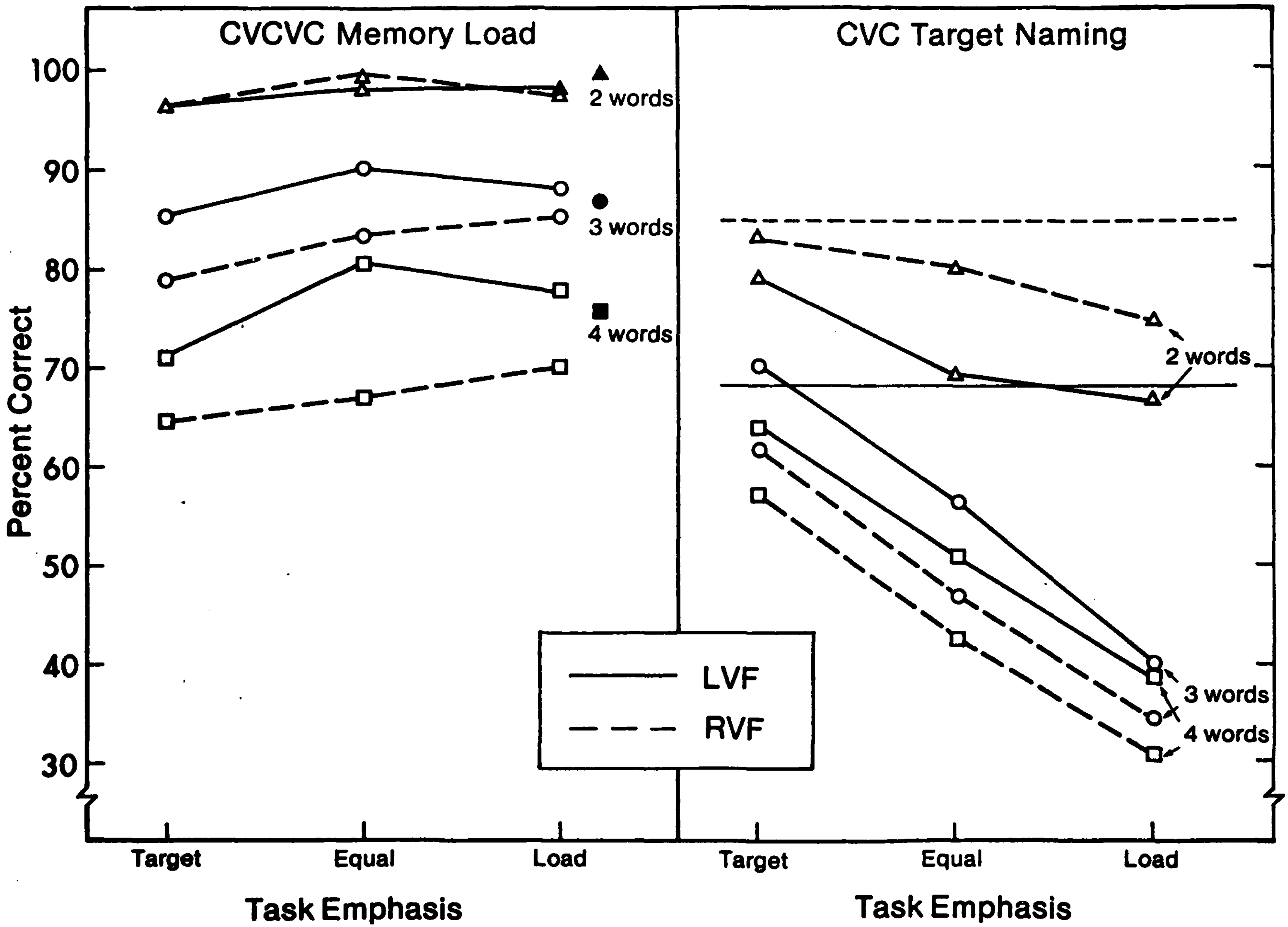
Figure 4. Percent decrements from single-task performance in the dual-task conditions, plotted as a function of task emphasis, memory load, and the visual field to which the target stimulus was presented. Zero is plotted at the top of the ordinate, so that points that are lower on the figure represent decrements that are more severe.

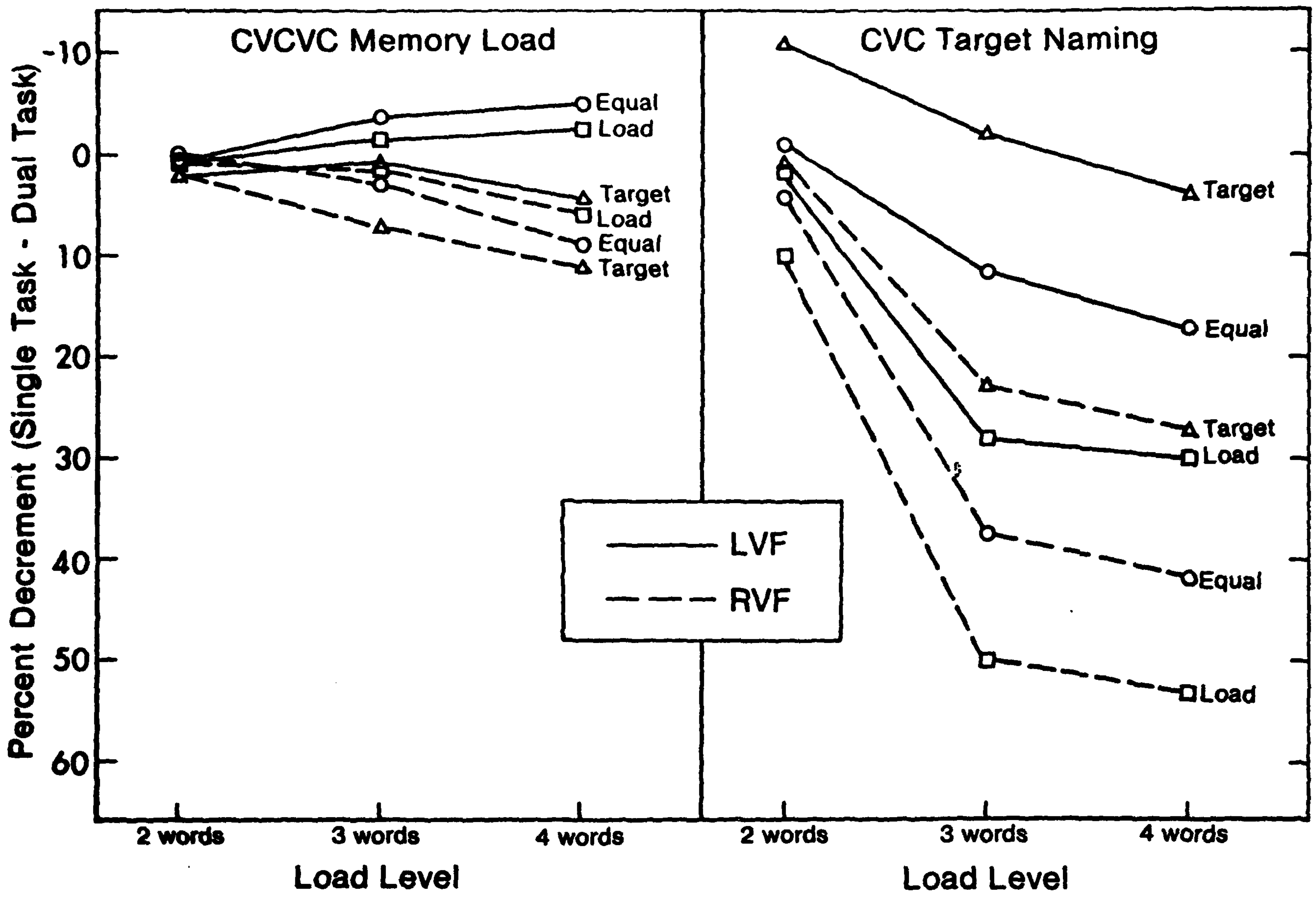
Right Visual Field Trials: Complete Overlap

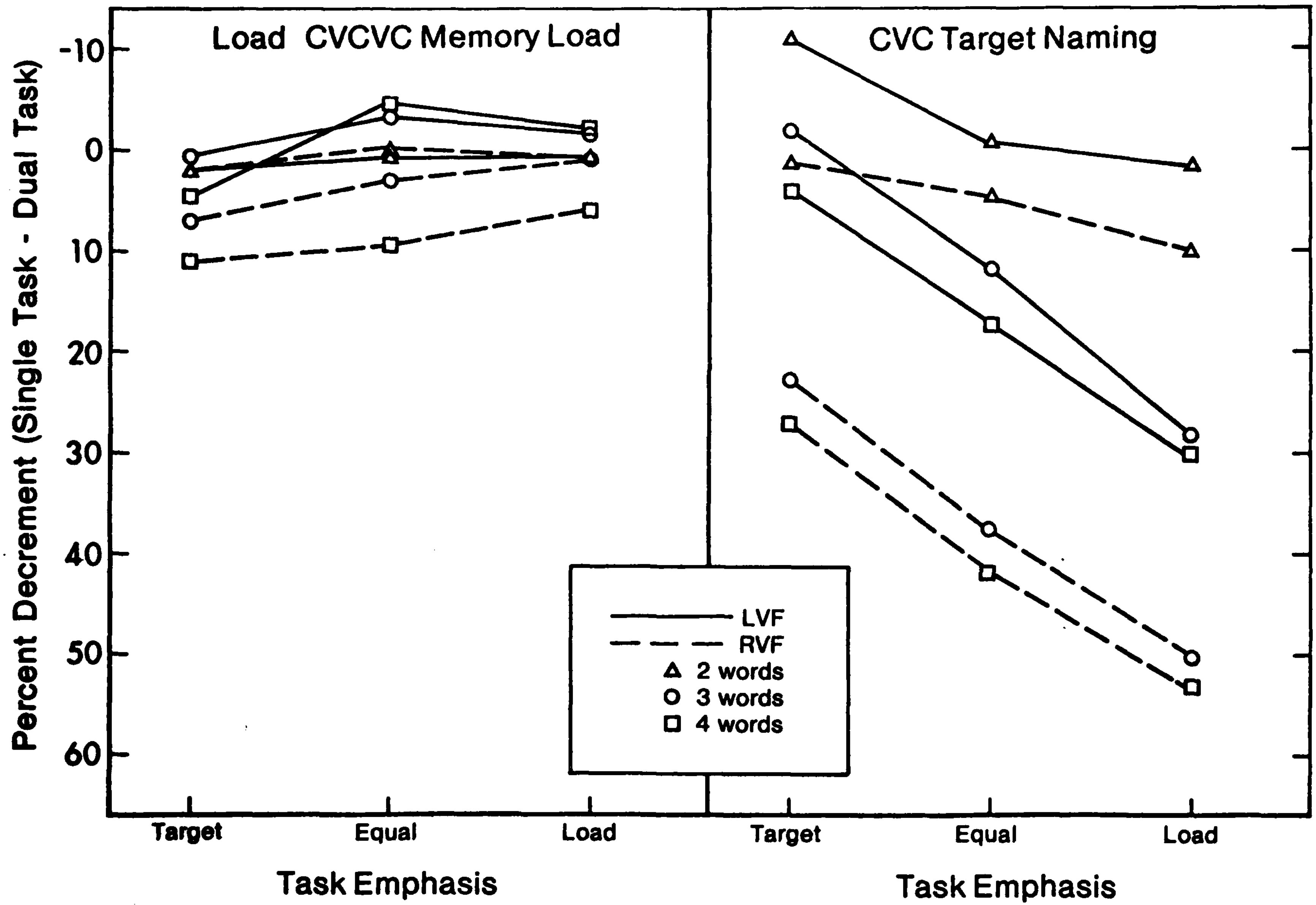
Left Hemisphere	Right Hemisphere
CVCVC Memory Load CVC Target Naming ● Perceptual Decoding ● Verbal Output	

Left Visual Field Trials: Partial Overlap

Left Hemisphere	Right Hemisphere
CVCVC Memory Load CVC Target Naming ● Verbal Output	CVC Target Naming ● Perceptual Decoding


CVCVC Memory Load
CVC Target Naming
Percent Correct
100
90
80
70
60
50
40
30
2 words
3 words
4 words
LVF
RVF
Target
Equal
Load
Task Emphasis


CVCVC Memory Load
CVC Target Naming
Percent Decrement (Single Task - Dual Task)
-10
0
10
20
30
40
50
60
Equal
Load
Target
Load
Equal
Target
Target
Equal
Target
Load
Equal
Load
LVF
RVF
2 words
3 words
4 words
2 words
3 words
4 words
Load Level
Load Level


Load CVCVC Memory Load
CVC Target Naming
Percent Decrement (Single Task - Dual Task)
-10
0
10
20
30
40
50
60
Target
Equal
Load
Target
Equal
Load
Task Emphasis
Task Emphasis
LVF
RVF
2 words
3 words
4 words

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