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An Investigation of the Dual Task Performance Relationship to Hemispheric Specialization

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The efficiency of dual task performance may be influenced by a number of variables such as the level of practice of the individual, the difficulty of the task, and the particular processing resources or capacities for which the two tasks compete. The current research investigates the relation between the capacities employed in two tasks--a verbal processing resource inferred to reside in the left cerebral hemisphere, and a spatial resource

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Experiment 1, employing the verbal Sternberg Reaction Time task confirmed that with practice, subjects time-shared more efficiently in the integrity condition. In Experiment 2, tracking was time-shared with a varient of the Sternberg task employing spatially-defined random 5 dot patterns. With this task, neither hand assignment could produce a configuration that maintained integrity for both tasks. The results of Experiment 2 indicated that time-sharing efficiency was no different across the two hand assignments. Some practical implications of these results with regard to task configurations are discussed. Specifically they suggest that when the overloaded operator is confronted with two tasks--one spatial and one verbal--that must be time-shared, greater efficiency should result if the spatial control (e.g., the tracking joystick) is operated with the left hand, while verbal responses such as digital data entry be assigned to the right.

Abstract

The efficiency of dual task performance may be influenced by a number of variables such as the level of practice of the individual, the difficulty of the task, and the particular processing resources or capacities for which the two tasks compete. The current research investigates the relation between the capacities employed in two tasks--a verbal processing resource inferred to reside in the left cerebral hemisphere, and a spatial resource in the right--and the controlling hand. Specifically a condition of task-hemispheric integrity is defined when the processing and responding of each task is carried out in a single cerebral hemisphere. In the experiment, this condition occurs when a tracking task, inferred to be spatial right-hemispheric in its processing, is controlled with the left hand, while a Sternberg memory search Reaction Time task with the letter stimuli, inferred to be verbal left hemispheric, is responded to with the right hand. A "mixture" condition is created with the opposite hand assignment, so that each hemisphere processes the information associated with one task, while responding to the other (i.e., Sternberg Task-left hand, Tracking-right hand).

Experiment 1, employing the verbal Sternberg Reaction Time task confirmed that with practice, subjects time-shared more efficiently in the integrity condition. In Experiment 2, tracking was time-shared with a varient of the Sternberg task employing spatially-defined random 5 dot patterns. With this task, neither hand assignment could produce a configuration that maintained integrity for both tasks. The results of Experiment 2 indicated that time-sharing efficiency was no different across the two hand assignments. Some

practical implications of these results with regard to task configuration are discussed. Specifically they suggest that when the overloaded operator is confronted with two tasks--one spatial and one verbal--that must be time-shared, greater efficiency should result if the spatial control (e.g., the tracking joystick) is operated with the left hand, while verbal responses such as digital data entry be assigned to the right.

The extreme processing demands imposed upon the pilot of the modern high performance aircraft at critical junctures in a mission, emphasize the importance of developing design innovations that can reduce the influence of information processing bottlenecks. Multiple resource models of attention (e.g. Wickens 1980; Navon & Gopher, 1979) suggest that parallel processing of multiple sources of information can be facilitated by the judicious selection of input channels that draw upon separate reservoirs of perceptual resources, and by the corresponding selection of independent response channels. For example, Wickens (1980) has argued on the basis of experimental data that auditory and visual processes may draw upon functionally separate resources (Treisman & Davies, 1973; Isreal, 1980; Rollins & Hendricks, 1980). A similar assertion can be made with regard to vocal and manual responses (e.g. Harris, North, & Owens, 1978).

In addition to input and output modalities, a third dimension along which processing resources may presumably be deliniated is in terms of spatial versus verbal codes of central processing (Baddeley & Leiberman, 1980; Wickelgren, 1979). Experimental evidence is available to suggest that two tasks that are spatial in their central processing demands will show greater mutual interference than a verbal and a spatial task; while a corresponding interference pattern may be shown with two verbal tasks (Brooks, 1968; Baddeley & Leiberman, 1980). Converging anatomical and experimental evidence suggests that this spatial-verbal distinction may well be associated with the right and left cerebral hemispheres respectively in approximately 95% of the adult population (Moscovitch, 1979) (practically all right handed individuals, and roughly 50% of the left handed populations). The design guidelines to be recommended from multiple-resource theory therefore suggest that, where possible, separate tasks should be displayed in separate modalities, processed by separate codes, and responded to with different modalities, in order to minimize interference. A consideration in task synthesis that is orthogonal to the recommendation of separate pools between tasks, is that within a task, there may be certain natural or compatible linkages between encoding, processing and response modalities. Thus the relatively high stimulus-response compatibility between visual information and manual responses, and between auditory information and vocal responses has been demonstrated experimentally (e.g., Teichner & Krebs, 1976; Brainard, Irby, Fitts, & Alluisi, 1962), while the "naturalness" of these linkages has been provided theoretical justification by Greenwald (1971, 1979) in terms of the concept of ideomotor compatibility.

An interesting possibility is that the natural linkage between stimulus and response might be mediated by a correlated association of each with processing hemisphere. Thus a condition of "task-hemispheric integrity" might be defined when a task of visual input (frequently in human experience associated with spatial processing) is processed directly by the right (spatial) cerebral hemisphere, and is responded to with a manual response (normally associated with spatial parameters). A corresponding integrity would occur if an auditory input, typically verbal, were processed by the left hemisphere, and responded to vocally. In fact just such a natural linkage may be postulated to exist in an investigation by Allport, Antonis, & Reynolds (1972) in which near perfect time-sharing was observed between sight-reading a piano piece, and verbal shadowing.

When considering the linkages of input and output to hemispheres, it is important to realize that encoding may be directly associated with one hemisphere or another by visual fields or ear of presentation, each ear and visual field directly accessing the contralateral hemisphere. Correspondingly each hemisphere directly controls the contralateral arm. Thus conditions of integrity may also be induced by presenting spatial information to the left visual field, to be responded by the left hand; or alternatively presenting verbal information to the right visual field, to be responded with the right hand.

The integrity association of encoding and processing has received considerable experimental support. Geffen, Bradshaw and Wallace (1971), measuring response latency, showed that visual stimuli which require verbal encoding are responded to more quickly when presented in the right visual field (i.e. left hemisphere), while stimuli that are spatially encoded have shorter latencies when presented in the left visual field (i.e. right hemisphere). A right-field (left hemisphere) advantage for the perception of verbal stimuli (Bryden, 1965; Kimura, 1966), and a left-field (right hemisphere) advantage for the perception of a dot in space (Kimura, 1969) have been found. Similarly, Schell and Satz (1970) showed a right hemisphere advantage in recognition of spatial block patterns.

The data concerning a benefit for integrity of processing and response (i.e. hemisphere of processing controls the response) is considerably less consistent. This ambiguity seems to result from the fact that the integrity benefits of maintaining both functions within the same hemisphere, are partially cancelled by the costs of overloading the single hemisphere with both processing and response demands. This follows from the association of processing hemispheres with resource reservoirs (Kinsbourne & Hicks, 1978).

The two factors competing in the integrity of processing and response may be detailed as follows: (1) *Extra crossover time* argues that tasks which require opposite hemispheres for processing and response require extra time to perform the necessary transfer of information across the corpus collosum connecting the two hemispheres. This concept, therefore, favors processing and response to be in the same hemisphere. (2) In contrast, *extra processing load* favors information processing and response to be in opposite hemispheres. The extra load concept argues that two tasks which share a common hemisphere will overload the hemisphere and create a performance decrement. Consider the analogy of a manuscript preparation in which the manuscript must be conceptualized (central processing) and written (response). These two stages can be performed by two individuals (*A* & *B*) in two possible ways. In accordance with the *extra crossover time* factor *A* would conceptualize and *B* would write (or vice versa). The problem here *would be the time taken for A to get the information to B.* This is analogous to the time necessary for information to cross the corpus collosum, which connects the right and left hemispheres. The extra time concept is consistent with the results of Bradshaw and Perriment (1970). They found the right hand was faster for a spatial task (right hemisphere). This consistency suggests that reaction time differences of spatial versus verbal tasks can be attributable to the extra time required to perform a "cross-over" of hemispheres (Teitelbaum, Sharpless, and Byck, 1968).

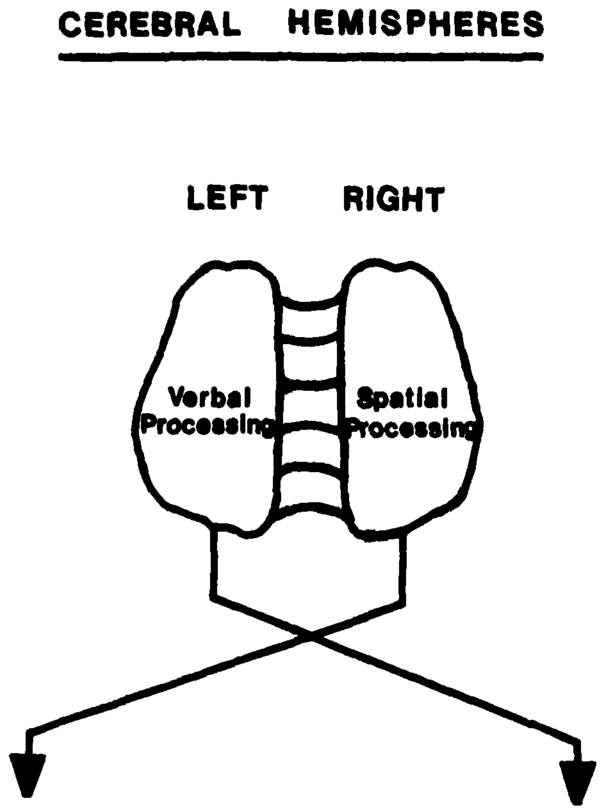
In accordance with the *extra processing load* factor, *A* (or *B*) would both conceptualize and write the manuscript, while *B* (or *A*) did nothing. The problem here would be the loss of efficiency because *A* (*B*) would have to perform both tasks while *B* (*A*) would be idle. This is analogous to the loss of efficiency because one hemisphere would have to perform both tasks.

In support of this view Gross (1972) found the left hand RT was faster for the verbal task, and the right hand RT was faster for the spatial task (although this difference was nonsignificant statistically). Similarly, Rizzolatti, Umilta, and Berlucchi (1971) found differences in reaction time of the hands responses in this same direction. Finally, Klatzky and Atkinson (1971) found a left hand-verbal processing task to be less interfering than a left hand-spatial processing task. Gross (1972) points out that although many of these results are not statistically significant they are extremely consistent. This consistency gives support to Kinsbourne and Hicks' theory of hemispheric overload, and therefore, Gross (1972) argues for the advantage of "sharing the load" between hemispheres.

While there is, therefore, some reason to believe that integrity effects in response might be attenuated by processing overload when only a single task is to be performed, different conditions may well exist in the more loading dual task situation. Here, when the subject performs both a spatial and verbal task concurrently, both hemispheres may be heavily loaded in the first place, so that alternate hand assignments will not vary the load imposed on a particular hemisphere, but _only_ the extent of integrity--that is the extent to which a given hemisphere performs the processing and response functions of a single task.

In terms of the manuscript preparation analogy, two manuscripts are now in preparation, and integrity exists when _A_ conceptualizes and writes one manuscript while _B_ conceptualizes and writes the second. This is analogous to each hemisphere performing both stages exclusively for a single task. Wickens, Mountford and Schreiner (1979) provided evidence showing a benefit to task performance when two tasks (a tracking task assumed to be spatial and a verbal digit classification task) were responded to with the hand directly controlled by that same hemisphere (that is, when "integrity" was preserved). With the opposite hand assignment, in accordance with a "mixing" concept, A would conceptualize the first manuscript and write the second, while B would conceptualize the second manuscript and write the first. The problem here would be that to conceptualize one manuscript and then proceed to write the second is less efficient than to both conceptualize and write the same manuscript. Similarly, when each hemisphere processes one task and responds to a second task it is predicted that the overall level of interference will be greater. That is, this dual task combination will be less efficient. The contrast of integrity and mixture is shown in Figure 1.

It should be noted that while the experiments considered to this point have been theoretical laboratory investigations, the concepts and variables have a high degree of face validity with the pilot's task, and with the design options available in the configuration of high performance aircraft. Thus the computer driven heads-up display allows for the choice between (or mixture of) verbal and spatial formatting of information, and this information may be presented to the left or right (as well as at the midline) of the pilot's center of fixation (thus insuring a tendency to lateralize the visual field). Responses are of course exerted by the left and



	LEFT HAND	RIGHT HAND (& VOICE)
INTEGRITY:	SPATIAL TASK RESPONSES	VERBAL TASK RESPONSES
MIXTURE:	VERBAL TASK RESPONSES	SPATIAL TASK RESPONSES

Figure 1: The Contrast of Integrity vs. Mixture

right hand, while at the central processing level a pilot's tasks may be categorized into those of a generally spatial nature (navigation, control of stability, maneuver profiles) and those more typifying the verbal categorical processing of the left hemisphere (ground control communications, logical decisions, threat evaluation, etc). Finally, recent design innovations suggest the potential of integrating both auditory verbal and spatial displays as well as vocal response capabilities, adding yet more possible degrees of design flexibility.

The point we wish to emphasize is that a potential criterion for choosing between design options (and combination of options) relates to considerations of task-hemispheric integrity, particularly in the high demand (dual task load) environment confronting the pilot. The purpose of the present investigation is to explore the potential contribution of integrity to dual task performance efficiency in a paradigm in which subjects time-share a spatial task (manual tracking) with a verbal task (Sternberg memory search) with alternate hand assignments.

EXPERIMENT 1: VERBAL STERNBERG TASK

Method

Subjects

Nine right handed male subjects were employed on a voluntary basis to serve in this experiment. All subjects were students at the University of Illinois at Urbana-Champaign and were paid $3.00/hour for their participation. Right handed male subjects were used because hemispheric specialization is most consistent in right handed subjects (Gross, 1972).

Apparatus

The tracking and Sternberg tasks were displayed on a Hewlett-Packard 7.5 x 10 cm 1300 CRT display. A Raytheon 704 16-bit digital computer was used to produce inputs to the CRT. In addition, the subjects' responses from the control stick and keyboard were processed by the Raytheon 704. The record of performance (each subject's keyboard responses and RMS tracking error) was stored on a Gould 4800 line printer for later analysis.

The subjects were seated in a sound and light attenuated booth. Positioned on a chair with two arm rests with interchangeable control sticks and control keyboards, the subject sat directly in front of the CRT facing the screen. The distance of the controls was adjusted according to the length of the subjects' arm. The keyboard control had two 1 cm^2 push button keys; one key was positioned higher and to the side of the other key. The control stick (for tracking) was a spring-loaded hand control which moved in a left-right horizontal motion. When positioned correctly the subject's eyes were approximately 110 cm from the CRT display. For a schematic representation of the experimental set up and display see Figure 2.

Each task was programmed so that the subject could perform it with the left or right hand as the controls were interchanged between arm rests. When the two tasks were performed simultaneously, the Sternberg stimulus was presented immediately below (1.5°of visual angle) the zero error reference of the tracking display.

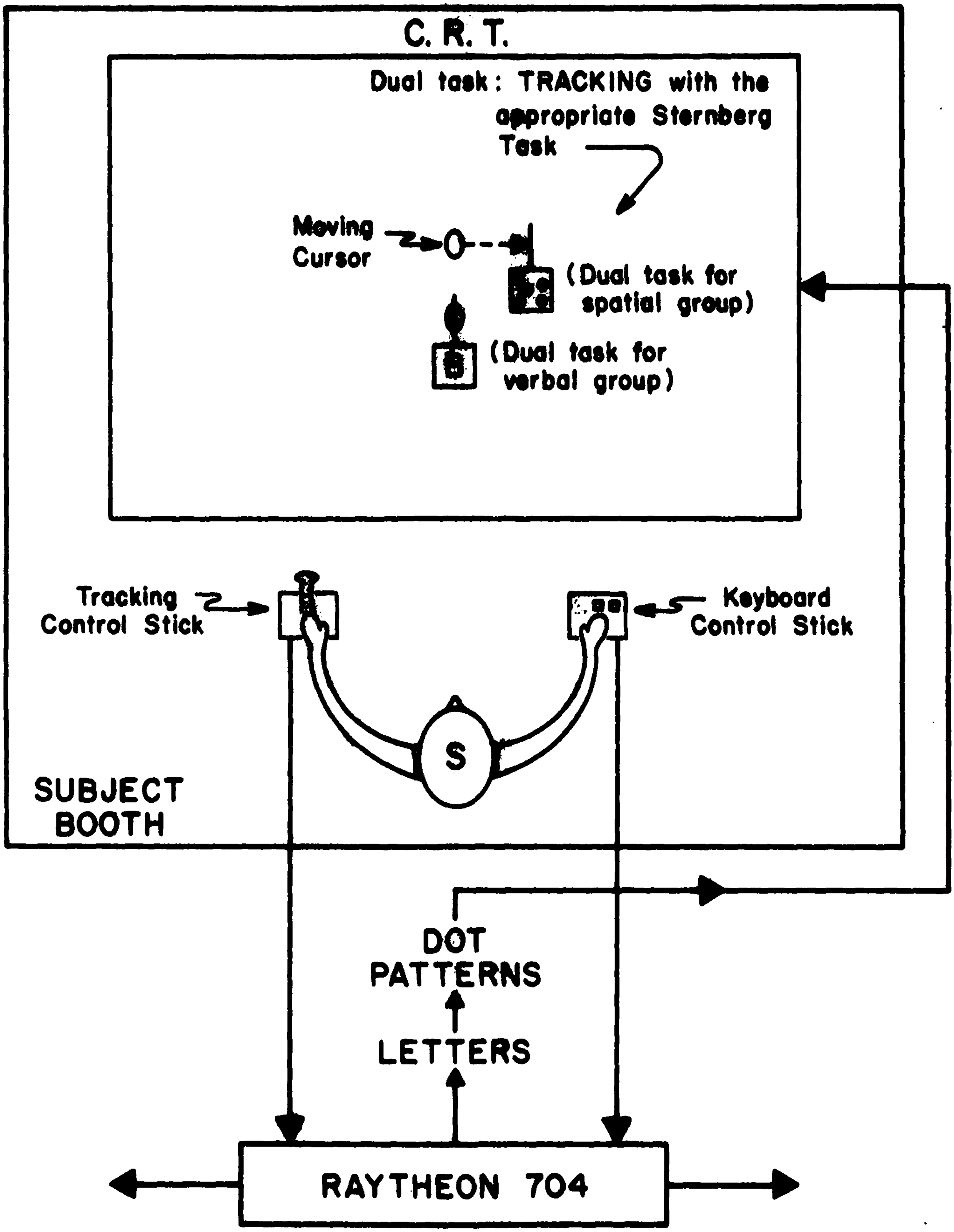


Figure 2: A Schematic Representation of the Experimental Set-up and Display

Task Description

Tracking task. The one-dimensional compensatory tracking task required the subjects to keep an error cursor (which appeared as a small circle on the display) centered on a vertical bar positioned in the middle of the display. Subjects controlled the moving cursor by applying force to a spring-loaded hand control which moved in a left-to-right direction. The control dynamics of this task were of the form $y = \frac{K}{S}$ or $O(T) = K \int I(T)\, dT$, which was a first order tracking function. That is, the cursor position moved with a velocity proportional to the displacement of the subject's control stick. In addition to inputs from the tracking control, the cursor was displaced by a random noise forcing function with a cutoff frequency of .40 H_z. Root mean square (RMS) error was recorded as a performance measure.

Sternberg memory search task (1969). A series of letter stimuli were presented, and the subject was required to make a positive response when the character was a member of a memorized "target" set of two characters visually displayed prior to each series of stimuli. If the character presented was not a member of the "target" set, the subject made a negative response. Subjects indicated their response by pushing the upper button on a control for "yes" and the lower button for "no." Following each response, a new stimulus was presented after a random interval from 3-5 seconds.

The character set consisted of the alphabet, excluding the letter Q because of its great similarity to the letter O. The target set for each 2 minute trial was randomized within each subject and across all subjects. The subject was told to respond as rapidly as possible, while maintaining a low error rate. RT and error percentage were recorded as performance measures.

Results

Figure 3(a) and (b) shows performance on the two dependent variables reaction time and tracking error respectively, for the two hand assignments in single and dual task performance, early and late in practice (Day 2 versus Day 3). Error rates for the reaction time task are shown in parentheses. Since these generally correlated positively with RT, differences in RT are not apparently the result of a speed accuracy tradeoff.

Examining first the single task data, the points on the left of each graph, it is evident that for reaction time, performance is better with the right hand at all stages of practice. For tracking the hand effect is not consistent, favoring the left hand early, but the right hand late. A separate ANOVA performed on the single task data for each dependent variable indicated that the handedness effect for RT was reliable ($F_{1,8} = 5.80$, $p < .05$), while the apparent interaction of hand with practice for tracking was not ($p > .10$).

The magnitude of the dual task decrement is indicated in Figure 3 by the slope of the tracking and RT functions. It appears that early in practice the mixture assignment generates more efficient time-sharing (a shallower slope). However on Day 3, a large decrease in the time-sharing decrement for the integrity assignment, on both dependent variables, favors this condition. Stated differently, on Day 3 the right hand benefit with the Sternberg task is enhanced with dual task loading, while the left hand cost to tracking is attenuated to near zero.

In order to perform statistical analyses on the interference measures, it was necessary to obtain a single value for each subject that corresponded to the combined performance decrement in Figure 3. The investigation and

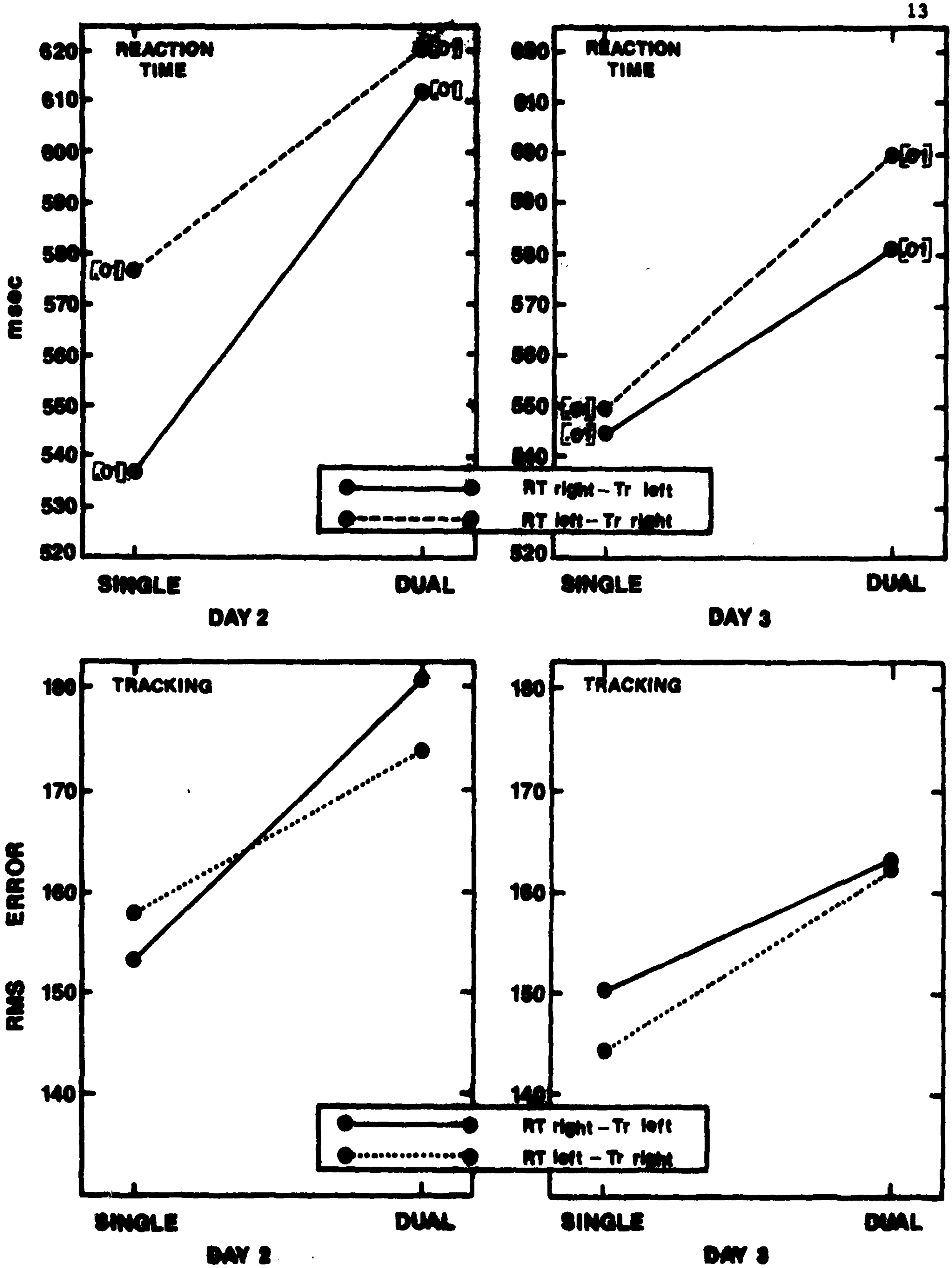


Figure 3: Two dependent variables, reaction time and tracking error, as a function of task load.hand assignment. and day (Experiment 1).

comparison of time-sharing efficiency across qualitatively different tasks, using different dependent variables presents a problem concerned with equating the measurement scales of single-dual task decrements across tasks. Using the data plotted in Figure 3, the following solution was adopted: assuming that subjects allocated resources equally to each of the two tasks the magnitude of the performance decrement indicated a 2:1 scale relationship between the tracking units in RMSE and the RT units in milliseconds. For instance, a 10 msec increase in RT was set equivalent to a 5 units increase in RMSE.

The equation $2[TE(D) - TE(S)] + [RT(D) - RT(S)]$ was then computed to derive the performance decrement, where $\underline{TE}$ and $\underline{RT}$ refer to tracking error and reaction time (in milliseconds), and the ($\underline{S}$)and ($\underline{D}$)refer to single and dual task conditions.

Measures were found for each subject for each hand assignment and day. An analysis of variance was then performed upon these measures to determine the statistical significance of any performance differences. The analysis employed a 3-way (hand (2) x day (2) x subject (9)) repeated measures design (Soupac BALANOVA program).

The dual task interference measures are shown in Figure 4. Reliable main effects were observed for day ($\underline{F}_{1,8} = 5.60$; $\underline{p} < .05$), and for the day x hand interaction ($\underline{F}_{1,8} = 6.96$; $\underline{p} < .03$). The latter interaction is reflected by a dramatic increase in efficiency for the integral hand assignment. A separate contrast performed between the two assignments on Day 3 revealed reliably better performance in the integral, as opposed to the mixed assignment ($\underline{t}(8) = 2.06$, $\underline{p} < .05$), thus replicating the effect observed by Wickens, Mountford, and Schreiner, 1979). No reliable differ-

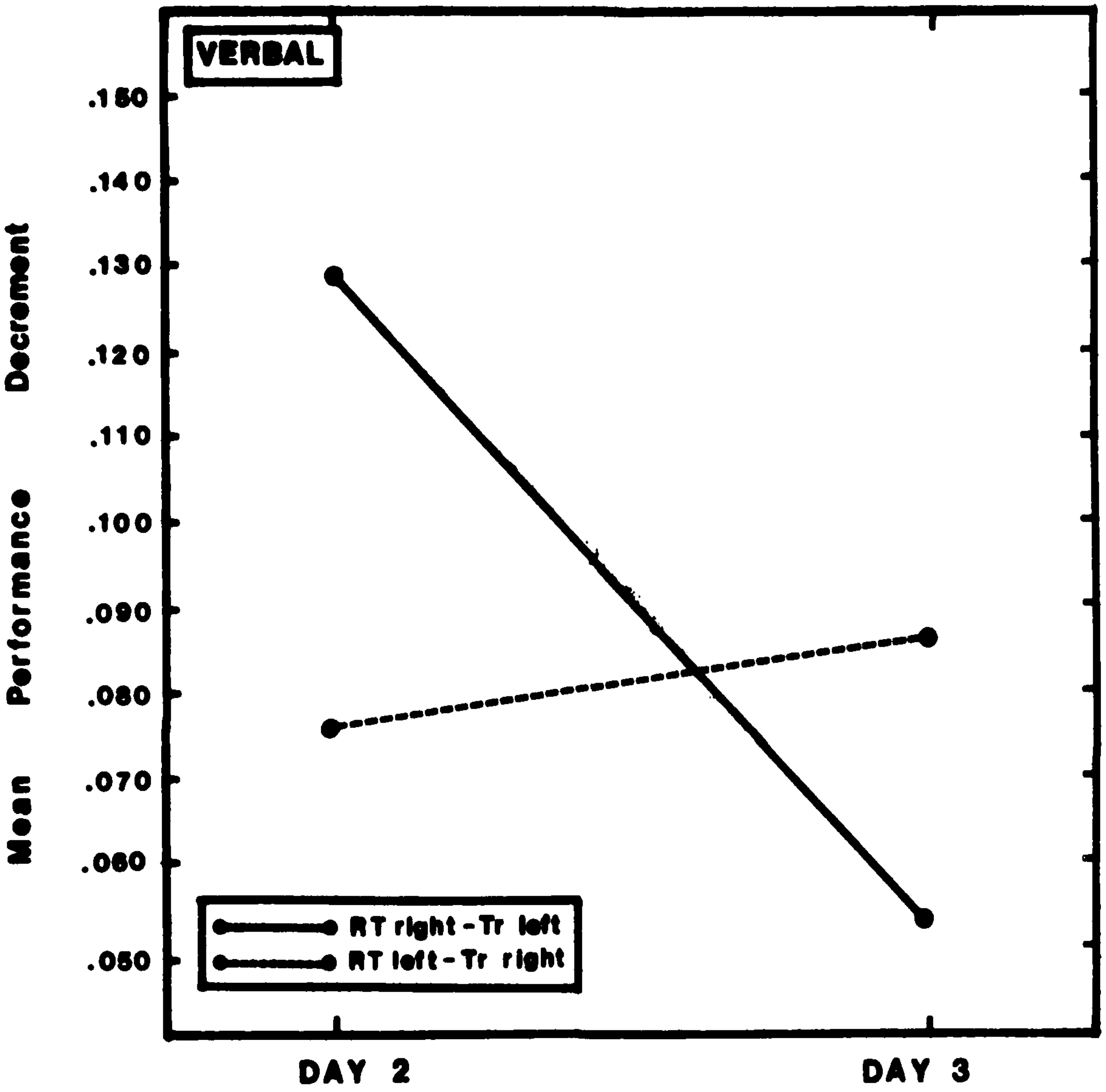


Figure 4: Dual Task Performance Decrements as a Function of Hand Assignment and Day (Experiment 1).

ence in assignments was observed on Day 2. The source of the apparent superiority of the mixed assignment here appears to be the contribution of one single subject, whose interference score was over 4 times greater than the mean for the other subjects in that condition.

While the results tend to confirm that the concept of task-hemispheric integrity is a valid one, further evidence in support of this concept can be provided if the elimination of an integrity affect is shown, with a task pairing in which integrity cannot be achieved, i.e., with the time-sharing of two spatial tasks. The purpose of Experiment 2 was to provide such a demonstration.

Experiment 2

Method

The second experiment was identical in all respects to the first, with the exception of the stimulus material chosen for the Sternberg memory search task. Instead of letters of the English alphabet, an alphabet of twenty five random 5 dot patterns was selected (see Figure 5). A careful series of pretests, described in Appendix A, were conducted to ensure descriminability of the stimuli from each other, and to ensure that none would be readily verbally coded. The latter precaution was employed because previous investigators have found that stimuli which are assumed to be spatial in their composition (e.g., faces, or geometric figures), in fact provide evidence for left hemispheric processing if their familiarity is such that verbal labels may be attached (e.g., Umilta, 1978). As in Experiment 1, nine right-handed male subjects were employed.

Results

The data from Experiment 2 are plotted in analogous fashion to those

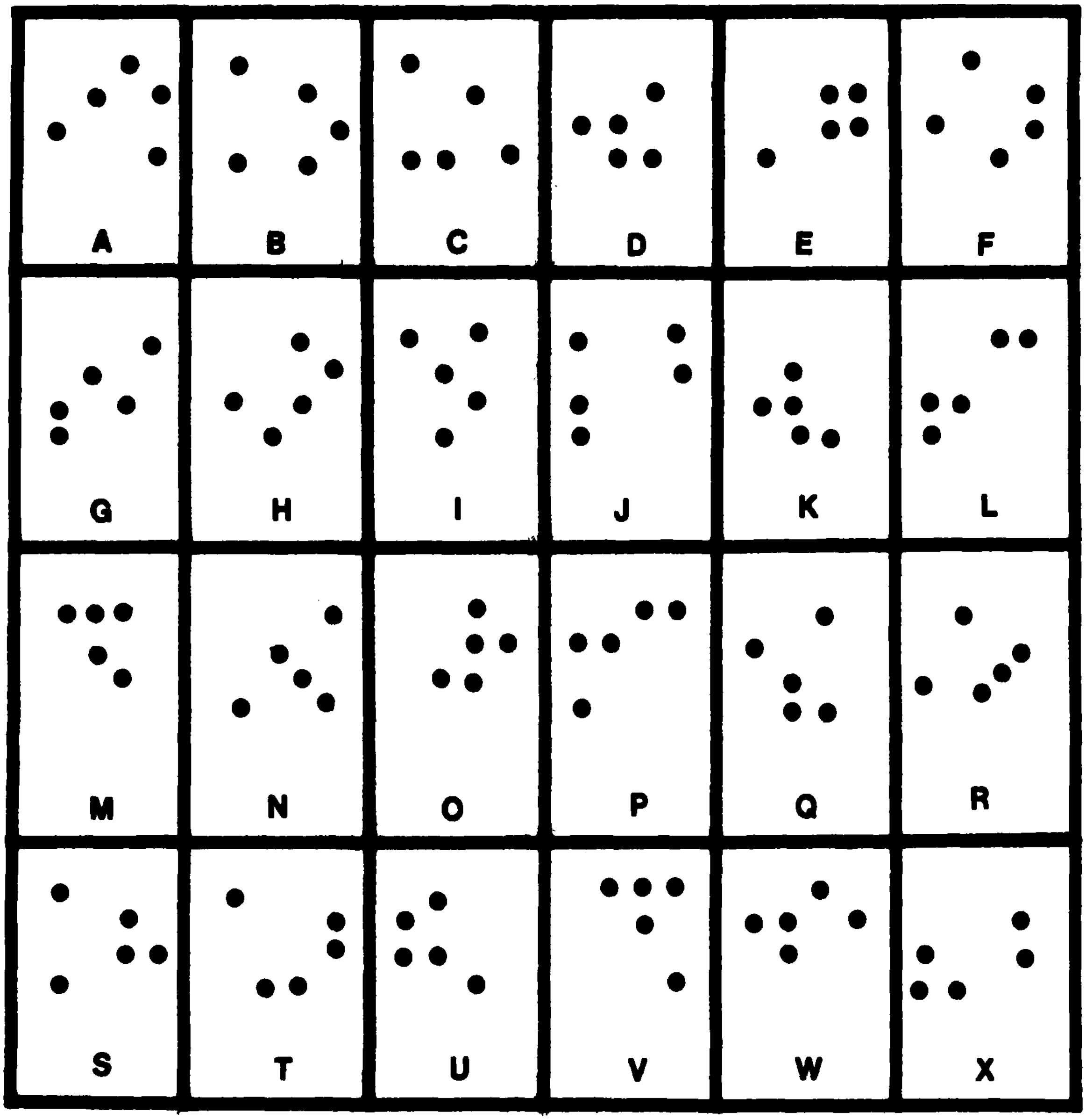


Figure 5: The Spatial Sternberg Stimuli: 5-dot patterns.

of Experiment 1, in Figure 6. The "integrity" description of the solid line (tracking - left, RT - right) is only really a valid label insofar as the tracking task is concerned, since the Sternberg task is also spatial. Following the same procedures as the single task analysis of Experiment 1, no effects were observed to be reliable for the RT variable (all $\underline{p}$'s > .10). For the tracking task, however, a robust effect of handedness was observed ($\underline{F}_{1,8}$ = 12.26; $\underline{p} < .01$), with the right hand showing significantly better performance.

Dual task interference scores representing the slope of the function in Figure 6 were computed in analogous fashion to the procedures employed with the verbal group. These measures are shown for the two experimental days in Figure 7. The 3 way (subject by day by assignment) ANOVA performed on these data revealed only the effect of day to be marginally significant ($\underline{F}_{1,8}$ = 7.63; $\underline{p} < .10$). Neither the main effect of hand assignment, nor the hand by day interaction approached the level of statistical reliability. The data would therefore seemingly confirm a conclusion that hand assignment does not influence dual-task efficiency when two spatial tasks are time-shared.

In a separate analysis, the overall level of time-sharing efficiency between the two experiments was compared. In this between groups design, the main effect of task (spatial versus verbal) was not statistically reliable. Only the task x day interaction approached statistical reliability ($\underline{F}_{(1,16)}$ = 1.74), with the spatial task benefitting more from practice than the verbal. Furthermore, as suggested by Figure 7, this benefit was greatest for the tracking-left, Sternberg-right combination. In fact, this interaction of hand by day was statistically reliable in the combined ANOVA for both groups ($\underline{F}_{(1,16)}$ = 4.33; $\underline{p} < .05$).

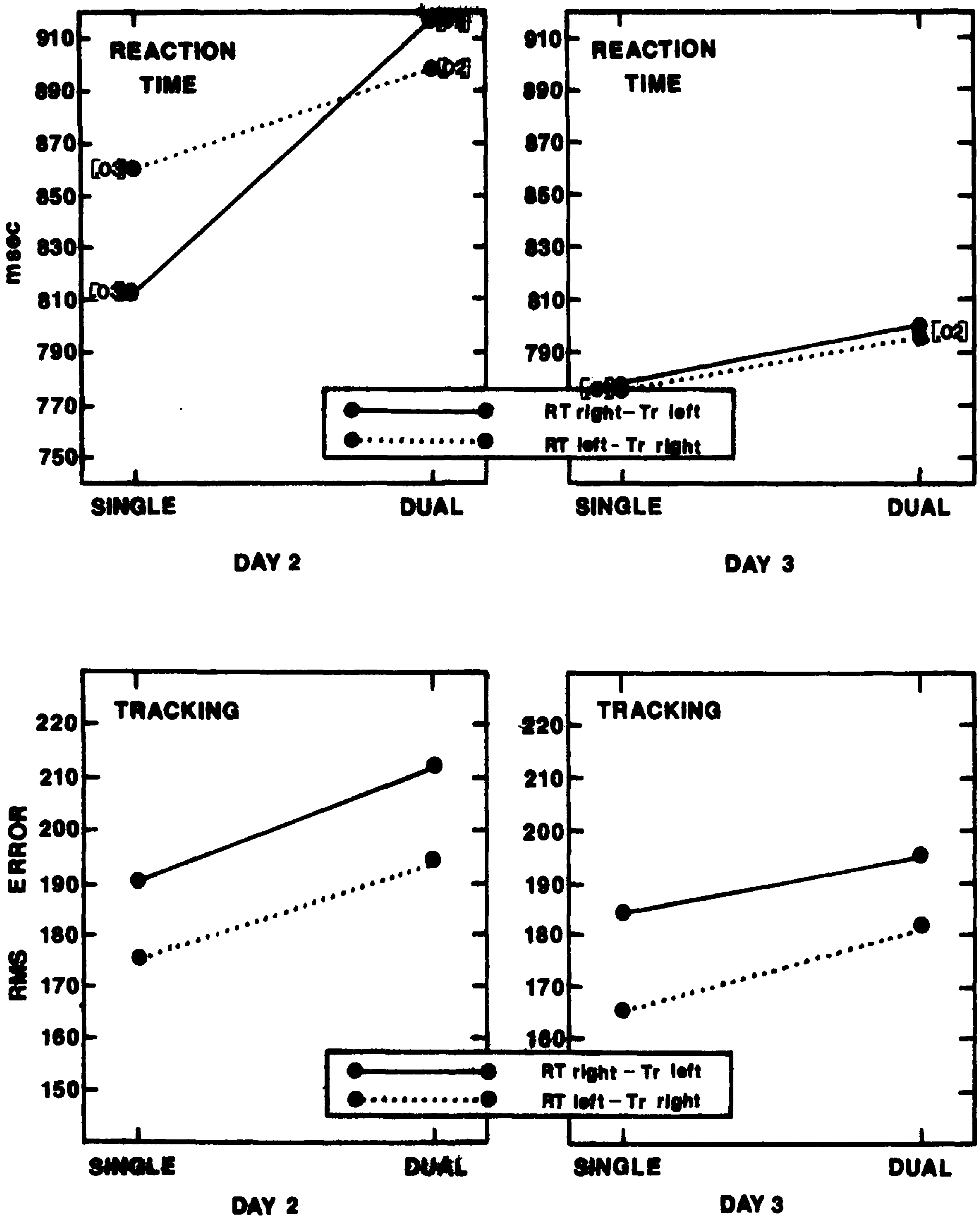


Figure 6: Two dependent variables, reaction time and tracking error, as a function of task load hand assignment, and day (Experiment 2).

Discussion

The results of Experiment 1 appear to replicate, with practice, the integrity effect observed by Wickens, Mountford, and Schreiner (1979). In Experiment 2, as predicted, no difference was observed between integrity and mixture conditions. Contrary to predictions, however, the time-sharing efficiency of the spatial group, in which the spatial processing hemisphere was presumably more heavily loaded, was no worse than that of the verbal group. A closer analysis of the results suggest that this particular effect (the absence of a spatial-verbal difference) may be attributable to the spatial subjects adopting verbal processing strategies.

Three characteristics are particularly relevant to an explanation that posits a processing strategy shift for the spatial group.

1. The spatial group in particular benefited from practice.
2. This benefit in the spatial group's performance was more apparent with the hand assignment that would have maintainted "integrity" for the verbal group (i.e., Tracking-left-Sternberg-right).
3. By the second experimental day, performance of the spatial group under either assignment was equivalent to that of the integrity verbal group..

Such a pattern of results is quite consistent with the inference that spatial subjects were acquiring, with practice, (i.e, on Day 3) a verbal code with which to label some or all of the spatial stimuli. By processing these with a verbal-left hemispheric code, a high degree of time-sharing efficiency with the spatial tracking task could be maintained. Furthermore, given an option of processing verbally or spatially, subjects may have selected a verbal coding strategy only when it was optimum for them to do so (e.g., with the hand assignment in which integrity could be obtained).

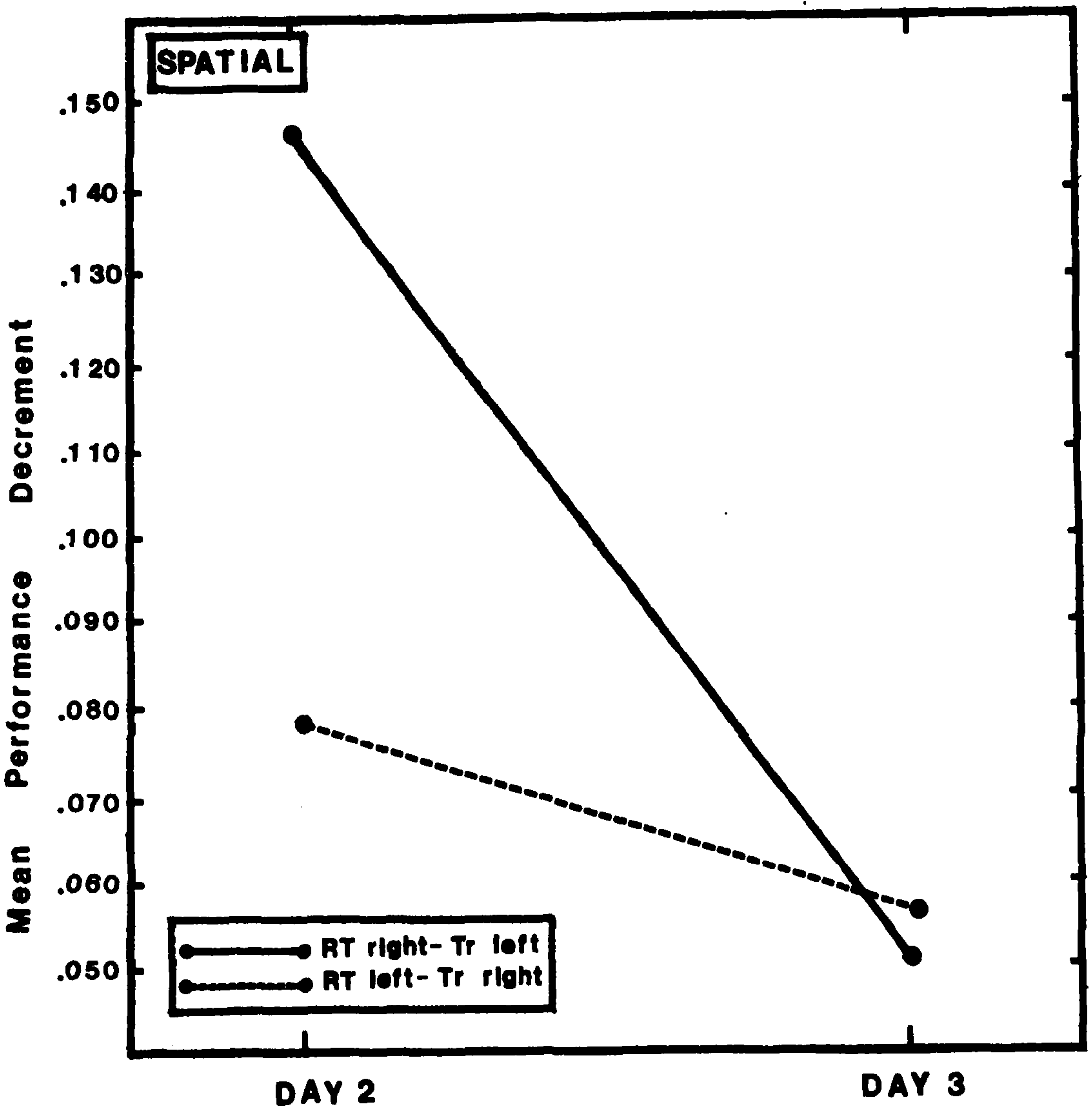


Figure 7: Dual Task Performance Decrements as a Function of Hand Assignment and Day (Experiment 2).

This would account for the greater practice effect observed with this hand assignment. When it was not possible to obtain integrity (e.g. when tracking with the right hand), subjects may have either processed the Sternberg stimuli verbally (thus separating cerebral hemispheres of central processing), or spatially (thus preserving integrity within the Sternberg task). Were subjects in fact performing according to these options, then better absolute efficiency would be observed, for the spatial group in the "integrity" assignment. In fact the difference observed in Figure 7 is in the appropriate direction (efficiency score of .49 vs. .55), although this difference was not statistically reliable.

This interpretation, it should be noted, is quite compatible with the conclusion of other investigators that subjects acquire verbal coding strategies with increasing stimulus familiarity (Umilta, 1978; Cohen, 1979), and that the employment of different processing strategies is to some degree flexible and under subject control (Cohen, 1979; Friedman & Polson, 1980).

This mixing of strategies is also consistent with the considerable degree of between-subject and between-stimulus variability that was found, as well as the reduced dual task interference. It was not assumed that every subject in the spatial group could change the task spatial stimuli to verbal stimuli, nor was it assumed that every spatial task stimuli was labeled verbally. Some subjects may be proficient at verbally labeling spatial stimuli while others may be incapable. Also, some stimuli may have been easier to verbalize relative to the others. These between subject and between stimuli differences may explain the spatial group variance. A study of individual differences in verbalization ability would perhaps give clarification to the finding of attenuated interference effects in the spatial group.

For example, if a subject in the spatial group improved his overall performance level through the use of an occasional "integrity" trial, he would increase variability in the spatial group data, yet would also possibly lower the group overall interference measure.

It should be noted that the reason for invoking the notion of verbal coding strategies with the spatial task in the first place, was because of the non-reliable difference in time-sharing efficiency found between the verbal and spatial groups where greater efficiency was predicted for the verbal group. There is some reason, however, to believe that the null hypothesis cannot be so easily accepted. Thus the power of the design was relatively low, and the variability in performance, particularly of the spatial group, was high. Furthermore, this group performed more poorly in single task tracking than did the verbal group, a difference that approached statistical reliability ($p < .10$), and is presumably due purely to sampling variability. Poorer single task performance for the spatial group would automatically reduce the extent of the dual task decrement. Thus it should be noted that the absolute level of dual task tracking was superior for the verbal, as opposed to the spatial group. Finally, the two groups also differed, for some unexplained reason, with regard to laterality effects of single task performance. The spatial group showed a handedness effect in tracking, whereas the verbal group did not.

The essence of the foregoing discussion is to suggest that the two groups may still have differed in time-sharing efficiency (in favor of the verbal group, but such difference was masked by other substantial between-group differences). In this case a coding strategy interpretation need not be invoked, and the results are quite consistent with the hypothesis that the spatial group processed their sitmuli spatially, and thereby will always time-share with a configuration that is mixed for one task, and integral for other, no matter what hand assignment is employed.

In light of the present results, it is worth reiterating some of the specific implications to systems design, mentioned in the introduction. The validation of the integrity concept argues for left handed placement of controls that reflect spatial processing and right handed placement of verbal processing controls, so long as the task demands are heavy. A relevant question that needs to be addressed, however, concerns exactly what determines the spatial processing qualities of a task. In this regard the present data suggest that a "spatial task," experimentally defined, may lose its spatial qualities with increasing familiarity. We might hypothesize that the requirement for stimulus recognition and identification (as with the Sternberg task used here), will increase the likelihood of verbal labelling of stimuli that are otherwise spatial in nature. While this may characterize some aspects of the pilot's task (e.g. identification of pertinent geographical features or landmarks), many others do not require absolute identification of visually displayed information, but instead processes of either tracking (matching the information with a spatially guided motor command), comparison (monitoring spatial information for out-of-tolerance configurations), or visual search. Provided that task analysis reveals a sufficient number of such activities, whose processing must be registered by overt responses, the hemispheric-integrity concept should be given serious consideration. It should be noted in conclusion that the association of vocal responses with the left hemisphere suggests that the integrity concept might apply with equal relevance when considering the appropriate use of voice, as opposed to manual responses.

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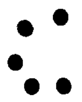
Appendix A

Pilot Study

In order to develop the character set for the spatial Sternberg task, and to assure that it was in fact a task of spatiality, the following steps were performed. One hundred and fifty patterns, each consisting of five dots spatially arranged in a two-dimension 4 x 4 matrix, were generated. The 150 dot patterns were given to four subjects, who were students at the University of Illinois paid for their participation. The subjects eliminated the patterns to which a verbal label could be assigned. For instance, the following pattern could be labeled "C" by the subject and thus, in this case, the subject would think "C" to classify the patterns--and the task would then be a verbal (not a spatial) one.



The subjects eliminated 42 dot patterns to which they could verbally assign a label. A classification scheme was then created to group together dot patterns with similar characteristics. A goal was set to find 24 characteristically different dot patterns. This was similar to the number of stimuli used in the verbal Sternberg task in which 24 letters of the alphabet were used. The 108 dot patterns were classified by rating them on the following characteristics:

1. 4 dots in a cluster
2. 3 dots in a diagonal line (• • •) down
3. 3 dots in a diagonal line (• • •) up
4. 3 dots in a vertical line
5. 3 dots in a horizontal line

6. One dot on each of 4 sides
7. COG (center of gravity) at the top
8. COG at the bottom
9. COG to the left side
10. COG to the right side
11. U-shape ∩ (point up)
12. U-shape ∪ (point down)
13. U-shape ⊂ (point left)
14. U-shape ⊃ (point right)
15. One dot in each of 3 corners
16. 2 dots on each of 2 sides
17. Appearance of a high positive correlation

The ratings were done in a matrix form, thus, when the ratings were complete, the matrix revealed which dot patterns were related characteristically. From these ratings, 24 distinct feature combinations were generated as follows:

1. 4 in a cluster (E)
2. 3 in a diagonal (I)
3. 3 horizontal dots (W)
4. 3 vertical dots (K)
5. One dot on each of 4 sides (F)
6. Center of gravity (T, B, L, R) (P)
7. U-shape (∩ , ∪ , ⊃ , ⊂) (B)
8. One dot in each of 3 corners (C)
9. Two dots on each of 2 sides (X)
10. High positive correlation appearance (G)

11. A diagonal; a COG; 2 dots on each of 2 sides (L)
12. A diagonal; one dot in each of 3 corners (N)
13. A diagonal; a COG (M)
14. 4 in a cluster; a COG (D)
15. 4 in a cluster; 3 horizontal; a COG (V)
16. A diagonal; one dot on each of 4 sides; U-shape (A)
17. A diagonal; one dot on each of 4 sides (H)
18. A diagonal; one horizontal line (S)
19. A diagonal; a COG (U)
20. A vertical line; a COG (O)
21. 4 in a cluster; 2 dots on each of 2 sides (T)
22. 4 in a cluster; a diagonal (Q)
23. One dot in each of 3 corners; 2 dots on each of 2 sides (J)
24. A diagonal; a U-shape (R)

As can be seen, many combinations had two or more characteristics in common. Since each one of the 24 separate types could have been filled with 2 or 3 of the 108 patterns, the one chosen of the 2 or 3 available was selected randomly. This process gave the experimenter the 24 spatially distinct dot patterns shown in Figure 5. Each pattern in Figure 5 corresponds to one of the above 24 descriptions. For example, pattern A corresponds to the sixteenth description (labeled A) which is "A diagonal; one dot on each of four sides; U-shape."

The next step in the pilot study was to find the 24 pairs (out of a possible 276) that were most distinct. To accomplish this task the 276 pairs were drawn and 8 subjects (students at the University of Illinois paid for their participation) rated them as to their similarity. The rating scale was numbered from 1 to 7, number 1 meaning "the pair is completely distinct" and 7 meaning "the pair is identical." These ratings were averaged across subjects for each pair and thus the most distinct appearing pairs were revealed. None of the pairs averaged were rated as being very similar, which means no one stimulus pattern was easily confusable with any other pattern. These 24 distinct patterns became the "alphabet of spatiality" used in the study.

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