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The aims of the research were to 1) study the effects of response mode and response complexity on basic cognitive tasks, and 2) to use the information obtained to develop more elaborated models of cognitive functioning which take these factors into account. Subjects were tested on a set of computer-administered cognitive tasks, using both keyboard and touchscreen response modes, and under varying sets of response load conditions. The results clearly show that response load has a substantial effect on the performance of cognitive tasks. A detailed investigation of the effects of response load in choice reaction time showed that Hick's Law, formerly attributed to cognitive decision factors related to task complexity, is largely due to response factors.

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Final Report to the Air Force Office of Scientific Research

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Abstract

This report is for two years of research conducted primarily at the Air Force Armstrong Laboratory, Project Lamp. The aims of the research were to 1) study the effects of response mode and response complexity on basic cognitive tasks, and 2) to use the information obtained to develop more elaborated models of cognitive functioning which take these factors into account. Subjects were tested on a set of computer-administered cognitive tasks, using both keyboard and touchscreen response modes, and under varying sets of response load conditions. The results clearly show that response load has a substantial effect on the performance of cognitive tasks. A detailed investigation of the effects of response load in choice reaction time showed that Hick's Law, formerly attributed to cognitive decision factors related to task complexity, is largely due to response factors.

Background

Models based on specific cognitive processes are important in understanding the role of individual differences in learning (e.g., Snow, 1980). Although progress has been made in developing models based on specific cognitive processes (e.g., Detterman, 1987; Jensen, 1982), there is substantial debate about the specific cognitive processes being measured by so-called basic cognitive tasks. While some researchers have argued that simple or elementary cognitive tasks tap basic biological processes (e.g., Eysenck, 1986), others have argued that performance on these tasks may be influenced by a range of incidental variables and are not an unequivocal result of individual differences in basic processing (Detterman, 1987). For example, variables such as prior knowledge and motivation can be directly influenced by instruction, practice, task complexity, and feedback (Rouse & Morris, 1986; Ackerman, 1987).

Clearly, incidental task variables which affect individual differences in performance need to be identified and controlled before any conclusions can be drawn about an individual's basic cognitive processes. If these incidental variables are not investigated, models based on specific cognitive processes may or may not be testing what they are alleged to test. Although these new aptitude models may appear to be testing individual differences in specific cognitive processes, they may be subject to the same 'prior knowledge and motivational' influences that plague current psychometric tests.

With computer administered cognitive tasks there is much greater opportunity for understanding the source of these effects and, ultimately, controlling them. Such an approach offers the opportunity of obtaining 'pure' measures of the cognitive processes of interest. These pure measures would be free of the confounding influences of less directly relevant variables. Thus, research on variables that are potentially confounding variables can be looked on as more than just methodological research attempting to disambiguate sources of individual differences. It can be regarded as an attempt to obtain purer measures of the basic processes really important to understanding individual differences by eliminating the effects of less central variables.

This line of argument is clearer when presented in concrete terms. In a choice reaction time task. a subject places a finger on a bar, waits for the appropriate signal to occur, lifts his finger from the bar and touches the appropriate position. The experimenter is interested in the amount of time the subject requires from the onset of the signal to make a decision to react. This is taken as the amount of time from the onset of the signal until the subject lifts his finger from the bar and is called the subject's decision time. The term 'decision time' suggests that the time measured reflects only decision processes the subject must engage in to detect a signal in one of several locations and it is decision processes that the experimenter is interested in as representative of cognitive activity which may be important in mental tasks, generally.

However, it is entirely possible that a portion of this decision time is devoted to the programming of the response or to verification of instructions about what is to be done. Including these processes in a measure of decision processes attenuates the measure of decision processes. So decision time could measure a number of different processes simultaneously. If decision time does measure multiple processes, then understanding those processes would allow better measures of decision processes alone to be developed because the confounding processes could be removed or controlled.

Previous Research

Two different sources of information indicate that measures of basic processes are probably not pure measures of the processes they are thought to measure. The first source of evidence comes from two separate studies conducted by Detterman. In the first study, 141 high school subjects were administered 10 computerized cognitive tasks. All responses were made by touching a touch sensitive screen mounted over the computer monitor. In the second study, approximately 900 Air Force enlistees took the same battery of cognitive tasks as the high school students. The only difference was that the Air Force enlistees made all responses on the keyboard.

Comparison of the results of these two studies indicated that Air Force enlistees demonstrated longer latencies for nearly all measures on all of the tasks. Some of the measures were specifically designed to measure movement time (the amount of time from picking the finger from the bar until the response is made) and it is not surprising that a keyboard response requires more time than a touchscreen response. But what is surprising is that parameters designed to measure cognitive decision processes were also lengthened by the use of the keyboard. For example, the decision time in a reaction time task was over half again as long for the Air Force enlistees (.68 sec) using the keyboard as for the high school students (.44 sec) using the touchscreen. Movement time was relatively less affected (.31 sec AF vs. .22 HS) suggesting that response planning processes take place during the period measured by decision time. Evidently response complexity affects the decision process as well as movement time. This finding strongly suggests that the relationship among processes is much more complex than the simple additive models most researchers favor.

A more formal demonstration of this point was made by Detterman and Andrist (1989). They gave subjects several cognitive tasks with differing instruction methods. One group of subjects was given no instructions about the task they were about to complete. A second group was given standard verbal instructions printed on the screen. The third group was given non-verbal instructions with the use of arrows, flashing displays, etc. which guided the subject through performance of the tasks.

Results, as judged by group differences and correlations among parameters, indicated that the different instructional conditions produced different results. When subjects failed to understand the task being presented, their performance was worse than subjects who were assumed to have a good understanding of task instructions. This decrement in performance was pervasive, affecting almost every measure of performance. The finding that performance can be depressed by a poor understanding of task instructions raises the possibility that the entire relationship between basic cognitive tasks and more complex measures of mental ability may be entirely mediated by the degree of understanding of the instructions.

Though there are a number of reasons to believe that basic cognitive tasks reflect more than an understanding of instructions, it is a possibility requiring investigation. Even if the understanding of instructions is not usually a large source of variance under standard administration procedures, the study conducted by Detterman and Andrist suggests that it is important to control instructions so that all subjects understand a task to the same degree. Unless instruction learning is controlled, instructions could impair the measurement of cognitive processes of interest.

As in the case of different response modes, variations in the quality of instructions would appear to affect the precision of measuring target cognitive processes. In both cases, variables not centrally important to what was being measured had an effect on the variable of interest. The important implication of these findings is that we have an incomplete, simplistic, and poorly elaborated conception of how cognitive processes operate. For example, the study by Detterman and Andrist suggests that subjects develop a mental model from instructions which is modified as the task proceeds. Common sense suggests that subjects must somehow maintain an idea about what is expected of them in a task yet few models of cognitive functioning include the correctness of the subjects model as a variable affecting performance.

Therefore, the research described in this proposal is more than a series of studies on potentially confounding variables. It is really an attempt to clarify some general factors which must be taken into consideration if good cognitive models are to be developed. In fact, it could be argued that research concerning models of cognitive functioning cannot be developed until an understanding of instructions and response are achieved since every cognitive task includes both of these.

Cognitive Abilities Test

All of the tasks in the battery are administered by computer and use the same stimuli and format. All tasks were extensively pretested so that the parameters obtained from each task are reliable and are known to discriminate between groups differing in mean intellectual level.

The ten tasks are:

*Learning(LR)** - In this task, subjects are required to learn sets of stimuli of from 3 to 9 items each. The task yields measures of learning rate.

Relearning(RL) - Subjects relearn the same sets they originally learned in LR. Measures of savings are obtained.

*Reaction Time(RT)** - Subjects are required to respond as quickly as possible to the onset of a stimulus. The task becomes increasingly complex by the addition of alternatives to which the subject must attend. There may be 1, 2, 4, 6, or 8 windows on the screen. These windows are displayed in a semicircular array. The subject begins a trial by pressing a bar.

When one of the windows lights up, the subject responds as quickly as possible by lifting his finger from the bar.

Several measures of speed and accuracy may be obtained from this task. One finding from reaction time tasks is Hick's Law. According to this law, the more complex the decision a subject must make the longer the decision time will be. When decision time is plotted as a function of the log base 2 of number of alternatives there is a linear relationship between the two variables. Increased time required for reacting to a more complex stimulus display is thought to be due to attentional factors. It takes longer to mentally attend to more stimuli.

*Stimulus Discrimination(SD)** - This is a modified match to sample task. The task is to match a probe to one of six alternatives. This task yields measures of stimulus encoding and search processes.

*Probe Recall(PR)** - Six stimuli are presented sequentially in 'windows' on the screen for 1 second each. The subject's task is to remember where each stimulus was presented and to indicate in which position a match to a probe stimulus appeared. Various parameters of memory accuracy and speed are obtained.

*Self-Paced Probe Recall(SP)** - This task is similar to PR except that the subject can study each stimulus item for as long as desired. Measures of strategy use are obtained.

Recognition Memory (RC) - A forced-choice recognition task uses stimuli from previously presented tasks.

Sternberg Memory Search(ST) - Memorized sets of stimuli are tested by presenting stimuli which either are, or are not, in the memorized set.

*Tachistoscopic Threshold(TT)** - Two stimuli are presented for a very brief duration and then are covered with a mask. Subjects are required to judge if the stimuli are the same or different. If the decision is wrong, the next presentation is for a longer interval. Over a series of trials, a threshold for discriminating same from different is obtained.

Tachistoscopic Delay(TD) - This task is the same as TT except that a subject must judge if there is a delay between the offset of the first stimulus and the onset of the second.

Progressive Matrices. This test, patterned after other progressive matrices tests, is a much more complex test than the others in the battery.

The six tasks followed by an asterisk (*) compose a shortened battery that will be used in the research presented here unless otherwise indicated.

During administration of the tasks, all pertinent data are recorded on a trial-by-trial basis for each task. When task administration is completed, preliminary analyses of the raw data files is conducted automatically.

Studies Conducted

Response Mode

As indicated above, response mode is almost certainly an important variable affecting nearly every measure of cognitive processing included in the battery. However, this conclusion comes from comparisons between studies and has never been directly confirmed. Study 1 is designed to show the effect of touchscreens vs keyboard on performance. Study 2 will further study the effect of response factors by manipulating response complexity.

Study 1

Purpose. The purpose of this study is to demonstrate that response mode makes a substantial difference in performance. Although the evidence presented earlier suggests that touchscreen responding is superior to keyboard responding, the data come from two samples which are markedly different. It is, therefore, necessary to compare performance with touchscreens to performance using keyboards in a single group of subjects.

Subjects. This experiment used 288 Air Force enlistees. Of these, 205 took a keyboard version of the tasks and 83 completed the same tasks using touch screens.

Procedure. Except for response device, the two groups will be identical and will receive the identical tasks.

When the keyboard is used for responding, numbers appear above each response position. The subject initiates a trial by touching the space bar and responds by pressing the appropriate number key. In the touchscreen version, the subject begins a trial by touching a bar at the bottom of the screen and responds by touching the appropriate position.

Results. The results leave no doubt that nearly every parameter in the battery is affected by response complexity. Subjects using the keyboard performed faster and more accurately. Figure 1 shows the results for the reaction time task. Decision time for subjects using keyboard input was about 150 msec slower than for subjects using touch screens.

Study 2

Purpose. If, as expected, touchscreens produce markedly different performance than keyboards, the next question is why. What is it about touchscreens that improves performance? It may be that touchscreens simply reduce response complexity thereby reducing cognitive demand which makes the task easier. This study is designed to test that position.

Subjects. Two-hundred-forty-six Air Force enlistees were used in this experiment.

Procedure. The purpose of this study was to purposely complicated the response required to see if explicit manipulation of response complexity affected decision time. There is no logical reason it should under current models of cognitive functioning.

The task chosen for study was choice reaction time using keyboard input. There were four conditions of response complexity: RN) In the simplest condition, when a position lit up the subject p... d his finger off of the space bar (Response None). RA) After lifting his finger from the space bar, the subject had to press either the D or the G key (Response Any). RS) After lifting finger his finger from the bar, the subject presses the D key if the response is on the left and the G key if the response is on the right (Response Same Side). RO) After lifting his finger from the bar, the subject pressed the D key if the response position was odd - 1, 3, 5, or 7 - and the G key if it was even (Response Odd). In all cases, the subject ended the response sequence by hitting the number key which specified the correct response position.

Results. The complexity of the actual response can be judged by the time required for the subject to execute the response. Figure 2 shows the movement time for each response strategy except for RN where subjects only lift their finger from the space bar and do not produce a movement time. As can be seen from Figure 2, those responses that seem to be most complicated take the most time.

Figure 3 shows the decision times for all of the response strategies. These are shown by level of complexity. Note that when there is only a single position on the screen, all of the response strategies are of equal difficulty. When there are two or more positions on the screen, the amount of decision time is a direct function of the response complexity.

Hick's Law predicts increasing reaction times with increasing stimulus information. Hick's Law is supported by these data. As the number of positions a subject must attend to increases, decision time increases. It has usually been assumed that Hick's Law resulted from cognitive or attentional factors. The data from this experiment show that the steepness of the slope of decision time over number of choices is due to response factors. The difference between the lowest and highest point as a measure of slope is between 100 and 150 msec.

Several experiments were conducted, not in the original proposal, following up this possibility.

Study 3

Subjects. This study employed 56 college students.

Procedure. All subject were instructed to lift their finger from the touchscreen bar as soon as possible. In addition, trials were not presented in blocked form. Instead, all trial were randomized. In addition, for any number of squares on the screen less than eight, the position of the squares was randomized. In previous versions of the task, the available positions always were clustered in the center of the screen.

Results. Results are shown in Figure 4. The difference between the first and last point is now about 50 msec. This result suggests that a large portion, if not all, of the Hick's Law effect is due to response factors.

Study 4

Subjects. Subjects were 67 college students.

Procedure. All subjects received the same task. The conditions of this experiment were the same as Experiment 2 except that the hardest strategies were associated with the easiest level of task complexity. When there were 8 position on the screen, subjects used the RN strategy, with 6 positions, they used the standard keyboard procedure response procedure, with 4 positions they used the RA strategy, with 2 positions the RS strategy and with 1 position the RO strategy.

Results. Figure 5 shows what happened. Response factors produced a negative slope for decision time. In other words, response complexity is capable of overwhelming any other factors that may produce Hick's Law. This experiment demonstrates the power of response demands in a simple cognitive task.

Study 5

Besides response factors associated with responding, there are also response factors associated with attending to the display. The more items on in the display, the larger the display. The larger the display is the more the subject will have to move his eyes. These response factors may also contribute to Hick's Law effects. To test this idea, Experiment 2a was repeated but with a display that took up less than .5 degrees of visual angle.

Subjects. This experiment used 50 college students.

Procedure. The display consisted of from one to eight, tightly packed Xs presented in a U-shaped display in the center of the screen. The subject sat six feet away from the display. The subject pressed the keyboard space bar. When one of the Xs turned red, the subtest lifted his finger from the space bar.

Results. The results indicate that the slope of decision time across number of alternatives was substantially reduced over other conditions. Highest to lowest decision time showed a range in the area of 20 to 30 msec. Much of this difference came from the fact that the when only one item was presented, times were faster than when more than one item was presented. This finding suggests that subjects are still using eye movements to attend to multiple stimulus items. An experiment that will be conducted this spring will increase the viewing distance. This should eliminate any eye movements and should result in a flat slope of decision time by number of alternatives.

Other Experiments in Progress

A number of other experiments are currently being analyzed. Results of these experiments appear promising but detailed reporting is not possible until analyses are completed.

Interpretation of Findings to Date

The results of this research clearly show that response factors have a large impact on cognitive decision processes. Figure 6 shows the typical model of the choice reaction time task that is usually presented. As a legacy of stimulus-response psychology, cognitive tasks are conceptualized as occurring in stages. Corresponding to the observed surface behaviors are parallel brain processes. According to this model, detection is seen as independent of response processes. First detection occurs and then the response is programmed and executed.

The data from the experiments conducted here indicate that this model cannot be right. The more complex the response, the longer the decision time. Hick's Law seems better accounted for by response factors than by decision processes. Hicks law relates decision time to decision complexity so it was easy to assume that it was the decision processes that caused the changes in decision time. What Hick and others failed to notice was that response factors were perfectly confounded with decision complexity. The more items there are to choose from, the more difficult the response will be.

Figure 7 shows a more likely model of cognitive performance on the choice reaction time task. In this model, detection and response factors do not occur serially in the brain. Any particular process is given a greater or lesser weight depending on its importance at the time. Such a model is supported by Mulder, Wijers, Smid, Brookhuis, and Mulder (1989). They found that motor responses during a reaction time task are not turned off and on. Preparation for the motor response may begin seconds before the trial even starts. The brain is preparing the response long before the subject knows the response that will be made.

According to the model being proposed, cognition must be regarded as a complex system whose parts are highly interrelated. Conceptualizing cognitive processes as if they occur in serial order is a misleading simplification. It is particularly important in the study of individual differences to have accurate models of cognition. If the models are not correct, it will not be possible to localize the source of differences we wish to account for.

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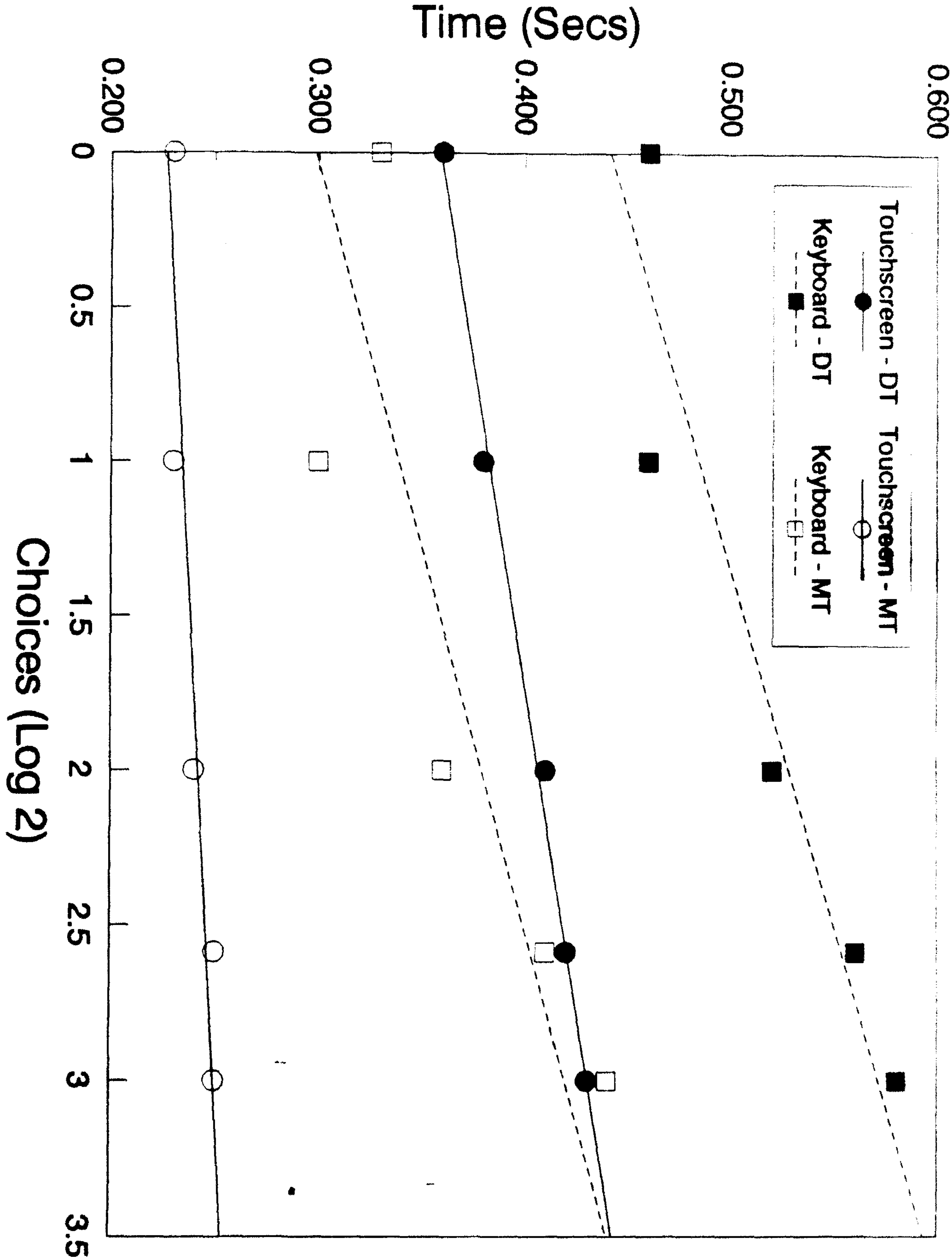
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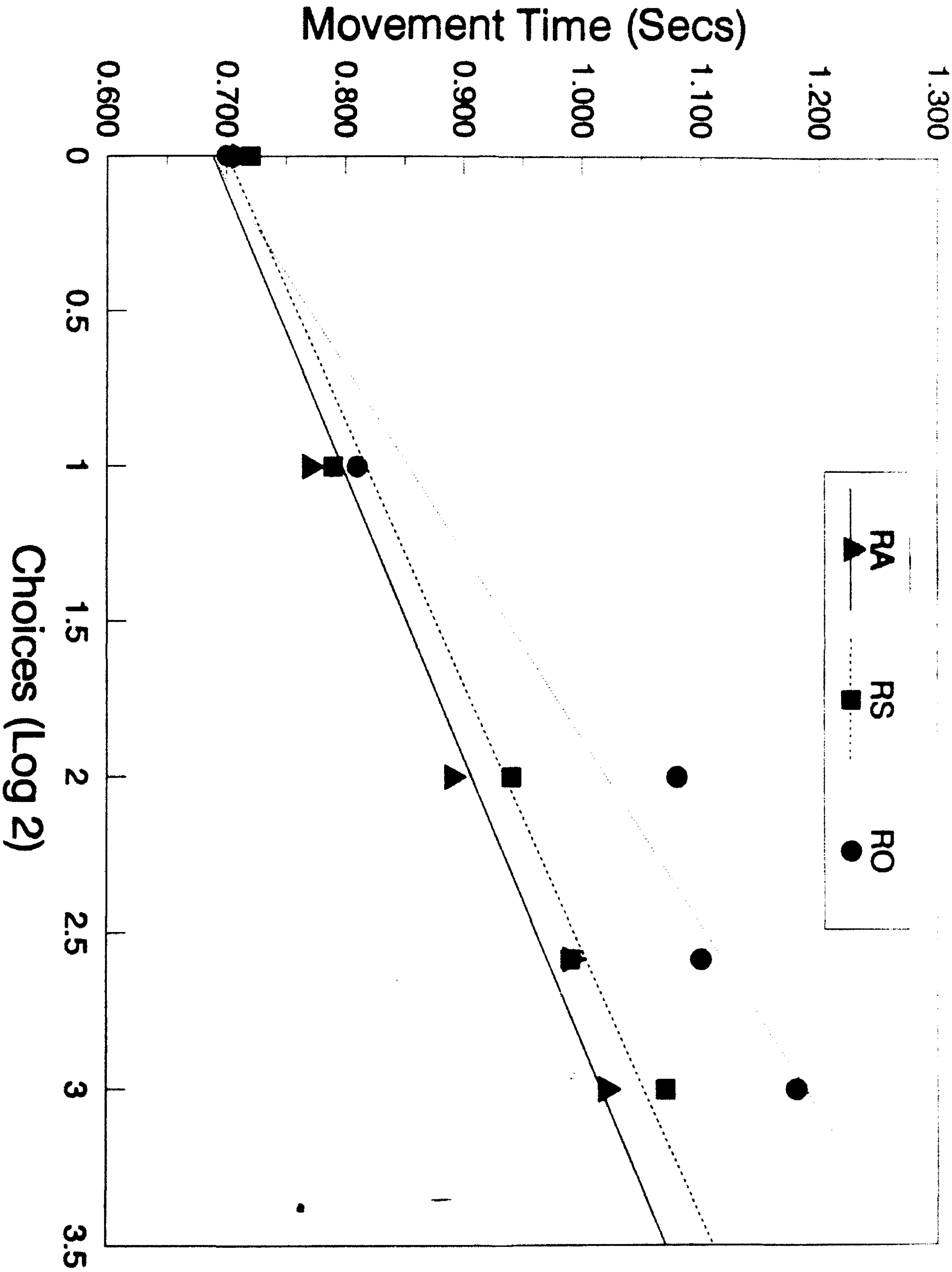
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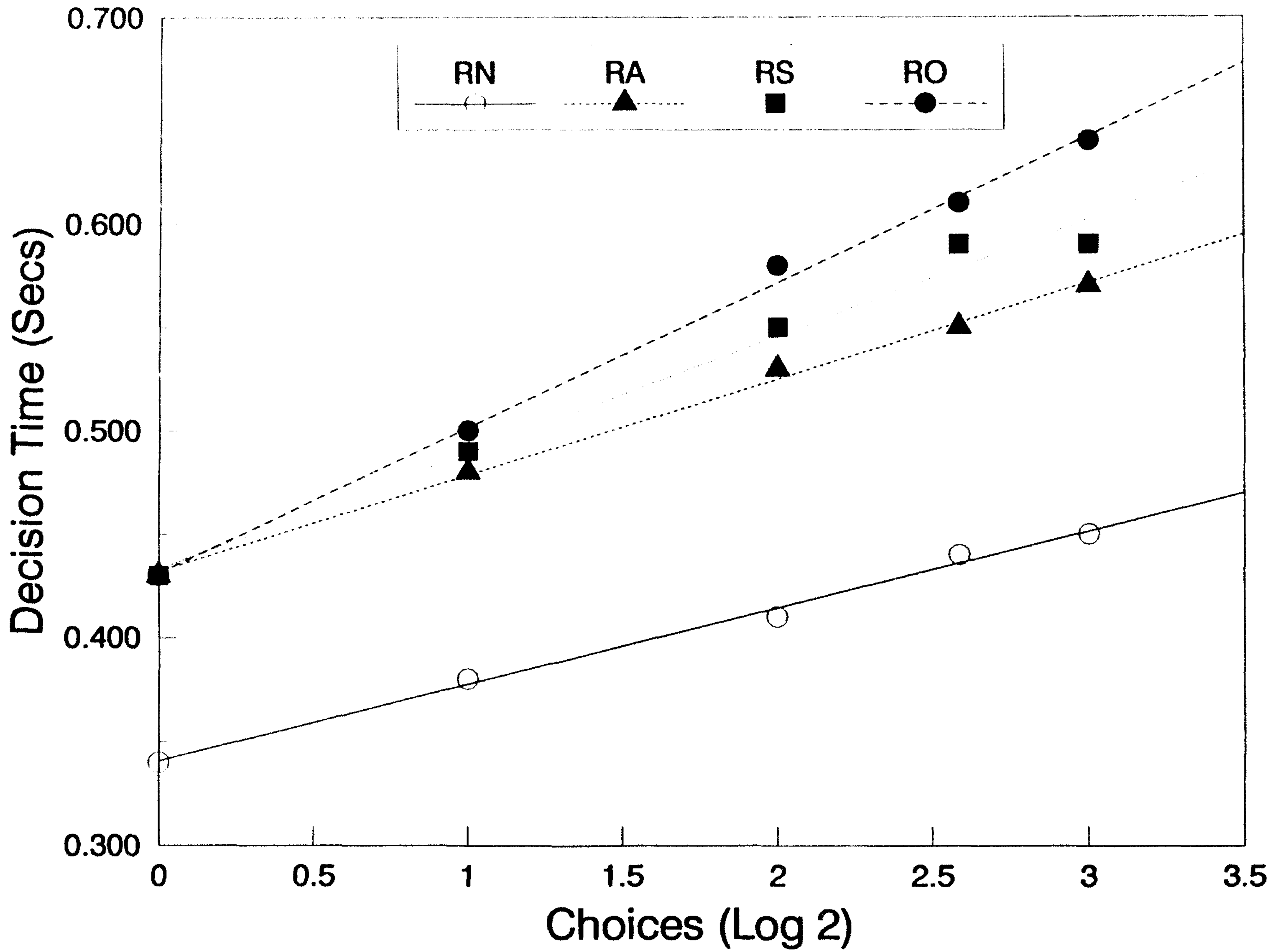
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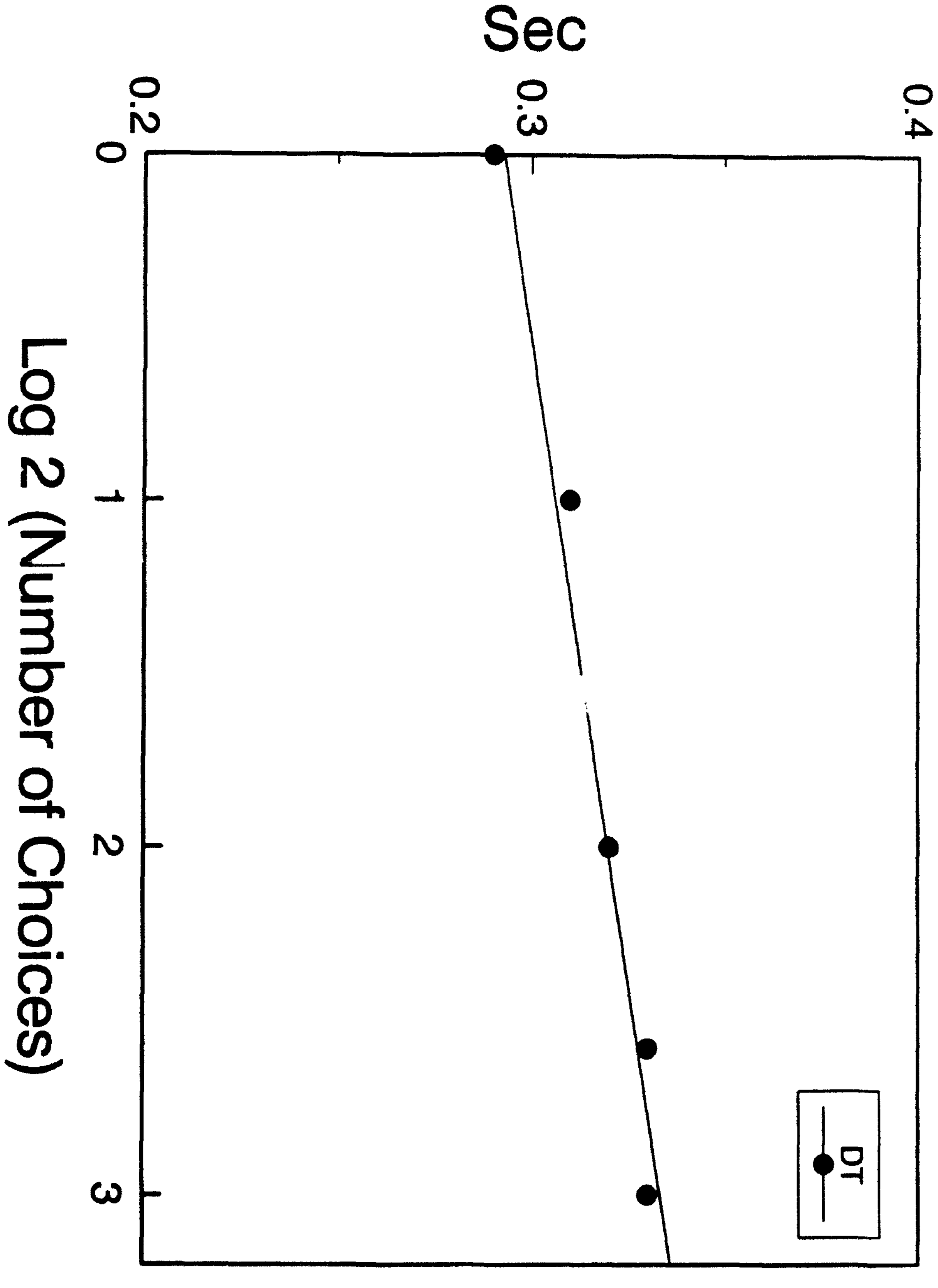
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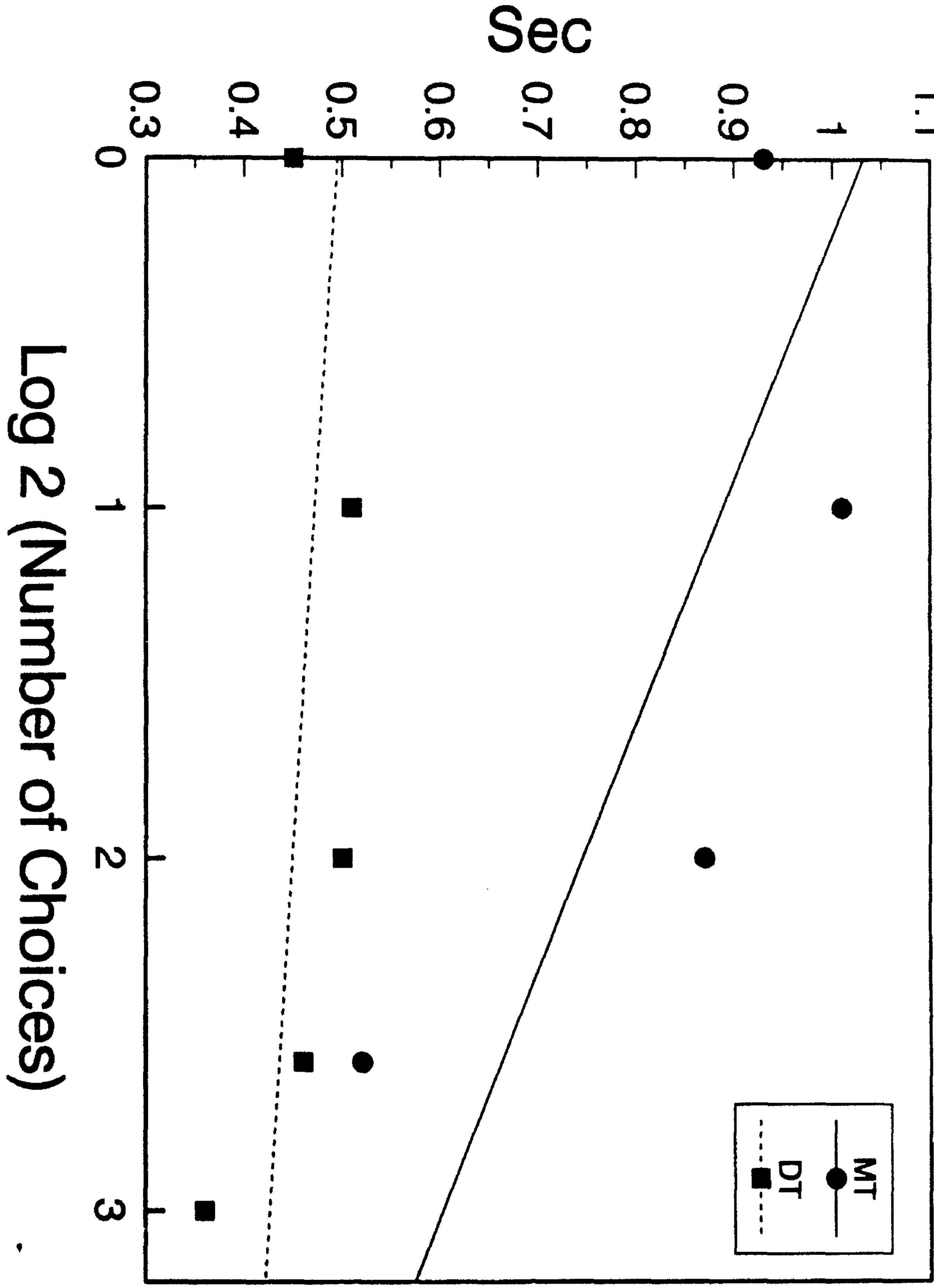
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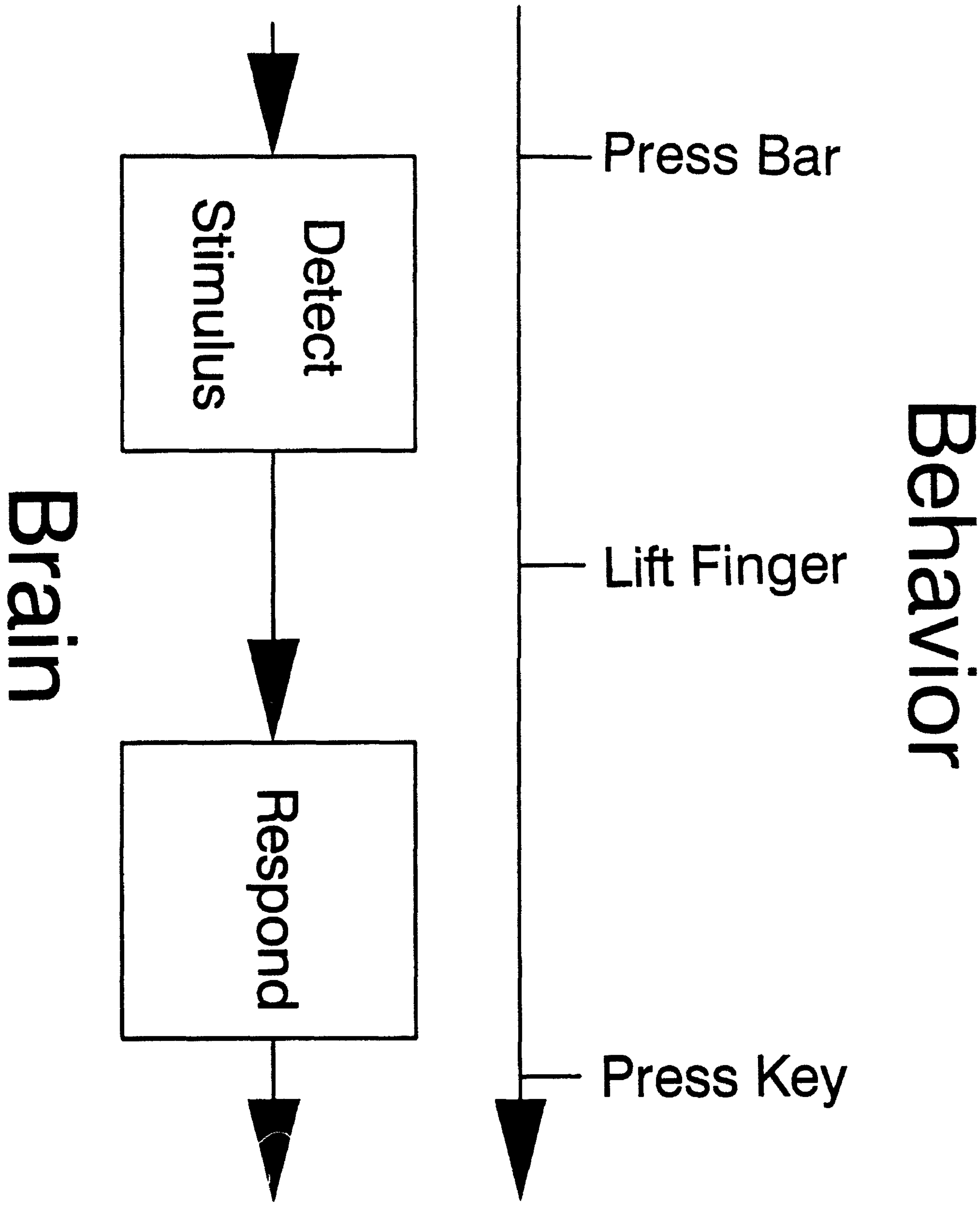
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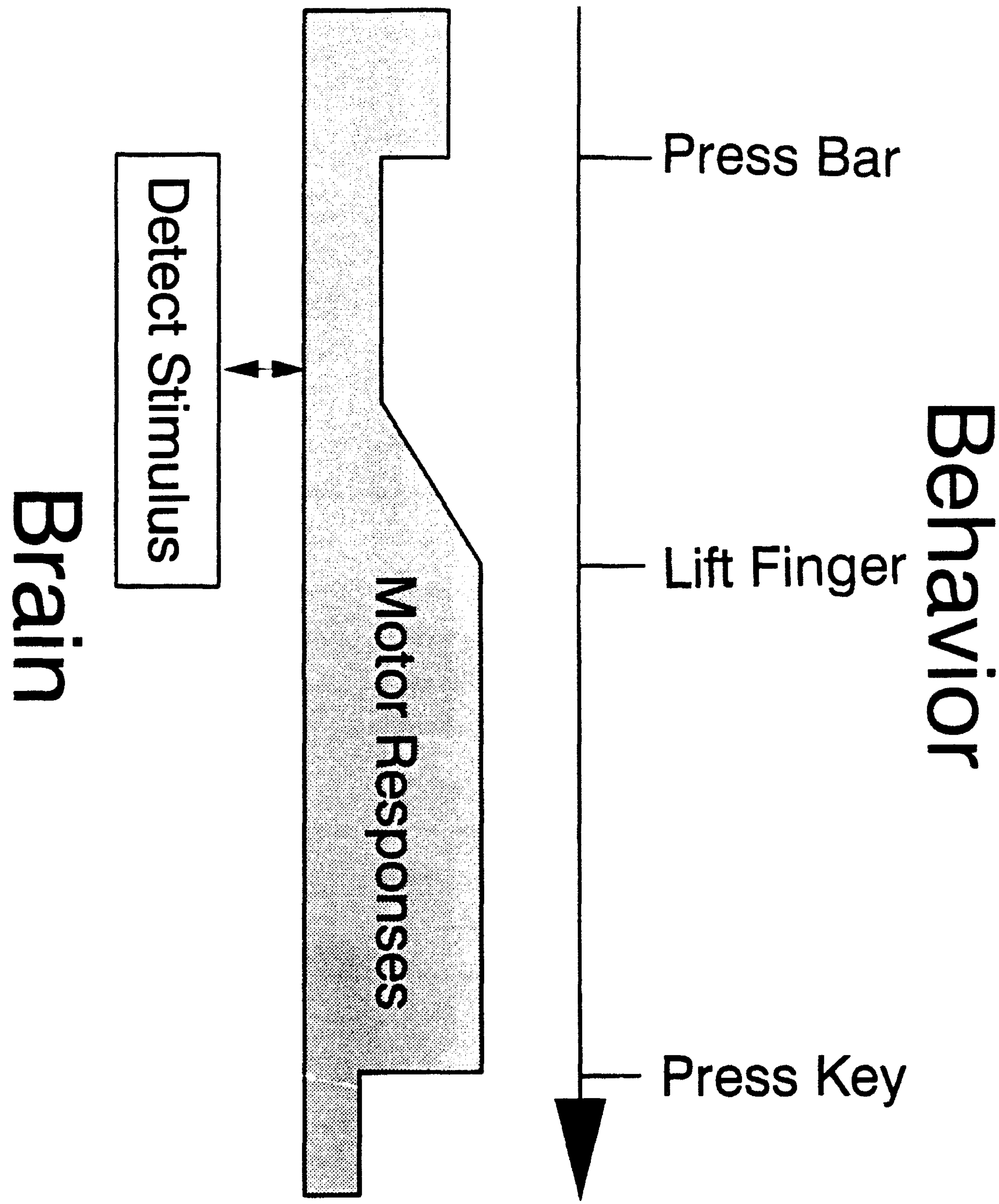
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