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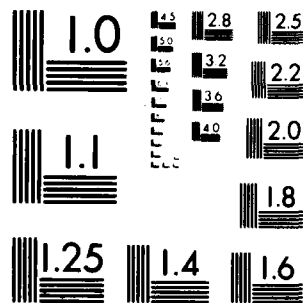
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task, on a target task in which pairs of stimuli were presented to either visual field and subjects performed physical or name identity judgments, and in a situation in which both tasks were combined. In our approach, right and left visual field trials of the target task combined with the verbal memory load are treated as two different dual-task situations, comprising cases of complete vs. no overlap in demand for left hemisphere resources, respectively. Subjects were paid for both single and dual-task performance; in the latter case, the payoff ratios rewarded them more for either their memory or target task accuracy. Decrements from single-task performance were less severe on both tasks when subjects were performing physical rather than name matches, and importantly, when the target stimuli were presented to the LVF rather than the RVF. Further, subjects were able to trade performance between tasks on RVF trials, indicating that left hemisphere resources were demanded and being used for both tasks on these trials. However, on LVF trials, there were no performance tradeoffs between tasks as a function of shifting emphasis, indicating that this was indeed a case of no overlap in demand. The data support the idea that the resource supplies of the left and right hemispheres are independent, and have implications for both cerebral specialization and divided attention issues.

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An increasing number of investigators have seriously questioned the view that the human information processing system has access to a single, limited-capacity pool of resources that it allocates as necessary to perform under particular sets of subject and task parameters. This idea has been criticized on logical grounds (Friedman & Polson, 1981; Navon & Gopher, 1979; Wickens, 1980), and there is growing evidence that has begun to render it empirically indefensible as well (Gopher, Brickner, & Navon, in press; Gopher & North, 1977; Navon & Gopher, 1980; Polson, Friedman, & Gaskill, Note 1; Wickens, 1980; Wickens & Kessel, 1980).

Ironically, some of the best available data in support of an alternative to the single-capacity approach--i.e., that there may be a number of different types of resources--comes from a literature that is typically regarded as being outside the domain of divided attention issues. Yet, implicit in well over a century of research in hemispheric specialization is the idea that the two cerebral hemispheres comprise separate, and perhaps independent, information processing systems. Further, in the interest of testing a model of selective activation in cerebral specialization (Kinsbourne, 1970, 1973), many studies have been conducted using some form of dual-task methodology (e.g., Hellige & Cox, 1976; Hellige, Cox, & Litvak, 1978; Kinsbourne & Cook, 1971; Moscovitch & Klein, 1980), and the results of these clearly suggest that there must be more than one type of resource supply. For example, when certain tasks involving stimulus presentations to either visual field or hand are combined with others in which the stimuli are at least nominally available to both hemispheres, the demands of joint performance do not necessarily produce equal decrements for the two presentation conditions. Indeed, sometimes one type of visual field trial produces performance decrements while the other results in either no change in performance or else an actual increase relative to single-task baselines (Hellige & Cox, 1976; Hellige, Cox, & Litvak, 1978; Kinsbourne & Cook, 1971).

Changes from single-task performance that differ as a function of visual field are difficult to reconcile with the idea that identical amounts of the same type of resource are required for processing on RVF and LVF trials. Indeed, Navon and Gopher's prescribed methodology for determining whether tasks demand resources from

different pools involves finding just such differences in decrements across sets of task pairs (e.g. A with B vs. A with C). A cornerstone of their argument, however, entails that B and C be similarly difficult and otherwise roughly equivalent in terms of subject and task parameters, and this is a difficult assumption to satisfy when they are actually two different tasks. However, if B and C represent the same task and stimuli presented to different visual fields, then finding that they produce performance decrements on A that differ is compelling evidence that each type of visual field trial entails different resource demands.

This brings us to another point. As Navon and Gopher (1979) point out, differences in performance decrements obtained when two equally difficult tasks are conjoined with a third may only be marshalled as a first line of evidence that one pair draws on a common resource while the other does not, because such differential decrements can occur if concurrence costs for the two combinations differ. These costs may arise when resources required for joint performance exceed the sum of those needed for each task alone, perhaps because it is necessary to coordinate the processes involved or to manage a joint allocation policy. Therefore, to obtain conclusive evidence that tasks make demands on a common supply, it is necessary to induce subjects to shift their attention between them, and to observe that when they do so improved performance on one task is accompanied by performance decrements on the other. For example, if AB and AC produce different decrements on A, and performance tradeoffs are observed as attention is shifted between A and B and between A and C, then all three tasks must require resources from a common supply, and the different decrements reflect different amounts demanded from that particular source for each combination. In contrast, if AB and AC both produce decrements on A but only AB, for example, allows performance to trade between tasks, then A and B require a common resource, but A and C do not.

It is unfortunately true that in trying to distinguish between a direct access and a selective activation model of hemispheric differences, none of the the cerebral specialization experiments that have used dual-task methodology to argue where information is being processed have taken the step of asking subjects to shift

attention between tasks. Further, it is sometimes difficult to tell, in this literature, whether the absence of a performance decrement, or especially the presence of an increment relative to a single-task baseline, is due to the fact that subjects have not been induced to perform at the maximum levels possible in either the single or dual-task situations (e.g. Hellige & Cox, 1976; Kinsbourne & Cook, 1971) (Footnote 1). Nevertheless the bulk of the evidence is enticingly favorable toward the idea that the hemispheres have independent resource supplies, and it led us to propose such a model as both logically preferable to the single-capacity point of view, and more empirically tractable than Navon and Gopher's general multiple-resources model (see Friedman & Polson, 1981, and Polson, Friedman, & Gaskill, Note 1).

One advantage that accrues to associating types of resources with gross brain anatomy is that it then becomes possible to use the cerebral specialization literature as a rough guideline in choosing tasks for which there is some *a priori* evidence about the nature of their resource demands. Further, the literature can also be used as a guideline for determining subject populations for whom certain kinds of information processing requirements are likely to make different demands on left and right hemisphere supplies.

This is not to say, for example, that simply choosing to have right-handed individuals perform a verbal task guarantees that left hemisphere resources will be more heavily demanded (see Polson, Friedman & Gaskill, Note 1). Indeed, from looking at the available data (e.g. Day, 1977; Moscovitch, 1976), as well as from our own experience in screening subjects, we have come to believe that efforts to dichotomize the hemispheres along dimensions of either the stimuli they are best suited for or their respective 'processing styles' are largely futile. Although there are probably a few activities that require a hemisphere-specific resource (e.g. speech production or simple motor movements), it seems clear that in normal individuals, both hemispheres can usually do some or all of the processing required for most tasks by applying their own resources to whatever processes they have available that are relevant. Any visual field, ear, or hand advantage observed when the system is not resource-limited (i.e. in most single-task situations) simply reflects the relative efficiency of applying

different types of resources to the same task. However, in a resource-limited dual-task environment, the relative performance of the hemispheres can change as a function of the current supply and demand situation depending on whether the resource demands of the conjoined tasks overlap completely, partially, or not at all.

In a previous study (Polson, Friedman, & Gaskill, Note 1) we compared the complete overlap case with the partial overlap case. Subjects were selected who had RVF-LH performance advantages on two different tasks when each was performed alone. The first involved remembering either 2, 3, or 4 nonsense words (CVCVCs), which, because of our screening procedure, was a task we knew would demand increasing amounts of left hemisphere resources from our particular subjects. The second task involved naming nonsense syllables (CVCs) presented briefly to either visual field. We assumed this would entail two major processing requirements: perceptual decoding of the stimulus display into some sort of phonemic representation and verbal output. For reasons we discussed elsewhere (Friedman & Polson, 1981; Polson, Friedman, & Gaskill, Note 1) when certain subjects show a RVF advantage on a laterally-presented naming task, it can be assumed that both their left and right hemispheres are able to perceptually decode the verbal stimuli (although the left hemisphere is typically more efficient), but that left hemisphere supplies alone are required for the spoken response. Therefore, when the naming task is conjoined with the verbal memory load, the two types of visual field trials comprise dual-task situations that differ in the amount of left hemisphere resources demanded. When the CVC is presented to the RVF-LH, left hemisphere supplies are available for its perceptual decoding, as well as for its verbal output and whatever processes are involved in the memory load task. This is therefore a case of complete overlap in demand. Conversely, LVF-RH naming trials are a case of only partial overlap in left hemisphere demand, because although left hemisphere supplies are still required for the memory task and the verbal output portion of the naming task, right hemisphere resources can be used to perceptually decode the CVC.

We obtained several results of interest in the present context. Most strikingly, although subjects maintained a consistent RVF advantage on the naming task when it

was performed alone, the effect of adding the memory load made left hemisphere resources so scarce that the visual field advantage actually reversed itself. When subjects were concurrently remembering either 3 or 4 nonsense words, naming performance was better on LVF trials than on RVF trials. Similarly, dual-task performance on the *memory* task, in which the stimuli were nominally available to both hemispheres, was also better on LVF than on RVF naming trials.

These results mean, of course, that left hemisphere supplies were more scarce in the complete overlap case (RVF trials) than in the partial overlap case (LVF trials). Importantly, our task emphasis instructions were successful, so that memory performance was better under load emphasis instructions at the expense of performance on the naming task, and vice versa. And equally important, these tradeoffs in performance between tasks as a function of emphasis were obtained regardless of whether the target stimulus was presented to the RVF or to the LVF; in fact, the slopes of the tradeoff functions were virtually identical on both types of trials. This confirmed that there was some demand for left hemisphere supplies in both cases.

There are several issues that remain to be clarified, however, as well as a further theoretical prediction that needs to be addressed. In the first place, both of the tasks in our previous study required a spoken response, so it is necessary to eliminate the possibility that the dual-task decrements and tradeoffs between tasks arose through the operation of output interference. We would like to provide additional evidence that the decrements from single-task performance we observed were primarily a function of resource scarcity in the left hemisphere.

More importantly, it is necessary to test our theoretical prediction regarding the situation in which the demands of two tasks do not overlap, in order to provide converging evidence for the theory in general and for our assumption that the resource supplies are independent. In particular, it might be argued that the equivalent tradeoff effects we found when comparing the complete with the partial overlap situation might be evidence for some sort of residual commerce between the hemispheres in terms of borrowed resources. Indeed, several other investigators have

recently attempted to explain hemispheric differences in information processing as reflecting some form of limited-capacity processing within two semi-independent systems (e.g., Kinsbourne & Hicks 1978, Moscovitch & Klein 1980). While these other models are somewhat limited in scope, insofar as they do not attempt to place cerebral specialization into a broader information processing context, the possibility that there might be some ability to share resources between hemispheres certainly warrants testing.

Having only compared the complete and partial overlap situation in our previous study, it was not possible to distinguish between some notion of semi-independent resources and the stronger claim that the supplies of the two hemispheres are independent. Thus, in the present study, we are interested in comparing the complete overlap case with the no overlap case. We combined the memory load task we previously used with a target task that involved making same-different judgments to pairs of nonsense syllables presented simultaneously to either visual field. The judgments were made on the basis of either physical or name identity. Since subjects responded bimanually to the same-different task prior to recalling the memory load words, none of our effects should be due to output interference. Furthermore, since the same-different task does not have a verbal output component, the stimulus analyses necessary to perform these judgments are likely to be similar to those necessary for the perceptual decoding aspects of the naming task we previously used. Thus, whatever their relative efficiency, the resources of each hemisphere should be completely sufficient for performing the same-different task.

This being the case, in the present dual-task environment, when physical or name match stimuli are presented to the RVF-LH, both the memory task and the identity judgments should demand left hemisphere resources, resulting in a situation of complete overlap. In contrast, when the target stimuli are presented to the LVF-RH, there should be no overlap in the types of supplies required for each of the tasks. Left hemisphere resources should still be needed for the memory task, of course, but right hemisphere supplies could in this case be used for the identity judgments. This means that in the no overlap case, the right hemisphere can free the left from its

obligation to process the target task stimuli

There are two sets of predictions we can address with the comparison between RVF and LVF dual-task trials, and they pertain to absolute decrements from single-task performance and the extent to which performance can trade between tasks. First, the independence assumption implies that there should be decrements from single-task performance for both tasks on RVF-LH trials, but hardly any at all on LVF-RH trials. Second, the difference between complete and no overlap implies that when we induce subjects to shift attention between tasks, on RVF-LH trials we should see memory task improvements at the expense of target task performance and vice versa. On LVF-RH trials, however, we should not see such mutual tradeoffs, since there should be no common resources demanded (Navon & Gopher, 1979). In other words, since the left hemisphere should be involved in the memory task on both types of visual field trials, memory performance should always shift as a function of the task emphasis instructions making left hemisphere resources more or less available for target task processing. But this should only make a difference to target task performance when the stimuli are presented to the RVF-LH. For example, under load emphasis instructions left hemisphere resources should be withdrawn from the target task, and memory performance should improve (i.e., it should be less severely decremented from its single-task level). In addition, there should be a concomitant decrease in target task performance on RVF-LH trials in this emphasis condition. Yet we should not see a concomitant target task decrease on LVF-RH trials, because the missing left hemisphere supplies are irrelevant to the resource requirements of the target task in this situation.

The predictions above follow straightforwardly from our theory, and will provide further support for its main assumption regarding the independence of the resource supplies of the two hemispheres. There are several other predictions of interest, however, and they pertain to the relative amounts of resources required to perform physical and name identity judgments.

For any given level of resource allocation in either hemisphere, it is likely that physical matches are performed more efficiently than name matches. This simply

means that when subject-task parameters are held constant, and they usually are then for any given allotment of resources, the usual advantage in speed and accuracy for physical matches will be obtained. This implies that fewer resources would be needed for physical matches to achieve a level of performance equivalent to that of name matches, and in the present study, we changed the task parameters for each subject to insure that this would be so. Therefore in the situation where resources are scarce--i.e. on dual-task trials when the same-different stimuli are presented to the RVF-LH--the decrements from single-task performance for both tasks should be greater on name match trials than on physical match trials. In contrast, the right hemisphere should not be involved in the memory task, so that even though more resources should still be required for name matches than for physical matches there should be little, if any, decrement from single-task target performance on LVF-RH trials for either type of match.

METHOD

There was one screening session, one practice session, and four experimental sessions, and each took between 70 and 90 minutes to complete. In the experimental sessions, we measured single and dual-task performance on the verbal memory load task in which subjects had to remember three nonsense words, and on the same-different judgment task, in which they judged whether pairs of nonsense syllables presented simultaneously to either visual field were identical on the basis of either their physical characteristics or their names. Subjects were paid for accuracy on both single and dual-task trials; on the latter, the memory task was combined with the same-different task, and the payoff ratios rewarded them more for either their memory performance or their same-different task performance.

Design and Stimuli

All experimental conditions were run each day and thus replicated four times across days for each subject. There were 9 blocks of trials per day, and the first of these always consisted of 16 trials of the memory load task performed by itself.

Each half of the remaining 8 blocks consisted of either physical or name

identity trials. Within each level (physical or name) there were always two blocks of single-task identity matches and two blocks of dual-task trials, on which the memory and same-different tasks were conjoined. For each type of match, one dual-task block was run under load emphasis instructions and the other was run under target emphasis instructions.

The single and dual-task blocks were always alternated, beginning with a single-task block. Each single-task block was therefore the control for the dual-task block which followed it. Note that if there are within-day practice effects, the arrangement of the blocks in this sequence biases against the possibility of finding dual-task performance decrements. Both types of blocks consisted of 40 trials, on which 20 of the target task stimuli were presented to each visual field, with no more than 3 trials in a row presented to the same visual field. Half the target task stimuli presented to each visual field required a *same* response and half required a *different* response, with no more than 4 of each type in a row. This means that across the four days of testing, there were 4 yoked pairs of blocks for each type of match and task emphasis condition, yielding 160 trials per condition, 80 for each visual field.

Four subjects began their first experimental session with physical identity matches and four began with name identity matches. Thereafter, subjects began each day with the opposite type of match and continued alternating for the 4 sessions. Within a session, the task emphasis order remained constant for each type of match, so that, for example, if the first physical match dual-task block required emphasizing the target task, so did the first name match dual-task block on that day. The second time that subject began a day with physical matches, the first dual-task block would then require emphasizing the memory task.

Two of the subjects who began with either physical or name matches began with a target emphasis block, and the remaining two began with a memory task emphasis block. Thus, each subject began two days with physical matches and two days with name matches and one of each of these days had a target emphasis-load emphasis order while the other had a load-target order. The sequences for the type of match and emphasis orders were counterbalanced across subjects.

The stimulus materials were also counterbalanced across conditions for each subject, as well as across subjects. 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 obvious associations. From this pool 1064 words were selected. 60 were used in the CVCVC screening procedure described below and during the experimental sessions 144 unique CVCVCs were used during the single-task blocks and 960 others were each used twice during the dual-task blocks. A particular CVCVC was seen once during a physical match block and once during the corresponding (in terms of target task stimuli) name match block. Both blocks were run under the same task emphasis condition, but never on the same day.

We used nonsense words to minimize the possibility that subjects could associate the words within each memory set to each other and refrained from showing them more than twice within the experiment, in order to minimize familiarity with the stimuli. Both measures were taken to assure that the effective memory load level would remain as constant as possible on each trial across conditions and days.

For the same-different task 480 different one-syllable nonsense words were drawn from a list of rated nonsense words (Noble 1961). Of these, 160 were used for *same* trials and 320 CVCs were used for *different* trials, half the CVCs for each type of trial were presented to each visual field. An additional 60 CVCs were selected for use in the screening procedure described below.

We made up 8 blocks of 40 trials each for physical matches, and 8 blocks for name matches that were identical except for the typefont of the stimuli on each trial. We selected stimuli in sextuplets, such that the six CVCs required for each group of 4 Visual Field X Same/Different trials within a block had nearly identical association values. Thus, the stimuli were equated within a block for the mean association value in each Visual Field X Same/Different condition they were also equated reasonably well across blocks. The mean association values across blocks ranged from 483 to 533 for RVF-Same trials, from 464 to 534 for RVF-Different trials, 487 to 531 for LVF-Same trials, and 470 to 537 for LVF-Different trials.

Each block of stimuli was seen four times by every subject but never more

than once on the same day. The stimuli were each used once for single-task physical and name matches and once for dual-task physical and name matches, the latter under only one of the two task emphasis conditions.

The memory and target task stimuli were drawn on microfilm with white letters on a black background, using computer graphics routines. The three CVCVCs were centered horizontally on the slide, one above the other. When projected, their width was 65 cm and their height (for all three) was 47 cm (3.4 by 2.4 degrees). When these stimuli were used singly in the screening procedure, they were printed vertically and centered about 3 degrees to either the right or the left of fixation, and measured 9.5 x 10 cm (5 by 0.5 degrees).

The target task stimuli were printed in pairs vertically on the slide, and were centered approximately 3 degrees to the left or right of fixation. Each pair measured 25 cm wide x 47 cm high when projected (1.3 by 2.4 degrees). For physical match stimuli, half the pairs presented for each type of visual field and same-different trial were printed in upper case letters and half were printed in lower case letters. For name match stimuli, one CVC in each pair was in upper case letters and the other was in lower case letters. On half of each type of visual field and same-different trial, the upper case CVC was leftmost, and on the other half it was rightmost.

Emphasis Manipulation

In order to induce subjects to vary the amount of resources allocated to each task in the dual-task blocks and to insure they were performing at maximum levels during the single-task blocks, we paid them on the basis of their trial-by-trial performance during the experimental sessions. On single-task memory load trials, subjects were paid 60¢ for each trial on which they correctly recalled all three words in the set, disregarding order of recall. On single-task physical or name match trials, they were paid 60¢ for each correct judgment.

On the dual-task trials, payment was divided between tasks in two proportions, but the same criteria for getting paid on each task were used. In the target emphasis condition, subjects were paid 50¢ for each correct same-different judgment

and 10 for each set of three load words recalled. In the load emphasis condition the reverse contingency was in effect. The subjects earned an average of \$57 in the experiment.

Apparatus

During the target task, the load task, and the visual field tasks used in the screening procedure, the subject sat with his head resting in a chinrest equipped with both forehead and lateral stops that prevented head movements. The subject's eyes were 110 cm away from a rear projection screen, and in front of him were two wooden boards, each equipped with a metal palm plate, two metal finger plates (for the index and middle fingers of each hand), and two strips of wood 1.8 cm high between the finger plates. The subject rested his fingers on the wooden strips between trials and touched the finger plates in order to respond.

The stimuli were shown using three Kodak Carousel projectors equipped with Gerbrand's shutters. The projectors were mounted on a stand outside the experimental room and their images were each displayed through two half-silvered mirrors and a glass window onto the rear projection screen. The projectors, shutters, response plates, auditory ready signal, timing intervals, etc., were all controlled by a Digital Equipment Corporation MINC11 computer, also located outside the experimental room. The experimenter sat at a terminal in the room with the subject, initiated all trials, and entered the recall data.

Subjects and General Procedures

Subjects Screening Subjects selected for the experiment were solicited from the Department of Psychology's undergraduate subject pool at the University of Alberta, and from among the male graduate students in the department. We screened 30 men who were among 89 right-handed men who had volunteered to participate for payment. Unlike Polson, et al. (Note 1), all subjects completed the entire screening procedure, rather than being eliminated at each stage, as we were interested in collecting normative data regarding degrees of "lateralization". Six undergraduate and two graduate students who met all of our selection criteria participated in the

remainder of the experiment. All were right-handed, used a noninverted writing posture (Levy and Prid, 1976, 1978), had no first-degree left-handed relatives (Hardyck & Petrinovich, 1977), had either normal or corrected-to-normal vision, and spoke English as their native language.

When a subject arrived in the lab, he was asked to sign an informed consent form and to copy a short phrase at the bottom of the form, at which point the experimenter confirmed that he was right-handed and used a noninverted posture. The subject was then seated at a computer terminal and asked to answer 15 items from a version of a behaviorally-validated handedness questionnaire (Raczowski, Kalat, & Nebes, 1974). The questions were displayed one at a time on the screen, and asked about preference for performing certain manual tasks. The response choices were right, left, or both hands preferred, which were scored +1, -1, or 0, respectively. Thus, a score of 15 represented a right-hand preference for all tasks; our selection cutoff was a score of 13. Of the 30 subjects, the scores ranged from 10 to 15, with a mean of 13.8. The mean for the 8 subjects who participated in the experiment was 14.4. After the subjects filled out the questionnaire, they indicated the hand used to write by all first-degree relatives.

The subjects next performed a series of four manual tasks, each of which was performed twice with each hand, starting with the preferred hand and then alternating (Thomas & Campos, 1978). For each task, the subject was scored a +1 or -1 for a right or left hand starting preference, 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 was zero, so that 8 points was the maximum right-handed score. Of the 30 subjects, the scores ranged from 4 to 8, with a median of 7.5. Our selection criterion was that the men receive at least 6 out of the 8 points.

Of the 30 subjects tested, 25 or 83.3 percent, met the combined criteria for the questionnaire and handedness tasks. Nevertheless, all subjects next received 10 practice and then 50 experimental trials of the single-task version of the CVCVC memory load task, in which a single, vertically-printed CVCVC was briefly presented to

either visual field and named. There were two different sets of slides used for this task, which differed only according to the visual field that each particular stimulus was presented to. Half the subjects saw a particular CVCVC in the RVF, and the other half in the LVF.

The subject first read all 60 CVCVCs aloud from a list. After the task was described, the experimenter initiated each trial 1 sec after a warning tone; a fixation point appeared in the center of the screen for 2 sec, followed by a 130 msec exposure of the nonsense word, 3 degrees to either the left or right. The subject named the word if he could, and the experimenter recorded whether he was correct or wrong.

In the group of 25 subjects who met our questionnaire and manual task criteria, 11 also met our criterion of having at least an 8% RVF-LH advantage. Thus, only 36.7% of the original subjects passed all three of the selection criteria. One was later eliminated because he was using the drug Ritalin and complained of attentional difficulties; one because we later found out his father was left-handed; and one could not participate further due to personal time constraints, leaving us with 8 subjects. The mean percent correct on the CVCVC naming task for these 8 subjects was 50% and 32% for RVF and LVF trials, respectively, $F(1,7) = 43.62$, $MSe = 29.71$, and the RVF advantage in accuracy for these men ranged between 8% and 28%. Interestingly, for the other 14 subjects who passed the questionnaire and motor task criteria but not the visual field task criterion, the mean percent correct for RVF and LVF trials was 39.1% and 45.7%, respectively, due to 6 subjects who actually had a *left* visual field superiority that ranged between 4% and 32%.

These data underscore the ubiquitous individual differences to be found in degree of lateralization, even among a group whose self-reports and motor performance would conventionally place them in a homogenous 'left hemisphere language dominant' population. The data also point out the importance of screening subjects, insofar as possible, for their performance on the tasks to be combined in a dual-task situation, in order to be able to state with some assurance what the hemispheric resource requirements of those tasks are for the particular subjects at

hand

After the CVCVC-naming task, all subjects participated in a parameter estimation procedure, described below, and then spent 20 minutes completing Form BB of the Minnesota Paper Form Board Test. The latter was not used as a basis for subject selection; for purposes of interest, the scores for our 8 experimental subjects ranged between 41 and 61 (out of 64) with a mean of 50.6. The subjects were paid \$5.00 for this initial screening session, were told in a debriefing that we were testing various things about handedness, and were informed that they would be contacted by phone regarding further participation.

Exposure durations for the same-different task. As noted in the introduction, for any given level of resource allocation, physical matches are likely to be performed more efficiently than name matches, leading to the usual performance advantage in both speed and accuracy. Thus, to produce the same level of accuracy for both types of matches, fewer resources should be needed for physical matches than for name matches. To insure that this would be so, it was therefore necessary to equate performance levels across both types of matches in the single-task condition.

Accordingly, all subjects were run through a psychophysical parameter estimation procedure (PEST, Findlay, 1978; Taylor & Creelman, 1967) to find separate exposure durations for the two types of matches that would yield 70% correct performance for both levels. The procedure used was identical to that described for the single-task target trials below, and the duration for physical matches was always determined first. Each subject was run in the main experiment using these individually determined durations. For the 8 selected subjects, durations for physical matches ranged from 7 to 94 msec, with a mean of 46.8 msec, and durations for name matches ranged from 49 to 188 msec, with a mean of 131.3 msec.

Practice and experimental sessions. Subjects were run for a practice session and 4 experimental sessions during the course of 5 consecutive days. They performed 9 blocks of trials each day, beginning with one block of single-task memory load trials, followed by 4 blocks of single and dual-task trials for one type of same-different match and 4 more single and dual-task blocks for the other type

of match in the sequences described above. The sequence of conditions and stimuli used in the practice session was the same as that used during the fourth experimental session. Each session lasted about 90 minutes.

The practice session was used primarily to familiarize subjects with the tasks and procedures and to stabilize their performance. They were paid a flat rate of \$5.00, and were not told how to divide their attention during the dual-task blocks. However, the method of payment during the remaining sessions was described in some detail, and subjects were given feedback after each practice block concerning how well they were doing on each task. During the experimental sessions, of course, subjects were paid for their trial-by-trial performance.

On the single-task memory load trials, the experimenter pushed a button at his terminal, which caused a warning tone to sound that was followed 500 msec later by the appearance of the three CVCVCs. These remained on for 2,500 msec, and the subject pronounced them aloud. There was a 3,000 msec pause after the nonsense words disappeared, followed by a second tone which was a signal to begin recall. The experimenter entered the number correct and began the next trial.

On single-task physical and name identity trials, the experimenter sounded a warning tone, which was followed 500 msec later by a fixation point at the center of the screen. The fixation point remained on for 1,000 msec, and then the target task stimulus was presented to either the left or right, for the predetermined exposure duration. The subject responded with both hands simultaneously, index fingers were used for *same* responses and middle fingers for *different* responses.

On the dual-task trials, the warning tone was followed 500 msec later by the appearance of the three CVCVCs, which remained on the screen for 2,500 msec, as before. The subject read them aloud during this time. The nonsense words were replaced by a fixation point for 1,000 msec, and then the same-different task stimulus appeared to either the right or left. The subject responded by touching either his index or middle fingers to the touchplates and 500 msec later a tone sounded, which was his signal to recall the memory load words. After he did so, the experimenter entered the number of words correctly recalled, and proceeded to

the next trial

Subjects received feedback after each of the 9 blocks concerning their earnings. On dual-task blocks, they received feedback separately for each task, so they could determine how effectively they were dividing their attention.

RESULTS AND DISCUSSION

The target task data were scored by dividing the number of correct same-different responses by the total number of trials presented in each visual field, type of match and task emphasis condition on each day, and expressing the results as percents. The memory task data were also scored separately for each of these conditions as the total number of words recalled divided by the total number of words presented, transformed to percent correct scores.

We will discuss three basic analyses. The first involves single-task performance on both the memory and same-different task, and serves as a baseline against which to compare dual-task performance. The second set of analyses looks at the absolute level of performance in the dual-task conditions for each of our major variables of interest.

The third set is of primary interest in terms of our theoretical predictions, as it is where the dual-task data are analyzed as percent decrements from their single-task controls. For the target task data, dual-task percent correct scores for each visual field were subtracted from the relevant yoked single-task control block. This entailed, of course, two different single-task constants in each case--one each for the right and left visual fields. For the memory data, dual-task percent correct scores for each type of match, task emphasis, and visual field trial were subtracted from the same single-task percent correct score for each day.

Single-Task Performance

The memory task data were analyzed in a repeated measures analysis of variance in which Days was the only factor. Subjects recalled 65.4% of the nonsense words on Day 1 and progressed to 79.7% by Day 4, $F(3,21) = 3.70$, $MSe = 76.24$.

The target task data were analyzed in a Type of Match (physical or name) X Visual Field (right or left) X Day (1-4) X Task Emphasis (load or target) repeated measures ANOVA. the task emphasis factor reflects the dual-task block to which each single-task block served as a control. Once again, only the main effect of days was reliable, $F(3,21) = 6.79$, $MSe = 67.29$ and reflected the fact that overall accuracy on the same-different task improved from 76.5% to 82.5% across the four days of testing.

It is not surprising of course that there was no effect of type of match on single-task accuracy since we ran subjects at exposure durations that had been set to produce equal levels of performance for both physical and name matches (the means for physical and name matches were 79.3% and 78.9% respectively). Similarly the visual field effect was not reliable (80.3% vs. 77.9% for RVF-LH and LVF-RH trials respectively), nor was the Visual Field X Type of Match interaction. This is evidence that both hemispheres are equally capable of performing the two types of matches using whatever processes and mechanisms are at their disposal whenever resources are not in short supply.

Dual-Task Performance

The dual-task data were analyzed in separate Type of Match X Task Emphasis X Visual Field X Days repeated measures ANOVAS, and in a combined analysis in which Task was also a factor. The main purpose of the individual analyses was to determine whether there were effects of visual field and type of match, and the main purpose of the combined analysis was to determine whether there was a Task X Emphasis interaction, since our predictions regarding differential performance decrements and tradeoffs as a function of visual field pertain to the difference score analyses below.

There was no reliable effect of type of match in the target task data (78.3% vs. 75.8% for physical and name matches respectively) but there was a reliable effect in the analysis of the memory data, $F(1,7) = 7.92$, $MSe = 53.71$ and in the combined analysis, $F(1,7) = 5.84$, $MSe = 141.43$. Performance on the memory task was worse when the subjects were concurrently performing name matches (66.5%) than when they

were performing physical matches (69.1%). This supports the idea that when performance on the two types of matches is equated, name matches demand more resources than physical matches, which can be revealed by finding differences in the performance of a concurrent task as a function of the type of match involved.

Similarly there was also no effect of visual field on absolute levels of accuracy in the same-different task (77.8% vs 76.3% for RVF-LH and LVF-RH trials, respectively) but the visual field to which the target task stimulus was presented did affect subjects' ability to remember the nonsense words in the memory task, $F(1,7) = 6.72$, $MSe = 101.00$. Recall accuracy was 66.2% on RVF-LH trials and 69.4% on LVF-RH trials. This is in accord with the idea that since the left hemisphere took primary responsibility for the memory task, when the right hemisphere could process the target task stimuli, memory performance could improve.

In addition to the effects above, there was a main effect of the task emphasis instructions that was reliable for the target task, $F(1,7) = 7.37$, $MSe = 57.71$, and that approached reliability for the memory task, $F(1,7) = 4.46$, $MSe = 75.29$, $p < .08$, which produced a reliable Task X Emphasis interaction in the combined analysis, $F(1,7) = 8.11$, $MSe = 93.57$. As subjects switched their attention from the same-different task to the memory task, same-different accuracy decreased from 78.3% to 75.7%, while memory performance increased from 66.7% to 69.0%. Thus, there were tradeoffs between tasks as a function of the emphasis condition, but as will be seen in the difference score analyses, the emphasis instructions produced decrements from single-task performance and tradeoffs between tasks that differed as a function of visual field.

Less interesting than the effects above are those due to practice and its interaction with some of the other factors. The main effect of Days was reliable for the memory task, $F(3,21) = 32.28$, $MSe = 106.19$, and for the combined analysis, $F(3,21) = 33.36$, $MSe = 78.67$, as were the interactions of Day and Task, $F(3,21) = 7.99$, $MSe = 126.10$ and Day, Level, and Visual Field in the combined analysis, $F(3,21) = 3.83$, $MSe = 31.29$.

Basically, the Task X Day interaction showed that practice affected memory

performance more than it did performance on the target task. Across days, recall accuracy improved from 58.9% to 76.3% while target task accuracy improved from 74.6% to 78.9%. The triple interaction showed that practice improved performance on RVF trials more than LVF trials, and this improvement was somewhat larger for name matches than for physical matches. Across days, performance improved by 10.7% and 14.0% when physical and name match stimuli, respectively, were presented to the RVF-LH, and by 8.7% vs. 10.1% when they were presented to the LVF-RH. Therefore, practice affected the complete overlap conditions more than the no overlap conditions, and more so for the target task situation in which resources were most scarce (i.e., during name match trials). This may reflect the fact that subjects were learning how to divide left hemisphere resources between tasks more efficiently as a function of practice (see Brickner & Gopher, Note 2).

Single-to-Dual-Task Decrements

The most important analyses from the point of view of our theoretical predictions, are those that examine the performance decrements in the dual-task situation relative to the single-task baselines. Accordingly, the percent decrement scores were analyzed in separate Type of Match X Task Emphasis X Visual Field X Days repeated measures ANOVAs, and in a combined analysis in which Task was also a factor.

The main effect of type of match was reliable for both tasks, $F(1,7) = 9.54$, $MSe = 29.86$ for the same-different task, $F(1,7) = 7.90$, $MSe = 53.86$ for the memory task, and $F(1,7) = 17.67$, $MSe = 39.79$ for the combined analysis. As expected, physical matches required fewer resources than name matches and thus produced dual-task decrements that were less severe. The mean percent decrements for the same-different task were 0.98% and 3.1% for physical and name matches, respectively, and were 4.2% and 6.8% for the memory task.

The main effect of visual field was not reliable in the same-different task, although the means were in the right direction (1.6% vs. 2.5% for LVF-RH and RVF-LH trials, respectively). Yet we can say with some assurance that RVF-LH trials were more burdensome than LVF-RH trials since the effect was reliable for the memory

task, $F(1,7) = 6.71$, $MSe = 101.07$, and approached reliability in the combined analysis, $F(1,7) = 5.38$, $MSe = 100.78$, $p < .06$. When the left hemisphere had to perform both the same-different task and the memory task, memory performance decreased from its single-task level by 7.1%, whereas when the right hemisphere was processing the target task stimuli, memory performance only decreased by 3.9%.

The effect of the task emphasis instructions was reliable for the same-different task, $F(1,7) = 9.97$, $MSe = 24.50$ and approached reliability for the memory task, $F(1,7) = 4.46$, $MSe = 75.28$, $p < .08$, which again produced a reliable Task X Emphasis interaction in the combined analysis, $F(1,7) = 18.41$, $MSe = 31.33$. Most importantly for our assumption of independence, the Task X Emphasis X Visual Field interaction was also quite reliable, $F(1,7) = 19.91$, $MSe = 15.44$. This interaction is shown in Figure 1. In Figure 2, the presence of tradeoff effects on RVF-LH trials and their absence on LVF-RH trials can be seen as a function of the two types of same-different matches.

Insert Figures 1 and 2 about here

Performance decrements on the memory task were worse under target emphasis instructions than under load emphasis instructions, and this was true on both types of visual field trials. Thus, there was no Visual Field X Task Emphasis interaction in the memory data. In contrast, the task emphasis instructions only influenced performance on the same-different task when the stimuli were presented to the RVF-LH; there was virtually no change in target task performance as a function of the emphasis instructions when the stimuli were presented to the LVF-RH. This showed up as a reliable Visual Field X Task Emphasis interaction in the analysis of the target task data, $F(1,7) = 6.59$, $MSe = 68.53$.

This difference in target task tradeoffs as a function of visual field was obtained for the majority of the subjects; all but one subject had more severe target task decrements under load emphasis instructions than under target emphasis instructions on RVF trials. In contrast, as subjects shifted their attention from the

target to the memory task on LVF trials, decrements from single-task target performance were actually less severe than they were under target emphasis instructions for five subjects, did not change for one subject, and increased only slightly for the remaining two.

The data shown in Figures 1 and 2 indicate that as expected, mutual tradeoffs in performance between tasks were only obtained in the complete overlap case when the target task stimuli were presented to the RVF-LH; allocating resources to the memory task decreased target task performance and allocating resources to the target task decreased memory performance. In contrast, on LVF-RH trials, subjects could take advantage of the fact that the right hemisphere was processing the target task stimulus insofar as this made more left hemisphere resources available for the memory task. Thus, memory performance was less severely decremented from single-task levels on LVF trials than on RVF trials in both task emphasis conditions. However, the fact that fewer left hemisphere supplies were available for the target task in the load emphasis conditions or that more left hemisphere resources were available in the target emphasis conditions did not affect target task performance on LVF trials, because the stimuli were being processed with right hemisphere supplies (Footnote 2).

That fewer left hemisphere resources were available on RVF than on LVF dual-task trials was also indicated by the relative speed of response to the same-different task by the right and left hands, respectively, of our subjects. Although we did not measure reaction times *per se* because subjects were operating under strictly accuracy instructions, we did record which hand reached the response finger plates first on each trial regardless of the correctness of the response. During the single-task conditions, the right hand responded first roughly half the time (47.70% vs. 47.66% for RVF and LVF trials, respectively) which is what one would expect in a situation that is not resource-limited. During the dual-task trials, however, when there was a left hemisphere supply shortage because of the memory load, subjects were slower to respond with their right hands than with their left on both types of visual field trials (the right hand responded first only 36.99% of the time on

RVF trials and 36.25% of the time on LVF trials)

Metaphorically speaking, the left hemisphere took primary responsibility for the memory task (and, of course, the right hand) under both task emphasis and visual field conditions. In following the task emphasis instructions, it could spend more or less of its resources on the processes necessary to remember the nonsense words, so that memory performance was always affected by the emphasis instructions. Thus, when left hemisphere supplies were added or subtracted from the memory task, and the target task stimulus happened to be presented to the RVF, concomitant fluctuations in target task performance were obtained. But the relative availability of left hemisphere supplies as a function of shifting emphasis made little difference to target task performance on LVF trials, as they were unable to be used by the right hemisphere when they were present, and were not particularly missed when they were scarce.

GENERAL DISCUSSION

In our previous study (Polson, Friedman & Gaskill, Note 1), we found different decrements from single-task performance for two dual-task situations in which there was either complete or only partial overlap between tasks in the amount of left hemisphere resources demanded, depending on the visual field to which the target task stimuli were presented. Since some of the same type of resource was demanded in both cases, we found equivalent tradeoff effects between tasks as a function of our emphasis instructions on both types of visual field trials, and though unlikely, the possibility remained that resources were being shared.

However, in the present study, we also obtained different decrements from single-task performance as a function of the visual field to which the target stimulus was presented, but only obtained tradeoffs in the situation in which we were assuming complete overlap when resources released from one task were entirely relevant to the other. In the no overlap case, when the right hemisphere was processing the target stimulus and the left hemisphere the memory load words, there were no changes in target task performance as a function of shifting emphasis. Thus, the verbal output requirement of the naming task we previously used led to left

hemisphere supplies being required on both RVF and LVF trials. In the absence of such a requirement for the same-different task, we achieved a situation of no overlap on LVF trials, and because of this, there were essentially no decrements from single-task performance levels on the same-different task. Similarly, the dual-task decrements were much less severe for the memory task on trials when the same-different stimuli were presented to the right hemisphere.

Moreover, although it was possible to attribute the different decrements we obtained in our previous study to some form of output interference, insofar as both tasks required spoken responses, this is not a plausible alternative in the present case because the response requirements for each task engaged different systems. Thus the simplest way to interpret the data across both experiments is to assume that dual-task performance was less severely decremented from single-task levels on LVF trials because the right hemisphere's resources could be used for part or all of the target task processing. With the naming task, the right hemisphere could perform only part of the target task processing (i.e., some left hemisphere resources were needed on LVF trials because of the spoken response required) and performance could therefore trade between tasks on both RVF and LVF trials. In the present study, however, the right hemisphere could perform all of the target task processing on LVF trials, and we did not obtain such tradeoffs. Thus, in addition to providing evidence for the existence of at least two resource supplies, the present data provide clear evidence for their independence.

Together, our results would be exceedingly difficult to explain within any single-capacity model. For example, within a single-capacity approach, the absence of decrements from single-task target accuracy on LVF trials but their presence on RVF trials, would have to be interpreted as meaning that either (a) performance was data-limited on LVF trials but not RVF trials, or else (b) processing the target stimulus could occur automatically when it was presented to the left of a fixation point but could not do so when presented to the right. Both of these interpretations seem unlikely.

It is similarly difficult to explain differences in tradeoffs between tasks as a

function of visual field from the single-capacity point of view: since from that approach neither the target task demands nor the tradeoffs observed should change as a function of presenting the identical stimulus to different sides of a fixation point. From our point of view, however, left and right visual field trials of the allegedly same task should be considered as two potentially different tasks, which may overlap to a greater or lesser extent with the hemispheric resource requirements of any other task they are combined with. To the extent that there is some overlap in demand, and to the extent that performance on both tasks is resource-limited, then tradeoffs between tasks can be obtained through shifts in resource allocation. On the other hand when there is no overlap in demand, making more or less of the wrong type of resource available can neither help nor hinder performance.

It would also be difficult to argue that the different dual-task decrements and tradeoff effects we observed arose because the task combinations we used were not equivalent in terms of subjects and task parameters. That is, in the usual method of testing a multiple-resources model against the single-capacity view, two different tasks would be paired with the same third task, and differences in performance decrements and especially in performance tradeoffs between tasks would be sought. However, it remains difficult to equate tasks that actually are different in terms of their subject and task parameters. Thus, it could still be argued that any performance differences observed across different task combinations are due to some factor idiosyncratic to the combinations themselves, having nothing whatever to do with whether they produce demands for different amounts of a common supply. In contrast, when identical stimulus materials are simply presented to different visual fields, and subjects are required to perform the same operations on them, differences in subjects' ability to trade performance between that task and any other as a function of visual field are difficult to attribute to any cause other than differences in resource demands. In summary, then, the most plausible explanation for the present data is that the different performance decrements and tradeoffs we obtained as a function of visual field means that at least two pools of supplies exist that can be drawn on in the processing of any task or combination of tasks, and they seem to be under the control of the left

and right hemispheres

The reason it is important to establish whether there is just one or else several pools of resources, and if the latter, which of these are required by the tasks at hand is that the interpretation of certain patterns of results between single and dual-task conditions becomes drastically altered as a function of which assumption is invoked. For example, many investigators use dual and secondary probe task techniques to address such issues as the extent to which making one task more difficult reduces 'spare capacity' for a second, or the extent to which processing has become 'automatic' with extended practice (e.g., Logan, 1979; Posner & Snyder, 1975). This usually involves assessing dual-task performance relative to either a single-task baseline or to performance in the easiest concurrent-task situation. Then if there is no decrement from single-task performance or if one task is insensitive to the increasing difficulty of a second or if an initially obtained performance decrement disappears with practice, the data are taken to imply that either one or both tasks require few or no resources.

However, this interpretation clearly rests on a single-capacity assumption; if the tasks demand resources from different pools it would be erroneous. For example, suppose two tasks demanded different types of supplies as was the case on LVF dual-task trials in the present study. Then if one task was made increasingly more difficult, so that there was an increasing supply shortage of the type of resource it needed and concomitant dual-task performance decrements, performance on the other task might be able to be maintained at or near baseline levels because this second task did not use the type of resource that was becoming scarce. Thus, one of the implications of our model is that when investigating divided attention phenomena the hemispheric resource requirements of the tasks that are combined need to be taken into account before conclusions regarding automaticity or spare capacity can be made.

A second implication of our model for those investigators interested in issues of cerebral specialization *per se*, is that simply observing differences in decrements from single-task performance as a function of the visual field, hand or ear to which a stimulus is presented (e.g., Lomas, 1979; Smith, Chu, & Edmonston, 1977) does not

by itself, imply which hemisphere is processing a particular task or pair of tasks. Further, such differences certainly do not imply anything about overall levels of resources allocated, as they are often interpreted to do within a selective activation approach (e.g., Hellige & Cox, 1978; Kinsbourne & Cook, 1971). Rather, in order to discover the type(s) of hemispheric resources required for performance, it is necessary to determine the pattern of performance tradeoffs between tasks that either does or does not occur as the resource allocation of individual subjects is carefully manipulated through the use of a payoff policy. These patterns, combined with different performance decrements measured from single-task controls, can then be used to make statements regarding the relative amounts of left and right hemisphere supplies demanded by any particular combination of tasks.

We also increasingly believe that it is necessary to screen subjects to ascertain their single-task "lateralization" pattern for the particular tasks at hand, especially when it is being assumed that the tasks are making demands for the resources of primarily one hemisphere, as was the case with the memory load task we used. This is because both our screening procedures and our data have made it clear that a model of cerebral specialization in which the left hemisphere is "verbal" and the right is mute is far too simplistic, even for those right-handed individuals for whom this may be true under many circumstances. In both our previous study and in the present case, many of our right-handed subjects did not have a single-task RVF-LH superiority for perceiving the nonsense words we used, and the individuals who were "lateralized" in the classic manner were clearly able to process abstract, unfamiliar, verbal information with their right hemispheres. That they could do so was revealed by diverting left hemisphere resources to another task entirely.

Finally, from a both theoretical and a pragmatic point of view, in future research that involves comparing single and dual-task performance, it will be useful, and probably necessary, to take into account the resource demands of the tasks being used with respect to the two hemispheres of the particular individuals tested. We have shown for example that performance on a memory task in which the stimuli are nominally available to both hemispheres is differentially affected by the hemisphere to

which the very same target task stimulus is presented. Thus, there is good reason to suspect that even when visual field techniques are not employed, mutual interference and tradeoff effects will reflect the degree to which the tasks overlap in their demands for resources of two different types. From the standpoint of cerebral economics, dividing labor as much as possible between the hemispheres makes a good deal of sense.

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- 2 Brickner, M. & Gopher, D. *Improving time-sharing performance by enhancing voluntary control on processing resources.* Technion-Israel Institute of Technology, Tech Report No AFOSR-77-3131C, 1981.

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FOOTNOTES

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1 When subjects are not paid for single-task performance, it is impossible to know whether they were allocating all available resources to the task at hand. Thus, it is difficult to interpret a finding of no change from single to dual-task performance and it is similarly difficult to know whether an increase in dual-task performance represents a bona fide concurrence benefit. We have previously discussed why, for example, when subjects aren't paid they are likely to increase their overall resource allocation in going from a single to dual-task situation, and why this increase is likely to produce an equal increment in the resources available in both hemispheres (Friedman & Polson, 1981).

2 It should be noted that the decrements from single-task performance on RVF trials of the same-different task were reliably different from zero for both physical and name matches when subjects were paying attention to the memory task, the only LVF condition in which the decrements from single-task target performance were reliable was during name matches when subjects were paying more attention to the *target* task. Indeed, for several of our subjects, actual increases from single-task target performance were observed on LVF trials under *memory* task emphasis instructions. If performance was trading off between tasks, the opposite result would have occurred. That is, had the target and memory tasks been able to trade resources on LVF trials, then target task performance should have decreased under load emphasis instructions, but it did not.

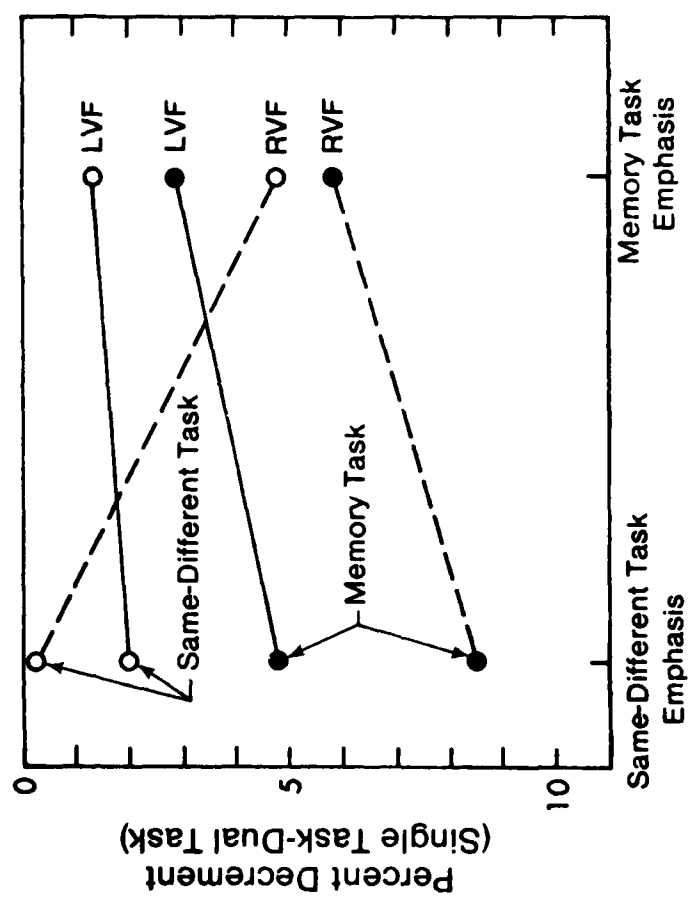
Of more concern are the decrements from single-task memory performance that were seen on LVF trials, particularly when conjoined with name identity matches.

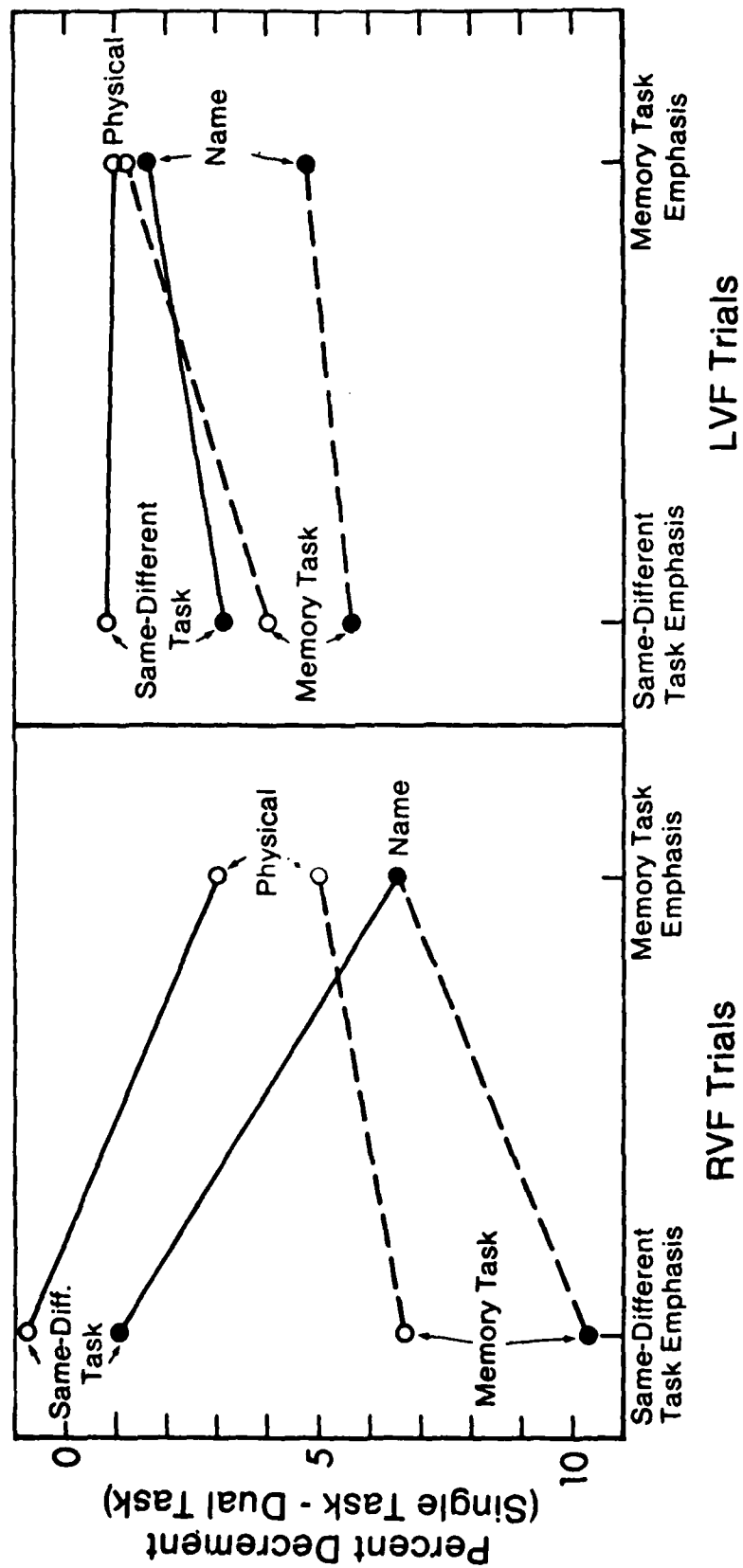
All of the decrements from single-task memory performance were reliable except during LVF physical matches under memory task emphasis instructions. Strictly speaking, in the no overlap case, performance decrements can only be attributed to concurrence costs. While it is not entirely clear what contributed to concurrence costs on no overlap trials, one possibility is the bimanual nature of the response to the same-different task. That is, although the right hemisphere could process the target task stimuli on LVF trials, it was still necessary to signal the right hand how to respond.

FIGURE CAPTIONS

Figure 1 Percent decrement scores for the Task X Emphasis X Visual Field interaction. The ordinate is plotted with zero at the top, so that points that are lower on the figure represent greater decrements from single-task performance.

Figure 2 Percent decrement scores for the Task X Emphasis X Visual Field interaction plotted separately for physical and name matches. Note that the only tradeoffs in performance between tasks as a function of emphasis instructions occur when the target task stimulus is presented to the right visual field.





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