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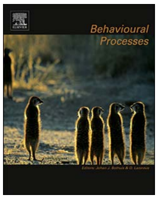

The effect of lever height on the microstructure of operant behavior

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ABSTRACT

The effect of lever height on the temporal organization of reinforced lever pressing was examined. Lever pressing was reinforced on a variable-interval 30-s schedule in rats, with lever height manipulated across six successive conditions. Parameters of the organization of responses in bouts (bout length distribution, bout-initiation rate, within-bout rate, and sequential dependency) were estimated. These estimates revealed (1) a qualitative change in the distribution of IRTs and their sequential dependency when the lever was too high, (2) a mixture of geometrically-distributed bout lengths at all lever heights, and (3) longer bouts at lower and intermediate lever heights. In accordance with previous data, these findings suggest that lower and intermediate lever heights favored lever pressing with longer bout lengths, faster bout initiation, faster within-bout responding, and more sequentially dependent timing. These results underscore the disociability of motoric capacity in operant performance, and may reflect the influence of the body size on the temporal organization of the operant.

1. Introduction

Operant responses reinforced under variable-interval (VI) schedules are typically organized in bouts of rapid succession (Brackney et al., 2011; Smith et al., 2014). That is, operant performance alternates between periods of engagement and periods of pause. Response bouts can thus be described with at least three parameters, the rate at which bouts occur (*bout-initiation rate*), the response rate during a bout (*within-bout response rate*), and the number of responses in a bout (*bout length*). Response-bout parameters are typically estimated by examining the distribution of inter-response times (IRTs). This distribution generally conforms to a shifted mixture of two exponential distributions. This mixture distribution is expressed formally as the bi-exponential refractory model (BERM; Brackney et al., 2011):

$$\begin{gathered}\Pr(IRT = \tau | \tau < \delta) = 0 \\ \Pr(IRT = \tau | \tau \geq \delta) = (1 - q)\mathrm{w}e^{-w(\tau-\delta)} + \mathrm{qb}e^{-b(\tau-\delta)}.\end{gathered} \tag{1}$$

In Eq. (1), δ is the shortest IRT (or *refractory period*), b is the bout-initiation rate, w is the within-bout response rate, and q is the probability that a response will be the last one in a bout. The mean bout length is $(1–q)/q$. The reciprocal of the bout-initiation rate and the within-bout response rate, $1/b$ and $1/w$, are the mean between- and within-bout IRTs, respectively. These parameters appear to be differentially sensitive to various manipulations (see Shull, 2011 for a review), such as rate of reinforcement (Shull et al., 2001), deprivation (Shull, 2004), extinction (Cheung et al., 2012; Shull et al., 2002), and effort (Brackney et al., 2011).

The goal of this study was to examine in rats the effects of lever height on the parameters of operant performance. Past research suggests that such manipulation should influence parameters associated not only with motoric capacity (Brackney et al., 2011), but also with reinforcer efficacy and motivation. In progressive-ratio schedules, for instance, higher levers yield longer median IRTs and lower break points (Skjoldager et al., 1993). Although it is unclear whether longer IRTs result from longer between- or within-bout IRTs (or both), shorter break points are associated with reduced reinforcer efficacy (Hodos, 1961), and the bout-initiation rate (b in Eq. (1)) is uniquely sensitive to reinforcer efficacy (Shull, 2004; Brackney et al., 2011). It thus seems reasonable that the bout initiation rate reflects a balance between response cost (exacerbated by lever height, to the extent that it makes responding more effortful) and reward value (sometimes expressed as efficacious reinforcement). Indeed, Brackney et al. (2011) confirmed that a higher, more effortful lever yields longer between-bout IRTs in a VI schedule, but did so using only two heights (21 and 165 mm).

Previous evidence with rodents (Chemero and Heyser, 2005, 2009; Heyser and Chemero, 2012) and humans (e.g., Jiménez et al., 2015; Newell et al., 1993; Warren and Whang, 1987), suggest that the distribution of behavior topographies is governed by the relation between an organism's abilities and the properties of the environment that enables those behavior topographies. Gibson (1979) called this relationship *affordance* (or *behavior-support*, Tolman, 1932). Warren (1984) proposed the π-number ratios (or intrinsic metric analysis),

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where the numerator corresponds to an environmental property (e.g., lever height) and the denominator is an organismic property (e.g., forepaw height while rearing). If both properties are measured in the same units (e.g., cm), these units cancel and the resulting quotient is a dimensionless π ratio that expresses a particular animal-environment fit, in contrast with extrinsic metric where measures are specified independently of the organism body size (Gibson, 1979).

A parametric manipulation of lever height may reveal the role of the intrinsic (or body-scale) metric in operant performance. Affordances of various activities (e.g., exploration, food seeking) may vary non-monotonically with lever height when height is scaled to the animal's own physical dimensions. Accordingly, response-bout parameters (Eq. (1)) may be sensitive to affordances. Thus, bout-initiation and within-bout responding may be more likely when the relationship between lever height and the abilities of the organism provide a better fit than when this relationship is awkward. Conversely, the shorter bouts may be more likely when the lever height does not support sustained action. In the absence of reinforcement, for instance, hamsters and rats display long bouts of slow lever pressing when the lever is located at a height of about 60% of forepaw height when rearing (Cabrera et al., 2013). This suggests that, at an intermediate height, levers support a particular pattern of exploratory behavior in rodents. The present study asks whether an analogous pattern is visible when lever pressing is occasionally reinforced.

With this purpose in mind, this study examined how parameters of operant performance varied over six lever heights. It incorporates an affordance analysis, an analysis of sequential dependencies between IRTs (BERM assumes no such dependency), and recent insights on the analysis of bout length (Brackney and Sanabria, 2015).

Consistent with Brackney et al. (2011), lever height was expected to influence both between- and within-bout IRTs (refractory periods were not isolated, and were expected to affect estimates of within-bout IRTs more noticeably than estimates of between-bout IRTs). Consistent with Cabrera et al. (2013), effects were expected to be non-monotonic, and include the production of longer bouts at intermediate lever heights. Such pattern of effects may reflect the differential impact of the intrinsic metric on the operant and its temporal organization.

2. Method

2.1. Subjects

Six experimentally naïve male Wistar rats, 110 days old at the start of the experiment and maintained at 85% of their free-feeding body weights, served as subjects. Rats were fed weight-maintaining amounts of Purina chow 20–30 min after the end of each daily session. Rats were housed individually in polycarbonate cages with free access to water in a temperature-controlled colony room on a 12:12 h light/dark cycle.

2.2. Apparatus

Experimental sessions were conducted in two identical Med Associates® chambers (ENV-007-VP), 305 mm long, 241 mm wide, and 300 mm high. The chambers were enclosed with wooden walls. Thin metal bars positioned above a catch pan served as the floor of the chamber. The front and rear walls and the ceiling of the chamber were made of clear polycarbonate; the front wall was hinged and served as a door to the chamber. The right aluminum side panel contained a centered aperture (51 mm sides), 20 mm from the chamber floor, that gave access to a liquid dipper (ENV–202 M) fitted with a cup (ENV-202C) that could hold 0.01 cc of a mixture of condensed milk (25%, La Lechera® Nestlé®, Glendale, CA) and whole milk (75%, Lala®, Omaha, NE). One lever (ENV–110 M), 45 mm wide and 20 mm long, was located either between the dipper and the chamber door (during part of shaping), or centered on the opposite wall (during training proper). A force of 0.2 N was required to activate the lever. Activations of the lever's micro switch were recorded every 10 ms. A white 28 V DC house light (ENV–215 M) installed 270 mm above the floor on the left wall, next to the rear polycarbonate wall, provided illumination to the chamber. A speaker was mounted above the liquid dipper unit. The speaker was connected to a white noise generator (ENV-225SM) and provided a constant white noise of approximately 80 dB. Attached to the chamber roof, a tone generator (Sonalert, ENV-223A) was used to produce a 5-s 2.9-kHz tone at approximately 65 dB every time the dipper was activated for milk delivery. Experimental events were arranged via a Med PC® interface connected to a PC controlled by Med-PC IV® software.

2.3. Procedure

Prior to the experiment proper, rats were trained to press the lever, drink from the dipper, and to respond on a VI schedule of reinforcement. The lever was set at a height of 100 mm on the same wall as the dipper, next to the chamber door. On the first three pretraining sessions, every lever press raised the dipper arm for 10 s, signaled by a concurrent 2.9-kHz tone at 65 dB. The fourth, fifth, and sixth sessions of pretraining reinforced lever pressing according to the following schedules of reinforcement: VI 7-s, VI 10-s, and VI 20-s. Because the variable of interest was lever height, and to prevent the lower levers facilitated a pattern of lever pressing combined with frequent head entries to the dipper, on the seventh session the lever was moved, centered on the wall opposite to the dipper, mounted 100 mm from the floor. During the seventh and eighth sessions lever pressing was reinforced on a VI 20-s schedule. In sessions nine and ten, lever pressing was reinforced on a VI 30-s schedule and the availability of the dipper (and the duration of the concurrent tone) was reduced to 5 s. During pretraining, VI schedules were programmed using Fleshler and Hoffman (1962) distributions, and sessions ended after the delivery of 90 reinforcers or when 30 min elapsed from the beginning of the session, whichever occurred first.

Once pretraining concluded, the experiment proper began. Sessions were conducted seven days a week. Lever pressing was reinforced on a VI 30-s schedule of reinforcement, with intervals selected randomly without replacement from a 90-item Fleshler and Hoffman (1962) distribution. The delivery of a reinforcer was contingent upon pressing (not releasing) the lever. When a lever-press was reinforced, the liquid dipper was activated for 5 s with the concurrent presentation of a 2.9-kHz tone at 65 dB for 5 s. The session ended with the 90th milk presentation.

The experiment consisted of six conditions; in each condition, the lever was placed at a different height. All conditions were replicated once, resulting in two blocks of six conditions each. In both blocks, each condition was in effect for two consecutive sessions. For the first block, conditions were implemented in the following order: 111, 30, 154, 235, 194, and 70 mm. For the second block, conditions were implemented in the following order: 235, 30, 154, 70, 111, and 194 mm.

The next day after the end of the experiment, each rat was placed into a clear polycarbonate cylinder, 300 mm high and 120 mm in diameter. Within the cylinder, each rat was videotaped long enough (between 2–3 min) to obtain the following measurements: 1) The maximum height of the nose while rearing, 2) the maximum height of the forepaws while rearing, and 3) the extension of the hind limbs while rearing (see Cabrera et al., 2013). With these measures, we determined the location of each lever height relative to the rat's anatomy, identifying potential affordances associated with variations in operant performance.

2.4. Data analysis

Significant differences in performance were observed between training blocks, suggesting a practice effect over blocks; therefore, only the second 2-session block was analyzed. To assess within-session