TECHNICAL NOTE

A REMOTE-CONTROLLED FORCE OPERANDUM¹

The effects of response-effort requirements on free-operant behavior have received more attention in recent years (Trotter, 1956; Chung, 1965; Notterman and Mintz, 1965). Two general methods of manipulating the force requirement of an operandum have been employed: mechanical weights or springs (Trotter, 1965; Chung, 1965) and a computer-based system (Notterman and Mintz, 1965) involving a strain-gage.

This paper describes an inexpensive operandum which can be quickly and accurately adjusted within a session and between sessions. It is compatible with existing 24 v dc equipment. A scale drawing is presented in Fig. 1. Constructed primarily of ¼-in. Plexiglass welded with ethylene dichloride, the general design consists of a bar connected to the plunger of a solenoid. When the bar is depressed the plunger is withdrawn from the solenoid, and the amount of current through the coil determines the force requirement at the bar. A small bolt (D in Fig. 1) attached to the bar engages the operate pin of a microswitch mounted on the front panel above the bar. The points of moving contact are labeled A, B, and C in the drawing. Point A is the axis around which the bar moves. It is a rigid polished-steel bar, 5 mm in diameter, suspended by two pieces of Plexiglass, one on each side of the bar, and attached to the base. The linkage connecting the back of the bar to the solenoid plunger consists of a piece of Plexiglass drilled to make a snug, but not tight, fit with the bolts at points B and C. An important part of the operandum, shown only in the back view in Fig. 1, is a strong back-stop to limit the excursion of the bar. It consists of a Plexiglass bridge attached to the base which has an adjustable stop. The switch engagement point and the excursion limit were adjusted so the total movement at the front and back of the bar was 2 mm.

The solenoid used was a Guardian Type 2HD, intermittent duty, with a 20-ohm coil rated at 24 v dc. The relationship between the force requirement at the bar and the current through the coil is shown in Fig. 2. All force values are to the nearest 50 g. The measurements were obtained at 15 v dc with a rheostat in the circuit which was adjusted to provide the current values used. Force measures were obtained by suspending weights from a point in the center and 1 cm back from the front of the bar. The measurement procedure began with the bar depressed; the bar was then lifted to

the normal position and weights were added until they pulled the bar down. Two measurement conditions were used: (1) after the bar had been in the normal resting state for 2 sec; and (2) after 30 sec in the nor-

Fig. 1. Scale drawing of the force operandum.

Fig. 2. The relationship between current through the solenoid coil and the force requirement of the bar.

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mal state. The two measurement conditions would represent force requirements during responding with 2 sec or less pause between responses and responding following a pause of at least 30 sec respectively. The reason for the force differential is that the magnetic force induced in the plunger is a function of the distance the plunger is displaced out of the coil. When the plunger is inserted after being located at a point 2 mm from the back of the coil, the magnetic force of the plunger increases somewhat as a function of time. Further measurement indicated that change in magnetic force occurred between 5 and 10 sec after the bar was placed in the normal state. Force changes were negligible before 5 sec and after 10 sec.

To check reliability of the force requirement over time at a constant current, force values were obtained every 15 min over a 2-hr period at the 0.5 amp setting. The first three measures were 5250 g with the remaining ones 5100 g. These measures demonstrate some force decrease associated with heat increase in the coil. By pointing a small fan to blow across the coil to facilitate heat dissipation, there should be no force changes over time for the amperage values tested. A constant force requirement is insured by adjusting the bolt which engages the operate pin of the switch so the bar must be released before the switch returns to the normal state. With the solenoid coil disconnected, the force requirement at the bar is 100 g.

The operandum described has several advantages over previously used methods of manipulating response-force requirements. It is reliable under constant

measurement conditions and less likely to need periodic recalibration than a system involving springs. Approximately 50,000 responses have been made on the operandum with no apparent wear. The small (2 mm) excursion and the ability to adjust the amount of excursion and the point at which the switch operates would suggest a fairly long life expectancy. The force requirement can be remote-controlled with conventional 24 v dc relay equipment making intra-session changes possible. Total cost of parts was less than \$20. The primary disadvantage of the operandum is the increase in force as a function of time after the plunger has been completely inserted into the solenoid coil. One way to compensate for this problem would be to increase slightly the resistance in the circuit through the coil after approximately 5 sec of no responding.

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