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DADTA III: AN ON-LINE COMPUTERIZED SYSTEM FOR THE EXPERIMENTAL ANALYSIS OF BEHAVIOR[1]

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Summary.—A fully computerized, low-cost behavioral testing device is described which has been in continuous operation for 3 yr. Named DADTA III (Discrimination Apparatus for Discrete Trial Analysis) it is characterized by flexibility, available software (programs), and on-line data analysis capability. The operation of the setup is detailed, the experiments completed to date are reviewed and an example of work in progress (ROC analysis) is presented.

The study of conditional operants has revolutionized the experimental analysis of behavior. Perhaps the most important change that has occurred in behavioral studies as a consequence is that precise automated control of the contingencies which guide or produce behavior is now possible and commonplace, as well as the unequivocal recording of stimuli and their behavioral effects.

Most studies employing operant techniques use continuous performance recordings of one sort or another. These have been eminently successful in analyzing situations in which the temporal course of behavior is being investigated. Further, ingenious modifications have allowed such innovations as the measurement of sensory thresholds in animals. The ease with which apparatus can be modified has allowed a rich search, only some of which has been reported in the literature.

In my experience, however, one application of operant techniques was consistently found wanting. Continuous performance procedures proved relatively inefficient when simple discrimination behavior was in question. With these procedures many more responses accumulate before a criterion is reached than when discrete manual techniques are used. This inefficiency was usually more than counteracted by the facility provided by automation. But, again, data analysis proved cumbersome—less was recorded than was needed and some of the fine grain of the behavior was difficult to extract from the record.

These limitations led to the modification of a system for the experimental analysis of behavior in the direction of being able to record more fully *discrete* happenings while retaining the capacity to study *Ss'* continuous performance. At

[1]The author is deeply indebted to Richard Robinson who designed and directed the building of the DADTA interface and supervised the entire programming effort; to John Fitzgerald who wrote early versions of the DADTA programs; and to James Bright who is responsible for the presently available library of DADTA routines and subroutines. Thanks are also due to John Glick whose skill in monitoring, maintaining and supplementing both the hardware and software operations has made DADTA the useful instrument it is; to Walter Tubbs for help in preparing this manuscript; and to Abraham Spevack for making available the ROC data. This work was supported by NIMH Grant MH 12970 and Career Research Award MH 15214.

first a special purpose device was constructed and used successfully for about 3 yr.; this was superseded by the present system which has now also been operating for 3 yr. and is reported in detail here. The original device was christened DADTA (Discrimination Apparatus for Discrete Trial Analysis) and was described in an earlier report (Pribram, *et al.*, 1962). The current configuration is known as DADTA III, since it is the third major version of the technique.

There are now some 18 or so studies reported in the literature (see Appendix) which were accomplished with the use of DADTA systems. Modifications have produced increased flexibility and reliability to a point where "down" time compares favorably with ordinary operant equipment and even manual testing. The result is that *E* deals with biological and behavioral rather than with electronic problems. Meanwhile costs have plummeted so as to make DADTA an attractive package even to the small laboratory. At least one manufacturer (Grason-Stadler) of behavior control equipment is making commercially available a complete DADTA-type system with capabilities similar to those described below.

Apparatus

The DADTA III system utilizes a small (12-bit, 4 K core storage) real time, on-line, general purpose computer with a cycle time of 1.5 μsec. This computer, a PDP-8 (Digital Equipment Corporation), is interfaced with a square matrix of 16 ID display panels each of which is covered with a clear plastic disc which, when depressed, closes a microswitch activating an IEE (Industrial Electronic Equipment) one-plane digital readout projection unit. Each unit is capable of displaying 12 patterns; 10 of these can be presented against the background of the other two, which are colors.

A particular computer program is commonly controlled through one of several input devices. Programs are usually initiated on a teletype which activates a magnetic tape read-in to place in the computer the desired program. As described in detail below, a unique subroutine system permits each *E* flexibility in selecting experimental parameters. The programs as a whole are initially composed and debugged on the teletype.

The entire constellation of events which determine the behavior of the organism and the consequences of this behavior are recorded on-line by the teletype and optionally on punched tape. As the organism performs, an instantaneous report is typed of the characteristic of the cue displayed on the panel pressed, the position of the cue on the display panel, the latency of response, the correctness or incorrectness of the response (according to the program in effect), and whether or not a reward was given. At the end of each testing session these parameter characteristics and their outcomes are automatically summarized in a simple numerical tally.

The construction of an appropriate interface makes all of this possible. The major tasks of interfacing the computer with its external devices are matching

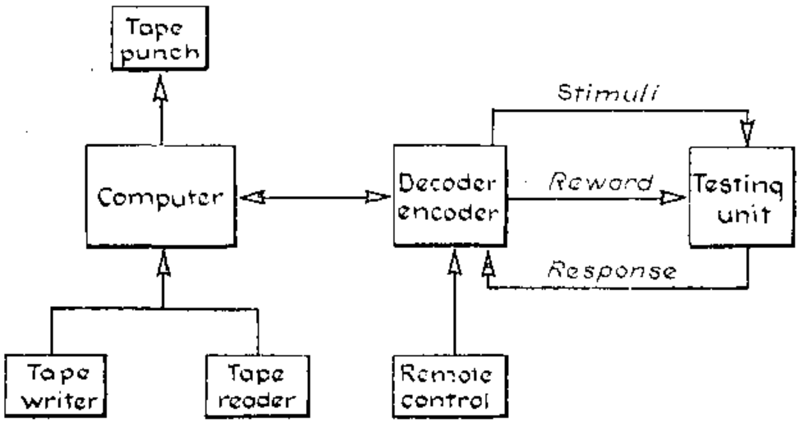

FIG. 1. Over-all schematic of DADTA III

the informational and electrical characteristics of the two systems and signalling the timing of a data transfer. Since DADTA III computer system interfacing components can be purchased from the computer manufacturer, the problem of such matching can be minimized.

Transfer of stimulus information is effected with a 64-bit flip-flop memory buffer. The codes for two symbols (8 bits) are loaded into the accumulator

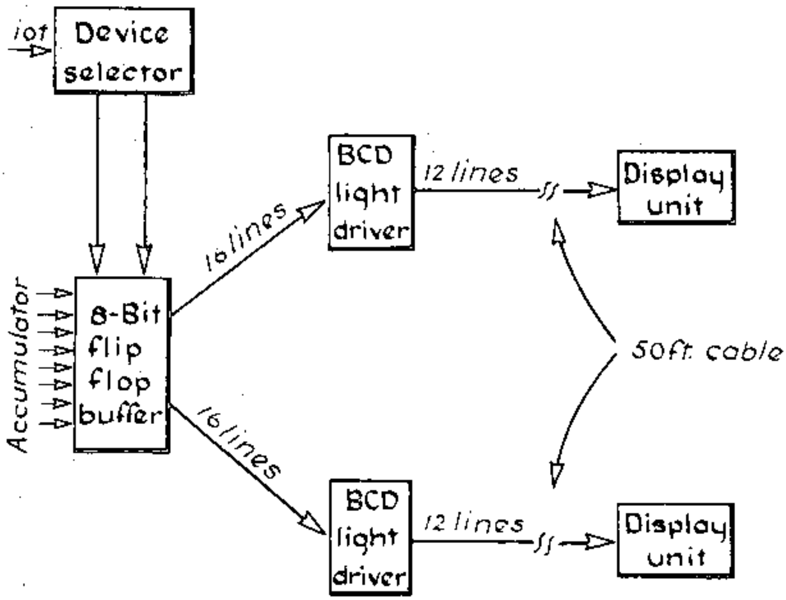

FIG. 2. Schematic of interface between computer and display panels

and transferred to the flip-flop buffer. An input-output command, with appropriate device-selector address, gates the data into the buffer. From the flip-flop, indicator-driver circuits decode and amplify the display signals.

When a response is made, an interrupt circuit sets the interrupt flip-flop within the computer and the particular response or control signal appears on line in the accumulator. Setting the interrupt causes the computer to transfer to a program which, via a device selector, gates the signals into the accumulator. Figs. 1 and 2 schematize some of the interface logic used to accomplish this.

The Programs

The crux of the control provided by the DADTA III system lies in programming. With earlier versions of the DADTA system, as in most operant setups, we accomplished our programming through hardware; with the advent of inexpensive general purpose computers—machines such as the PDP-8—we were able to turn to the more flexible facility of software manipulations. This is achieved via a unique (and extensive) library of sub-routines each of which can be added or removed in moments by simple keyboard commands. At present we have accomplished a software package for our interface; should another interface be employed, a skilled programmer must be enlisted to meet the specific needs of the system and laboratory. A typical core program will include the following basic characteristics.

First, of course, is *stimulus* control. Each of the 16 ID panels is capable of 12 possible displays without any hardware change (with an exchange of masks the number of possible displays becomes unlimited). A subroutine stores the symbols representing the display in a buffer in a form available to a calling sequence. When called, the contents of this symbol buffer are moved into the display buffer and are transmitted to the ID panels via another DADTA buffer in which are represented the panels by location. Another subroutine operates on the symbol-display location table and presents the next symbol display. It also saves the time of the display for the latency calculation. This is done by clearing the symbol buffer and filling it with the next symbol in the table. The latency measure is stored in a latency buffer until printed out.

Second, the computer must control the scheduling of *reinforcement*. For accomplishing this a "reward" subroutine activates the pellet dispenser according to the investigator's parameters for that program. In addition to the activation of the dispenser, the routine must set a flag to signify that the reward was given and, when completed, bump the reward counter, i.e., increase it by one. Another subroutine determines whether or not to reward a press based on whether a particular symbol was displayed in the panel pressed. This subroutine works by checking a prestored reward table, provided by the investigator, for the presence of the appropriate symbol.

Third, a *print-out* subroutine provides a response-by-response record of which panel and symbol were pressed. The operation of this subroutine is typically as follows: As already noted, both a symbol and a panel buffer are available. In these a record can be readily made of each response (panel depression) as it occurs. A subroutine then loads these records into the accumulator prior to on-line print-out. In addition, when it is desired, a latency subroutine computes and prints the latency between the time of display of the symbols and either the press or the release of a lighted panel. The operation resembles a skip-on-a-hardware flag instruction: when the software latency flag is set as a lighted panel is released, the program proceeds to print out the latency. Until this occurs the program stays in a tight loop continually checking the latency flag and the clocks. Once the flag is down the display time is subtracted from the release time and the print-out is activated; minute, second and millisecond differences are recorded.

These are, of course, only overviews of some of the critical subroutines needed to compose the desired program. They give a flavor of what is necessary; the specifics depend on the particular configuration needed to make the behavioral analysis sought.

An Experiment

In order to demonstrate the power and flexibility of DADTA-type installations, a specific experiment performed with this instrument will be detailed. The chief concern of my laboratory is the analysis of brain-behavior relationships. Many experiments accomplished over a 20-yr. period have established the fact that bilateral resection of the inferior gyrus of the temporal lobes of monkeys markedly impairs the acquisition of visual (but no other) discriminations. Since this impairment comes about without any invasion of the primary visual mechanism of the brain, the question has repeatedly been asked whether the defect in discrimination is due to an inability to process cues or to shifts in the criterion for making a response.

An analytic technique has been devised to tease apart behavioral situations in which just this sort of question is raised. This is the technique of signal detection in which the response-operator characteristics are plotted as curves (ROC curves) from which sensitivity to differences among cues can be separated from other factors which bias responses. While this technique has been extensively applied in human studies, it has only recently been adapted, at considerable cost in labor and limitation, to studies with animals. DADTA III seemed to be the ideal instrument to automate ROC procedures for the extensive analysis of discrimination behavior necessary to our interests.

The complete results of an ROC analysis of the behavior of monkeys with bilateral resections of the inferior temporal cortex will be presented elsewhere. Here I want to present only the details of the procedure and some ROC curves obtained when normal monkeys are tested.

A. *Shaping*

The actual testing in the DADTA begins, of course, with a shaping procedure. This procedure has been standardized, and one of the dividends of using DADTA has been its ability to record a large segment of the changes produced by shaping. Several such reports have been prepared and published (Blehert, 1966; Dewson, 1967; Pribram, Douglas, & Pribram, in press) both for unoperated and brain-operated monkeys.

We begin shaping by accustoming the monkey to the pellets used in the dispenser, then presenting him with the pellets in the DADTA feeder cup, then delivering the pellets to him by remote operation of the feeder (behavior is observed through a one-way window) until the monkey makes a response toward the cup upon hearing the click of the feeder relay. We then shape this contingent behavior upward until the monkey actually presses a panel (on rare occasions we might have to attach a pellet to a panel with transparent tape). Learning is remarkedly swift: an average of only two or three daily sessions of a half hour accomplish the first panel press.

After this point *E* does not intervene; the procedure is completely automated. Twelve of the 16 panels display the numeral "1"; the other four are dark, i.e., blank; lit and dark panels are randomized over trials. Whenever a display is pressed, reward is given. Thus the monkey immediately works on a .75 fixed-ratio distributed-response schedule. After this becomes well established (2 or 3 days of 50 trials per day) the number of displays is cut to 10, 8, 6, 4 and finally, 2. The number of presses made to the displayed panels vs the number made to the blank panels determines the ratio of reinforcement obtained. A complete record of each response (panel pressed and whether rewarded) is printed out instantaneously by the teletype—as is a trial-by-trial summary at the end of the run.

B. *The Discrimination Task*

On completion of shaping, the monkey was presented the discrimination problem. The middle two ID panels of the fourth row displayed a red disc. The monkey was required to press either of these in order to initiate the stimulus display, thus self-pacing the task and providing precise reaction time latencies. Once he pressed, a green disc and a blank panel simultaneously appeared in the middle two panels of the second row. The light intensity of the green disc was varied. This was accomplished by flickering the displayed figure at varying rates, all above the fusion threshold of monkeys (Mishkin & Weiskrantz, 1959). Reward was given only if the panel on which the green disc appeared was pressed, but report of reinforcement or of nonreinforcement due to press of the blank panel extinguished the display, and five seconds later the lower panels again lighted up in red, preparatory to the initiation of another stimulus display.

A record of each response was printed out by the teletype. Each trial record detailed which panel was pressed; the latency between the press of the red trial-initiating panels and the press of the discrimination panels; the intensity of the green disc on that particular trial; and whether reward was or was not obtained.

At the end of a run (100 trials) a summary was collated and printed. The summary showed how many responses were made at each "stimulus" location, how many responses were made at all other panels, and how many rewards were obtained.

C. The ROC Experiment

The study was performed with monkeys who had been shaped and had learned consistently to accomplish discrimination at the highest intensity of the green disc which was expressed as points in an ROC space and evaluated according to Norman's techniques (Norman, 1964). Reaction time latencies were used in accordance with Blough's procedure (Blough, 1967) to construct ROC curves. An example is shown in Fig. 3.

This experiment represents only an initial examination of the uses of signal-detection techniques to separate performance into its input and output dynamics. Current research now in progress attempts to extend these analytic procedures to the successive discrimination conditioning paradigm which will allow the use of choice as well as latencies to constant ROC curves. Successful completion of this work should sharply enhance the usefulness of signal-detection procedures in the evaluation of brain-behavior relationships.

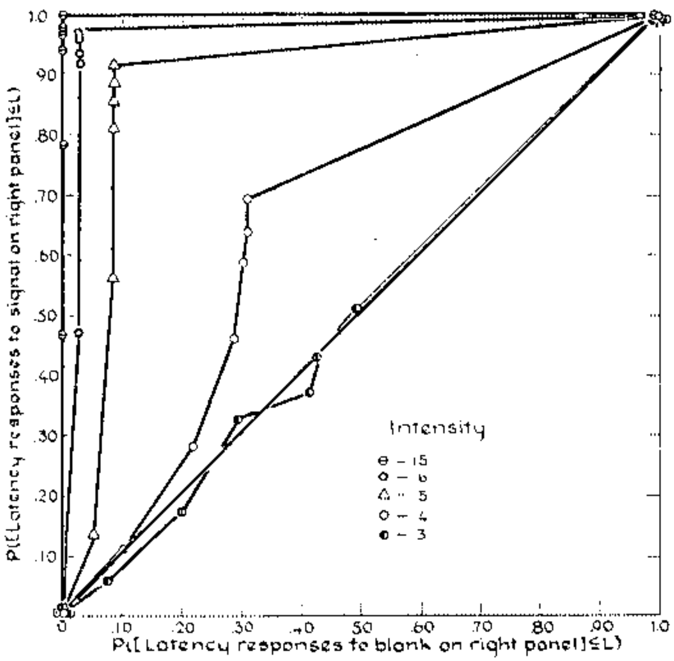

FIG. 3. Receiver operator characteristic curve based on latency of responses made to various intensities of panel illumination as indicated

D. *The ROC Program*

In order to accomplish the ROC paradigm a fairly complex program is demanded. A synopsis of the way in which one trial in the ROC procedure is programmed follows: At the end of the intertrial time, the program lights the two middle red panels in the bottom row of the display board. At this point in time, the monkey initiates the trial proper by pressing and releasing any one of the four red panels. Blank panel presses are ignored. The signal to the program to start the trial is the actual release of the red panel. No response is allowed from the monkey for .5 sec. after the release in order to permit the panel lights to come on completely and to discourage spurious presses in the bottom panels.

On detecting the release of the red panel, the program saves the time in the clock counters for computation of the latency, looks in a user-supplied list to see which display is to be presented and displays this in the predetermined location. The relative intensity of the given symbols is set by constants in the program (which may be changed by loading in new values from the switch register).

After the trial display is presented, the monkey decides and responds. The program proceeds to the next trial, printing out the data for the current trial and starting the intertrial time. On a rewarded trial the program delivers to the monkey one pellet during this period. On a non-rewarded response the panels go dark and the intertrial time starts. Blank panel presses do not alter stimulus display or reinforcement contingencies but are recorded for later summary.

Discussion

It is not my purpose here to discuss the value or lack thereof of ROC psychophysical procedures in brain and behavior research. This will be reported subsequently. Rather, I have detailed this procedure as an example of the flexibility and power of computer-controlled, automated experimental analysis of behavior. For my laboratory the use of a computerized setup has clearly proved a remarkably powerful tool in various behavioral testing situations. But these by no means exhaust the possibilities. Another of my interests directs the use of the same computer to the analysis of electrical signals recorded from the brains of behaving *S*s. Until recently, such recordings were often made on analogue magnetic tape and subsequently (and tediously) analyzed. Now, however, several on-line sets of experiments using both macro- and micro-electrodes are being carried out with the system (Pribram, Spinelli, & Kamback, 1967). The next logical step is that the on-line recordings of neuroelectric data be combined with the on-line control and recording of behavior; this is being done. In a current experiment, for instance, the electrical activity of the inferior part of the temporal lobe is being monitored while a monkey is learning and performing a simple two-choice visual discrimination. Local electrical seizures are then induced by stimulation either just before or after the trial and the effects on brain state and on behavior recorded.[2]

The future also promises a continuing reduction in the cost of the computerized system of behavioral analysis. DADTA Mark IV is already on the drawing board. Tektronix has just announced a character generator which will interface the PDP family of machines with any television set. This means that we can now increase the flexibility of stimulus display and reduce the amount of interface that needs special construction. Only the response and reinforcement recording device needs to be put together. This more limited interface has been designed.

Cost for an entire system of the DADTA Mark IV type can thus be kept under $20,000. This cost would include the general purpose computer, input-output devices and special high speed tape reader. With a magnetic tape system another $5,000 must be added.

Considering the short time the present technology has been available at a reasonable price, I feel awed at the accomplishments already made possible through the computer control of the experimental analysis of behavior. Obviously, this is *the* direction to go in the coming years.

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APPENDIX

Listed below are studies which provide evidence of the workability of the techniques described above.

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