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The Effect of Alerting Drugs on Planning Performance during Sustained Operations

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INTRODUCTION

Planning is a fundamental and critical activity in the accomplishment of military missions. Sometimes planning can be carried out well in advance of an operation; at other times it is subject to extreme time pressure — the need to "plan on the fly". Like other activities in the military, planning during an operation can be required at any time around the clock, and for intensive periods. In fact, it is acknowledged that a good Commander is always planning. Thus it is of concern to determine whether and how sleep deprivation (SD) affects planning and whether alerting substances can successfully ameliorate any deterioration in planning performance. The experiment described here addresses these issues and, in particular, investigates how two alerting drugs, amphetamine and modafinil, affect planning. This study was carried out in the context of a larger experiment addressing the effects of amphetamine and modafinil during 64 hours of sleep deprivation as described in Pigeau et al. (1995) in these proceedings.

Military planning, of the type carried out in command and control, is primarily a cognitive activity by which the resources and constraints associated with an aim or mission are analysed to create a set of temporally-ordered actions to be carried out in the future (McCann & Essens, 1991). Military planning problems typically involve the following:

a) space (terrain) and time
b) many units of varying capabilities (e.g., mobility, sensing ability) whose actions must be co-ordinated
c) an uncertain environment
d) an active adversary.

McCann and Essens (1991) have proposed and partially developed a planning problem that includes the first two of these characteristics. A military adaptation of this problem was used for this experiment.

METHOD

Subjects. 34 Canadian Forces regular and reserve personnel participated, 11 in each of the amphetamine and placebo conditions and 12 in the modafinil condition.

Task. The planning task was an ammunition dumping problem where Ss determined an efficient dumping order for 15 types of ammunition required at different locations in a military area. Ss planned using a map provided for them on paper boards and a computer interface to order the ammunition dumping. The map of the area was configured on a 14 x 14 grid, as shown in Figure 1, with the 15 dumping sites to be visited highlighted. The task required that the ammunition for dumping be distributed exactly between two vehicles with different carrying capacities and travelling speeds. One vehicle (a 2-1/2T) travelled at 10 Km/hr and the other (a MLVW) travelled at 20 km/hr. The order in which the ammunition was assigned to the vehicles determined the order in which they visited the dumping sites. Vehicles were to start their dumping routes at the "12 DEP START" location and to end at "13 DEP END" location. The aim in planning was to make the most efficient use of the vehicles and have them spend the least amount of time in the operational area.

Ss used a computer interface showing a list of the ammunition to create their plans, i.e., make the allocation of ammunition between the vehicles and the ordering for drop-off. (Drawing of routes on the paper map was not permitted.) Ammunition items could be dragged from the original list into slots in the pallets for the two vehicles and re-arranged as desired. All interaction with the interface was done using a mouse to click and drag items or make selections. Once a plan had been completed, it could be submitted to the computer for scoring.

Problems. The 36 problems used in the experiment were based on 3 layouts of dumping sites. By varying the relative capacity of the vehicles (between 4 and 11 slots in the pallet) a set of comparable but different problems were created. The optimum solution for each problem was computed using a program especially written for the purpose. The solution for a layout-vehicle capacity combination consisted of two parts: the allocation and order of ammunition items assigned to the 2-1/2T, plus the score for that route; and the allocation and order of items assigned to the MLVW, plus score. The optima for the problems ranged from 25 steps (equal to a move from one square to the adjacent one) to 40 steps.

To avoid having Ss solve the same problem, and yet have some basis on which to assess performance across the SD period, two strategies for configuring the problems were adopted. First, Ss were given the same problem (a relatively difficult one having vehicle capacities of 7 and 8 for the 2-1/2T and the MLVW respectively) every third time they performed the task. Second, that replicated problem was presented in different versions created by rotating and/or reflecting the map layout, re-naming the dumping sites and randomizing the list to be allocated. (These procedures were also carried out for the non-replicated problems.) Although they looked quite different to the Ss, the replicated problems were topologically equivalent, and so had exactly the same optimum solution (score - 28).

Procedure. A description of the overall experiment is given in Pigeau et al. (1995). One planning problem was given every two hours during SD,

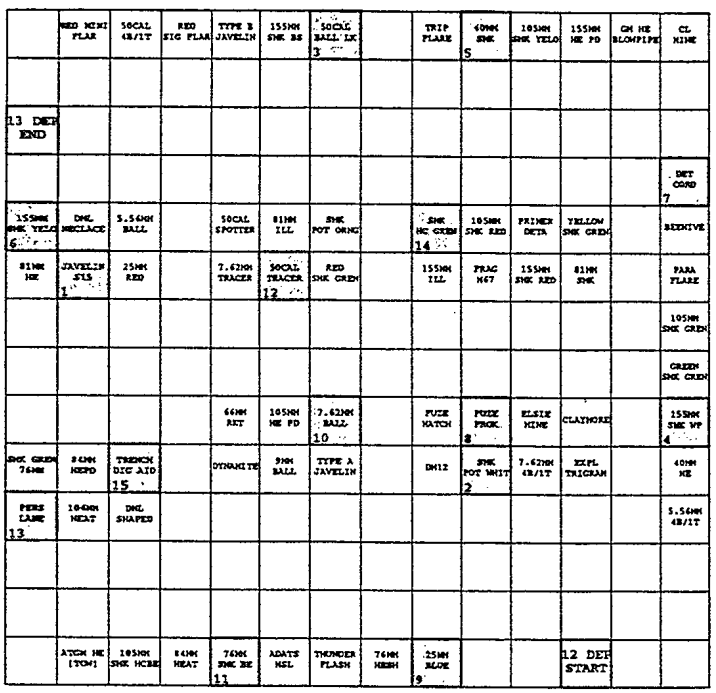

Figure 1: Example of the map layout provided for a planning problem

with every third problem being a replicated one. Subjects were given the map for the next problem in an envelop which they opened upon seeing the planning problem interface appear on the PC. Ss had 10 minutes to create the best plan that they could, i.e., one that minimized the time that the vehicles spent in the operational area. Ss created and submitted plans using the computer interface whereupon a score was returned for each vehicle's part of the plan. After receiving feedback on their plan, the subjects were asked to "Try to improve the plan". The previous plan remained on the screen and could be used as a basis on which to make the next. A warning signal was given when two minutes remained in the 10 min planning period.

Ss were instructed that they would be scored on the best plan that they completed during the session, and that it was to their advantage to provide as many plans as possible, since this would increase their chances of improving their plans.

RESULTS

Results will be discussed in terms of the following dependent variables: the time taken to create the first plan in a session; the number of plan attempts in a session; and the best score achieved for the problem in the session.

Due to a combination of unfortunate circumstances — fire alarm at 1645h on Thurs for a placebo group which required that Ss be evacuated from the building and a series of power failures between 1045h and 1645h on Thurs for one modafinil group — there was some data loss late in the experiment. Therefore, the problem at 1645h on Thurs was removed from further analysis.

Time to First Attempt

Figure 2 shows the time taken by Ss to submit their first plan, for the replicated problems only, which were exactly the same in difficulty and given once every six hours. A three between (Drug) by seven within (Session) mixed analysis of variance (ANOVA) yielded a significant Sessions effect ($F(6,180) = 9.62$, $p < .0001$) and a Drug by Session interaction ($F(12, 180) = 1.91$, $p < .04$). Groups in all drug conditions began by taking an average of 175 sec to create their first plan. Group performance degraded with SD, with the placebo (PL) group suffering a 40% increase in time to submit the first plan after the first night and a 57% increase by the end of the second night. Subjects in the amphetamine (AM) condition and, in particular, the modafinil (MO) condition did not experience such a steep decline during the first night, although performance of AM declined to that of the PL condition by the end of the second night.

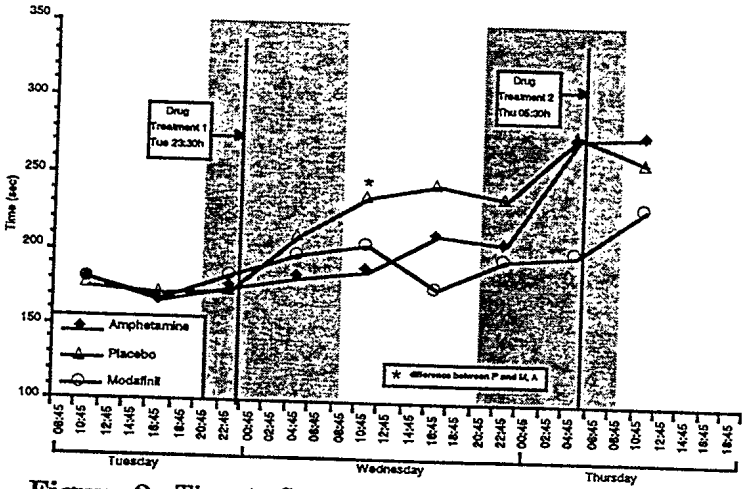

Figure 2: Time to first attempt - replicated problems

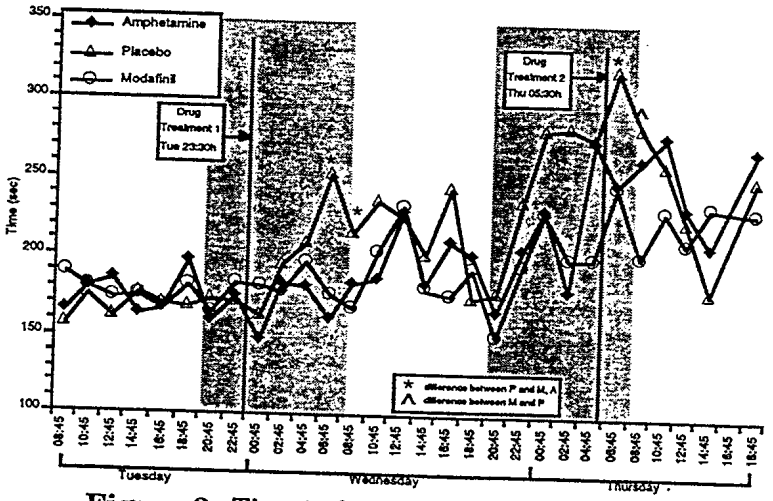

Figure 3: Time to first attempt - all problems

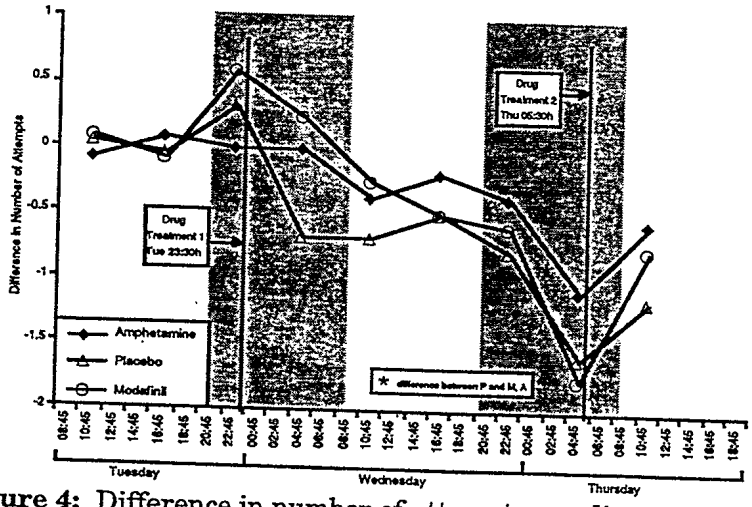

Figure 4: Difference in number of attempts - replicated problems

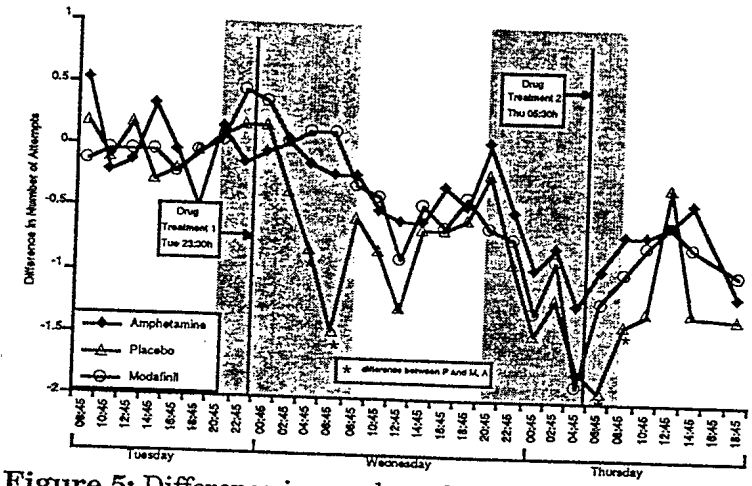

Figure 5: Difference in number of attempts - all problems

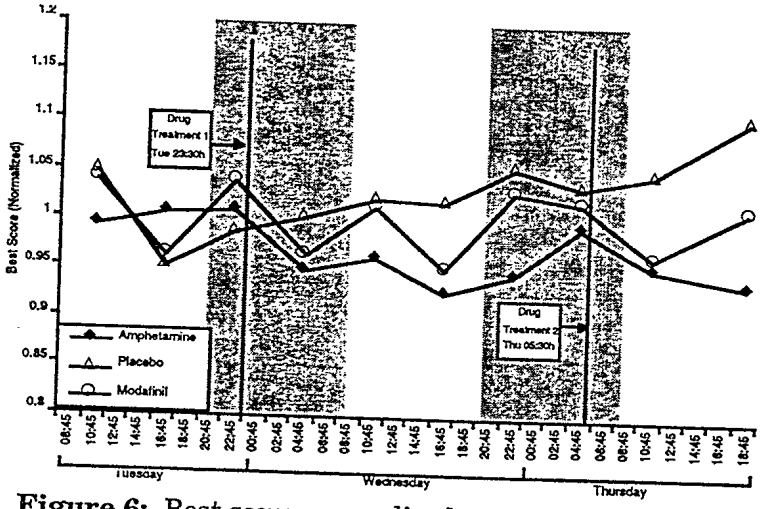

Figure 6: Best score, normalized - replicated problems

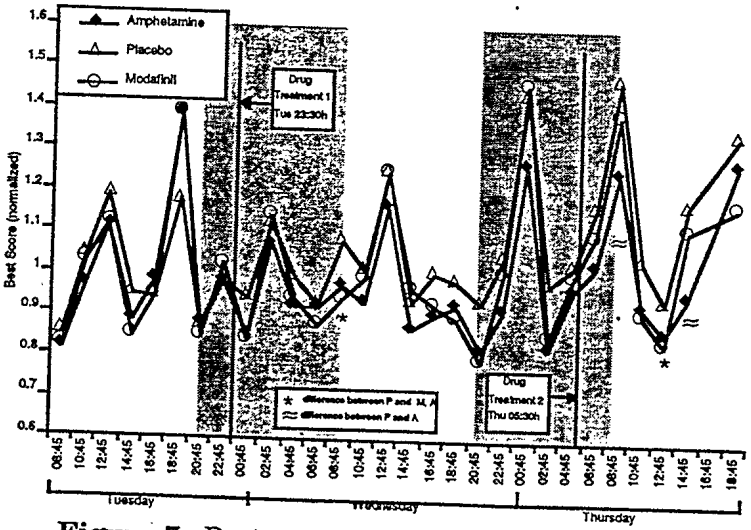

Figure 7: Best score, normalized - all problems

Figure 3, showing the time required to create the first plan for all problems, indicates the same overall decline in performance, with an especially steep increase in plan time for the placebo condition during the first and second nights. Analysis of variance indicates a Drug by Session interaction ($F(56, 843) = 1.57$, $p < .006$). Post hoc analyses yielded significant differences between the AM and MO conditions and the PL at both 8 and 10 hours after the first drug treatment, and at two hours after the second drug treatment, as shown in Figure 3. The difference between MO and PL continues to be significant up to four hours after the second treatment.

Number of Attempts

During the first 11 sessions (up to 2245h on Tues), Ss made an average of 3.4 attempts to create a plan during the ten-minute period allotted. Figure 4 shows that the number of attempts on the replicated problems declines during SD. The data are presented as the difference against the mean number of attempts (calculated by subject) for the first two replicated sessions on Tues, to account for initial differences between Ss. ANOVA yields a significant Sessions effect ($F(8, 242) = 14.79$, $p < .0001$), but no interaction. The data mirror those of time to first attempt, with an overall reduction in the number of attempts for all conditions, especially during the two nighttime periods, and a stabilizing of performance during the intervening day. Again, the PL group declines more dramatically than either of the AM or MO groups on the first night. The AM group experiences a reduction in number of attempts comparable to that of PL at the end of the second night, resulting in an average of almost two fewer attempts per planning session than on the first day. Both AM and MO groups recovered more quickly than the PL group after the second treatment.

The results for all problems are presented in Figure 5 (normalized as a difference from the S's mean of the first 8 sessions). They show the same pattern, with a particularly severe decline in PL performance on the first night, compared to AM and MO.

To investigate the effect of the drug treatments, we performed an ANOVA on the data from the two 10-hour periods starting just before each drug treatments. This revealed a Session by Drug interaction ($F(24, 348) = 1.65$, $p = .03$). Post hoc analyses indicated significant differences between the AM/MO and PL groups at 6 and 8 hours after the first treatment, at the bottom of the circadian cycle. It appears that the effect was stronger for MO than AM, as it succeeded in maintaining that group's performance during the nighttime period at a level comparable to the daytime. The second drug treatment appears to cause a faster recovery in performance for both drug conditions, as reflected in the significant differences in performance between AM/MO and PL 2 and 4 hours afterwards.

Best Score

Score is an indicator of the quality of the S's plan. Scores on the replicated problems provide a consistent way of measuring plan quality during SD, as these problems all had the same optimum solution (a score of 28 steps). The data on mean best score achieved in a session for the replicated problems are given in Figure 6, normalized as a ratio against the individual S scores in the first two sessions on Tues. Thus Figure 6 shows how the best score achieved in a session increases (i.e., plan quality degrades) or decreases (i.e., plan quality improves) as SD progresses. There is a slight tendency for plans created by the placebo group to degrade (about 5%), and for the AM group to improve (also about 5%); quality of the modafinil plans stays constant. Unfortunately, the analysis of variance yielded no effects for Session, Drug or their interaction for these replicated problems.

The scores for all problems provide a finer-grained view of how plan quality varies (based on a two-hour resolution, rather than a six-hour resolution). Figure 7 shows the best scores achieved for all problems normalized as a ratio against the mean S scores for the first 8 problems given on Tues. Since Figure 7 includes problems that are not-replicated, the optimum scores vary between 25 and 40 (i.e., the best plan the Ss can produce is never less than the optimum). This accounts for the "spikiness" in the data across sessions. Overall the PL group degrades slightly more than the AM or MO by the end of the SD period, although this is difficult to see due to the inherent differences between problems. ANOVA confirms, in addition to an effect of Session ($F(27, 31) = 46.2$, $p < .0001$), both a Drug effect ($F(2, 31) = 10.09$, $p < .0004$) and an interaction between Session and Drug ($F(54, 813) = 1.77$, $p < .001$). Overall, the PL group performed worst on this measure (mean 1.056) with MO slightly better at a mean of 1.012, and AM best at 0.977. Post hoc tests carried out on the 10 hour period after the first drug treatment indicate significant differences between the scores of the AM and MO groups and the PL group at 10 hours after the first treatment. Tests after the second treatment show significant differences between AM and PL at 4 and 10 hours post treatment and a difference between AM/MO and PL at 8 hours.

In over 54% of the replicated sessions (51% non-replicated), the best score for the problem was achieved on the first attempt. In 84% of the replicated sessions (82% non-replicated), best score was achieved on either the first or the second attempt.

The similarity in these distributions of achieving best score suggests that Ss were not recognizing the replicated problems, and thus were forced to solve them "from scratch".

CONCLUSIONS

Taken together the results show that performance on the planning task was affected detrimentally by SD. The effect was manifest primarily in the longer times taken to create an initial plan (almost 60% longer for the placebo group at the end of the second nightime period); and in the fewer attempts that Ss made to improve their plans (almost 2 fewer, compared to the average of 3.4 attempts at the beginning of the SD period). The quality of the solutions to the replicated problems, which were equivalent in difficulty, did not degrade to a statistically significant degree, as measured by the best score achieved in a session. However, there were small, but significant effects of Drug on the best score when the whole problem set was considered, with amphetamine being associated with the best results overall and placebo with the worst. These results are consistent with Angus and Heslegrave (1985) where typically the time taken to carry out a task increases under sleep deprivation, but the accuracy is less affected.

There were significant effects due to drug, with amphetamine and modafinil both reducing the detrimental effects of SD as compared to placebo. The ameliorating effect of the first drug treatment showed most strongly at the end of the first night (the bottom of the circadian cycle), when the influence of SD on performance was most severe. The effect of the treatment showed first in a difference in the number of attempts compared to placebo (Wed at 0445), followed later by a difference in time to create the first plan (at 0645) and finally a difference in best score showing 2 hours later (at 0845). Post treatment planning performance on these three measures seemed to be slightly better for modafinil than amphetamine, especially in maintaining a higher number of attempts.

A similar effect is evident after the second treatment, especially in respect of best score, where both amphetamine and modafinil restore performance. Time to plan and number of attempts are also improved within 2 hours of treatment with amphetamine and modafinil (compared to placebo); however these results should be viewed with some caution, because of the differences in group performance that already existed before treatment.

In summary, plan performance degrades overall under sleep deprivation, in terms of the time to create an initial plan and the amount of effort Ss are willing to put into improving their plans (as reflected in the number of attempts). Plan quality degrades only slightly. Subjects seem to compensate for fatigue by putting more time into creating plans at a certain level of quality. A definite and beneficial effect of the modafinil (and amphetamine) on planning performance is seen at the end of the first night of sleep deprivation (the bottom of the circadian cycle). The beneficial effect of the second drug treatment is less conclusive but also suggests an improvement in planning performance.

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Effects of Modafinil and Amphetamine on tracking performance during sleep deprivation

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Introduction

This study was part of a comprehensive study of the effects of the drug modafinil on various aspects of human performance during sleep deprivation (Pigeau et al., In Press). In military operations, the behaviour of various elements and aspects of a situation often must be tracked continuously, perhaps by sleep-deprived personnel. The study reported here simplifies the problem of tracking a complex evolving situation down to its minimum, a single item that is affected by influences outside the control of the observer.

In each of six tracking tasks, the subject was required to maintain the relation between an on-screen cursor and a marker during a period of 50 sec. In any one task, either the cursor position or the marker position was affected by a disturbance generated from a number sequence previously computed. The subject could use the mouse either to compensate for a disturbance added to the cursor, or to cause the cursor to follow the movements of a marker that was affected by the disturbance.

According to the experimental design, twelve subjects were to be given modafinil three times during the sleep deprivation period, twelve were to be given amphetamine, which is believed to counter the effects of sleep deprivation, and twelve were to be given a placebo. One subject in the placebo group declined at the last minute to participate, and one subject in the amphetamine group fell ill midway through the sleep deprivation period, leaving eleven whose data could be used in each of those two groups.

Tasks

There were six different tasks, only five of which are included in the results described here; the sixth task was characteristically different in that it employed two markers and two cursors.

In two of the tasks, the marker and the cursor were vertical lines approximately 3 cm long. In one, the disturbance affected the marker, and the subject used the mouse to keep the cursor aligned with it vertically (pursuit tracking); in the other, both the disturbance and the marker affected only the cursor, and the subject was required to compensate for the disturbance in order to keep the cursor vertically under the marker (compensatory tracking).

The third task presented the subject with a circle of about 10 cm diameter, and a small disk of about 0.5 cm diameter that progressed slowly counterclockwise around the perimeter of the circle. The disturbance moved the small disk radially, and the subject used the mouse to compensate so as to keep the disk on the circle perimeter. The mouse affected the radial position of the disk, which meant that as the disk moved around the circle a left-right mouse movement might make the disk move left, right, up or down.

The fourth task presented what looked like a pendulum swinging from a point near the top-middle of the screen. Outside the arc of the pendulum bob, a disk moved in an arc at a speed that was affected by the disturbance. The mouse also affected that speed, and the subject's task was to keep the disk aligned with the shaft of the pendulum as the pendulum swung back and forth.

The fifth task was visually quite different, in that the display consisted only of a two-digit (or three-digit) number with digits about 2 cm tall. The disturbance added a positive or negative increment to the number, as did the mouse movement, and the subject used the mouse to keep the number as close to "50" as possible. In this task, both cursor and marker are conceptual numeric values, rather than being physical locations. The cursor is the value of the number represented by the digits on the screen, and the marker a memory for the value "50."

Each task was run with three different kinds of disturbance, two of which varied smoothly, and the third in jumps. Each kind was run at two difficulty levels. With six tasks and six combinations of disturbance type and difficulty, there were 36 distinct task-disturbance combinations, 6 of which were run during each individual hour of the experiment, in two group of three. Each group of three had one of each kind of disturbance, and each group of six had one of each task type and one of each disturbance-difficulty

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[1]The studies reported here were conceived and programmed by W. T. Powers, whose Perceptual Control Theory (Powers, 1973) provides the conceptual background for the tasks and the analyses. Powers was also responsible for much of the analysis, and provided valuable assistance by e-mail, but generously declined participation in the authorship of this paper. The author assumes responsibility for all errors and omissions.

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