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Influence of amount and delay of reward on choice and response rate: A free-operant, multiple-schedule analogue of a discrete-trial procedure

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Abstract

The current study explored a free-operant analogue of discrete-trial procedures to study the effects of amount and delay of reinforcement on choice and response rate. Rats responded on a multiple variable-interval (VI) 45-s, 45-s schedule, with interspersed choice probe trials. Comparison of relative response rates and percentage of choice revealed some discrepancies between the free-operant analogue and discrete-trial procedures. Amount of reward controlled choice behavior when the ratios of delays were similar. When reward delays were more discrepant, delay length controlled choice behavior. Whereas the percentage of choice was larger for the larger magnitude reward, the relative rate of response for the larger magnitude was less than .50. In contrast, when the percentage of choice generally fell to below 50% (with large amount and large delay differences between alternatives), relative response rate indicated a preference for the larger amount alternative. This study shows the feasibility and utility of a free-operant analogue of discrete-choice studies that could be used to develop an analysis of preference.

KEYWORDS

amount, choice, delay, lever press, multiple schedule, rat, variable interval

Much attention has been given to analyzing preference (choice) in situations when both amount and delay of reinforcement are varied (e.g., Ainslie, 1974; Grace & McLean, 2015; Holt & Wolf, 2019; Inzlicht et al., 2021; Logan, 1965; Patt et al., 2021; Rachlin & Green, 1972; Young, 2018). However, there are multiple procedures that have been used to examine preference (e.g., concurrent chains, adjusting delay, delay discounting, discrete trials in mazes) and multiple ways in which preference has been indexed (e.g., choice between alternatives vs. response rates for alternatives). The observed control over behavior exerted by reward and delay size may be differentially sensitive to such procedural manipulations. The current study explores a procedure that will permit a comparison of two measures (choice and response rate) over the same conditions.

In terms of the previous procedures employed, some studies have noted a preference (choice) for larger than for smaller rewards with equal delays of reinforcement (Bonem & Crossman, 1988; Catania, 1963; Logan, 1965; Neuringer, 1967; Reed, 1991), but others indicate that smaller immediate rewards tend to be chosen over larger delayed rewards (Green et al., 2004; Richards et al., 1997; Rachlin & Green, 1972). Additionally, although larger rewards tend to lead to choice more than smaller rewards when the presentation of reinforcement is immediate, this effect appears to decrease as reinforcement delays to both increase (Rachlin & Green, 1972; Richards et al., 1997); however, this effect is more explored in humans than nonhumans (see Reynolds, 2006; Vanderveldt et al., 2016).

In terms of response rate (rather than choice) being used as used as an index of preference (e.g., Davison & McCarthy, 2016; Herrnstein, 1974), larger rewards tend to produce higher response rates than smaller rewards when they presented together, as in concurrent or multiple schedules (Catania, 1963; Davison & McCarthy, 2016) but not when compared across simple schedules (Reed, 1991; Reed & Wright, 1988). In fact, some free-operant studies suggest that reward magnitude is not as critical a factor in the control of preference as is reinforcer delay (Green et al., 2004; Green & Snyderman, 1980; Holt & Wolf, 2019). However, such findings are not always noted using free-operant procedures (Green et al., 1981; Logue et al., 1984) and they stand in contrast to conclusions drawn from studies using discrete-trial procedures in runways and mazes (see Logan, 1965) and from studies using simple schedules of reinforcement that result in either larger or smaller rewards (Reed, 1991).

In part, this apparently divergent pattern of results may depend on the behavioral index of preference that is taken. For example, Neuringer (1967; see also Reed, 1991) noted that reinforcer magnitude has varying effects depending on whether preference is assessed in terms of response rate or choice for an alternative. For example, in concurrent-chains schedules, pigeon preference for an alternative varies as a function of reinforcement amount when measured by choice between alternatives but not when assessed by response rates to the alternatives (Neuringer, 1967). However, it is hard to tease apart the effects of preference index in the same study, as free-operant procedures can conflate response rate and choice, making it hard to observe any separable effects of different measures (Holt & Wolf, 2019; Mazur, 1984).

Free-operant studies with nonhumans tend to use either concurrent-chains (e.g., Green & Synderman, 1980) or modified concurrent-chains (e.g., Rachlin & Green, 1972) schedules, with some studies adopting adjusting-delay (Mazur, 1984) or adjusting-amount (Richards et al., 1997) procedures. These free-operant procedures may have problems in addition to some degree of conflation of response rate and choice such as allowing differential exposure to outcomes (Mazur, 1984), too little direct comparison of outcomes (Holt & Wolf, 2019), or too short an exposure to particular sets of outcomes to produce clear control over behavior (Grace & McLean, 2015; Grace et al., 2012). Without adequate consideration of these issues, preference tends to favor shorter delays rather than greater magnitudes as the primary controlling factor. The concurrent-chains procedure may confound preference for the terminal components with the initial link duration (see Mazur, 1984, for a discussion of this point). It is also possible that the programmed outcomes are not sampled with equal frequency in the modified concurrent-chains procedure. The adjusting-delay procedure, which can overcome these issues, is relatively complex and time consuming (Mazur, 1984), and this may explain its relatively greater use with human participants (see Richards et al., 1997).

The issues of adequate sampling and comparison of alternatives have been raised by Grace et al. (2012; Grace & McLean, 2015), who varied delays from their starting levels during the course of the experiment and found that preference (assessed by choice) for larger than for smaller rewards decreased more slowly with increasing delays, suggesting the importance of reinforcement magnitude. In fact, the clearest demonstrations of the importance of reward magnitude for preference give several trials of forced exposure to both alternatives before a choice is given (e.g., Green et al., 1981; Logue et al., 1984). These results suggest that procedures such as the adjusting-delay procedure do not give enough opportunity to directly compare outcomes, make a comparison of relative sizes difficult, and diminish the effects of reinforcer amount. Interestingly, when relative rates of response are used as a preference index, even when equating exposure to alternatives, no effect of magnitude is reported (Holt & Wolf, 2019). Holt and Wolf (2019) presented pigeons with two panels in an operant chamber, each associated with an independent adjusting-amount delay-discounting task with differing reinforcer amounts. However, the use of a relatively complex adjusting-delay procedure with no contemporaneous comparison between reinforcer amounts may have been an issue with this study, again making it difficult to unambiguously determine whether the index of preference or some other factor is important for the expression of behavioral preference.

The above considerations suggest that a relatively uncomplicated procedure, ensuring equal exposure to the different outcomes and allowing dissociation between choice and response rate indices, may be beneficial in further analyses of preference. Logan (1965) investigated rats' choice between outcomes that differed both in reinforcement amount and delay in a discrete-trial maze study. In this study, each animal was exposed to one pair of alternatives in a two-arm maze (one magnitude and delay combination was constantly associated with each arm). Preference was measured by allowing the animal a free choice between the arms after several forced trials to each arm. Under such conditions, which satisfied many of the procedural issues noted above, control of choice (measured by entry to an arm on a free trial) was exerted by magnitude of the reward, even with relatively long delays and high delay ratios. This suggests that developing a free-operant analogue of the discrete-trial procedure developed by Logan (1965) may allow a baseline from which to explore multiple controlling factors of choice, as suggested to be important by Rachlin (1974, 1997, 2000).

A multiple schedule allows the possibility of equal exposure to two alternative outcomes, each associated with a different lever (for discussions, see Logan, 1965; Mazur, 1984), as well the potential for the inclusion of choice probe trials (Logan, 1965) in which both levers are available to explore preference. This addition of a choice probe allows a separation of choice and response-rate indices of preference (see Neuringer, 1967). To optimize the probability of reinforcement delays affecting choice behavior, delays to the larger reinforcer can be gradually increased over the course of training (see Logue et al., 1984). Thus, the use of such a multiple-schedule design may allow an analysis of the effect of differing amounts and delays of food on response rates and choice for the two components (Raclin, 1974, 2000). In doing so, it may serve to explore the relative contributions of reward amount and delay to preference and resolve some apparent discrepancies regarding whether amount or delay is the more potent contributor to behavioral control.

METHOD

Subjects

Eighteen, experimentally naïve, male Lister hooded rats, approximately 4 months old at the start of the experiment, served. The rats were maintained at 85% of their free-feeding body weight, housed in pairs, and had water constantly available in their home cages.

Apparatus

Six operant-conditioning chambers (Campden Instruments Ltd., Model 4108), housed in sound- and light-attenuating enclosures were used. A ventilating fan provided a 65 dB (A) background-masking noise. The chambers were equipped with two retractable levers, positioned 5 cm above the grid floor and 11 cm apart. The reinforcer consisted of 45 mg Noyes food pellets, delivered to a recessed food tray that was located midway between the levers. Jeweled houselights were located 5 cm above each lever, which could be illuminated from a 24 V power supply to provide either constant or flashing (100 ms/100 ms on/off) white lights for discriminative stimuli.

Procedure

The rats were first placed in the chamber and allowed 60 min to adapt to the apparatus. During this time, the levers were retracted and the rats were allowed free access to the food tray, which was filled with pellets. After the rats were consistently eating the pellets, they were trained to lever press in a total of four 30-reinforcer sessions. During lever-press training, a two-component multiple continuous reinforcement (CRF) schedule was in operation (MULT CRF CRF). The session commenced with the insertion of a response lever (random side from day to day) and the illumination of the stimulus light located above the lever. A steady houselight was associated with one lever, and a flashing houselight was associated with the other lever (random across subjects, but constant for a particular subject). Following a response, the lever was retracted, the light stimulus extinguished, and a food pellet reinforcer was delivered. After 3 s, one lever, randomly determined, was inserted into the chamber and the appropriate light stimulus illuminated, whereupon the sequence described above was reinstated. A session lasted until 30 reinforcers had been obtained, 15 on each lever.

Following this training, all rats were exposed to 10 sessions of a MULT variable interval (VI) 45-s, VI 45-s schedule (MULT VI 45 s VI 45 s). Each interval comprised 10 values, using a standard method to create interval distributions proposed by Fleshler & Hoffman (1962), with a range of 1 to 135 s. The multiple schedule was programmed to operate as detailed above in the initial lever-press training phase but with VI schedules rather than CRF schedules. There was no changeover delay in operation. Sessions ended when 30 reinforcers, 15 on each lever, were obtained.

For the critical experimental phases of the study, behavior was reinforced according to the MULT VI 45-s, VI 45-s schedule. Each component was constantly associated with a different combination of reinforcer magnitude and delay. The sessions were divided into blocks (Figure 1).

During each block, there were two presentations of the multiple schedule (i.e., two presentations of each reinforcer magnitude/delay combination). Those were followed by two discrete choices. First was a free choice between the MULT schedule components when both levers were inserted into the chamber and both stimuli were illuminated (i.e., the probe). The subject's first response to a lever retracted the other nonchosen lever. This response was taken as a measure of the preference for the two components. This probe continued until the reinforcer associated with that component was delivered. Second was a forced choice that involved exposure to the nonselected component on the preceding probe to equate exposure. This commenced with the insertion of the nonchosen lever. Each session comprised six such blocks.

For each rat, one of the levers was designated as the "standard component" in the multiple schedule. In this component, the amount and delay of reinforcement received were not altered over the course of the study. The other lever was deemed the "varied component." The levers associated with the standard and varied components were fixed for a particular animal. In the successive phases of the study, the varied component was associated with an increasing delay of reinforcement. The reinforcer amount obtained upon completion of the schedule in this component was constant for a particular rat but varied between subjects. Two subjects experienced each set of conditions, and these were counterbalanced for the levers associated with standard and varied components (one rat experienced the standard condition on the left lever and varied conditions on the right lever, and the other rat experienced the opposite arrangement). The magnitude and delay parameters employed for all rats can be seen in Table 1.

Reinforcer delays were signaled by the removal of the lever from the chamber. During the delay period, the stimulus associated with that component remained illuminated until the delivery of the food reinforcer. To equate the overall frequencies of reinforcement associated with the components, the difference between the lengths of the delay periods experienced in the two components was added onto the component associated with the

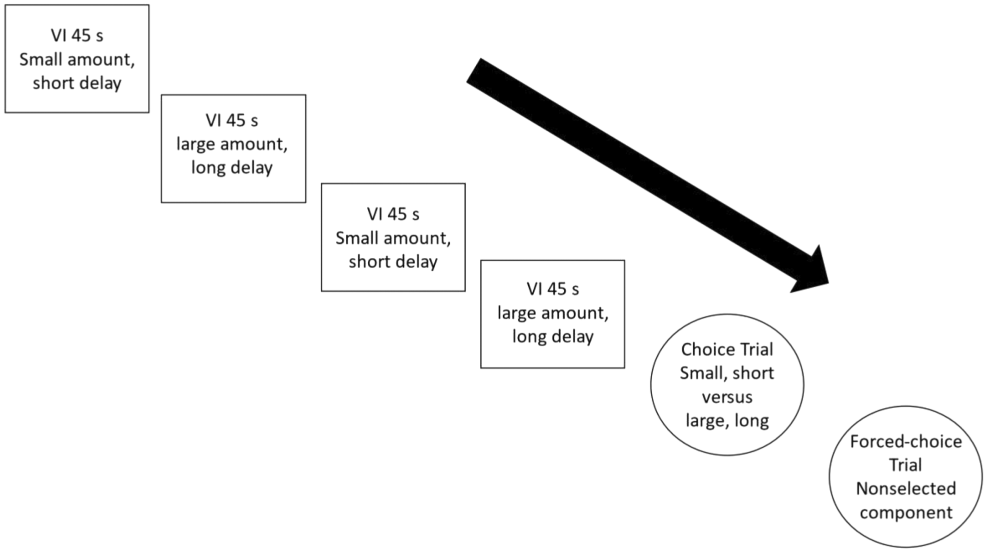

FIGURE 1 Schematic representation of the structure for the choice procedure.

shorter delay in the form of a postreward "detention" period. That is, following the delivery of reinforcement, the lever remained out of the box, with the stimulus for that component still illuminated for a period. Following this, the stimulus was extinguished and a 3-s interval ensued prior to the next exposure commencing. Twenty sessions at each of the reinforcement parameters shown in Table 1 were given, which has previously been shown to establish stable behavior in studies of amount and delay of reinforcement (see Reed, 1991).

Analysis plan

The results are all based on the last six sessions at each combination of amount and delay of reinforcement experienced by the subjects. Preference was assessed using two separate dependent variables averaged over the last six sessions of each phase. First was a measure of the relative choice between the two response options on the free choice, given by the proportion of choices for the component associated with the larger reward. Second was the relative rate of response to the two components of the MULT schedule on the four trials preceding the choice trial, given by dividing the rate of response for the larger reinforcer component in the MULT schedule prior to the free choice by the rate of response in the varied component plus the rate of response for the standard component. For each measure of preference (relative choice and relative rate), the coefficient of variation was calculated for each phase to assess stability. Although there is no absolute criterion available for a "good" coefficient of variation in terms of determining stability, Killeen (1978) suggests that a value of 0.14 strongly correlates with other indices of stability and is a good guide.

RESULTS

Figure 2 shows the proportion of choices on the free choice/probe for the component associated with the larger reinforcer, averaged over the last six sessions of each phase, for all subjects. These data are also shown in Appendix 1 (Table A1.1).

The top row of three panels in Figure 2 show data from the rats that experienced standard parameters of 1 pellet delivered immediately. In Phase 1, when the larger reward obtained in the varied component also was delivered immediately, it was almost always chosen in preference to the standard component on the probe. In the presence of a delay, however, this preference was reduced. In rats R52 and R53, who received 2 pellets in the varied condition, the preference was almost abolished. In the remaining four subjects, who received 4 or 8 pellets in the varied condition, the preference was attenuated.

The middle row of subjects received 1 pellet delayed for 3 s in the standard component. When they were given 2, 4, or 8 pellets in the varied condition, this was generally chosen when the delay was smaller than or equal to that of the standard component. Preference was still generally for the larger magnitude when the delay was slightly longer for this outcome (5 s) but reversed in four of the six rats when it became substantially longer (8 s). The exceptions being subjects R61 and R63, who received 4 and 8 pellets, respectively.

The bottom row of rats received 1 pellet delayed 5 s in the standard component. All subjects preferred the larger reward in this condition irrespective of the length of the delay associated with the varied component.

To examine the degree of stability for these data, the coefficient of variance (standard deviation divided by the mean, where lower values are better in terms of stability)

TABLE 1 Magnitude and delay parameters employed during the experiment.

Rat	P	SM	SD	VM	VD	Rat	P	SM	SD	VM	VD	Rat	P	SM	SD	VM	VD
R52	1	1	0	2	0	R58	1	1	3	2	0	R64	1	1	5	2	0
	2	1	0	2	3		2	1	3	2	3		2	1	5	2	3
	3	1	0	2	5		3	1	3	2	5		3	1	5	2	5
	4	1	0	2	8		4	1	3	2	8		4	1	5	2	8
	5	1	0	2	0		5	1	3	2	0		5	1	5	2	0
R53	1	1	0	2	0	R59	1	1	3	2	0	R65	1	1	5	2	0
	2	1	0	2	3		2	1	3	2	3		2	1	5	2	3
	3	1	0	2	5		3	1	3	2	5		3	1	5	2	5
	4	1	0	2	8		4	1	3	2	8		4	1	5	2	8
	5	1	0	2	0		5	1	3	2	0		5	1	5	2	0
R54	1	1	0	4	0	R60	1	1	3	4	0	R66	1	1	5	4	0
	2	1	0	4	3		2	1	3	4	3		2	1	5	4	3
	3	1	0	4	5		3	1	3	4	5		3	1	5	4	5
	4	1	0	4	8		4	1	3	4	8		4	1	5	4	8
	5	1	0	4	3		5	1	3	4	0		5	1	5	4	0
R55	1	1	0	4	0	R61	1	1	3	4	0	R67	1	1	5	4	0
	2	1	0	4	3		2	1	3	4	3		2	1	5	4	3
	3	1	0	4	5		3	1	3	4	5		3	1	5	4	5
	4	1	0	4	8		4	1	3	4	8		4	1	5	4	8
	5	1	0	4	0		5	1	3	4	0		5	1	5	4	0
R56	1	1	0	8	0	R62	1	1	3	8	0	R68	1	1	5	8	0
	2	1	0	8	3		2	1	3	8	3		2	1	5	8	3
	3	1	0	8	5		3	1	3	8	5		3	1	5	8	5
	4	1	0	8	8		4	1	3	8	8		4	1	5	8	8
	5	1	0	8	3		5	1	3	8	0		5	1	5	8	0
R57	1	1	0	8	0	R63	1	1	3	8	0	R69	1	1	5	8	0
	2	1	0	8	3		2	1	3	8	3		2	1	5	8	3
	3	1	0	8	5		3	1	3	8	5		3	1	5	8	5
	4	1	0	8	8		4	1	3	8	8		4	1	5	8	8
	5	1	0	8	0		5	1	3	8	0		5	1	5	8	0

Note: P = phase; SM = standard component magnitude; SD = standard component delay; VM = varied component magnitude; VD = varied component delay.

was calculated for each rat in each phase. The top panel of Table 2 shows the mean (standard deviation) coefficients of variation for the relative choice data for each of the phases. On these grounds, the current data, on average, could be said to show reasonable stability across all phases (the coefficients are generally < 0.14). For the six rats with the 1p, 0 s standard condition, the mean coefficient of variation was 0.17 (*SD* ± 0.15, range: 0–0.45). For the rats with the 1p, 3 s standard condition, the mean coefficient of variation was 0.12 (± 0.04, range: 0.09–0.20). For the rats with the 1p, 5 s standard condition, the mean coefficient of variation was 0.03 (± 0.03, range: 0–0.07). There was no consistent effect of phase in these data.

Figure 3 shows each rat's relative response rate, averaged across the last six sessions of each phase for the component associated with the larger reinforcer (Appendix 2, Table A2.1). Relative response data were calculated by dividing the rate of response for the varied component in the MULT schedule prior to the free choice by the rate of response in the varied component plus the rate of response for the standard component.

The rats shown in the top row of the three panels (two rats in each panel) received a standard component of 1 pellet, delivered immediately. This standard component with the shorter delay produced a higher relative rate of response for all subjects irrespective of the varied component (i.e., the relative rate for the varied component with the larger reinforcer is below .50). For the middle row of rats, a higher magnitude produced a higher relative rate than did the component with 1 pellet, delayed 3 s for all subjects. The relative rate for the higher magnitude in the varied component declined as the delay was increased, but it was always greater than 0.50 at all combinations of parameters. A similar higher relative rate in the varied

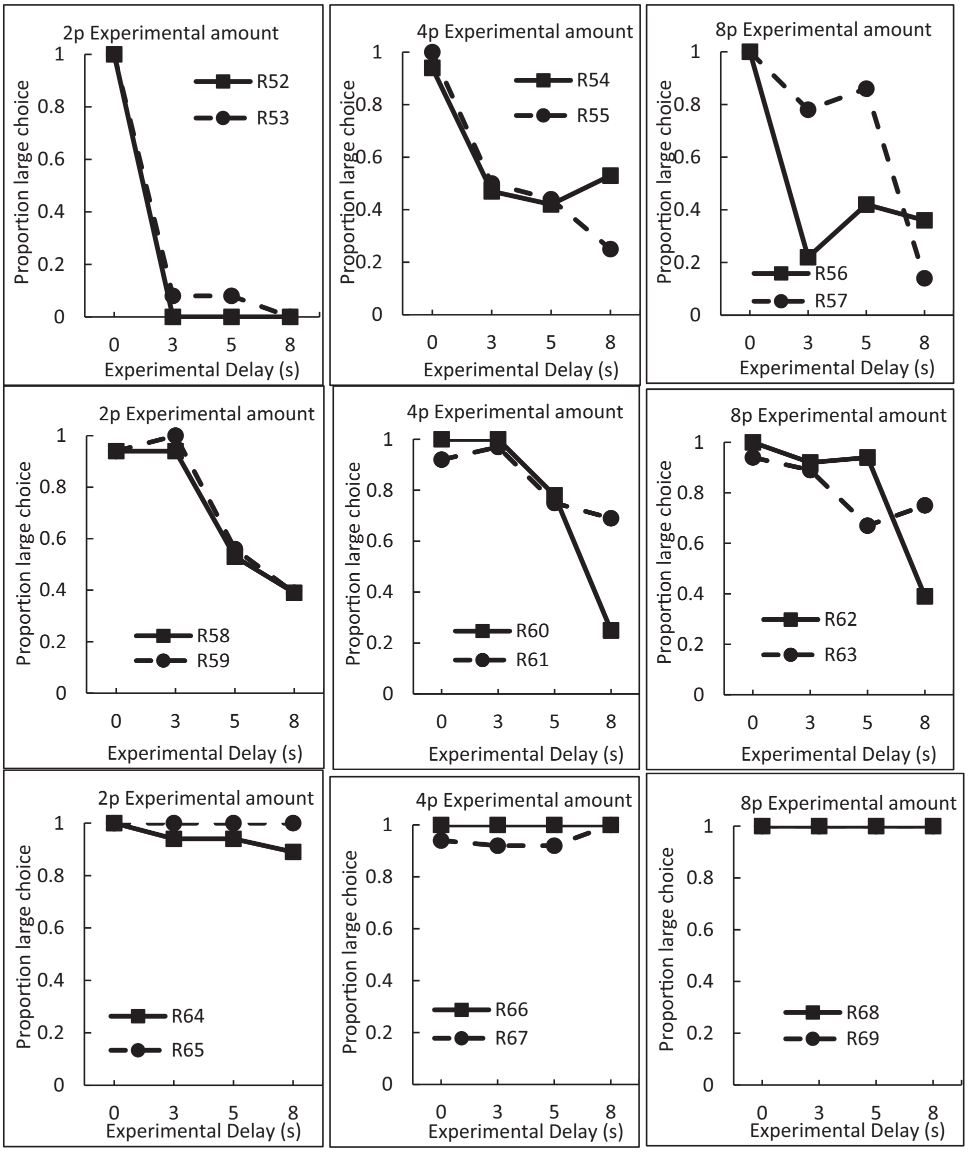

FIGURE 2 Proportion of choices for the larger magnitude during freechoice and probe parts in the varied component for each rat. Each panel shows the data from the two rats experiencing that condition. Top row = 1p, 0 s standard. Middle row = 1p, 3 s standard condition. Bottom row = 1p, 5 s standard condition.

TABLE 2 Mean coefficients of variation for the relative choice (top panel) and relative response rate (bottom panel) components across the last six sessions of each phase.

	Experimental delay			
Relative choice	**0 s**	**3 s**	**5 s**	**8 s**
1p 0 s standard	0.015 (0.036)	0.318 (0.431)	0.31 (0.416)	0.227 (0.200)
1p 3 s standard	0.062 (0.048)	0.182 (0.263)	0.100 (.053)	0.220 (0.087)
1p 5 s standard	0.015 (0.037)	0.040 (0.065)	0.040 (0.063)	0.017 (0.041)
	Experimental delay			
Relative rate	**0 s**	**3 s**	**5 s**	**8 s**
1p 0 s standard	0.117 (0.065)	0.137 (0.027)	0.133 (0.048)	0.143 (0.039)
1p 3 s standard	0.070 (0.025)	0.123 (0.047)	0.102 (0.037)	0.088 (0.037)
1p 5 s standard	0.053 (0.012)	0.050 (0.014)	0.075 (0.018)	0.058 (0.017)

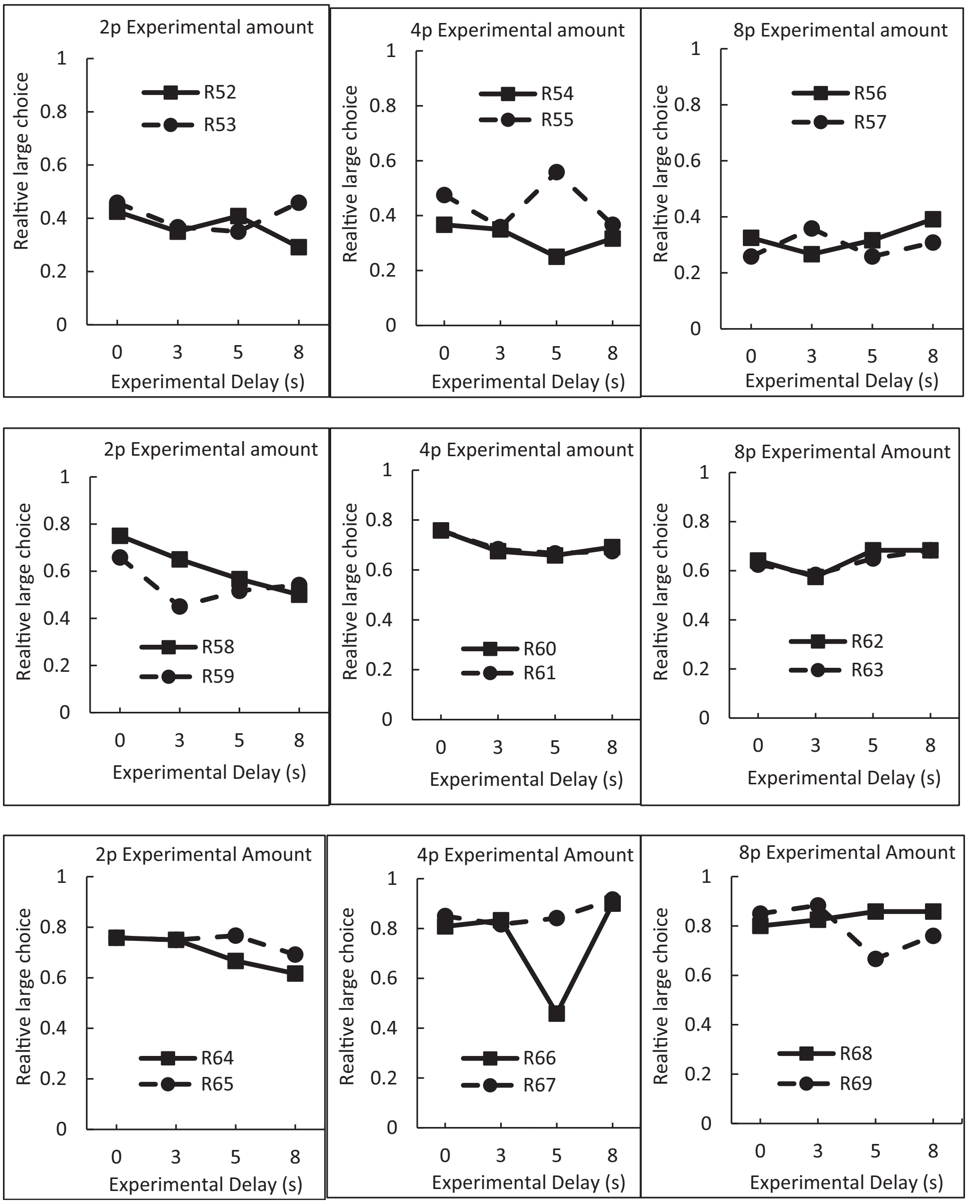

FIGURE 3 Relative response rate for the larger magnitude (rate for the larger component divided by rate for the larger plus the smaller) for each rat. Each panel shows the data from the two rats experiencing that condition. Top row = 1p, 0 s standard. Middle row = 1p, 3 s standard condition. Bottom row = 1p, 5 s standard condition.

component than in the standard component was noted for all subjects receiving a standard component of 1 pellet, delayed 5 s (bottom row of three panels). For no subjects was the relative rate lower than 0.50, except for subject R66 when comparing 1 pellet, delayed 5 s, with 4 pellets, delayed 5 s.

The bottom panel of Table 2 shows the mean (standard deviation) coefficients of variation for the relative rate for each of the phases. All values were generally < 0.14, and there was little consistent effect across the phases. The coefficient of variance for the six rats with the 1p, 0 s standard condition was 0.11 (± 0.04, range: 0.01–0.18). For the rats with the 1p, 3 s standard condition, the mean coefficient of variation was 0.09 (± 0.02, range: 0.07–0.12). For the rats with the 1p, 5 s standard condition, the mean coefficient of variation was 0.06 (± 0.01, range: 0.01–0.07).

The contrast between the relative choice data and the response rate indices can be seen by inspection of Figure 4. Figure 4 shows the mean preference for the larger reinforcer in the varied component (averaged across the two rats receiving each combination), using choice (top panel) and relative response rate (bottom panel) at reinforcement delays smaller than or equal to that in the standard component and reinforcement delays greater than that in the standard component. For example, for the two rats whose standard component was 1p reinforcer and 0 s delay (1p, 0 s), the varied component

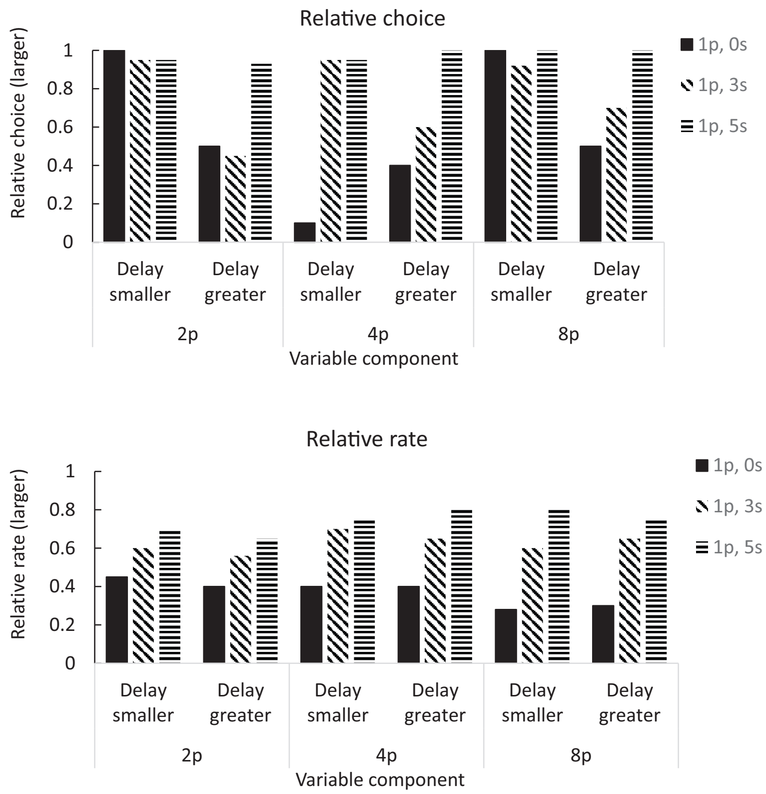

FIGURE 4 Mean relative preference for larger reinforcer amount (varied component) using choice (top panel) and relative response rate (bottom panel) at delays smaller or equal to standard component and delays greater than standard component.

2p, 0 s would be smaller than or equal to the delay in the standard component, whereas the 2p, 3 s; 2p, 5 s; and 2p, 8 s would be greater than the delay in the standard component. In contrast, for the rats receiving the 1p, 5 s standard, then the 2p, 0 s; 2p, 3 s; and 2p, 5 s varied components would be smaller or equal to the standard and 2p, 8 s would be a greater delay than the standard. Inspection of these data show clearly what is apparent from a cross-measure comparison between Figures 2 and 3. Using the choice measure, choice shows that preference is affected by reinforcer magnitude. With short delays to the standard, the larger magnitude in the varied component is always chosen. As the reinforcer delay of the standard component increases, the effect of a larger magnitude is very pronounced in terms of choice. However, with response rate, at shorter delays in the standard condition, preference favors immediacy. However, this is affected by the reinforcer magnitude in the varied component; as the standard delay increases, preference for the larger amount in the varied component is never as pronounced as it is when using choice as an index.

DISCUSSION

The current study explored the feasibility of developing a free-operant analogue of Logan's (1965) discrete-trial runway procedure to study the control of behavior by amount and delay of reinforcement. The development of such a procedure could allow further analysis of several factors that, cross-procedurally, appear to control behaviors in different manners, which would advance the analysis of complex behaviors (Rachlin, 1997, 2000). For example, it allows a relatively simple procedure that equates exposure to two alternative outcomes (Logan, 1965; Mazur, 1984, for discussions) and includes choice probes to separate choice and response rate indices in the same procedure (Logan, 1965; Neuringer, 1967).

The results suggest that magnitude of reward controls preference when the reinforcer delays experienced were similar (Rachlin & Green, 1972). This finding was especially pronounced when choice as opposed to response rates was the index of choice (Logan, 1965). However, when reward delays associated with both alternatives were more discrepant, a different pattern of apparent preference emerged depending on the preference index used. Performance in terms of a choice response between the two alternatives was almost exclusively for the larger magnitude reinforcer than for 1 pellet when neither was associated with a delay. However, in no case did the relative rate of response for the larger magnitude come to be greater than 0.50. In contrast, the probe choice data indicate that preference for 1 pellet delayed 3 s fell below 50% relative to that for larger amounts delayed by 5 s. However, the relative response rate indicated a preference for the larger alternative.

Thus, when using the choice measure, reinforcer amount tended to control preference to a greater extent than reinforcer immediacy, especially when the delays in the components were short. These findings are consistent with studies from the runway (Logan, 1965) and from free-operant procedures that have focused on choice measures and equated exposure to the alternatives (Green et al., 1981; Logue et al., 1984). However, when response rate was used as an index of preference, shorter delays tended to control preference more than larger rewards (Green & Snyderman, 1980). These findings ae generally consistent with those obtained in concurrent-chains procedures (Green & Snyderman, 1980; Holt & Wolf, 2019; Rachlin & Green, 1972).

There is an argument to be made that relative response rate may be a more reliable measure for preference due to the greater sampling of behavior it involves relative to the limited number of choice trials (although this could be extended in a longer training procedure). These issues point to the need for further analyses of the controlling factors and what precisely is meant by preference and choice (see Rachlin, 1974, 1997). However, theories based on procedures that take response rate or relative response rate as an index of preference may be incorporating different factors from those that use choice. It is known that response rate can be shaped and that the same reinforcer amount can increase or decrease rates of response depending on the schedule in operation (see Reed, 1991). Response rate can be a conditionable property of behavior, and this factor can play a role in studies of preference when rate is taken as an index (Neuringer, 1967). On this basis, it may be that choice is a clearer index of preference.

In addition to the consideration of the type of index of preference used, Grace et al., (2012) and Grace and McLean (2015) note that many existing free-operant procedures restrict the exposure the organism has to the alternatives and suggest that this may create problems when analyzing preference. Holt and Wolf (2019) suggest an account of reinforcer value based on organisms' prior experience with the consequences to be compared, and they suggest that this factor may explain the inconclusive findings regarding magnitude effects. In fact, if this is correct, then both the adjusting and concurrent-chains procedures may have some procedural difficulties. This issue is of relevance for the current manuscript, as the procedure developed here, based on the work of Logan (1965), was also designed to overcome issues of differential exposure.

It should be noted that the current procedure is not conventional in terms of free-operant studies, differing in two ways from procedures that are typically employed. First, with multiple schedules, the second element is not randomly determined but is the other alternative (e.g., left lever then right lever; right lever then left lever). However, there is no reason that this has to be the case, and such alternations can be learned as signals, complicating the interpretation. Second, the current procedure resembles a discrete-trial procedure in that the termination of a component in a MULT schedule occurs when the reinforcer is delivered rather than after a specified period. Again, there is no reason that this should not be classified as a MULT schedule, but it may have an influence on behavior.

The purpose of the current study was not to produce a quantitative analysis of these effects but to explore different patterns of choice based on two measures and highlight how this may influence the development of theorizing. The discrepancies between the results from the two measures reported here suggest that this needs further consideration and that the current procedure may allow direct comparisons of these indices, ultimately allowing the integration of data derived from studies of free-operant and discrete-trial maze studies. This would certainly aid the development of experimental analyses of choice behaviors, initiated by Howard Rachlin, among others.

AUTHOR CONTRIBUTIONS

All authors contributed equally.

CONFLICT OF INTEREST STATEMENT

The authors have no conflict of interest.

DATA AVAILABILITY STATEMENT

Data are available from the corresponding author.

ETHICS APPROVAL

The treatment of nonhuman subjects was in accordance with established ethical guidelines and was approved by the University Ethics Committee.

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APPENDIX 1

TABLE A1.1 Relative choice for experimental component (larger magnitude) on free choice and probe components during all phases. p = number pellets, s = seconds of delay.

Rat (VC amount)	Phase (varied component delay)				
	1 (0 s)	2 (3 s)	3 (5 s)	4 (8 s)	5 (0 s)
Standard 1p, 0 s					
52 (2p)	1	0	0	0	1
53 (2p)	1	.06	.06	0	1
54 (4p)	.96	.44	.39	.50	1
55 (4p)	1	.47	.42	.25	.94
56 (8p)	1	.22	.39	.33	1
57 (8p)	1	.75	.86	.14	1
Standard 1p, 3 s					
58 (2p)	.94	.94	.50	.39	1
59 (2p)	.96	1	.53	.36	1
60 (4p)	1	1	.78	.28	.94
61 (4p)	.89	.97	.72	.67	1
62 (8p)	1	.91	.94	.39	1
63 (8p)	.89	.89	.64	.74	.94
Standard 1p, 5 s					
64 (2p)	1	.94	.97	.88	1
65 (2p)	1	1	1	1	1
66 (4p)	1	1	1	1	1
67 (4p)	.97	93	94	1	1
68 (8p)	1	1	1	1	.94
69 (8p)	1	1	1	1	1

APPENDIX 2

TABLE A2.1 Relative response rates for larger magnitude component over the last six sessions of each phase.

Rat (VC amount)		Phase (varied component delay)			
Stand 1p, 0 s	1 (0 s)	2 (3 s)	3 (5 s)	4 (8 s)	5 (0 s)
52 (2p)	.41	.35	.40	.29	.41
53 (2p)	.46	.38	.35	.44	.46
54 (4p)	.38	.34	.24	.32	.38
55 (4p)	.47	.34	.57	.36	.50
56 (8p)	.33	.27	.32	.39	.27
57 (8p)	.27	.37	.27	.31	.31
Stand 1p, 3 s					
58 (2p)	.74	.65	.57	.50	.75
59 (2p)	.63	.43	.52	.54	.67
60 (4p)	.73	.67	.67	.69	.72
61 (4p)	.74	.68	.63	.67	.70
62 (8p)	.67	.58	.68	.68	.60
63 (8p)	.62	.58	.65	.68	.62
Stand 1p, 5 s					
64 (2p)	.75	.75	.67	.62	.73
65 (2p)	.76	.75	.77	.69	.76
66 (4p)	.80	.83	.46	.90	.79
67 (4p)	.86	.82	.84	.90	.86
68 (8p)	.81	.83	.86	.86	.84
69 (8p)	.85	.88	.67	.75	.78