TECHNICAL NOTE

A CUMULATIVE RECORDER FOR EXPERIMENTS ON CONCURRENT SCHEDULES¹

The cumulative recorder is widely used in single-key operant experiments because it makes immediately visible the experiment's primary datum: rate of responding. Unfortunately, the cumulative recorder is of limited value with a two-key procedure for concurrent schedules, in which the primary datum is the *relative* rate of responding, defined as the rate of responding on one key divided by the overall rate of responding on both keys. A response recorder for concurrent schedules has been designed and constructed. This recorder, instead of plotting cumulated responses as a function of time, plots cumulated responses on one key as a function of cumulated responses on the other. The slope of the pen trace at any point is equal to the ratio of the rates of responding on the two keys. The ratio is a simple transformation of the relative rate. For a given ratio, R , the relative rate is equal to $R/(R+1)$. Usually, the relative rate of responding is determined only for an experimental session as a whole. With this recorder, the slope of a straight line drawn between any two points on the pen trace gives the ratio of response rates for the time period separating the two points. The number of responses separating the points may be determined by projecting the two points onto the two axes. In addition, run lengths on the two keys, change-over rates, changeover points, and similar features of the behavior are immediately apparent.

One important feature of the behavior cannot be determined from the record, the absolute response rate. Since the pen and the paper move only when a response occurs, no determination can be made of the time interval between two points on the record. To solve this problem, a fixed event-marking pen was added at one edge of the paper. This pen was pulsed at regular intervals to provide a time base. This system gives an unambiguous record as long as at least one response occurs between successive timing pulses.

CONSTRUCTION²

The simplest recorder would step the recording paper for responses on one key and step the pen for responses on the other key. However, if the responses are all made on the key that steps the pen, when the pen reaches

the top of the paper it will reset on top of the line it has just drawn. To avoid this problem, the axes of the plot were rotated 45 degrees by making a response on one key step the pen one unit up and the paper one unit forward. A series of responses on this key produces a line with a slope of 1 with respect to the direction of paper movement. Responses on the other key, by stepping the pen one unit down and the paper one unit forward, produce a line with a slope of -1 . The resulting response step size is $\sqrt{2}$ unit. The rotation requires that the origin of the plot be moved to the center of the paper, and that the pen be able to reset to the center from either edge. Since the range of possible slopes is only from -1 to 1 the vertical reset line can never cross or cover any other pen trace.

The recorder is a modification of a Gerbrands Model C-3 cumulative recorder (available from the Ralph Gerbrands Co., Arlington, Massachusetts, for \$372). The parts needed for the modification, costing a total of about \$120, are listed below:

- 1 Genalex Model C3314G Bothway Selector (Available from the Imtra Corp., Medford, Massachusetts, for \$37.50). This is the 12-v model, which operates well on 24 v.
- 1 small reversible dc motor. Our motor, obtained from a local hobby shop for \$10, was rated for 10,000 RPM (without load) at 12 v. It came with integral 15:1 reducing gears.
- 1 pair 3:2 spur gears. One is a 64-pitch, 48-tooth spur gear, and the other is a 64-pitch, 72-tooth spur gear (Boston Gear Co. part numbers Y6448 and Y6472). These gears, which must be machined to fit the recorder, can be specially ordered from the Gerbrands Co., already machined, for \$25.

The following small parts can be salvaged from a Gerbrands Model C-1 Cumulative Recorder or purchased individually:

- 2 32-tooth, 1.88 in. pitch diameter sprockets (Boston Gear Co., part number 1A, \$2).
- 1 single-spiral worm and worm gear (available from the Gerbrands Co. for \$16).
- 1 cumulative recorder event pen assembly (less reservoir pen) (Gerbrands Co., part number C3115, \$19.25).

All wiring and switches were stripped from the C-3 recorder. The Gerbrands pen-drive stepper and the plate on which it was mounted were removed. The con-

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²In this section only English units are used because the specifications of all parts originally on the recorder and of all parts used in the modification are in these units.

tact assembly and the wipers were removed from the Imtra stepper and its frame was cut so that it could be installed in the recorder with its wiper drive shaft where the Gerbrands stepper's shaft had been. The upper wiper bearing on the Imtra stepper was cut away so that the gear used to drive the flexible coupling between the stepper and the quick-change gears could be attached. The Imtra stepper was then loosely screwed to the original stepper mounting plate through large-clearance holes, and the mounting plate was replaced within the recorder. Large holes were drilled through the back of the recorder to allow tightening of the stepper mounting screws when the final location of the stepper had been determined. It was necessary to file a clearance slot in one of the hexagonal shafts that support the clutch solenoid to allow mounting of the stepper. The four mounting-holes in the quick-change gear plate were enlarged so that the plate could be adjusted for minimum backlash at the worm gear.

The quick-change gears supplied with the recorder were replaced by the 3:2 spur gears, with the smaller gear driven by the larger. With this gear ratio, there are approximately 1200 steps in the usable pen range.

Figure 1 shows the paper drive mechanism. The paper platen was driven by the Gerbrands pen stepper (A, Fig. 1). A Gerbrands single-spiral worm (C, Fig. 1) was mounted on the stepper shaft. The corresponding worm gear was reamed to fit the right end of the platen shaft (D, Fig. 1). A hole was cut through the right end plate of the recorder to accommodate the stepper, which was then mounted through the hole on a piece of aluminum angle stock (B, Fig. 1). Precise alignment of the worm with the worm gear is necessary so that each step will move the paper the same distance.

Figure 2 shows the pen-drive mechanism. The fixed and movable recording-pen assemblies, the bead chain, right-hand drive hub, and spring-powered reset motor were removed from the top of the recorder. The left hub was disassembled and all parts except the aluminum clutch plates and the shaft were discarded. The

sprockets and ladder chain were then installed in place of the bead chain and its hubs (see Fig. 2). The left sprocket (A, Fig. 2) was installed on the upper clutch plate (B, Fig. 2). It was necessary to turn down the upper half of the clutch plate on a lathe and to ream the sprocket hub to fit. A 2-in. (5-cm) diameter vee-pulley was screwed to the other sprocket (D, Fig. 2), concentric with it and 0.5 in. above it. A shaft and mounting plate to hold this assembly in the same plane as the left-hand sprocket, was mounted on a 0.5-in. (1.3-cm) thick spacer block that covered the hole where the right hub had been. The ladder chain (C, Fig. 2) was then mounted on the two sprockets and the right-hand one adjusted to take up the slack and to align the chain parallel to the pen guide rails. The vee-pulley on the right sprocket is for the drive belt from the reset motor; the ladder chain is a closed loop that permits the use of a single reversible motor to reset the pen in either direction.

The reset motor (E, Fig. 2) was mounted on a vertical bar behind the right-hand sprocket on the outside rear of the recorder. A small pulley was attached to the motor shaft. A 6-in. (15.2-cm) circumference rubber O-ring served as the drive belt between the motor pulley and the sprocket pulley; the size of the smaller pulley was determined by experimentation. Tension on the belt was adjusted by moving the motor mounting shaft laterally, until the motor would drive the ladder chain reliably and quickly in either direction. It is important that the two vee-pulleys be centered carefully for smooth operation.

The bi-directional marking pen was then constructed. The original pen solenoid was removed from the recorder's movable carriage and the pen holder was removed from its armature. A bracket to attach a second solenoid to the armature of the first was made of aluminum (G, Fig. 2). The pen holder was then installed in the armature of the second solenoid (H, Fig. 2). The original solenoid mounting bracket was removed from the carriage and replaced with another one oriented so that the solenoids, when mounted, would be approximately parallel to the ladder chain. This assembly can be seen in Fig. 2. A small bracket was used to attach the movable carriage to the ladder chain. Operation of the original solenoid moves the second solenoid and pen one direction; operation of the second solenoid moves the pen the other direction.

The pen is automatically reset in the following manner. A grounded wiper arm was mounted vertically on the pen carriage. The wiper, made by bending one of the wiper arms removed from the bi-directional stepper, runs along a Plexiglas bar in which three contacts were embedded. The bar was mounted directly above the larger pen carriage guide rail and held in place by screws through the two cumulative recorder end plates (see Fig. 2). The end contacts were located so that the carriage can go as far left as possible without hitting the left end plate, and as far right as possible without hitting the fixed pen assembly. The center contact was located midway between the two end contacts. When the grounded wiper reaches either end contact, it operates a conventional relay circuit that energizes the clutch and motor. When the wiper reaches the center contact, the clutch is re-engaged and the motor is turned off. Two stop plates were mounted on the top surface of the recorder under the guide

Fig. 1. View of the platen drive mechanism. (A) drive stepper. (B) stepper mounting bracket. (C) worm. (D) worm gear.

Fig. 2. View of the top of the recorder. (A) left sprocket. (B) upper clutch plate, on which the left sprocket is mounted. (C) ladder chain. (D) vee-pulley mounted on right sprocket. (E) reset motor with vee-pulley. (F) solenoid attached to carriage. (G) bracket that holds movable solenoid. (H) movable solenoid. (I) Plexiglas bar with three reset contacts.

rails to eliminate carriage overshoot at the edges of the paper.

All the electrical devices in the recorder, the three reset contacts, and the wiper were wired to an 18-prong plug mounted on the rear of the recorder. A cable connected the recorder plug to a standard relay rack panel, on which the relay circuit for the pen reset and the dropping resistors for the motor and stepper were mounted. The values of the resistors were determined by experiment. The snap studs for operating the various recorder functions were also mounted on this panel.

The recorder has been in regular use for over a year. During this time no failures have occurred. Two minor

flaws have been observed. First, the curve produced when all responses are on the same key is slightly wavy. This is caused by inaccurate centering of the worm gear on the platen shaft. Second, there is a one-response backlash in the pen gear train. This could probably be eliminated by replacing the worm and worm gear driven by the quick-change gears with high-precision bevel gears. This change did not seem to be worth the additional expense. Neither of these flaws seriously impairs the usefulness of the recorder.

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