Processing Resources and Timesharing Performance

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Introduction

A central issue in the human performance literature concerns the nature of information processing limitations within the human system. A number of major theoretical positions that address the issue have held that processing restrictions arise primarily from structural limits in the system (e.g., Broadbent, 1958) or from the unavailability of some type of capacity or resource that is necessary to process information (e.g., Knowles, 1963; Kahneman, 1973). Regardless of the specific basis that is offered for limitations within the processing system, most theories have held that the source of processing restrictions is unitary (i.e., a single perceptual channel or a single undifferentiated pool of resources). Such unitary capacity theories provide little basis to predict differences in the efficiency of timesharing performance between different combinations of tasks, since all tasks draw on the same limited capacity source. If the demands of a task combination exceed the processing capacity of the system, degraded performance will result, regardless of the specific source (e.g., central processing, motor output) of the load.

Recent evidence (e.g., Navon & Gopher, 1979; Wickens, 1984) however, has indicated that unitary capacity positions may not be the most viable explanation of human processing limitations, and has suggested a multiple resources theory as an alternative. Essentially, multiple resources theory (e.g., Navon & Gopher, 1979; Wickens, 1984) maintains that the processing system can be best described as a series of mechanisms or structures, each with its own limited capacity or resources that cannot be shared with another. In this view, a considerable amount of processing resources may go unused in responding to the demands of a particular task, depending on its particular demand composition. According to multiple resources theory, the timesharing efficiency between two tasks will be determined by the degree of overlap in their demand composition. Tasks with a high degree of overlap will show large decrements in timesharing performance, while tasks with little overlap will be timeshared efficiently.

A critical issue in the multiple resources approach is that of specifying the dimensions or characteristics of the processing system that define the various resources. Several theorists (e.g., Friedman, Polson, Dafoe, & Gaskill, 1982; North, 1977; Sanders, 1979) have discussed a number of such dimensions, but the most comprehensive position is that of Wickens (1984), who has proposed that resources may be defined as the orthogonal combination of three dimensions, each with two levels: (1) stages of processing (perceptual/central processing vs. motor output), (2) modality of processing (visual vs. auditory), and codes of processing and response (verbal/vocal vs. spatial/manual). Although some data exist to support these dimensions, the evidence is not exhaustive, and in some instances, was not developed under recently proposed methodologies (e.g., Navon & Gopher, 1979; Roediger, Knight, & Kantowitz, 1977) for investigating capacity/resource interference under timesharing conditions. Therefore, more extensive tests of the current theory are required to fully evaluate it.

The present study was conducted to investigate the proposed distinction between the two codes of information processing, spatial and verbal. A number of other investigations (e.g., Wickens, Mountford & Schreiner, 1981; Wickens & Sandy, 1982) have included this dimension as a variable, but have manipulated other dimensions (e.g., stages of processing) as well. The purpose of this experiment was to investigate the spatial-verbal distinction in a timesharing paradigm which permitted stages and modalitites of processing to be held constant across the timeshared tasks. This was accomplished by examining concurrent performance of two central processing memory tasks which were visually presented and required manual responses. One memory task was spatial in its processing requirements, and the other verbal. The spatial task was a modified version of a histogram pattern recognition task originally developed by Chiles, Alluisi, and Adams (1968). In the current version, subjects were required to hold the image of a "target" bar graph figure in memory for later comparison with a second histogram. During the retention interval of the spatial task, subjects performed a fixed memory set version of the Sternberg (1966) memory search task. Letters of the alphabet were used as the memory set materials in the Sternberg task, so it was considered to be predominantly verbal in its processing requirements.

In keeping with current methodology (e.g., Navon & Gopher, 1979; Roediger _et al_., 1977) for investigating resource/capacity competition between concurrently performed tasks, two types of manipulation were included in the design. First, each task was performed at two levels of difficulty in both single-task and dual-task conditions. The effect of difficulty of one task on concurrent performance of the second can provide important information about the degree of overlap in processing resources required by the tasks (e.g., Roediger _et al_., 1977). Should either task prove sensitive to difficulty manipulations of the other, some evidence of competition for a common resource(s) is provided. Conversely, instances of difficulty insensitivity (Wickens, 1984) in concurrent task performance would provide evidence which suggests that the two tasks do not compete for a common resource(s).

A second manipulation included in this experiment required that subjects vary the allocation of their attentional capacity or resources between the spatial and verbal tasks under concurrent performance conditions. It has been argued (e.g., Navon & Gopher, 1979) that concurrently performed tasks which share a common resource will demonstrate a "trading relationship" when allocation priorities are manipulated, since capacity/resources released from the low priority task can be used to increase performance on the higher priority task. On the other hand, joint performance of two tasks that do not share a common resource should be relatively unaffected by a priority manipulation, since resources released from one task cannot be shared with the second task. Therefore, evidence of a trading relationship between tasks as priorities are manipulated would support the position that the tasks draw on a common resource/capacity, while failure to demonstrate such a relationship would support the position that separate resources/capacities are required by the two tasks.

Method

Subjects

Subjects were 12 right-handed undergraduate students at Wright State University, 4 of whom were male, 8 female. Each subject received extra course credit for the introductory psychology course in which he or she was enrolled.

Apparatus

Both memory tasks were driven by a Commodore VIC-20 microcomputer with expanded memory. Memory stimuli appeared on a 12 inch black and white video monitor positioned approximately 50 cm directly in front of the subject. Subjects responded to the memory stimuli by pressing the appropriate button on a keypad which was positioned at a comfortable distance in front of their right hand.

Memory stimuli appeared on the monitor in the center of the screen, a black pattern or letter on a white field. The histogram patterns varied in size, depending upon the number of bars in the pattern and the length of the bars. Each bar, however, ranged in length from 8 to 48 mm. The bars were 5 mm in width throughout the experiment, and each bar was separated from other bars by 4 mm of blank space. The letters used in the memory search were constructed by dot patterns from an 8x8 dot matrix which measured 9 mm on all sides.

<u>Procedure</u>

Dual task trials began after the subject had been instructed how to divide his or her attention between the two tasks. Three priority levels were included in the design: (a) a 50/50 condition, in which attention was to be divided equally between tasks; (b) a 75/25 condition, in which 75% of attentional capacity was to be allocated to the histogram task and the remainder to the memory search task, and, (c) a 25/75 condition, in which 25% of attentional capacity was to be allocated to the histogram task and the remainder to the memory search task. The set of letters that would make up the memory set in the memory search task were then presented on the video monitor. In order to manipulate memory search task difficulty, memory set size was varied from 2 to 4 items. The memory set was presented for 10 seconds, and was replaced on the screen with a target histogram for 3 seconds. To increase the difficulty of the task, target histograms were rotated 180° from the upright position. At the conclusion of the histogram presentation interval, memory search letter probes began appearing at a rate of 1 per second. Subjects were to indicate whether or not each probe was member of the memory set by pressing the appropriate button on the response pad. When the 18 second retention interval for the histogram task was completed, letter probes stopped appearing and a comparison bar graph was presented in the upright position. Subjects were given 3 seconds to indicate if the comparison histogram was the same or different than the target. If a subject failed to respond in the time allotted, that trial was counted as an incorrect response.

After the comparison disappeared, a new target pattern appeared. The process was repeated a total of 5 times within each block.

Single task trials used the same procedure with the exception that the screen was blank during the time at which the other task would have appeared in dual task trials. The same number of stimuli appeared in the single conditions as in the dual conditions.

Before testing began, subjects were given one block of practice under each of the following conditions: the pattern recognition task at both levels of difficulty, the memory search task at both difficulty levels, and the four possible combinations of difficulty for dual task practice. During practice on dual task trials, subjects were instructed to divide their attention equally between the tasks.

Design

Each subject participated under all experimental conditions. Each combination of the two levels of difficulty was performed three times, once at each priority level. Presentation order of both task combinations and priorities were counterbalanced across subjects. Each subject also performed each level of difficulty for both tasks singly before and after the dual task trials. The order of these blocks was also counterbalanced across subjects.

Results

Primary interest in the data analyses was focused on the reaction time data, which were expected to be more sensitive than errors to difficulty manipulations in both tasks. Mean error rates were very low in the memory search task data (5-10% across single and dual-task conditions), and were relatively low in the histogram task data (12-30%

across single and dual-task conditions). Although the percentage of histogram task errors was higher than in the memory search task, mean histogram errors were minimal (0.6-1.6 across single and dual conditions). Because of the restricted range of variability, analyses of the error data were principally intended to determine if any trends in the reaction time data were attributable to speed-accuracy tradeoffs.

Dual-Task Priority Analyses

Dual-task reaction time data in both the memory search and histogram tasks were initially analyzed using three-factor repeated measures analyses of variance (ANOVAs). Two levels of memory search difficulty (memory sets of 2 and 4), two levels of histogram difficulty (2 and 6 bars), and three priority levels (75/25, 50/50, 25/75) were included in each ANOVA. The major purpose of each ANOVA was to determine if the effect of priority or any priority x difficulty interactions were significant. Significant priority effects could indicate that resources released from one task could be used to increase performance on the other task. None of the priority manipulation effects proved significant in either reaction-time analysis, thereby failing to provide support for the presence of a trading relationship between tasks.

Comparable ANOVAs on the error data produced the same priority results for the histogram task. However, the memory search error analysis demonstrated that the main effect of priority was significant [$F(2,22) = 11.17$, $p < .001$]. Post-hoc Newman-Keuls analyses indicated that the 75/25 priority condition produced significantly more memory search errors than the other two conditions. The 75/25 condition required that subjects emphasize performance of the histogram task over the memory search task. The result is therefore in the direction expected for a trading relationship with such a manipulation. However, the failure to demonstrate significant priority effects with either histogram task dependent variable indicates that the effect was asymmetrical and that resources released from the memory search task in the 75/25 condition did not significantly improve performance on the histogram task.

There are several potential explanations for such asymmetry in the priority effect. One potential reason for the failure to demonstrate improved histogram performance is that it was in a data limited region (Norman & Bobrow, 1975) of the underlying performance-resource function. The histogram error and reaction time ANOVAs did not suggest that this was the case, and indicated that the main effect of histogram difficulty was significant in the reaction time analysis [$F(1,11) = 12.99$, $p < .005$], and marginally significant in the error analysis [$F(1,11) = 3.11$ $p > .10$]. Since reaction times were significantly affected by difficulty and since the effect on errors approached significance, the data do not strongly support the conclusion that the histogram task was data limited.

Another possible explanation of the asymmetry involves greater resource efficiency in the memory search task than in the histogram task. If this were the case, a number of resource units released from memory search under the 75/25 condition could cause significant decrements in that task, but not significantly affect histogram task performance. However, under this explanation, it appears that there should have been a significant difference in memory search errors between the 25/75 (memory search emphasis) and the 50/50 (equal emphasis) conditions, since resources released from the histogram task should have significantly improved memory search performance. Mean errors in the 25/75 condition (5.1) were quite similar to those in the 50/50 condition (6.8), and the Newman-Keuls indicated that there was no significant difference between the two. Therefore, this explanation is also not supported by the data.

A third possible explanation for the asymmetrical priority effect is that subjects in the 75/25 condition chose to follow instructions by de-emphasizing memory search performance, but that resources released from the memory search task could not be used to improve histogram task performance. This explanation requires the assumption that subjects chose to reduce the resources invested in the memory search task under the 75/25 condition to a greater extent than they did from the histogram task under the 25/75 condition, and the present data provide no means of evaluating this assumption. In contrast to the two explanations noted above, this explanation assumes that no trading was possible between resources of the memory search and histogram tasks.

Overall, therefore, the results of the dual-task priority analyses provide very little evidence of substantial resource trading between tasks as priorities were manipulated. Neither reaction time variable demonstrated a priority effect, and the histogram error analysis also failed to indicate that the priority manipulation was significant. Neither resource trading explanation of the priority effect in memory search errors is completely supported by the data, and an alternative explanation that involves no resource trading appears just as feasible. Therefore, it is concluded that the priority analyses did not provide strong support for the trading relationship between the memory search and histogram tasks that would be expected if they were drawing from the same resource(s).

Difficulty Manipulation Analyses

Because the effects of priorities were minimal and limited to one condition in the memory search errors, the data were collapsed across priorities for subsequent analyses of difficulty manipulation effects.

In order to investigate the effects of task difficulty manipulations and timesharing requirements on memory search and histogram performance, individual repeated measures ANOVAs were conducted on the memory search and histogram reaction-time data. Memory search reaction time data were analyzed with a 2 difficulty level (memory sets of 2 and 4) x 3 condition (single task memory search; dual-task memory search with easy histogram; dual-task memory search with difficult histogram) ANOVA. A comparable 2x3 ANOVA was performed on the histogram data, with histogram difficulty as the two-level factor and single and dual task histogram performance at each memory search difficulty level as the three-level factor.

Figure 1 shows mean memory search reaction time as a function of memory search task difficulty and performance condition (single vs.

Insert Figure 1 about here

dual-task performance at two histogram difficulty levels). As is clear from the figure, memory search task difficulty had an appreciable effect on reaction time, while condition had a minimal influence. The memory search reaction-time ANOVA confirmed these trends, and indicated that the main effect of memory search difficulty was significant [$F(1,11) = 61.07$, $p < .001$], while the effect of conditions [$F(2,22) = 0.75$, $p < .50$], and the difficulty x condition interaction [$F(2,22) = 1.83$, $p < .20$] were not significant.

Figure 2 illustrates the effect of histogram difficulty and conditions on mean histogram task reaction time. The pattern in

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Insert Figure 2 about here

Figure 2 is very similar to that of the memory search data, in that the difficulty variable had a substantial effect on reaction time, while condition did not. The histogram task ANOVA again confirmed the noted pattern, and indicated that while histogram difficulty significantly [$F(1,11) = 13.73$, $p < .005$] affected performance, condition did not [$F(2,22) = 0.53$, $p < .60$]. The difficulty x condition interaction also failed to reach significance [$F(2,22) = 0.50$, $p < .65$].

The results shown in Figures 1 and 2 are therefore consistant with the pattern of difficulty insensitivity discussed earlier, in that neither memory search nor histogram reaction times were significantly affected by increases in the difficulty of the timeshared task. In each instance, however, difficulty manipulations in the task itself were associated with significant variations in performance, thereby confirming the effectiveness of manipulations that were employed.

In order to ensure that the pattern of difficulty insensitivity evident in Figures 1 and 2 was not the result of speed-accuracy tradeoffs, both memory search and histogram task errors were subjected to analyses that were comparable to those conducted on the reaction-time data. Figure 3 shows mean percent error in the memory search task as a

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Insert Figure 3 about here

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function of memory search difficulty and condition. It is clear that the pattern of data in Figure 3 is quite similar to the reaction-time data, and this was confirmed by the ANOVA conducted on the data. The ANOVA indicated that the main effect of memory search task difficulty was significant [$F(1,11) = 17.57$, $p < .005$], but that neither condition [$F(2,22) = 1.08$, $p < .40$] nor the difficulty x condition interaction [$F(2,22) = 0.70$, $p < .55$] were significant. The failure to find a significant condition effect confirms that the difficulty insensitivity pattern observed in the reaction-time data was not the result of a speed-accuracy tradeoff.

Figure 4 illustrates the effect of histogram difficulty and condition on histogram errors. The pattern in Figure 4 is somewhat

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Insert Figure 4 about here

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different than in previous figures, in that histogram difficulty had a small effect relative to condition. The 2x3 ANOVA conducted on the data indicated that the effect of histogram difficulty was marginally significant [$\underline{F}(1,11) = 3.16$, $\underline{p} < .11$], the condition effect was significant [$\underline{F}(2,22) = 3.79$, $\underline{p} < .05$], and the difficulty x condition effect was marginally significant [$\underline{F}(2,22) = 2.21$, $p < .14$]. Post-hoc Newman-Keuls analyses of the condition data indicated that both dual-task conditions produced a greater number of errors than the single-task condition ($p < .05$). Dual-task conditions did not differ from one another. The marginally significant histogram effect confirms a trend noted in the dual-task priorities analyses, and may be partially attributable to a floor effect in histogram errors which averaged less than 1.0 in the easy single-task condition. Although there was a significant single to dual task decrement in histogram performance, the failure to find a significant difference between the easy and difficult dual-task memory search conditions confirms that the difficulty insensitivity noted in dual-task histogram reaction-time data is not attributable to a speed-accuracy tradeoff.

Discussion

The overall pattern of results in both the priority and difficulty manipulation analyses provide strong support for current multiple resource approaches (e.g., Wickens, 1984) which propose that tasks which are predominantly verbal in their processing requirements draw on resources that are separate from those involved in processing of spatial information.

Priority manipulations in dual task situations proved generally ineffective and provided no consistent evidence of the trading relationship (e.g., Navon & Gopher, 1979) expected between two tasks that were competing for the same limited resource(s). Memory search task error data provided the one exception to this general trend, but since histogram task performance failed to demonstrate a comparable result, the effect was asymmetrical. Two explanations for this asymmetry which presuppose that the tasks were drawing on the same resource(s) maintain that: (a) the histogram task was in a data limited region of the performance-resource function; or (b) resource efficiency in the memory search task was greater than in the histogram task, causing "x" units of resources released from memory search to be associated with significant decrements in that task but not with significant improvements in histogram task performance. Analyses of histogram difficulty manipulation effects failed to provide strong evidence for the first explanation, and post-hoc analyses of memory search priority shift effects did not support the second explanation. It therefore appears just as feasible that the noted priority effect could have arisen from subjects attempting to follow priority instructions by de-emphasizing memory search task performance with no resulting capability to increase histogram performance. This explanation assumes, of course, that the memory search and histogram tasks draw on separate processing resources, which is consistant with the priority results with the other dependent variables. The overall pattern of priority manipulations therefore appears most supportive of the position that the verbal memory search and spatial histogram tasks draw on separate processing resources.

The effects of both memory search and histogram difficulty manipulations on concurrent performance of the timeshared task also support the view that verbal and spatial processing functions draw on independent resources. Analyses of difficulty manipulations indicated that increases in memory search task difficulty had no significant effect on concurrent histogram task performance, and that increases in histogram difficulty caused no significant decrements in memory search performance. In most instances, there was also no evidence of a significant decrement from single to dual task performance, although histogram errors did show such a decrement. Because single-to-dual decrements can be attributed to factors (e.g., concurrence costs) other than resource/capacity interference (e.g., Navon & Gopher, 1979; Roediger et al., 1977), the noted decrement cannot be clearly interpreted as reflecting such competition between the tasks. Therefore, the overall pattern of difficulty insensitivity is also completely consistent with the position that the verbal memory search and spatial histogram tasks draw on separate processing resources.

Further support for the distinction between verbal and spatial processing resources could be obtained by additional research designed to supplement the current priority and difficulty insensitivity findings. This research would take the form of demonstrating that the verbal memory search task used in this experiment would demonstrate priority and difficulty sensitivity when timeshared with a second memory task that was predominantly verbal in its processing requirements, and that comparable results would be obtained if the present histogram task were timeshared with a predominantly spatial central processing task. These patterns of priority and difficulty sensitivity are consistent with current multiple resources theory, and confirmation of the predicted pattern would complement the present results. Work is currently underway in our laboratory on the first of these additional experiments.

In addition to their theoretical importance, the current difficulty insensitivity data have significant practice implications as well. One of the most extensively used workload assessment methods, for example, is secondary task methodology (e.g., Ogden, Levine, & Eisner, 1979; Williges & Wierwille, 1979). This approach requires concurrent performance of two tasks, under the assumption that performance levels in the secondary task will reflect any difficulty variations that are present in the primary task. Unitary capacity theories (e.g., Boradbent, 1958) provide no basis to predict differences in the sensitivity of the secondary task to difficulty variations in the primary task. However, the current difficulty insensitivity results, which are consistent with multiple resources theory, indicate that a predominantly verbal secondary task would be ineffective in assessing demand manipulations in a spatial primary task. The same insensitivity would, of course, be true of a spatial secondary task used in conjunction with a verbal primary task. The present data, therefore, indicate that the effectiveness of a secondary task will be directly related to the degree of overlap in the spatial and verbal processing resources demanded by the primary and secondary tasks.

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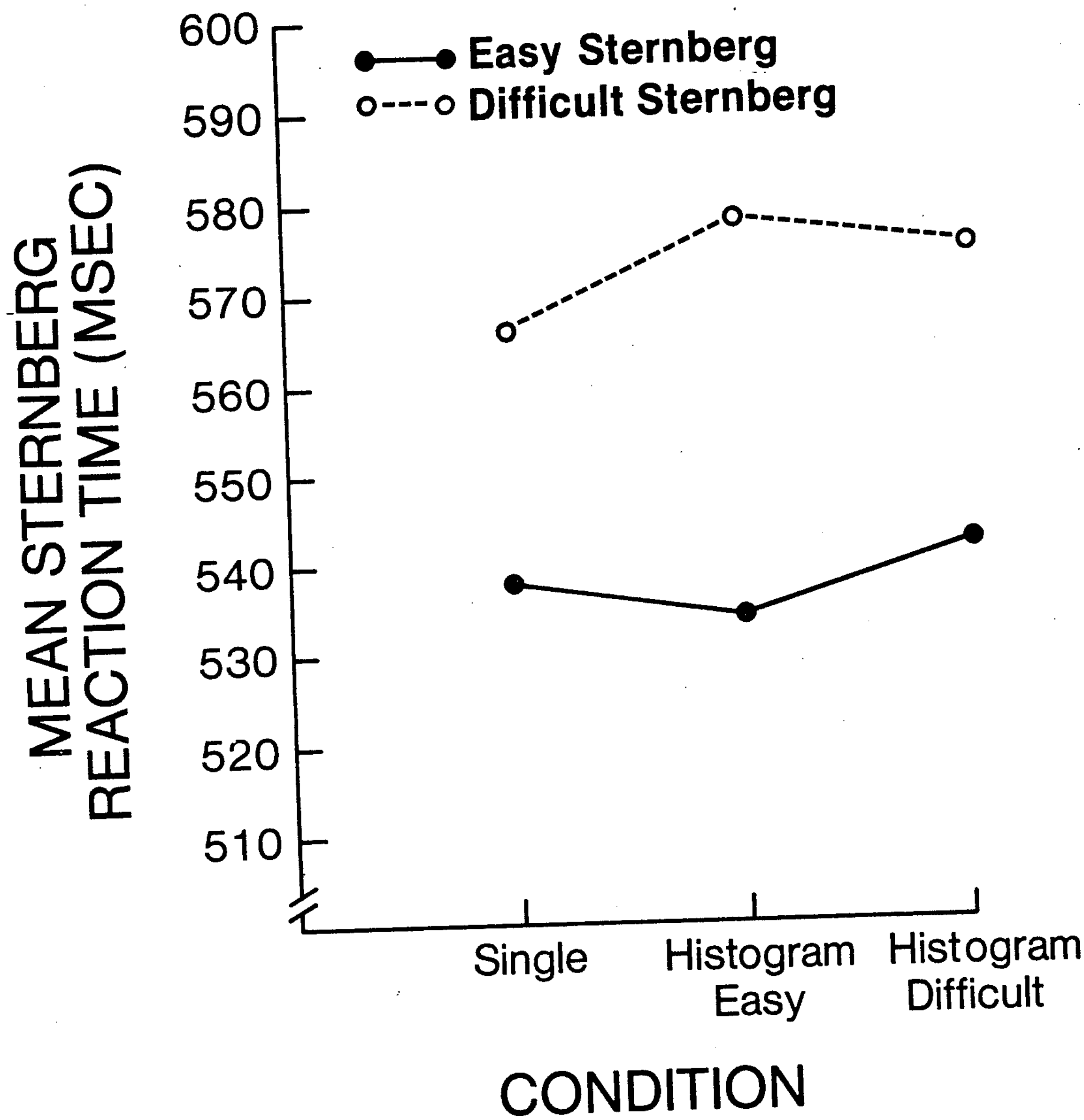

Easy Sternberg
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MEAN STERNBERG REACTION TIME (MSEC)
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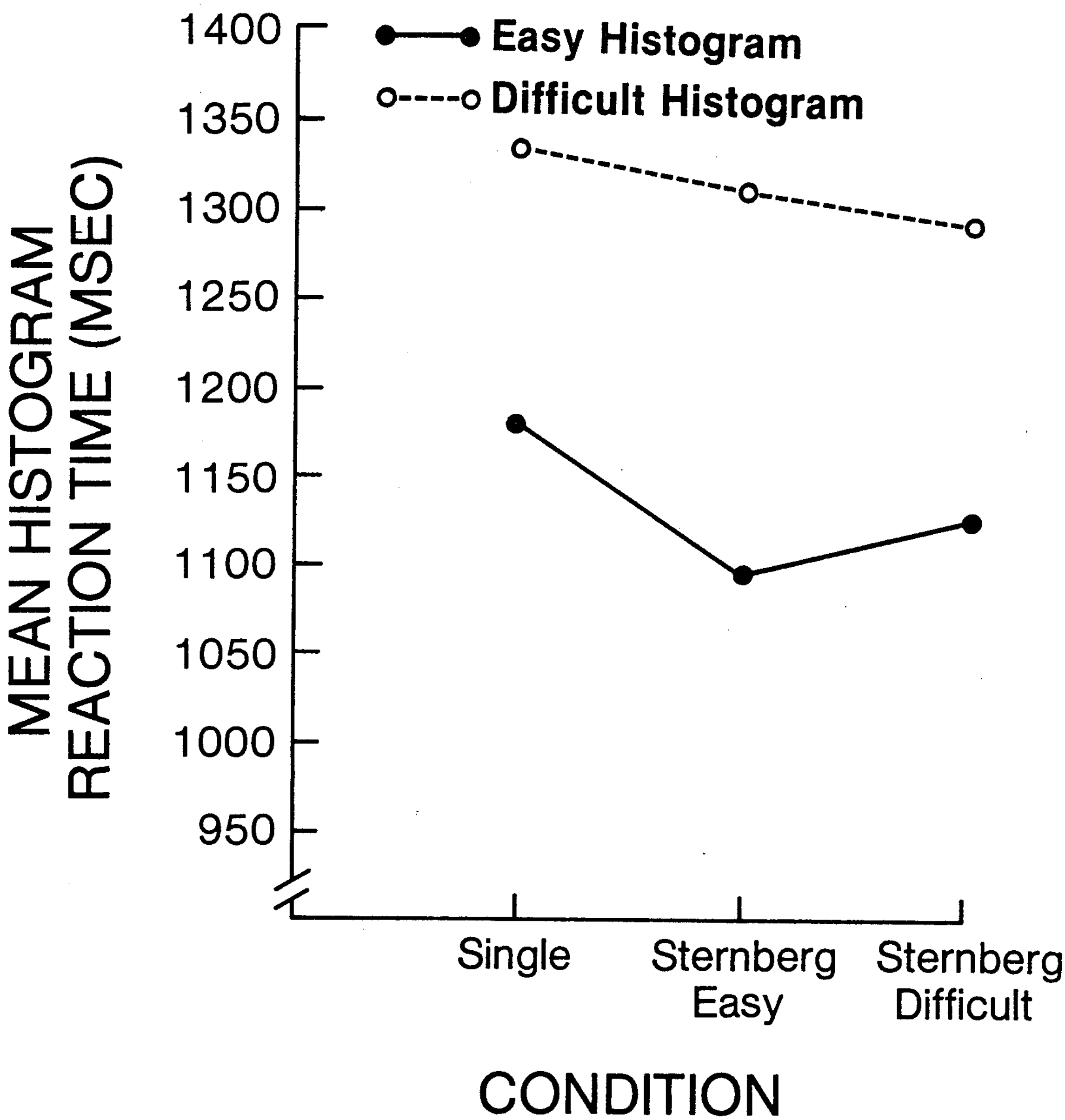
Easy Histogram
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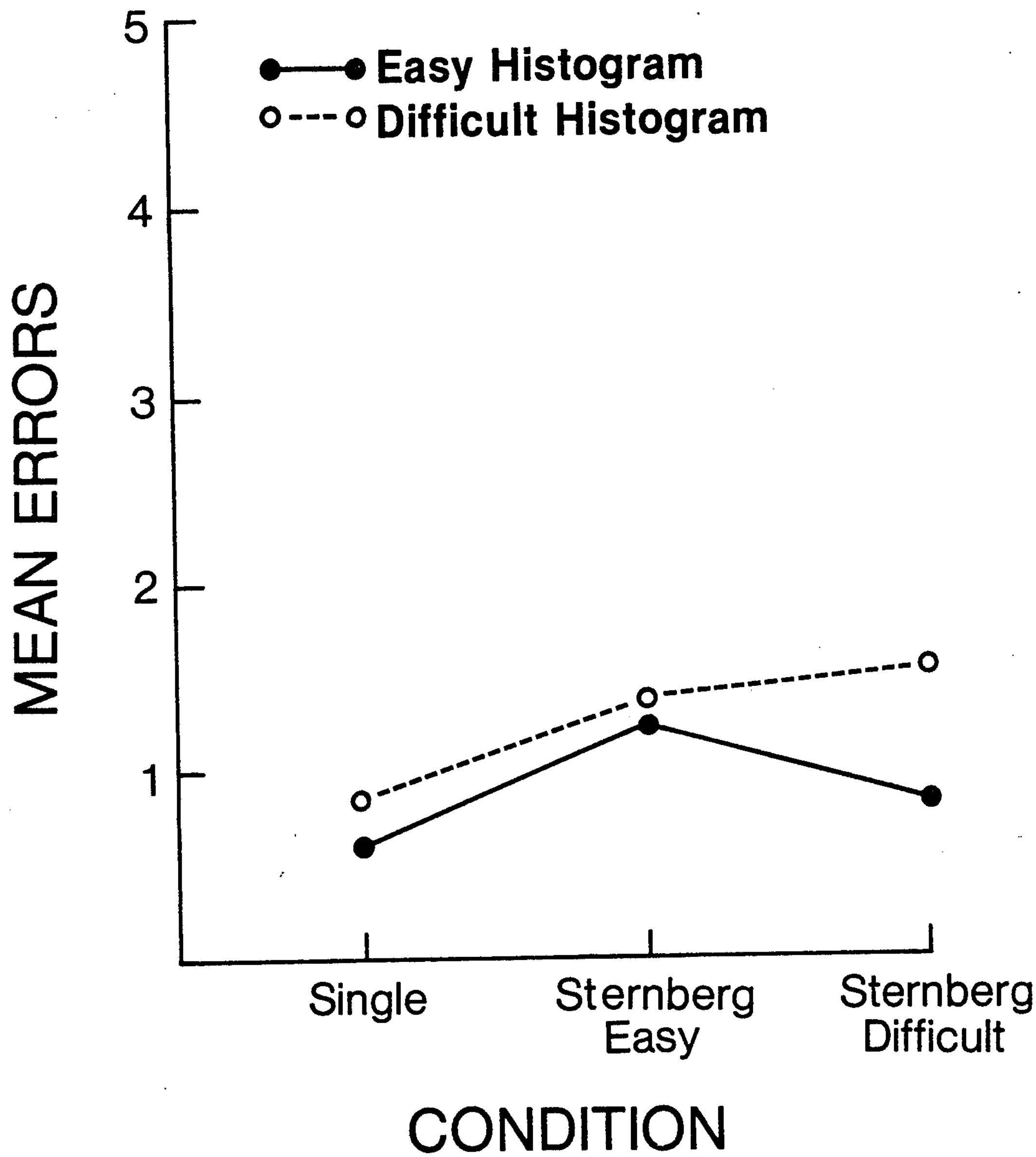
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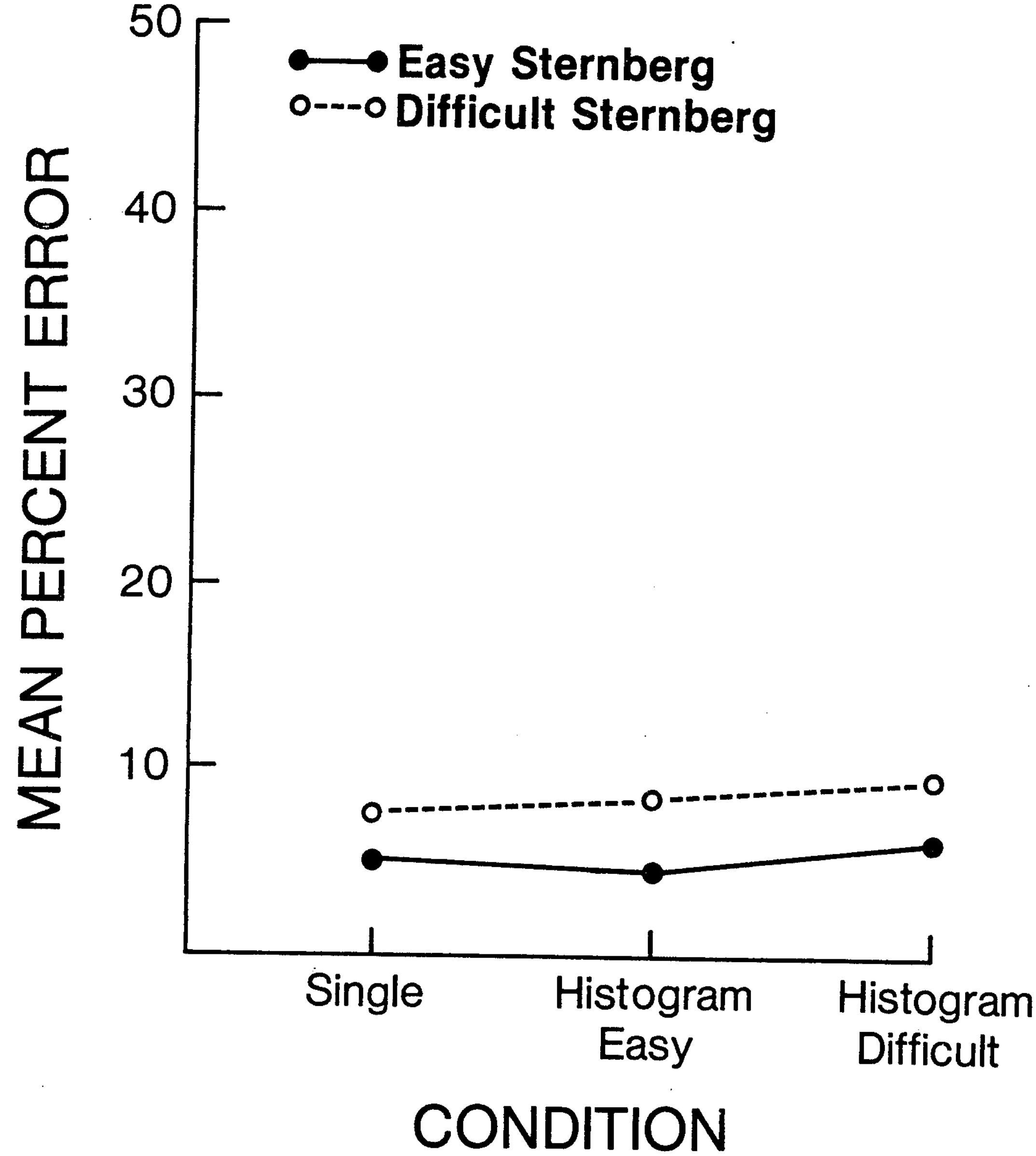
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