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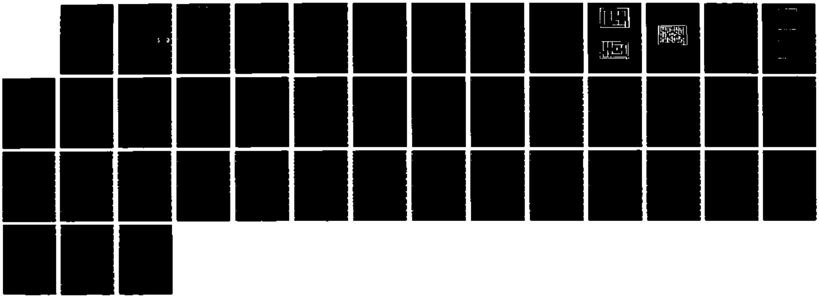
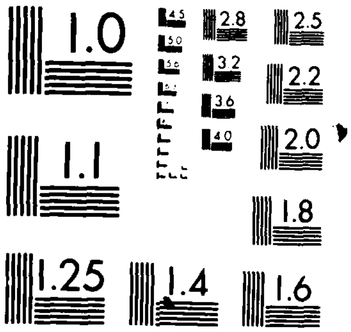
WITH MULTIPLE COMPLEXITY LEVELS(U) ARIZONA STATE UNIV
TEMPE D L DAMOS ET AL. 01 AUG 86 96416-TE1A
UNCLASSIFIED N00014-82-C-0179 F/G 5/10 NL





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A PRELIMINARY EVALUATION OF A COMPUTERIZED MAZE TASK WITH MULTIPLE COMPLEXITY LEVELS

Interim Technical Report

Contract # N00014-82-L-0179

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DISTRIBUTION STATEMENT A
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Department of Human Factors
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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

AD-A170 651

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188
Exp. Date Jun 30 1986

1a. REPORT SECURITY CLASSIFICATION: Unclassified
1b. RESTRICTIVE MARKINGS: N/A
2a. SECURITY CLASSIFICATION AUTHORITY: N/A
2b. DECLASSIFICATION / DOWNGRADING SCHEDULE: N/A
3. DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release; distribution unlimited
4. PERFORMING ORGANIZATION REPORT NUMBER(S): 96416-TE1A
5. MONITORING ORGANIZATION REPORT NUMBER(S):
6a. NAME OF PERFORMING ORGANIZATION: Arizona State University
6b. OFFICE SYMBOL *(If applicable)*:
7a. NAME OF MONITORING ORGANIZATION: Naval Medical Research and Development Command
6c. ADDRESS *(City, State, and ZIP Code)*: Tempe, AZ 85287
7b. ADDRESS *(City, State, and ZIP Code)*: Office of Naval Research, Arlington, VA 22217-5000
8a. NAME OF FUNDING / SPONSORING ORGANIZATION:
8b. OFFICE SYMBOL *(If applicable)*:
9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER: N00014-82-C-0179
8c. ADDRESS *(City, State, and ZIP Code)*:

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO

11. TITLE *(Include Security Classification)*: A Preliminary Evaluation of a Computerized Maze Task with Multiple Complexity Levels.
12. PERSONAL AUTHOR(S): Diane L. Damos and Elizabeth A. Lyall
13a. TYPE OF REPORT: Interim Technical
13b. TIME COVERED: FROM 9/85 TO 7/86
14. DATE OF REPORT *(Year, Month, Day)*: 86-8-01
15. PAGE COUNT: 41
16. SUPPLEMENTARY NOTATION: Mazes, spatial, maze learning (human), orientation

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

The first section of this report discusses the problems involved in quantifying the complexity of mazes and several measures of complexity are developed. The second section describes two versions of a program that generate mazes at several levels of one of the complexity measures. The rest of the report discusses five pretests that examined the characteristics of the mazes generated at these levels. Generally, subjects understood the task easily and learned the task quickly. More importantly, the average time to solve the maze increased with increases in the complexity measure. This result indicates that it may be possible to quantify maze complexity, which would increase the usefulness of mazes as experimental tasks.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT: ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS
21. ABSTRACT SECURITY CLASSIFICATION: Unclassified
22a. NAME OF RESPONSIBLE INDIVIDUAL: Diane L. Damos
22b. TELEPHONE *(Include Area Code)*: (213) 743-3221
22c. OFFICE SYMBOL:

DD FORM 1473, 84 MAR
83 APR edition may be used until exhausted
All other editions are obsolete

SECURITY CLASSIFICATION OF THIS PAGE

Acknowledgments

The authors would like to thank Mr. Eric Grose for his help in conducting the pretests and Dr. Kim Wilson for his review of an earlier version of this manuscript. The authors also wish to thank Ann Stewart for her help in typing this report.

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Introduction

To complete a series of experiments on multiple-task performance, it became necessary to identify a spatial task that did not require extensive use of visual short-term memory. The task had to be presented on a computer but, because of the limitations of the available graphics systems, the task could not require color discriminations or movement in three-dimensional space.

Very few tasks met these requirements. Of these, the most promising were maze tasks. However, there was one serious problem associated with the use of mazes as experimental tasks: There was no way to describe a maze quantitatively, (Ward and Poturalski, 1983). Such a description is necessary to relate maze characteristics to solution behavior.

If the problem of maze quantification could be solved, several other problems remained. One problem was strictly practical in nature: To use mazes in research, it was necessary to develop a computer program that could generate a large number of mazes with specified characteristics. These characteristics could subsequently be quantified and related to solution behavior. A second problem was that the cognitive processes required to solve mazes had never been identified. To use mazes as spatial tasks, it was necessary to demonstrate that verbal information processing is not required to solve mazes.

The approaches used to deal with the problems of quantifying maze difficulty, developing computer programs to generate mazes, and identifying the processes required to solve mazes are described in the next three sections.

Quantification of Maze Complexity

Even the most cursory inspection of a set of mazes reveals that they differ along a number of dimensions. For example, two mazes may differ in the length of the solution path, the number of paths intersecting the solution path, the total number of dead ends, the length of the longest dead end, and the physical size of the maze. Any combination of these may significantly affect the time to reach the maze exit. The problem, then, is to express the complexity of a maze in a relatively simple fashion that can be easily related to observed performance.

Mr. Neil Bechdel, a staff member at Arizona State University, was approached with this problem. He developed two different methods that could be used to quantify the complexity of computer-generated mazes. The first of these expresses the complexity of a maze by the ratio of the number of pixels used to form the paths of the maze to the total number of pixels contained in the maze (PP/TP). The greater this ratio, the greater the proportion of the area within the maze composed of paths and the greater the apparent complexity of the maze.

The second method translates a maze to a structure similar to a decision tree. All decisions points are represented as nodes. Each successive decision point on a given path results in a node at the next higher level of the tree. The height of the tree is equal to the number of node levels and the width of the tree is the maximum number of nodes at any level. The complexity variable is the ratio of the width of the tree to its height. A high ratio reflects a complex maze with many bifurcations of each path. A low ratio represents a maze with few bifurcations of the paths.

The first method was selected initally for investigation because it could be obtained on-line and because it reflected a simpler conception of maze complexity than the second method. However, the PP/TP ratio is significantly affected by the resolution of the graphics system used to display the maze. Thus, while the meaning of the ratio is clear, the relation between solution time and the ratio is system dependent.

The height-to-width ratio is not subject to this limitation. However, it represents a more abstract quantity that is difficult to derive from the existing programs. Therefore, several other measures that are related to the height-to-width ratio but are easier to obtain were calculated off-line and used in subsequent analyses. The results of these analyses are described in the General Discussion Section.

Program

Two versions of the maze generation program have been written by Mr. In Sup Kwon. One version was written in Fortran for a PDP 11/23 with an RT-11 operating system. The other was written in Pascal for an IBM XT. Both programs generate a large number (for practical purposes, an infinite number) of mazes at selected PP/TP ratios. Each maze has one and only solution. All mazes are rectangles with the entrance near the upper left corner and the exit near the bottom right corner. Thus, the solution paths typically angle downward from the upper left of the matrix to the lower right. In both versions the subject moves the cursor left, right, up, or down by pressing one of four keys. The cursor flashes to allow it to be easily identified and it is not possible to move the cursor off a path. That is, the cursor can never be moved through a "wall."

The same four performance measures are obtained and stored in both versions: the number of key presses used to move the cursor from the entrance to the exit, the minimum number of key presses required to move the cursor from the entrance to the exit, the total number of pixels used to form the paths of the maze, and the time from the appearance of the maze to the time the cursor reached the exit. Both versions display the last measure to the subject after every trial.

To begin either program, the experimenter must enter a seed number(s), which determines the sequence of the mazes (two seeds are required for the PDP 11/23 version and one for the IBM XT version). The same seed(s) will always result in the same sequence. Seeds are stored with other descriptive information in the data file.

PDP 11/23 Version

This version generates mazes at six different PP/TP ratios: .125,.167, .215, .250, .333, and .424. To simplify the discussion of the pretest results, these PP/TP ratios are referred to as pixel ratios (PR) 1 through 6. Thus, a maze with a high PR number has more visual complexity than one with a low number. Figure 1 shows a maze with a PR of 2; Figure 2 shows one with a PR of 4; Figure 3 shows a maze with a PR of 6. There are no options to display the maze or the cursor in color. The maximum time required to display the maze is 30 ms.

In this version each key press causes the cursor to be displaced by a distance equal to the height of the cursor (the

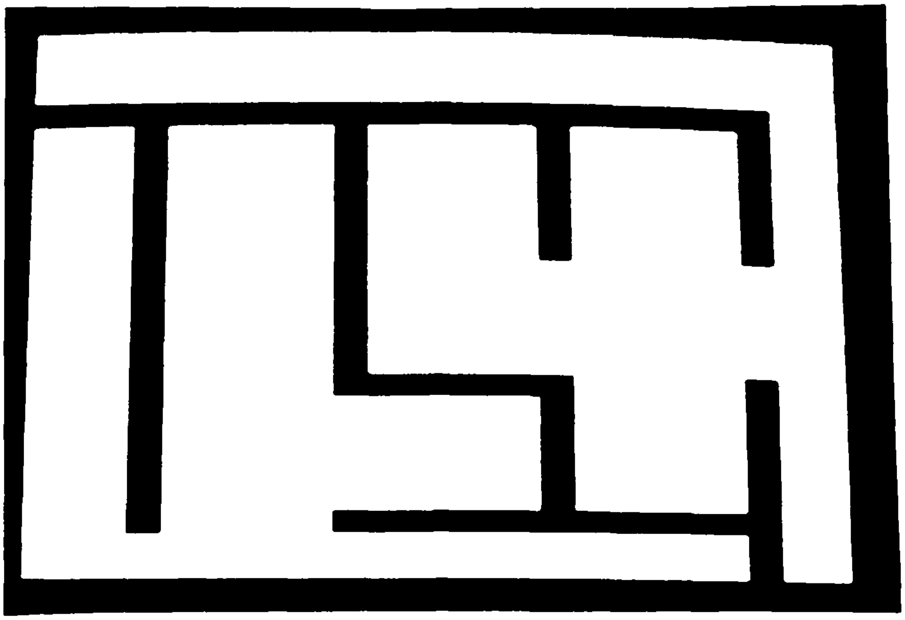

FIGURE 1. AN EXAMPLE OF A PR 2 MAZE GENERATED BY THE PDP 11/23 PROGRAM

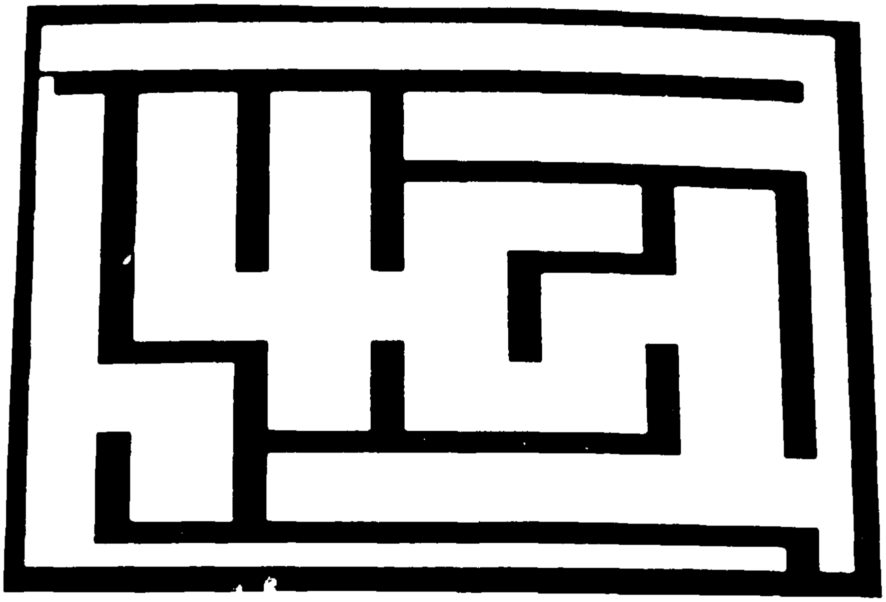

FIGURE 2. AN EXAMPLE OF A PR 4 MAZE GENERATED BY THE PDP 11/23 PROGRAM

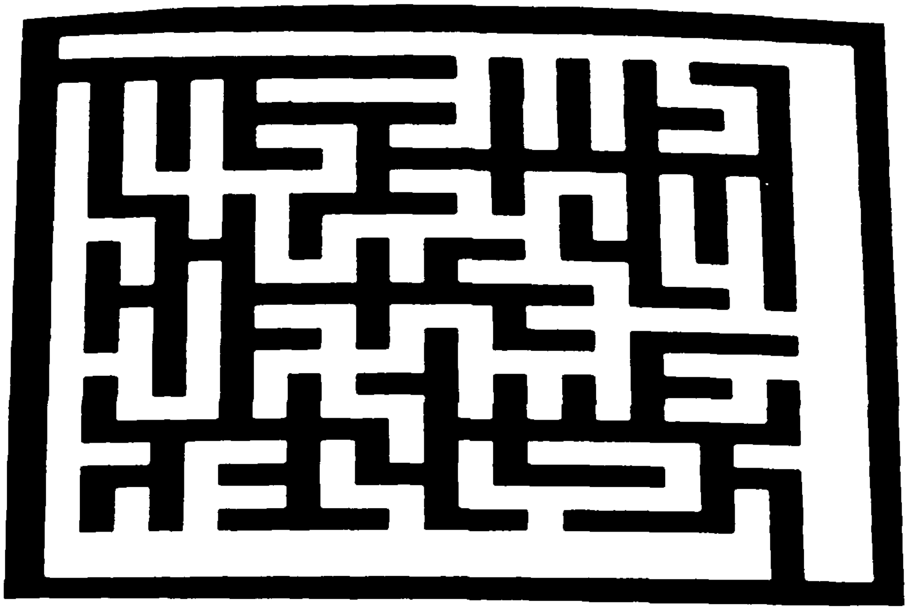

FIGURE 3. AN EXAMPLE OF A PR 6 MAZE GENERATED BY THE PDP 11/23 PROGRAM

cursor is a rectangle). The program will not allow the subject to move the cursor by depressing a key and holding it; each key press results in a displacement of one and only one unit.

This version also can display just the solution path for a given maze. This option is used primarily to train subjects to move the cursor. This version also has a dual-task option that presents a maze concurrently with the running difference task, a mental arithmetic task. Stimuli for the running difference task may be presented either visually or auditorily. The subject may respond to the running difference task either manually using a different keypad from the one controlling the maze task or vocally using a voice recognition device. Finally, this version has an option that displays the maze for 5 s and then erases it, leaving only the cursor and the outside wall of the maze to show the entrance and the exit of the maze. This option may be combined with the dual-task option described above. These tasks are described in more detail in the General Methods Section.

IBM XT Version

This version generates mazes at 11 different PP/TP ratios: .040, .058, .077, .100, .116, .137, .154, .200, .231, .308, and .500. These ratios are referred to as PR 1 through 11, respectively. Figure 4 shows a maze with a PR of 8; Figure 5 shows one with a PR of 11. The cursor may be displayed in one of 16 colors; the background and the paths may be displayed in one of eight colors. The time to display the maze is approximately 1 microsecond. This version has the same options as the PDP 11/23 version except that there is no provision for dual-task performance and the experimenter may select the performance measures to be displayed to the subject after each trial. There is an option that allows the solution path to be displayed in a different color from the other paths. This option, again, is used primarily to train subjects to move the cursor. In this version subjects can move the cursor repeatedly in a given direction simply by keeping the appropriate key depressed or they can move the cursor in discrete increments. Each increment is equal to the height of the cursor (in this version the cursor is a square).

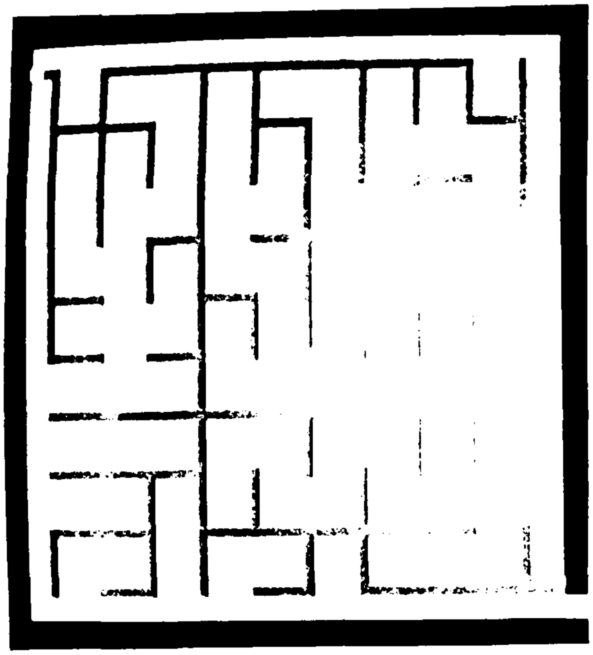

FIGURE 4. AN EXAMPLE OF A PR 8 MAZE GENERATED BY THE IBM XT PROGRAM

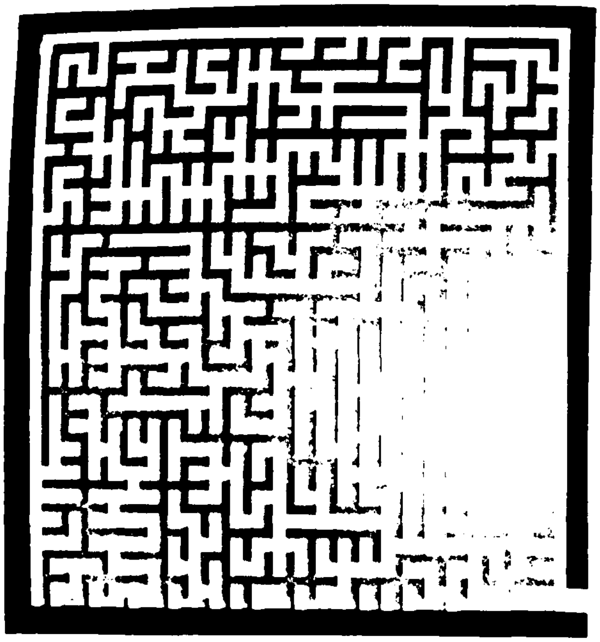

FIGURE 5. AN EXAMPLE OF A PR 11 MAZE GENERATED BY THE IBM XT PROGRAM

Spatial Versus Verbal Processing

There are several approaches to demonstrate that solving a maze requires spatial rather than verbal processing. One approach is to use the maze task as one member of a task combination. Wickens' Multiple Resources Model (Wickens, 1980) predicts that a spatial task and a verbal task should be performed better concurrently than combinations consisting of two verbal or two spatial tasks when performance is measured in terms of the single- to dual-task decrement. Thus, it should be possible to determine the nature of the central processing used to solve mazes by pairing the maze task with several other known spatial and verbal tasks. The obvious drawbacks of this approach are that it is both time consuming and expensive. Thus, no attempt was made to use this approach.

Another approach is based on the idea of consistent individual differences. That is, if a person scores highly on one spatial test, he should score highly on another spatial test if both tests measure primarily the same spatial processes. To use this approach, a large group of subjects must complete a battery of spatial tests and the maze task. Each score from the tests in the battery is correlated with the average solution time of the maze task. If the average correlation is high, the maze task is assumed to measure the spatial processes present in the other tests in the battery. (Factor analysis may also be used to identify the underlying processes). This approach, like the one above, is both time consuming and expensive. Additionally, it usually requires large numbers of subjects. Therefore, this approach was not used to establish the spatial processing requirements of the maze tasks.

A third approach involves verbal suppression (Murray, 1967). To use this approach, subjects must repeat some simple phrase or set of words--such as "a, b, c, d"--while solving the maze task. The subjects must speak in time with a metronome that is set to a relatively fast pace, such as two beats per second. It is assumed that subjects can not use verbal strategies to perform a task while they are repeating some simple phrase. Therefore, if the average time to reach the exit does not increase while the subject is repeating a phrase, the maze task is assumed not to require verbal processing. This approach is easy to administer, quick, and inexpensive. It was used in several of the pretests described in this report to demonstrate that verbal processes are not required to solve mazes.

Report Organization

The remainder of this report describes five pretests in the order in which they were completed. These pretests were designed primarily to explore systematically the characteristics of the mazes produced by the two versions of the program described earlier. A secondary purpose of these pretests was to obtain baseline data for subsequent experiments. Because these studies were pretests, relatively small numbers of subjects were used in most of them and the number of subjects per group was not always equal. The unbalanced designs coupled with the small number of subjects made parametric data analyses inappropriate. This did not actually adversely affect the data analyses; in all cases the questions that generated the study could be answered using only the most basic descriptive statistics or simple graphs.

General Methods

This section provides general methodological information for the five pretests. Methods information that is specific to each pretest is presented in the appropriate pretest section.

Subjects

All subjects were right-handed, between the ages of 18 and 35, and native English speakers. Additionally, no subject had received any flight training. Subjects in the first two pretests were paid $5.00 per hour. Those participating in Pretests 3, 4, and 5 were paid $5.50 per hour. Subjects were recruited through advertisements placed in student newspapers and in academic buildings.

Apparatus

A DEC PDP 11/23 computer was used for Pretests 1 through 4 (the IBM XT used for Pretest 5 is described in that section). The maze was displayed on an AMDEK Video 300 cathode ray tube. The cursor was manipulated using a four by four matrix keypad attached to the left arm of the subject's chair. An identical keypad that was used for the running difference task was attached to the right side of the subject's chair. The ambient illumination in the laboratory was approximately 10.7 lx.

Tasks

Solution path only. In this version of the maze task, only the solution path for the maze was displayed. The subject's job was to move the cursor as quickly as possible from the entrance to the exit.

Maze. The subject's job in this task was to find the solution path from the entrance of the maze to the exit and to move the cursor along this path as quickly as possible.

Blind maze. At the beginning of this task, the subject saw a maze for 5 s. During this period the cursor was not displayed and, therefore, the subject could not move the cursor. Then, all of the maze except the outer wall with the entrance and the exit was erased and the cursor displayed. The subject attempted to move the cursor from the entrance to the exit as quickly as possible. If the subject could not remember the solution path, he could see the maze again for 5 s by pressing a fifth key on the keypad. During this interval, the cursor was not displayed and the subject could not move the cursor in any direction. At the end of the 5-s period the maze was erased, the cursor was redisplayed, and the subject again attempted to move the cursor to the exit as quickly as possible. The subject could redisplay the maze as often as necessary. The number of times the maze was redisplayed was stored in the data file.

Verbal suppression. The subject repeated the letters "a,b, c, d" in time to a metronome set at two beats per second. No dependent measures were obtained but the subject's performance was monitored by the experimenter.

Running difference. In this task randomly selected digits between 0 and 8 were presented sequentially to the subject. The subject responded with the absolute difference between the most recently displayed digit and the preceding digit. The possible responses consisted of the numbers 1 through 8. All nine stimulus digits were presented with approximately the same frequency and a digit was never allowed to repeat. The digits were 2.5 cm high and were displayed for 343 ms in the middle of the screen. Digit presentation could be terminated by a response before the end of the presentation interval. To enter a response, the subject pressed one of eight keys on the right-hand keypad. The middle two horizontal rows of keys were used. The keys in the lower row were numbered 1 to 4 from left to right and those in the upper row were numbered 5 to 8 from left to right. The response to the first digit of any trial was always "1." As soon as a response was made, a new digit was presented. Two dependent variables were recorded: correct response time and the percentage of correct responses. At the end of each trial, the average correct response interval (the number of correct responses divided by the trial length) and the percentage of correct responses were displayed to the subject. The trial length for this task was 60 s and the intertrial interval was 45 s.

Maze-running difference combination. In this combination the digit for the running difference task was presented to the right of the maze and vertically centered. The subject was told that the tasks were equally important. A dual-task trial ended when the cursor reached the exit of the maze, i.e. the trial length was equal to the solution time. At the end of each trial the same feedback was presented for each task as under single-task conditions.

Maze-verbal suppression combination. In this combination the subject performed the verbal suppression task while solving the maze. Again, no performance measures were obtained for the verbal suppression task but the subject's performance was monitored to insure that both tasks were performed concurrently.

Procedure

All subjects were assigned at random to the experimental treatments. Each subject read and signed an informed consent form before beginning the pretest. All instructions given in Pretests 3 and 4 were taped; those in Pretests 1, 2, and 5 were read to the subjects. Instructions always immediately preceded the corresponding experimental condition. All intertrial intervals in Pretests 1, 2, 3, and 5 were 45 s. The intertrial interval was 30 s for Pretest 4 for all tasks except the running difference task, which was 45 s. At the end of each pretest, the subject was given a written debriefing sheet explaining the purpose of the pretest and was allowed to ask questions about the pretest. After any questions had been answered, the subject was paid.

Pretest 1

Experimental Rationale

This pretest was conducted to answer two questions. First, how long does it take to learn to manipulate the cursor at each of three PRs available in the PDP 11/23 version of the program? Second, is there evidence of asymmetric transfer between PRs? Previous research (Damos, 1985; Damos and Lyall, 1986; Poulton, 1982; Poulton and Freeman, 1966) indicated strong asymmetric transfer between a variety of experimental conditions. It appeared necessary, therefore, to determine if asymmetric transfer could occur between solution-path-only mazes at different PRs.

Methods

Task. Solution-path-only mazes were used.

Subjects. Twelve Arizona State University students, seven females and five males completed this pretest.

Design. A three-factor, mixed-model design was used. Trials was a within-subject factor. PR also was a within-subject factor with three levels: 1, 3, and 6. Order of PRs was a between-subjects factor with six levels. Two subjects were assigned to each order.

Procedure. Each subject performed 15 trials at each PR in the order assigned to his group. A 2-min break was given between PRs. All subjects saw the same sequence of solution paths at each PR. The session lasted approximately 45 min.

Results and Discussion

The average time to move the cursor from the entrance to the exit (movement time) is shown in Figure 6 for each PR. These data were averaged over the order in which the PR was performed. Figure 6 demonstrates that the subjects learned to manipulate the cursor quickly; there is little evidence of continued learning after the eighth trial at any PR.

A detailed examination of the data showed some evidence for asymmetric transfer between PRs. It was decided, therefore, to use PR as a between-subjects variable in all subsequent pretests to avoid any problems with asymmetric transfer.

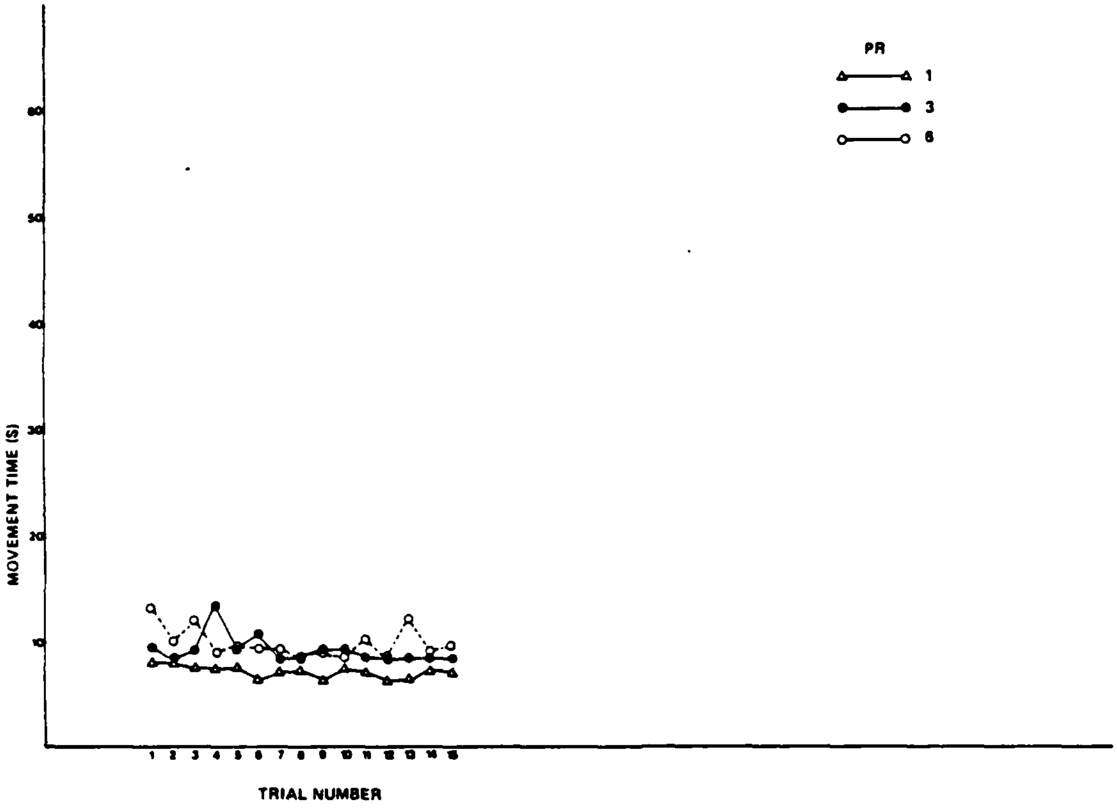

FIGURE 6. THE AVERAGE MOVEMENT TIMES AS A FUNCTION OF PR AND PRACTICE

Pretest 2

Experimental Rationale

This pretest addressed two questions. First, is the time required to solve a maze (find the solution path and move the cursor to the exit) greater than the corresponding movement time? Second, if the answer to the first question is yes, does the difference between the movement time and the solution time increase with increasing PRs?

Methods

Tasks. The solution-path-only and the maze tasks were used at all six PRs.

Subjects. Twenty-three Arizona State University students, 15 females and 8 males, were subjects.

Design. A two-factor, mixed-model design was used. PR was a between-subjects factor and trials was a within-subject factor. Three subjects were assigned to PR 1; four subjects were assigned to each of the other five PRs.

Procedure. The subjects performed 20 solution-path-only mazes followed by 30 mazes. Finally, the subjects performed two solution-path-only mazes.

Both versions of the maze task were performed in blocks of ten. A short break was given between the end of the solution-path-only mazes and the beginning of the mazes. The same seeds were used to generate the second block of the solution-path-only mazes and the third block of mazes. Thus, the solution paths for these two blocks were identical. This pretest required approximately 75 min per subject.

Results and Discussion

As in Pretest 1, the subjects learned to manipulate the cursor quickly; after the tenth trial at all PRs for the solution-path-only mazes there was little reduction in the movement time.

The average solution time for mazes at PRs 1 through 6 was 8.650, 10.349, 10.523, 11.775, 14.233, and 18.989 s, respectively. Thus, solution time increased monotonically with PR. There was no evidence of learning after the first maze at all PRs. However, there was a large amount of between-maze variance in solution times within each PR.

As noted above, the second block of solution-path-only mazes and the third block of mazes had the same solution paths. Thus, an estimate of the cognitive processing time required to identify the solution path can be obtained for a given maze by subtracting the movement time from the solution time of the maze with the same solution path (movement time plus cognitive processing time). The difference between these two times is shown in Figure 7 as a function of trial and PR. Apparently, little cognitive processing was required to identify the solution path for mazes at PRs 1, 2, and 3 (an examination of Figure 1 shows that this is probably the case for college students). The difference scores for PRs 4, 5, and 6 appear to be different from 0 s, indicating that some processing was required to identify the solution paths at these PRs. More importantly, the difference increased with increasing PRs.

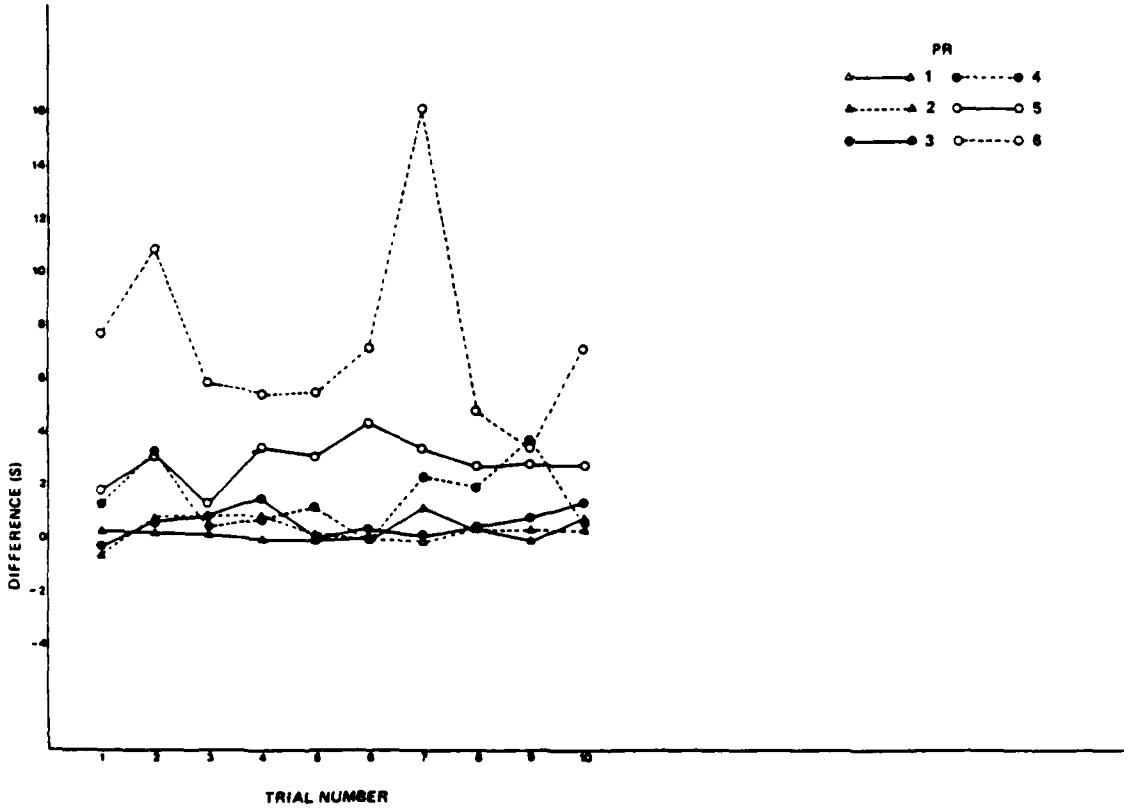

FIGURE 7. THE DIFFERENCE BETWEEN THE MOVEMENT TIME AND THE SOLUTION TIME FOR TEN MAZES AS A FUNCTION OF PR

Pretest 3

Experimental Rationale

The results of both Pretests 1 and 2 were encouraging for three reasons. First, subjects in both studies learned the motor skills necessary for the maze task quickly. Therefore, it was not necessary to spend much time training subjects to move the cursor. Second, there was little learning evident on the maze task, indicating that this task may reach differential stability very quickly. Rapid acquisition of differential stability is a very important characteristic of any task to be used for exotic environment or individual differences research. Third, at least for PRs 4, 5, and 6 some type of cognitive processing appeared to be required to identify the solution path.

Determining the nature of the processing required by the maze task was the next logical step in identifying the characteristics of the maze task and was the primary purpose of Pretest 3. This pretest also made an initial attempt to examine the characteristics of the blind maze task and determine the nature of the processing required by this task.

Methods

Subjects. Twelve University of Southern California students, six males and six females, completed this experiment.

Tasks. Four different tasks were used in this pretest: solution path only, maze, blind maze, and verbal suppression. The maze-verbal suppression and the blind maze-verbal suppression combinations also were used.

Design. A two-factor, mixed-model design was used. PR was a between-subjects factor with two levels, 3 and 5. Trials was a within-subject factor.

Procedure. Each subject in this pretest performed all six tasks mentioned above. All tasks except verbal suppression were administered in blocks of five trials. There was a break of approximately 1 min between blocks. The subjects began the pretest by performing three blocks of the solution-path-only maze followed by two blocks of the maze task. Next, the subjects performed four blocks of the blind maze. After either the second or third block the subjects received a 5-min rest. Next, they performed two 1-min trials of the verbal suppression task followed by two blocks of the maze-verbal suppression combination. Finally, the subjects performed two blocks of the blind maze-verbal suppression combination.

The same seed numbers were used for the second blocks of the solution-path-only mazes, the mazes, and the maze-verbal suppression combination. Similarly, the same seed numbers were used for the fourth block of the blind maze task and the second block of the blind maze-verbal suppression combination.

Results and Discussion

As expected, the subjects in the PR 5 group had longer solution times on all the maze-related tasks than subjects in the PR 3 group. This difference was greatest in the blind maze condition (see Figure 8). The difference between the two PRs was also evident in the number of times the maze had to be redisplayed; the average number of times the maze was redisplayed per trial was 0.39 for PR 3 and 0.96 for PR 5. The blind maze task also differed from both the solution-path-only and the maze tasks in that extensive learning was involved. It is difficult to estimate the final level of performance on this task; the performance curves for both PRs in Figure 8 show little evidence of asymptotic performance.

Estimates of the cognitive processing time required to locate the solution path were obtained for the second block of the PR 3 and PR 5 mazes using the technique described in Pretest 2. The results were essentially the same as those of Pretest 2. The difference between the movement time and the solution time for a given PR 3 maze was approximately 0 s. The corresponding difference was approximately 4 s for PR 5 mazes.

One of the major purposes of this pretest was to determine if the maze and the blind maze tasks could be performed without verbal processing. Because one block of the maze task and one block of the maze-verbal suppression task were generated using the same seeds, both blocks had an identical sequence of mazes and performance on corresponding trials could be directly compared. The same comparison can be made for one block of the blind maze task and one block of the blind maze-verbal suppression task. To determine if verbal processing was required to perform a specific maze, it is necessary to subtract the

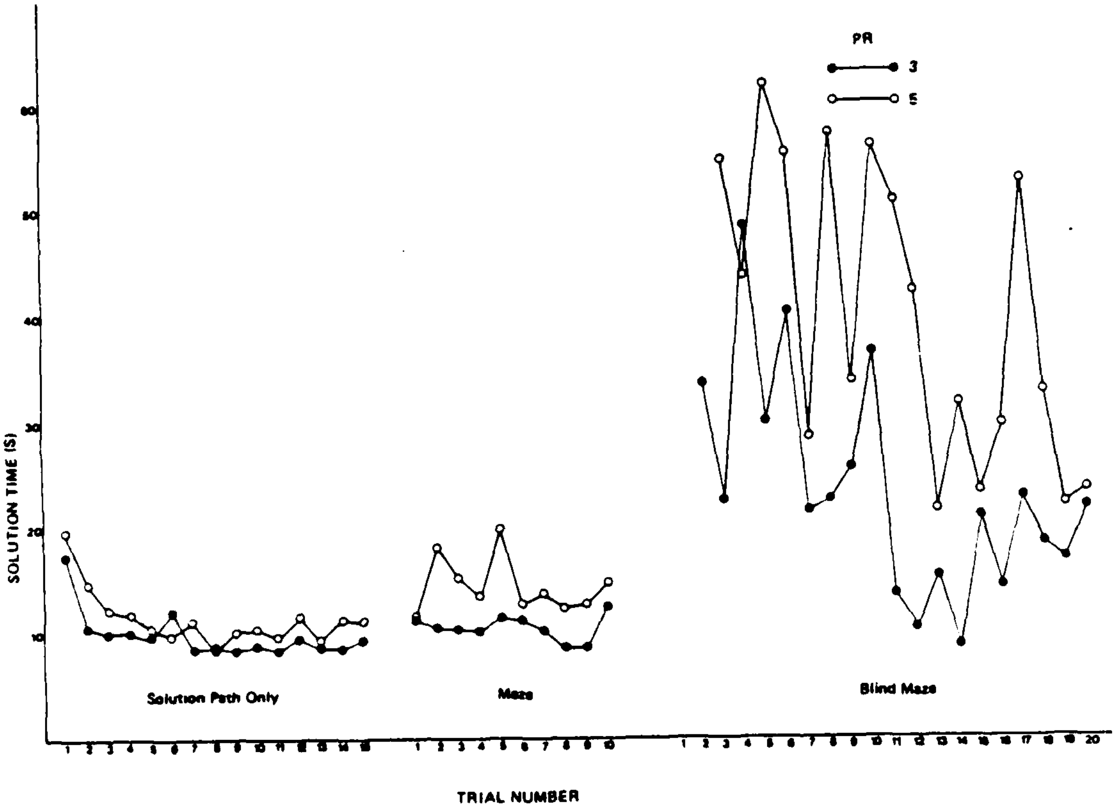

FIGURE 8. THE AVERAGE SOLUTION TIMES FOR THE SOLUTION-PATH-ONLY, MAZE, AND BLIND MAZE TASKS AS A FUNCTION OF PR AND PRACTICE

solution time for a given maze performed with the verbal suppression task from the solution time of the maze performed alone.

The difference scores for the maze task at both PRs showed evidence of continued improvement with practice. The PR 3 difference scores were negative (faster solution times with the verbal suppression task than without it) for each of the five trials; those for PR 5 were positive for the same trials. The PR 3 difference scores for blind mazes bounced erratically from positive to negative. The corresponding PR 5 scores showed strong evidence of continuous learning over the five trials; these difference scores initially were positive and rapidly became negative.

The learning shown in the difference scores for the maze task at both PRs and for the blind maze task at PR 5 is unusual and makes interpretation of the results difficult. The erratic fluctuation of the PR 3 blind maze difference scores is impossible to interpret. Therefore, it was decided to obtain more data from the verbal suppression combinations before making a judgement about the nature of the processing required by the maze and the blind maze tasks.

Pretest 4

Experimental Rationale

As noted in the Introduction, the maze task was examined for use in a series of multiple-task experiments. This series of experiments will examine performance on the maze task when it is performed alone and in combination with a variety of other tasks. It was necessary, therefore, to conduct a pretest to examine the characteristics of the maze task under dual-task conditions. The running difference task was selected for use in this pretest.

This pretest also examined asymmetric transfer between PRs under both single- and dual-task conditions. Previous research (Damos, 1985; Damos and Lyall, 1986) indicated strong asymmetric transfer between stimulus modality combinations and response modality combinations under dual-task conditions, but the possibility of asymmetric transfer between difficulty levels was not explored. Therefore, this pretest was designed to identify asymmetric transfer between PRs under both single- and dual-task conditions.

Methods

Subjects. Eight University of Southern California students completed this pretest. Two of the subjects were males and six were females. One other subject did not complete this pretest because she could not reach criterion (75% accuracy or better on the last five single-task trials) on the running difference task.

Tasks. The running difference, the solution-path-only, and the maze tasks were used in this pretest. The maze-running difference combination was also used.

Design. A three-factor, mixed-model design was used. Trials and PR were within-subject factors. PR had two levels, 3 and 5. Order of performance of PR was a between-subjects factor.

Procedure. Subjects first performed 12 trials of the running difference task followed by five trials of the solution-path-only task at PR 5. Next, the subjects performed four blocks of five trials of the maze task. Two of the blocks used PR 3 mazes; the other two used PR 5 mazes. Half of the subjects performed the PR 3 mazes first; the other half began with the PR 5 mazes. Finally, the subjects performed six blocks of five trials of the maze-running difference combination. Three of the blocks were performed using PR 3 mazes; the other three blocks used PR 5 mazes. The order in which a subject performed these PRs was the same as the order of the PRs of the maze task. This pretest required from 1.5 to 3.0 hours.

Results and Discussion

The dual-task data are shown in Figures 9 and 10. Although no single-task data are shown in Figure 9, the difference in the correct reaction times for the running difference task between the average of the last five single-task trials and the average of all 15 dual-task trials (without taking order of performance into account) was 2138 ms when the running difference task was performed with PR 3 mazes. The percentage correct calculated on the same set of data fell 15.72% from single- to dual-task conditions. The corresponding values for the running difference task performed with the PR 5 mazes were 2363 ms and 16.49%, respectively. As shown in Figure 10, the average solution time for the PR 3 mazes increased 13025 ms from the single-task trials to the dual-task trials (without taking order of performance into account). The corresponding increase for the PR 5 mazes was 21688 ms. It should be noted that the decrements for the running difference and the maze task at both PR 3 and PR 5 were not unusually large.

As noted earlier, the subjects were instructed that both tasks were equally important. The performance decrements described above indicate that performance on both tasks deteriorated under dual-task conditions. It appears then that the subjects attempted to follow the priority instructions. The experimenter also observed that most subjects attempted to interweave the two tasks rather than concentrating first on one and then on the other. Both Figures 9 and 10 show some evidence of learning.

Finally, although not depicted in Figures 9 and 10, there was evidence of asymmetric transfer between PRs under dual-task conditions. This effect was evident only for the running difference task. The size of the asymmetric transfer was not as large as seen in other studies (Damos, 1985; Damos and Lyall, 1986) but still indicates serious problems for the use of PR as a

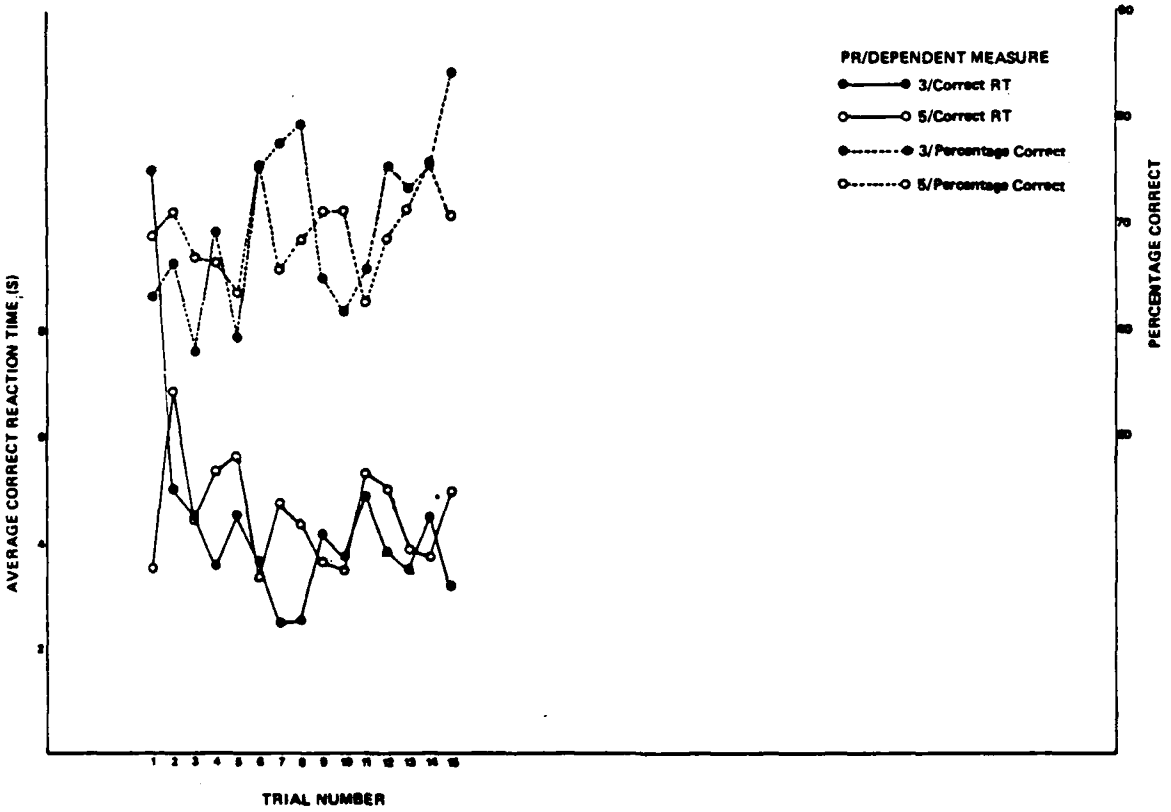

FIGURE 9. THE AVERAGE DUAL-TASK CORRECT REACTION TIMES AND PERCENTAGE CORRECT AT PR 3 AND PR 5 AS A FUNCTION OF PRACTICE FOR THE RUNNING DIFFERENCE TASK

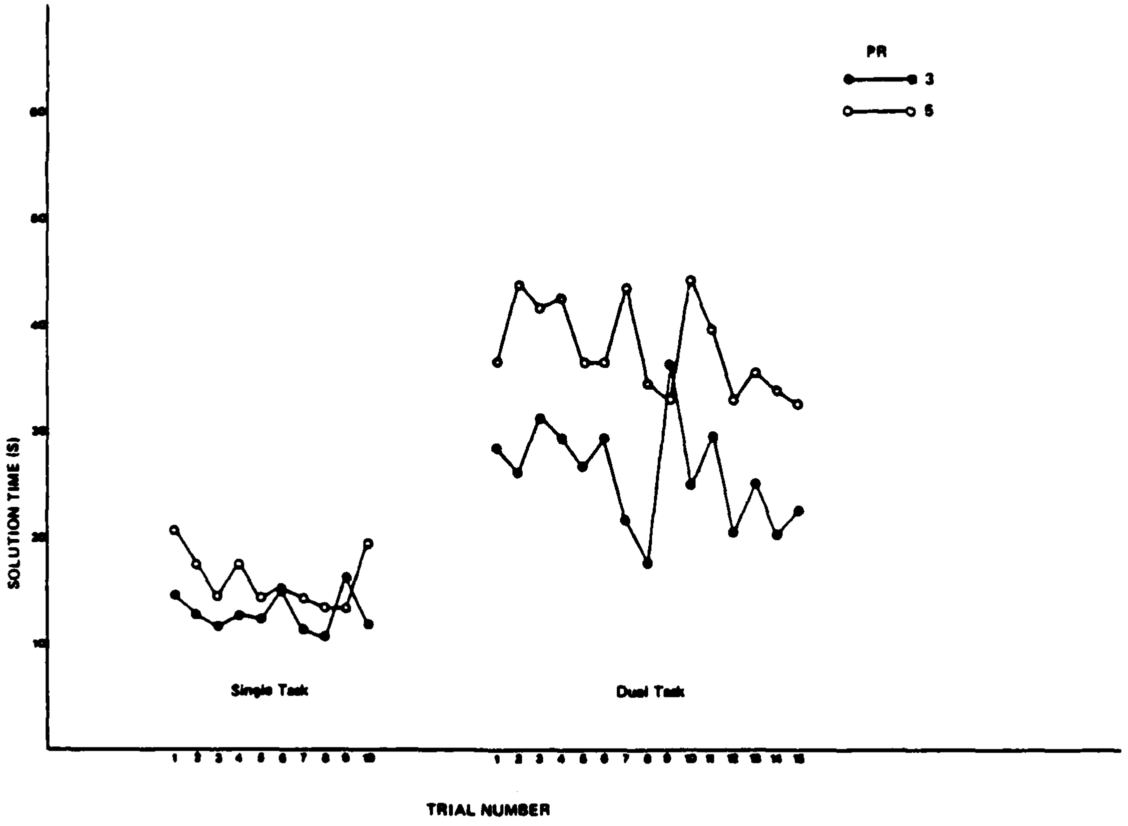

FIGURE 10. THE AVERAGE SINGLE- AND DUAL-TASK SOLUTION TIMES AT PR 3 AND PR 5 AS A FUNCTION OF PRACTICE FOR THE MAZE TASK

within-subject factor. There was no evidence of asymmetric transfer under single-task conditions.

Pretest 5

Experimental Rationale

There were several reasons for conducting this pretest. The primary purpose was to determine if the IBM XT and the PDP 11/23 versions of the program resulted in comparable data. Another purpose was to obtain baseline data for mazes that appear to be more complex than those available on the PDP 11/23. A third purpose was to obtain more data using the verbal suppression task to examine the nature of the processes used to perform the maze task. A fourth was to determine the effect of a different training system on solution time; the IBM XT version of the program has a task not available on the PDP 11/23 version. This task, the highlighted-solution-path task, displays a maze at a given PR but the solution path and the dead ends are displayed in different colors. In this task the cursor can be moved off the solution path along dead ends as in the maze task. This is different from the solution-path-only tasks; because only the solution path is displayed, the cursor can not move off the solution path in either version. The effect of training under the highlighted-solution-path condition versus the solution-path-only condition can be determined by examining subsequent solution times for the maze task.

Methods

Subjects. The subjects were 13 males and 19 females recruited from the University of Southern California.

Apparatus. This pretest was performed on an IBM XT with 640K of RAM, one 5 1/4 floppy disk drive, and one 20 MB hard disk. The IBM XT keyboard has a keypad to the right of the QWERTY keyboard with four keys marked with arrows. The subjects used these keys to manipulate the cursor in the direction indicated by the keys. The ambient illumination in the laboratory was 85.6 lx.

Tasks. The highlighted-solution-path, solution-path-only, maze, verbal suppression, and maze-verbal suppression tasks were used. The subject's job in the highlighted-solution-path task was to move the cursor as quickly as possible from the entrance to the exit.

Design. A three-factor, mixed-model design was used. PR was a between-subjects factor with four levels: 4, 6, 8, and 11. Training method was also a between-subjects factor with two levels: solution-path-only and highlighted-solution-path. Trials was a within-subject factor. Four subjects were assigned to each of eight groups formed by all combinations of PR and training method.

Procedure. All subjects first performed 20 trials of either the solution-path-only or the highlighted-solution-path task. After a short break (approximately 3 min) they performed 30 trials of the maze task. They then performed two 30-s verbal suppression task trials followed by five trials of the maze-verbal suppression combination. The testing session required approximately 1.5 hours.

Trials 21 through 30 of the maze task had the same solution path as Trials 11 through 20 of the highlighted-solution-path and the solution-path-only tasks. Trials 1 through 5 of the maze-verbal suppression combination and Trials 21 through 25 of the maze task had the same solution paths.

Results and Discussion

General characteristics. The data obtained from this pretest showed a different pattern of results than the data from the PDP 11/23 version. Although the subjects learned to manipulate the cursor quickly, the time to approach asymptotic movement performance was affected by the PR. However, there was no simple relation between the time to learn to move the cursor and PR for either the solution-path-only or the highlighted-solution-path groups. Subjects who received PRs 4 and 6 required about ten trials to approach asymptote; those who received PR 8, seven trials; and those who received PR 11, one trial.

The time to approach asymptotic performance on the maze task also varied with PR. Subjects at PR 4 showed no evidence of learning. Subjects at PR 6 required about ten trials. Subjects at PR 8 needed at least 12 trials and those at PR 11 never approached asymptote during the 30-trial testing session.

In one respect the results of this pretest were similar to those obtained from Pretests 2, 3, and 4: The average solution time increased with PR. The average solution time was 13.417 s at

PR 4, 15.739 s at PR 6, 20.378 s at PR 8, and 60.121 s at PR 11. As the average solution time increased with increasing PR, the between-subjects variance also increased. Additionally, the maze-to-maze variance at a given PR also increased with higher PRs.

The type of cognitive processing used to perform the maze task was examined using the technique described in Pretest 3. Unlike the results of Pretest 3 the difference scores at all four PRs showed no evidence of learning. The difference scores did vary erratically from trial to trial again, making interpretation impossible. There were no consistent differences between the training groups across the four PRs.

Training techniques. The training data indicated that the movement times increased with increasing PRs for both the solution-path-only and the highlighted-solution-path tasks. For PRs 4, 6, and 8 the movement times were longer for subjects in the highlighted-solution-path groups than for subjects in the solution-path-only groups. At PR 11, however, there was no difference in the movement time between these two groups. Figure 11 shows the data for subjects receiving the two training techniques at PR 4 (the two lower functions) and PR 11 (the upper two functions). The functions for the two training groups at PR 6 and at PR 8 were similar to those for PR 4.

Why did the two training techniques result in performance differences at PRs 4, 6, and 8 but not at PR 11? One explanation is that the visual clutter of the dead ends in the highlighted-solution-path task distracted the subjects. However, if this were true, there should have been a difference in performance between the two training techniques at PR 11.

A second explanation is that subjects in the highlighted-solution-path groups had to manipulate the cursor more carefully than those in the solution-path-only groups; as noted earlier, the cursor could be moved off the solution path in the highlighted-solution-path task but not in the solution-path-only task. Thus, subjects in the solution-path-only groups could simply depress a key and move the cursor as quickly as possible in one direction until it struck a "wall." They could then change keys to move the cursor in a new direction, keeping the new key depressed until the cursor again struck a "wall." In contrast subjects in the highlighted-solution-path groups could use a similar strategy only when the solution path was straight for a long distance. But, even in this situation, the subjects had to execute the turns carefully if dead ends intersected the solution path near the turn. The difference in strategy between the two groups could explain the performance differences at PRs 4, 6, and 8.

PR 11 solution paths, however, have many turns. Thus, the cursor can not be moved rapidly in any direction by simply depressing a key. If differences in movement strategies caused

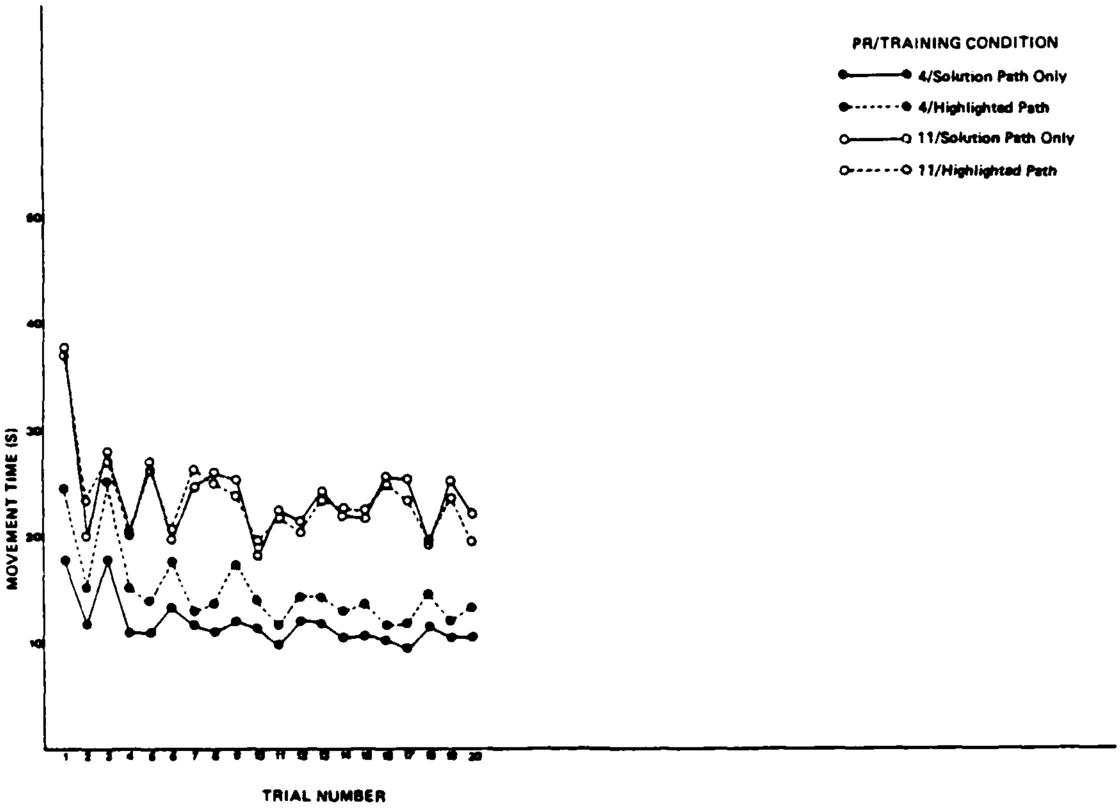

FIGURE 11. THE AVERAGE MOVEMENT TIMES FOR THE SOLUTION-PATH-ONLY AND THE HIGHLIGHTED-SOLUTION-PATH GROUPS AT PR 4 AND PR 11 AS A FUNCTION OF PRACTICE

the differences in solution times at the lower PRs, then the performance differences between the two training groups should have been eliminated at PR 11, which was the case.

The effect of training technique on maze solution time differed as a function of PR. Subjects in the solution-path-only groups had faster solution times than those in the highlighted-solution-path groups at PRs 4 and 6, similar solution times at PR 8, and slower solution times at PR 11.

Again, these data are difficult to explain in terms of the presence or absence of visual clutter during training. The pattern of results may be explained to some extent by differences in the movement strategies described above. However, since the pattern of results was not identical to the pattern found in the training data, movement strategies can not account entirely for the differences in the solution time between the training groups. Another possible explanation concerns the strategy used to find the solution path in the maze. Subjects in the highlighted-solution-path groups may have been more likely to identify the solution path first before moving the cursor. In contrast subjects in the solution-path-only groups may have been more likely to move the cursor while looking for the solution path. Currently, it is impossible to determine the extent to which either movement strategies or solution path identification strategies account for the differences in maze solution time found in this pretest.

General Discussion

The purpose of this technical report is to describe the characteristics of a maze task and methods for quantifying the complexity of a maze. Both of these topics are discussed below. Because the results of the PDP 11/23 version occasionally differed from those of the IBM XT version, the characteristics of the maze task are discussed separately for each program. The last topic in this section describes additional research needed to establish the characterisitics of the maze task more conclusively.

Maze Characteristics

PDP 11/23 version. Figures 6 and 8 show that subjects required only eight trials of the solution-path-only task to learn to manipulate the cursor. Thus, the total time required to learn to move the cursor was only about 100 s, a very minimal training time.

Figures 8 and 10 both show that subjects also learned the maze task quickly; in both figures there is little evidence of learning after the fifth trial. Thus, most of the learning was accomplished in 50 to 75 s of testing. The short learning period indicates that this task may achieve differential stability very quickly. This, of course, is a very desirable trait for a task that may be used in selection batteries or for testing the effects of exotic environments.

Although the time to learn the maze task was not affected noticeably by the PR, the average time to solve the maze after the initial learning period was a monotonic function of PR (see Pretest 2 and Figures 8 and 10). It could be argued that this increase occurred only because the length of the solution path and the number of direction changes increases with increasing PR. However, Figure 7 demonstrates that something beyond simply moving the cursor along the solution path is involved in solving a maze, at least at PRs 4, 5, and 6 and that this factor also increases with complexity. These results were replicated in Pretest 3.

It is of interest to determine the nature of the processing used to solve a maze. Pretest 3 attempted to determine if verbal processes were involved in solving mazes, but the data were uninterpretable. Additional research on this topic is suggested in a later section.

Based on the limited results obtained in Pretest 3, the characteristics of the blind maze task appear to be somewhat different than those of the maze task. Figure 8 indicates that subjects learned this task relatively rapidly. However, there is no indication of exactly what the subjects learned. That is, they may have learned some type of response strategy or they may have learned to use their visual short-term memory more effectively. As noted in Pretest 3, the results of the blind maze-verbal suppression combination on the whole were uninterpretable. Therefore, no statement about the nature of the processing required by this task can be made.

Pretest 4 examined performance on the maze-running difference combination. Figure 10 shows that the solution times for the PR 5 mazes were longer than for the PR 3 mazes under both single- and dual-task conditions. The dual-task solution times also decreased with practice, a common finding. Figure 9 shows essentially the same results: the percentage correct and correct reaction times on the running difference task were poorer when it was performed with PR 5 mazes than with PR 3 mazes and performance generally improved with practice. The single- to dual-task decrement for both tasks was not unusually large and it appears that subjects complied with the priority instructions. On the whole, therefore, the maze task seems to be a good candidate for research on multiple-task performance, at least when it is combined with a verbal memory task.

IBM XT version. The results from Pretest 5 concerning the time to learn to move the cursor and the time to approach asymptotic performance on the maze task differed considerably from the results obtained with the PDP 11/23 version of the program. The time to learn to move the cursor was affected by the PR but not monotonically. Additionally, the time to learn to move the cursor was affected by the type of training; typically subjects in the highlighted-solution-path groups had longer movement times than those in the solution-path-only groups except at PR 11 where the two groups had similar times. The time to approach asymptotic performance on the maze task was monotonically related to the PR, with subjects at PR 4 showing no evidence of learning and subjects at PR 11 showing no evidence of approaching asymptotic performance.

Like the results from the other version, solution times were directly related to the PR; as the PR increased, the solution times increased. However, the average time to solve a maze was determined both by the PR and by the type of training (highlighted-solution-path versus solution-path-only) the subjects received. At PR 8 the type of training had no effect on the solution time. At PRs 4 and 6 subjects who received the highlighted-solution-path training had longer solution times than those who received the solution-path-only training; at PR 11 the opposite was true.

No new insights were gained from Pretest 5 on the nature of the processing required by the maze task; the results of the maze-verbal suppression combination were uninterpretable.

Maze Quantification

As stated in the Introduction, one of the greatest drawbacks to using mazes as experimental tasks is that there is currently no way to quantify maze complexity. Figures 8 and 10 show that the PR is a good first approximation of complexity; as the PR increases, the solution time increases. More importantly, this increase is not due entirely to increases in the time needed to move the cursor along the solution path. However, obviously the PR can not account for the fluctuations in performance found within a given PR (see Figures 8 and 10).

Other measures--such as the total number of dead ends, the length of the longest dead end, and the number of paths intersecting the solution path--appear to be related to the visual complexity of the maze and vary within a PR, particulary at higher PRs. At these higher levels the solution times also vary the most from maze to maze. Thus, it seemed promising to relate these measures to solution times at a given PR. To examine the effect of these variables on solution time, an extremely simple approach was adopted: The correlation between solution time and each of these variables was calculated at PR 11 using data from Pretest 5. The correlation of solution time with the number of dead ends was -.014 ($p > .05$); with the length of the longest dead end, .227 ($p < .01$): and with the number of paths intersecting the solution paths, .008 ($p > .05$). The square of each of these correlations indicates the percentage of variance of the solution times accounted for by the respective measure. Obviously, none of these varibles accounted for much variance in the solution time and future efforts must either use a different statistical approach or identify other parameters for investigation .

Future Research

The pretests described in this report were designed to determine the basic characteristics of the maze task. Generally, the results of the five pretests were encouraging and imply that more research examining the task may be profitable. This research should concentrate on three topics.

The first topic concerns the identification of the processes involved in solving a maze. The results of the verbal suppression task were generally uninterpretable. Therefore, it seems that other approaches should be used. Two other possible approaches are described in the Spatial and Verbal Processing Section.

Individual differences in performance also need to be investigated. Casual observation indicates that there are large individual differences in solution times at a given PR. These could reflect differences in problem-solving approaches or in the skills and abilities needed to solve mazes. In any case, consistent individual differences in performance are extremely useful for selection testing.

Finally, the blind maze task should be explored further. As noted earlier, performance on this task improves rapidly although it is not possible to identify the source of the improvement. If some of this improvement is caused by increased use of visual short-term memory, it may be possible to train individuals to use this memory system. Such training might improve real-world performance in tasks such as flying.

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