TECHNICAL NOTE

*A SYSTEM FOR THE RECORDING AND ANALYSIS OF
INTERRESPONSE-TIME DATA USING AN AM TAPE RECORDER
AND DIGITAL COMPUTERS¹*

The use of a digital computer for the analysis of operant behavior has proven valuable not only because of the time and effort saved in performing calculations but also because it is possible to analyze data in a manner and with a degree of precision and complexity which would not be feasible without the computer. Measurement of interresponse times (IRTs), rather than total number of lever presses (Skinner, 1938), is a useful method for the analysis of operant data. Both *on-line* (Weiss and Latties, 1964) and *off-line* (Herrick, 1963) systems have been described which facilitate this type of data analysis. In general, the off-line systems require that the time of the event (*e.g.*, lever press) be recorded at the time that it occurs, with further analysis carried out later. A frequently used method for recording the IRTs is punching on paper tape the coded real time as the event occurs (Barry, Kinnard, Watzman, and Buckley, 1966; Herrick, 1963).

The present paper describes a system in which an audio tape recorder is used to record lever presses and reinforcements as they occur; a Programmed Data Processor-8 (PDP-8) is used to convert the intervals between these events on the tape to binary numbers; the IRT data so obtained is converted to real time and analyzed on an IBM 7094 computer. This system permits the recording of IRTs in an inexpensive manner; the computer/s used can in practice be determined by what is available to the individual investigator and can be part of a general computer facility shared by several investigators. It is possible to analyze IRT data using counters (Anger, 1955; Kelleher, Fry, and Cook, 1963) or the time period of a cathode-ray oscilloscope to give a graphic display of an array of IRTs (Blough, 1963); however, these methods transform data immediately following or simultaneous to its acquisition and thereby lose the individual data points as well as sequential order. Recording a signal on a magnetic tape when a lever press occurs, and subsequently transforming the distance between two such signals into an IRT, makes it possible to preserve each individual IRT in a sequential order.

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Material and Methods

Data are recorded on a four-channel Crown Series 800 tape recorder, and computed with the PDP-8 computer (Digital Equip. Corp.). Figure 1 shows the relationship between the components of the system; the clipping interface is unique and enables the recording of pulses of a specific size, shape and duration as to be compatible with the tape recorder.

Fig. 1. Diagrammatic representation of computer system for the recording and analysis of operant behavior.

Recording of Pulses

Depression of a lever in the operant chamber closes a miniature switch which is connected to a pulse generator, the output of which is a -15-v , 100-msec square wave. The pulse is then routed to other modules concerned with the schedule contingencies as well as to the tape recorder interface. Due to the lack of a dc response by the AM tape recorder, the square wave, if fed directly into the tape recorder, would be differentiated into two *bipolar pulses* which correspond to the leading and following edge of the square wave. Since information is conveyed to the PDP-8 by the polarity of the recorded signal, the pulse must undergo modification before recording. To record discrete signals of either positive or negative polarity and of the proper amplitude, the circuit in Fig. 2 is used as an interface between the pulse generator modules and the tape recorder.

The initial part of the circuit is an RC network with a time constant much smaller than the input pulse width ($R = 5\text{K}$, $C = 0.05\ \mu\text{f}$). This differentiates the leading edge of the square wave into a pulse ($5\ \mu\text{sec}$) of negative polarity and the following edge of the square wave into a pulse of positive polarity. The

Fig. 2. Schematic diagram of circuit used as interface between schedule control equipment and tape recorder. An equivalent circuit is used for each operant chamber,

series resistor and three parallel diodes form a shunt limiter which serves to reduce one of the pulses from -15 v to -2 v, while the series diode completely suppresses the unclipped pulse. By reversing all diodes, the same functions will be performed upon the opposite edge. Recording is done at $1\frac{1}{2}$ ips on 0.25-in. magnetic tape. At the start of a session a positive pulse is manually placed on the tape (*synch* pulse). The diodes are then reversed, and a negative pulse is recorded each time the animal presses the lever (*unit* pulse). Each channel of the recorder corresponds to a separate operant chamber.

In addition to the *synch* and *unit* pulses, a negative pulse is recorded each time a response produces a reinforcement. This pulse is generated 20 msec after the lever press.

Generation of IRTs

The recorded data is played into the PDP-8, one channel at a time at a playback speed of 15 ips. Interfacing of the recorder to the computer is accomplished

by three pulse discriminators which convert the pulses to -3 -v square waves (Fig. 3). One is triggered by positive pulses and sets a *synch* flag of the PDP-8; a second is triggered by neg. pulses and sets the *unit* flag; and the third is manually triggered and sets the *end* flag. The PDP-8 flags are unique for this system. In essence, they are flip-flops that have been connected to the input-output lines of the PDP-8 in a manner such that they may be tested and reset by the program. They must be set as described above. The tape recorder is equipped with high output playback amplifiers which supply adequate output to drive the discriminators.

Sampling of the flag conditions by the PDP-8 is under program control (see Fig. 4) and occurs every 20 msec. Timing is based on the cycle time of $1.5 \mu\text{sec}$. By iterating a sequence of instructions n times (an instruction loop) it is possible to use the execution time of the instruction as a clock. A register (Reg. C) is incremented every 100 msec and is used to measure the elapsed time between unit pulses. Whenever the unit flag is set, the computer stores the value of Reg. C in a data buffer, resets the register to 0, clears the flag and then continues sampling. The time elapsed between a lever-press pulse and reinforcement pulse is about 20 msec; therefore, Reg. C will be zero and reinforcements are distinguished from lever presses whose minimum time interval is 100 msec. In the latter case, the value of Reg. C will be 1 or more.

Upon completion of the playback of a single session, the sampling is discontinued by manually pulsing the end flag, and control of the computer is then turned over to the experimenter via the teletype con-

Fig. 3. Schematic diagram of circuit used as interface between tape recorder and PDP-8.

Fig. 4. Flow chart of portion of PDP-8 program that controls sampling of flag conditions and generates interresponse times.

sole. The teletype is used to direct the PDP-8 to perform its various functions (position tapes, receive input, write data buffer on digital tape, *etc.*) as well as to relay data to the PDP-8 (such as animal number, date of experiment, *etc.*) which can also be written on the digital tape (IBM 729 Tape Deck) as an identification (ID) record for each animal. The finished IBM compatible data tape thus consists of a series of ID records, each one of which is followed by a variable number of data records (999 IRTs/record).

Reliability and Cost

The system was calibrated by recording pulses at time intervals generated by a Massey-Dickinson time base; the number of pulses generated was recorded with an electromechanical counter. The results of the calibration are shown in Table 1. This calibration tape has been run several times over a year and the exact

times are reproduced on each run indicating that the errors were in either the recording or in the time base which generated the points. The latter is probably the case because the error is always the first point in the sequence for a given interval. In addition, it was found that data records were also reproducible to the nearest 0.1 sec; some discrepancies (<5%) existed when a given animal record was run several times, but these were due to an interaction between rounding and sampling times. With double precision storage, the maximum error in this system under usual circumstances would be reduced to 0.02 sec. Increasing the rate of sampling (checking for unit flag) would decrease this further. The tape recorder costs \$2500 and the interfacing was less than \$200. Any tape recorder with a constant speed and relatively good gain could be used. Reproducibility will be dependent on the former while the latter may be compensated for by increasing the sensitivity of the pulse discriminators. However, the probability of artifacts becomes greater with increased pulse discriminator sensitivity.

Table 1
Calibration Data

	Interval (sec)				
	0.1	0.2	0.7	1.1	10.0
Number of signals recorded on tape	288	97	60	66	7
Number of signals of given duration recovered	288	96	59	65	7
Number of errors (± 0.1 sec)	0	1	1	1	0
Zero artifacts	1	0	0	0	1

On-line systems have the advantage of allowing the computer program to interact with contingencies set forth by the experimental animal (Weiss and Laties, 1964), but there is a one-to-one correspondence between experimental time and computer time. In the present system, the taped record of the session is played back into the computer at eight times the speed at which it was taped. Furthermore, data are collected on the basis of interest before they are computer-analyzed. The particular computer and interrupt system described are not the only systems that would work. The LINC computer, along with its external sense lines, could interface with the recording system described. In addition, the analog-to-digital conversion interrupts could be used as inputs. The main advantage of this type of system is that it is possible to share a small computer with a group of investigators, thus obviating the cost of purchase and maintenance of a computer in an individual laboratory. The advantages of computer systems in general for the analysis of operant behavior are twofold: (1) It is possible to acquire useful detailed data which would be too voluminous to analyze without the aid of a computer. (2) The versatility of computations makes it possible to perform statistical analysis on IRT data where the individual IRT is considered a data point.

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