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Choice Between Reinforcers With and Without Delayed Shock

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ABSTRACT

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Some problematic human behaviors can be conceptualized as choice of a large immediate reinforcer followed by a delayed aversive event, in lieu of a small immediate reinforcer and no delayed aversive event. For example, a night of binge drinking may result in ample social reinforcers and other fun in the short-term, but it is followed the next day by an intense hangover. Alternatively, opting for moderate alcohol consumption might not produce as intensely pleasing of an evening, but it avoids the aversive hangover. The aim of the present experiment was to develop an animal laboratory model for studying such choice situations. Rats could choose multiple pellets delivered immediately plus a delayed electric shock, or a single pellet delivered immediately. Using a titrating procedure, adjustments were made in the delay to shock based on the rat's choices. Exclusive choice of multiple pellets and shock decreased the delay in subsequent trials; exclusive choice of a single pellet increased the delay. Adjustments continued until the delay stabilized. The mean delay over the stable period was taken as an estimate of the indifference point – the delay at which shock devalued multiple pellets to equal the value of 1 pellet. Indifference points were generated for different combinations of shock intensity and shock duration. Stable adjusting delay was an increasing function of shock intensity and shock duration. As shock was made more intense, it needed to be further delayed to obtain indifference. As shock was made to last longer, it also needed to be further delayed to obtain indifference. An analysis of response latency showed that when indifference points were obtained, latencies did not differ substantially between the two response types, consistent with the notion of indifference as equal value between alternatives. This procedure is a viable model of choice between a large immediate reinforcer followed by a delayed aversive event, versus a smaller immediate reinforcer. Possible refinements to the procedure are offered, and an interpretation is explored in terms of impulsivity.

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Many everyday choices involve an option that results in conflicting immediate and delayed consequences, often with the immediate consequences being positive in valence and the delayed consequences being aversive. A common example is the choice frequently faced by a hungry person who suffers from acid reflux. The individual may choose to consume a spicy meal with delicious immediate consequences and then suffer a painful burning sensation in the esophagus hours later. Alternatively, the individual can opt for a blander food (a less reinforcing immediate consequence) that will not cause any acid reflux later. This choice situation can be construed as one between an immediate large reinforcer plus a delayed aversive event, or an immediate smaller reinforcer with no delayed aversive outcome.

The combination of immediate reinforcement with a delayed aversive consequence is seen in a wide variety of human problem behaviors. Examples include poor dietary choices (and the delayed obesity, heart disease, etc. that results), cigarette smoking (and the delayed cancer, emphysema, etc. that results), or even self-injurious behaviors such as trichotillomania (and the delayed social embarrassment that results). Although most people would probably agree it is in their best long-term interest *not* to consume junk food, smoke cigarettes, lead a sedentary lifestyle, or exacerbate acid reflux, large numbers of people engage in these behaviors nevertheless. At most points throughout the day, the individual with chronic acid reflux presumably places more value on not experiencing heartburn (versus consuming a tasty food item). But when faced with the immediacy of consuming tasty food, the individual’s behavior suddenly is not consistent with the prior preference. He or she acts impulsively and consumes a food guaranteed to produce heartburn, an option that was lowly valued earlier. The delayed outcome of heartburn – or even esophageal cancer – fails to exert control over current behavior.

Some of the above choices might be described as impulsive or lacking self-control. Impulsivity has been studied in a variety of ways, from questionnaires about planning ahead and acting without thinking (e.g., the Barratt Impulsiveness Scale; Patton, Stanford, & Barratt, 1995) to the go/no-go task (e.g., Bezdjian, Baker, Lozano, & Raine, 2009). Some of the earliest work on delay of gratification was conducted by Walter Mischel and colleagues (e.g., Mischel & Grusec, 1967) in which children were presented with a choice between a small immediate reward and a larger delayed reward. In famous follow-up studies using marshmallows as rewards, Mischel and colleagues found that preschoolers' inability to tolerate delays to reward was correlated with a variety of negative life outcomes in adolescence, including academic and social difficulties as rated by parents (Mischel, Shoda, & Peake, 1988) and poorer scores on the SAT test (Shoda, Mischel, & Peake, 1990). With these outcomes, plus evidence that higher scores on the Barratt Impulsiveness Scale are positively correlated with drug use, mood disorders, attention-deficit/hyperactivity disorder, suicide attempts, and criminal violence (Stanford et al., 2009), research on impulsive behavior has high social relevance.

There is a large extant body of literature on impulsivity and self-control in choice situations specifically. Because many of these studies focus on delayed outcomes and the devaluation of consequences, these experimental procedures and choice situations are referred to as instances of *delay discounting*. The typical delay-discounting procedure involves a choice between a small immediate reinforcer and a larger delayed reinforcer (Madden & Bickel, 2010). A significant amount of this research has been conducted both with non-human animals, including rats (e.g., Green, Fisher, Perlow, & Sherman, 1981; Evenden & Ryan, 1996) and pigeons (e.g., Rachlin & Green, 1972; Oliveira, Green, & Myerson, 2014), and with humans (e.g., Green, Fry, & Myerson, 1994; Bickel, Odum, & Madden, 1999). In a few studies, aversive consequences are examined, as when impulsive choice is studied by arranging a choice between an immediate short-duration shock and a delayed long-duration shock (e.g., Deluty, 1978). Other variations of studies on impulsive choice of aversive events include allowing rats to commit to the immediate short-duration shock (e.g., Deluty, Whitehouse, Mellitz, & Hineline, 1983), testing humans' discounting of delayed monetary losses (e.g., Estle, Green, Myseron, & Holt, 2006), and using aversive academic-task completion in children diagnosed with autism (e.g., Perrin & Neef, 2012). Delay-discounting studies have generated a wealth of knowledge about maladaptive-choice situations in which the potency of a delayed consequence is degraded due to its delay, yet less is known about choices involving immediate reinforcement followed by a delayed aversive event. The aim of the present study was to construct a viable model for studying such choice situations.

Although the present study employs a different choice situation than is used in typical delay-discounting studies, it is still useful to review prior studies because their procedural arrangements and findings have informed the design of the present experiment.

With choice between a small immediate reinforcer and a larger delayed reinforcer, it is possible to experimentally identify the delay to the larger reinforcer at which a subject responds equally often for both alternatives. This delay is known as the *indifference point,* and it represents the point at which both alternatives have equal value (Madden & Bickel, 2010, p. 42). It is concluded that the ordinarily higher value of the larger reinforcer (if it were immediately available) is degraded due to the delay, and at the indifference point, the devaluation results in equal value between the alternatives. If a child is indifferent between two marshmallows available after 20 minutes versus one marshmallow available immediately, it is concluded that 20 minutes of delay reduces the value of two marshmallows to that of one.

One way to identify an indifference point is by using an adjusting-delay or "titrating" procedure. Mazur (1987) arranged a procedure in which a subject's responses in a given block of trials influences the parameters used in the subsequent block. More specifically, delay to the large reinforcer could be adjusted up or down dependent on the subject's response allocation in the prior block of trials. Pigeons could choose between 2-s access to grain immediately or 6-s access to grain after some delay. If pigeons exclusively chose the immediate reinforcer, then delay to the larger reinforcer was decreased in the next block of trials. If pigeons exclusively chose the delayed reinforcer, then the delay was subsequently increased. When the pigeon chose the two alternatives equally often – an indication of indifference – Mazur concluded that 2-s access to grain immediately was equivalent in value to 6-s access to grain after the delay that generated indifference.

Whereas a large amount of research has been conducted on choice between two reinforcers of different magnitudes and delays, there is a shortage of research on choice involving immediate reinforcement coupled with a delayed aversive event. (However, for some examples of related choice situations, see: Epstein, 1984; Simon et al., 2011; Woolverton et al., 2012.) Work has been conducted, however, on the delay-to-punishment gradient and with parameters of shock intensity and duration.

Studies of electric-shock punishment have shown that delaying the shock reduces its punitive effect. Baron (1965) trained 54 water-deprived rats in a runway response, where water was available in a goal box and the rat's speed could be recorded by multiple photobeams. Both the start box and the goal box were enclosed by guillotine-type doors, and the rat's entry into the goal box was recorded by a photobeam. After training, rats were divided into six groups, five of which were shocked after entering the goal box at delays of either 0, 5, 10, 20, or 30 s (the shock was 0.7 mA and lasted 500 ms). The sixth group was not punished and instead functioned as a control group. Following the punishment phase, there was a return to the baseline procedure (water reinforcement of the runway response) to test recovery. For each experimental group, the mean running speed during the punishment phase was substantially slower than both the pre-punishment speeds and the mean speed of the control group. Most important for the proposed experiment, the effectiveness of punishment decreased with longer delays. However, even at the longest delay of 30 s, the runway response was suppressed to levels markedly lower than in the pre-punishment phase. Removal of the punishment contingency resulted in recovery of the running response to speeds closer to those observed during the pre-punishment phase and closer to the control-group speeds. Baron's study highlights the delay-to-punishment gradient, in which the suppressive effect of a punisher decreases with longer delays to its onset.

Presumably, an incredibly intense experience of acid reflux that results in a hospital visit would have a stronger effect than merely mild acid reflux on the future likelihood of consuming the given food item. This situation highlights the effect of punisher *intensity*, in addition to delay to punishment, on suppression of a response.

Cohen (1968) tested the interaction of delay and intensity of shock in rats. Twenty-four rats were divided into four groups, to test different delay intervals between a response and shock: 0, 7, 14, or 28 s. Trials began with the onset of an auditory clicking stimulus, and a lever press produced condensed milk, retraction of the lever, and initiation of the appropriate delay interval (depending on the assigned group). After the delay, a 500-ms duration shock was administered simultaneously with termination of the clicking stimulus, followed by a 15-s intertrial interval. Across sessions, rats were exposed to an ascending series of shock intensities, ranging from 0.05 mA to potentially 1.6 mA, until a punishment criterion was reached: completion of less than 10 trials over a 6-hr period. The shock intensity that produced this suppression was the maximum intensity to which the rat was exposed. Regardless of delay interval, the punishing effect of shock was greater with increases in shock intensity, replicating prior research: As shock intensity was increased, the number of trials completed decreased and response latency increased. Furthermore, and most relevant to the proposed research, the mean shock intensity required to meet the punishment criterion was a function of the delay interval. The longer the delay interval, the higher the shock intensity required to suppress responding. For instance, a mean shock intensity of 0.29 mA was required to suppress responding when the shock was immediate, whereas a mean shock intensity of 1.3 mA was required when the delay was 28 s.

A third important variable that determines a punisher's suppressive effect is its *duration*. Consider the impact of a relatively moderate case of heartburn lasting 24 hrs instead of a more typical 2 hrs. Heartburn lasting 24 hrs would likely have a larger suppressive effect on the afflicted individual's eating behavior than heartburn lasting just 2 hrs. Punisher duration has been shown to suppress responding in the same functional direction as punisher intensity.

Church, Raymond, and Beauchamp (1967) conducted a parametric investigation of shock duration's effect on response suppression in rats. After training on a variable-interval (VI) 1-min schedule of reinforcement, rats were assigned to five groups based on shock duration: 0, 150, 300, 1,000, and 3,000 ms (Experiment 1). For each group, ten punishment sessions were conducted in which 0.16-mA shocks were delivered based on a VI 2-min schedule while the VI 1-min reinforcement schedule remained in operation. The resulting response suppression was an increasing monotonic function of shock duration. In Experiment 2, various combinations of shock intensity (0.05, 0.15, and 0.25 mA) and shock duration (250, 500, 1,000, and 2,000 ms) were tested in twelve new groups with the same schedules of reinforcement and punishment.

Suppression was again an increasing function of shock duration. Additionally, across all three groups of a particular shock duration (at the three different possible shock intensities), greater suppression was observed at greater shock intensities, highlighting how these variables can interact to substantially increase suppression.

The above punishment studies informed the approach taken with the present experiment, which is concerned with choice situations in which one of the consequences produces immediate reinforcement and a delayed aversive event. More specifically, it is assumed that a shock will result in greater devaluation of an immediate reinforcer when (a) the delay-to-shock interval is brief, (b) the shock intensity is high, and (c) the shock duration is long.

The purpose of the present experiment is to develop a model to assess how changes in the delay, intensity, and duration of an aversive event affect the value of an immediately reinforcing consequence in a choice situation. To measure the change in value produced by a delayed aversive event, a choice procedure was employed similar to the adjusting procedure developed by Mazur (1987). Rats were exposed to a series of choice trials in which a press on one lever produced 1 food pellet immediately and a press on another lever produced multiple pellets and, after a delay, an electric shock. The delay to the shock was adjusted across blocks of trials, based on the rat's prior choices. When the rat chose the two alternatives equally, showing indifference, this indicated that 1 immediate pellet was equivalent in value to multiple immediate pellets plus shock of a given delay, intensity, and duration.

Method

Subjects

Five experimentally naïve, male Sprague-Dawley rats were maintained at 80% (± 2%) of their free-feeding body weights by food reinforcers during the experimental sessions and supplemental feedings of standard lab chow in the home cage at least 30 min after the sessions. Target weights were adjusted periodically according to growth charts provided by the supplier, and water was freely available in the home cages. All rats were housed individually in a temperature-controlled room with a 12:12 hr reversed light/dark cycle. Sessions were conducted 7 days per week at approximately the same time each day.

Apparatus

Sessions were conducted in four operant-conditioning chambers enclosed in ventilated sound attenuating chests (Med Associates Inc., St. Albans, VT). The interior of each chamber was 29 cm long, 22 cm high, and 24 cm deep. The ceiling and sidewalls were constructed of Plexiglas, and the end walls of stainless steel. The floor consisted of 19 stainless-steel rods 0.5 cm in diameter spaced approximately 1.3 cm apart. On the front wall were two retractable levers. Each lever was 4.4 cm wide, 1.3 cm thick, and protruded 1.9 cm into the chamber when inserted. The inside edges of the levers were spaced 11.4 cm apart (5.7 cm from the middle of the wall). The tops of the levers were positioned 8 cm from the floor. Approximately 5 cm above each lever was a white cue light (No. 1820 bulb). A 3.5-in audio speaker was located behind the back wall. Food pellets (45-mg, BioServ) were delivered into a magazine centered on the front wall. Each pellet delivery was accompanied by a 1000-Hz tone lasting 1 s. When multiple pellets were delivered, the accompanying tone lasted an equivalent number of seconds as the number of pellets delivered (e.g., 2 pellets were accompanied by a 2-s tone). If pellet delivery was contingent on a lever press, the levers were retracted for the duration of the tone. Aversive stimuli consisted of scrambled foot shock controlled by a constant-current shock generator (Med Associates ENV-413). General illumination was provided by a houselight (No. 1820 bulb) located on the back wall. White noise (80 dB) masked extraneous sounds.

Experimental events were controlled and recorded with computers running programs written in Visual Basic 2010; computers were connected to the chambers via digital interfaces (Measurement Computing, model PCI-PDIS08).

Preliminary Training

Because the rats were experimentally naïve, each rat received preliminary training to establish food pellets as reinforcers and to engender responding on both levers. Throughout the sessions, the houselight illuminated the chamber and the white noise was turned on.

Magazine training. The purpose of magazine training was to establish the delivery of a pellet as a reinforcer. Magazine training was complete when the rat reliably consumed the pellet promptly upon delivery, regardless of what it was doing at the time of delivery. Both levers were retracted throughout magazine training. Before the start of the first session, 3 pellets were placed in the magazine. The session began with the onset of the houselight and white noise. Once the rat consumed these pellets, individual pellets were delivered manually in progressively increasing intervals of time, starting at 15 s between deliveries. Magazine training was complete when: (a) the time between the last 5 pellet deliveries averaged at least 60 s; (b) the rat's head was at least 3 in away from the magazine during these last 5 deliveries; and (c) the rat consumed each of the last 5 pellets within 3 s of delivery.

Lever pressing. Once the rat reliably ate the pellet promptly upon delivery, lever-press training began. One lever was extended, and each press produced a food pellet (a fixed-ratio 1 schedule, FR 1). This continued until 10 pellets had been delivered, after which the other lever was extended, and the same FR-1 schedule was in effect until 10 pellets were delivered. The FR-1 schedule was alternated between the levers in blocks of 10 pellets until 100 pellets had been delivered or until 1 hr elapsed.

Adjusting-Delay Procedure

A discrete-trial choice procedure presented the rat with two alternatives: a single response on the *single-valence* lever produced 1 pellet; a single response on the *dual-valence* lever produced multiple pellets (2 or 3 pellets, depending on the rat) plus a delayed shock. The delay to shock was adjusted based on the rat's prior choices. If, after the most recent pair of choices, the rat responded exclusively on the single-valence lever, then shock delay was increased. If the rat responded exclusively on the dual-valence lever, the delay was reduced. If the rat responded equally on the two levers, the delay was maintained. The purpose of this adjusting delay procedure was to identify the delay at which the rat was indifferent between a small reinforcer alone versus a larger reinforcer followed by a shock.

Four trials constituted a block, and sessions lasted for a total of 16 blocks or 300 min, whichever occurred first. Each block consisted of 2 forced-choice trials followed by 2 free-choice trials (described in detail below). Lever assignment was counterbalanced across rats. For each experimental condition, the initial delay to shock was 30 s. Trials were programmed every 60 s and at least 15 s following the completion of the consequence (1 pellet or multiple pellets plus shock), whichever occurred later. The 15-s rule avoided temporal contiguity between the consequence of responding and the onset of a trial, and ensured that the rat emitted a response before a new trial began. If the delay to shock became sufficiently long to extend trial duration beyond 60 s, a yoking requirement was in place to prevent trial duration from differing between trial types (see Trial-Duration Yoking section, below).

Forced-choice trials. Only one lever was extended into the chamber in each forced-choice trial. If the *single-valence* lever was presented, a response produced immediate delivery of 1 pellet and retraction of the lever. If the *dual-valence* lever was presented, a response immediately produced multiple pellets (2 or 3 pellets), retraction of the lever, and, after some delay, an electric shock (details of the shock delay, intensity, and duration are discussed below). Within each block, the lever presented in the first forced-choice trial was randomized; the other lever was presented in the second forced-choice trial. The purpose of the forced-choice trials was to ensure that the rat contacted the programmed consequences on both levers.

Free-choice trials. After the forced-choice trials, 2 free-choice trials were conducted. A free-choice trial began with both levers extended into the chamber. Once the rat responded, both levers were retracted and the consequence was delivered. As in the forced-choice trials, pressing the single-valence lever produced 1 pellet, and pressing the dual-valence lever produced multiple pellets plus delayed shock. As in Mazur's (1987) procedure, the rat's response allocation during these 2 free-choice trials determined the delay in the subsequent block of trials. If the rat pressed the dual-valence lever on both free-choice trials, the delay-to-shock was *decreased* by 2 s in the next block. If the rat pressed the single-valence lever on both trials, the delay was *increased* by 2 s. Finally, if the rat pressed each lever once, no adjustment was made in the delay. The minimum possible delay allowed by this procedure was set to 4 s to prevent shocks from being administered before food pellets could be consumed.

Within each experimental condition, these adjustments continued across blocks and sessions until an indifference point was identified according to Mazur's (1988) criteria: After dividing each session into halves consisting of 32 trials, the mean delay was calculated for each half. Responding was considered stable when the following criteria were satisfied: (a) Neither the highest nor lowest mean delay could occur within the last six half-sessions; (b) the mean adjusting delay across the last six half-sessions could not be the highest or the lowest six-half mean of the condition; (c) the mean delay of the last six halves could not differ from the mean of the preceding six halves by more than 10 percent or by more than 1 s (whichever was larger). Mean adjusting delays from all 32-trial half-sessions, except those in the first two sessions, were used to evaluate stability for a given condition. Once stability criteria were satisfied, the mean adjusting delay of the last 12 half-sessions was treated as an estimate of the indifference point.

The stability criteria were eventually modified to improve the likelihood of capturing a period of responding that was indicative of indifference between the two alternatives. Because part (c) of the stability criteria compares the mean adjusting delay of the last three sessions to the mean adjusting delay of the prior three sessions, this averaging process sometimes deemed the adjusting delays stable when, in fact, one or more of the last six sessions showed virtually exclusive choice of one alternative. To reduce the possibility of judging such responding as stable, additional criteria were included. Once Mazur's criteria (above) were met, the number of responses for either alternative, over the last six sessions, could not be below 10 or above 22 (out of the 32 free-choice trials per session) for at least five of these six sessions. This range of 10 to 22 was chosen based on probabilities obtained from the binomial distribution. Across 32 choices, if responding were truly indifferent – that is, if the probability of responding on either lever were .5 – the probability of either alternative being chosen less than 10 times or more than 22 times is .01. This probability is seen as sufficiently extreme to reject the null hypothesis of indifference. The only exception to the above requirement was if an indifference point was reached in the range of 4 to 6 s due to the floor effect created by the minimum possible delay of 4 s. Lastly, over these last six sessions, there could be no monotonic trend in the proportion of free-choice responses for either alternative.

No-shock baseline. Before implementing the adjusting-delay procedure, it was necessary to establish that the rats preferred multiple pellets to 1 pellet in the absence of any shocks. The no-shock baseline preceded the main adjusting procedure and was identical to it in all ways described above, except that no shock delays were programmed and no shocks were administered. For the first few sessions, one lever (the one that would become the dual-valence lever) was programmed to produce 2 pellets. For rats that did not choose this lever in 80% or more of free-choice trials (Rats AD3 and AD5), the number of pellets produced by this lever was increased to 3. By the end of the no-shock baseline, the number of pellets produced by this lever was maintained throughout the remainder of the experiment: 2 pellets for AD1, AD2, and AD4; 3 pellets for AD3 and AD5.

Trial-duration yoking. Although the default trial duration was set to 60 s, the procedure allowed the shock delay to extend a trial beyond 60 s. For instance, on a dual-valence trial (a trial on which the dual-valence lever was pressed), a 70-s shock delay, followed by the 15-s post-shock period, would result in a total trial duration of at least 85 s (plus the rat's initial latency to respond). If subsequent single-valence trials (trials on which the single-valence lever was pressed) lasted only 60 s, this would introduce a confound to the experiment: Reinforcement density would vary in an unintended manner between the two response alternatives, and the extended trial durations on dual-valence trials could potentially even serve an aversive function as a timeout period from the opportunity to respond for food. To prevent such a situation, a yoking requirement was in place. When a dual-valence trial lasted more than 60 s, all subsequent single-valence-trial durations were yoked to this dual-valence-trial duration. A new yoked duration was established whenever the rat pressed the dual-valence lever. Because the need for this yoking requirement was unforeseen at the outset of the experiment, it was not introduced into the procedure until session 47 for Rats AD1, AD2, AD3, and AD4, and session

33 for Rat AD5. Prior to the yoking procedure, only AD1 and AD2 experienced dual-valence trial durations longer than 60 s (due to lengthened delays to shock).

Experimental Conditions

Whereas shock intensity and shock duration remained constant *within* a condition, these variables were manipulated *across* conditions. Once a stable adjusting delay was obtained with a given combination of shock intensity and duration, a different combination was tested, using the same adjusting-delay procedure. Table 1 shows the conditions for each rat and the number of sessions conducted in each condition. To avoid any unintended long-term or permanent suppression of lever pressing due to overly intense shocks, the experiment was designed with a sequence of shock intensities increasing from low to high (0.05, 0.1, 0.2, 0.4, and 0.8 mA). Additionally, all shocks in this initial sequence lasted 100 ms. A conservative approach was taken with the initially tested shock intensities and duration because this procedure was designed to produce indifference, which requires a maintenance – rather than a suppression – of responding on both levers.

When a condition resulted in a substantial change in the obtained adjusting delay relative to a previous condition, a series of replications was conducted to demonstrate experimental control. For example, after a 0.8-mA condition resulted in a substantially higher stable adjusting delay than the previous 0.4-mA condition, a replication was conducted at 0.4 mA, followed by a replication of the 0.8-mA condition. After an ABAB series of replications was conducted for 0.4-mA and 0.8-mA conditions with shocks of 100-ms duration, shock duration was increased to 200 ms. With shock duration set to 200 ms, a series of 0.8-mA and 0.4-mA conditions were conducted, again with replications. Because Rat AD5 did not show any change in exclusive choice of the dual-valence lever during the initial 100-ms sequence, it was

Table 1

Number of sessions per experimental condition for each rat. Conditions are defined in terms of shock intensity (mA) and shock duration and are listed in order of presentation. Numbers in parentheses indicate the number of sessions completed before the yoking procedure was introduced.

AD1		AD2		AD3		AD4		AD5	
mA	Sessions	mA	Sessions	mA	Sessions	mA	Sessions	mA	Sessions
100-ms Shock									
0.05	(8)	0.05	(8)	0.05	(8)	0.05	(8)	0.05	(8)
0.1	(8)	0.1	(8)	0.1	(8)	0.1	(8)	0.1	(8)
0.2	(8)	0.2	(8)	0.2	(8)	0.2	(8)	0.2	(8)
0.4	(8)	0.4	(8)	0.4	(8)	0.4	(8)	0.4	(8)
0.8	57 (14)[a]	0.8	30 (10)[a]	0.8	30	0.8	30	0.8	8
0.4	12	0.4	21[b]	0.4	8	0.4	8		
0.8	32	0.8	15	0.8	24	0.8	8		
		0.2	13						
		0.4	22						
		0.8	14						
		0.4	10						
		0.8	28						
200-ms Shock									
0.8	30	0.8	18	0.8	25[b]	0.8	25[b]	0.4	8
0.4	28	0.4	55	0.4	13	0.4	9	0.8	29
0.8	10	0.8	25	0.2	8	0.8	8	0.4	8
				0.6	36	0.4	8	0.8	9[b]
				0.4	9	0.8	13	0.6	17
				0.8	44				

[a] Number in parentheses is included in total number of sessions for the condition.
[b] These conditions did not meet the amended stability criteria.

unnecessary to conduct replications, so this rat was moved directly to the sequence of 200-ms shocks. Some of Rat AD2's 0.4-mA conditions did not replicate well, so additional replications with 0.2, 0.4, and 0.8 mA were conducted before increasing shock duration to 200 ms.

Results

Each condition was continued until the rat chose equally often between 1 pellet alone (single-valence lever) versus multiple pellets and a delayed shock (dual-valence lever) – in other words, until the rat was indifferent between the two outcomes. The delay to shock was controlled by the rat's choices. Exclusive choice of 1 pellet increased the delay by 2 s, and exclusive choice of multiple pellets plus shock reduced the delay. At the indifference point, the two outcomes are equal in value – that is, multiple pellets plus a delayed shock is equal to a single pellet.

Figure 1 shows the duration of the delay to shock ("adjusting delay") over the stable 6 sessions of each condition. Data are excluded from any conditions that did not retroactively meet the modified stability criteria. The left panels show conditions in which the shock lasted 100 ms; the right panels show conditions in which the shock lasted 200 ms. Within each panel, the delay is shown as a function of shock intensity. Individual data points show obtained adjusting delays from each iteration of a condition, and a line connects the means of these adjusting delays. In most conditions with shock intensities of 0.4 mA or below, the rats predominantly chose multiple pellets plus shock, resulting in shock delays adjusting downward until the minimum of 4 s was reached and maintained. The steady-state 4-s delay represented the limit of the procedure and therefore cannot be interpreted in terms of indifference between one pellet and multiple pellets plus shock. At these conditions, shock delayed by 4 s was not sufficient to degrade the value of multiple pellets to equal that of 1 pellet. At most 0.8-mA conditions, however, choices were allocated between the two levers in a way that did not reduce delays to the 4-s minimum. Instead, delays adjusted sufficiently above 4 s to permit interpretation of the results in terms of indifference. For Rats AD1, AD2, and AD3, 0.8-mA shocks of 100-ms duration needed to be delayed, on average, 17.6, 85.0, and 9.4 s, respectively, to maintain indifference; only Rats AD4 and AD5 continued to choose multiple pellets and delayed shock predominantly over one pellet, yielding adjusting delays of 4 s. When 0.8-mA

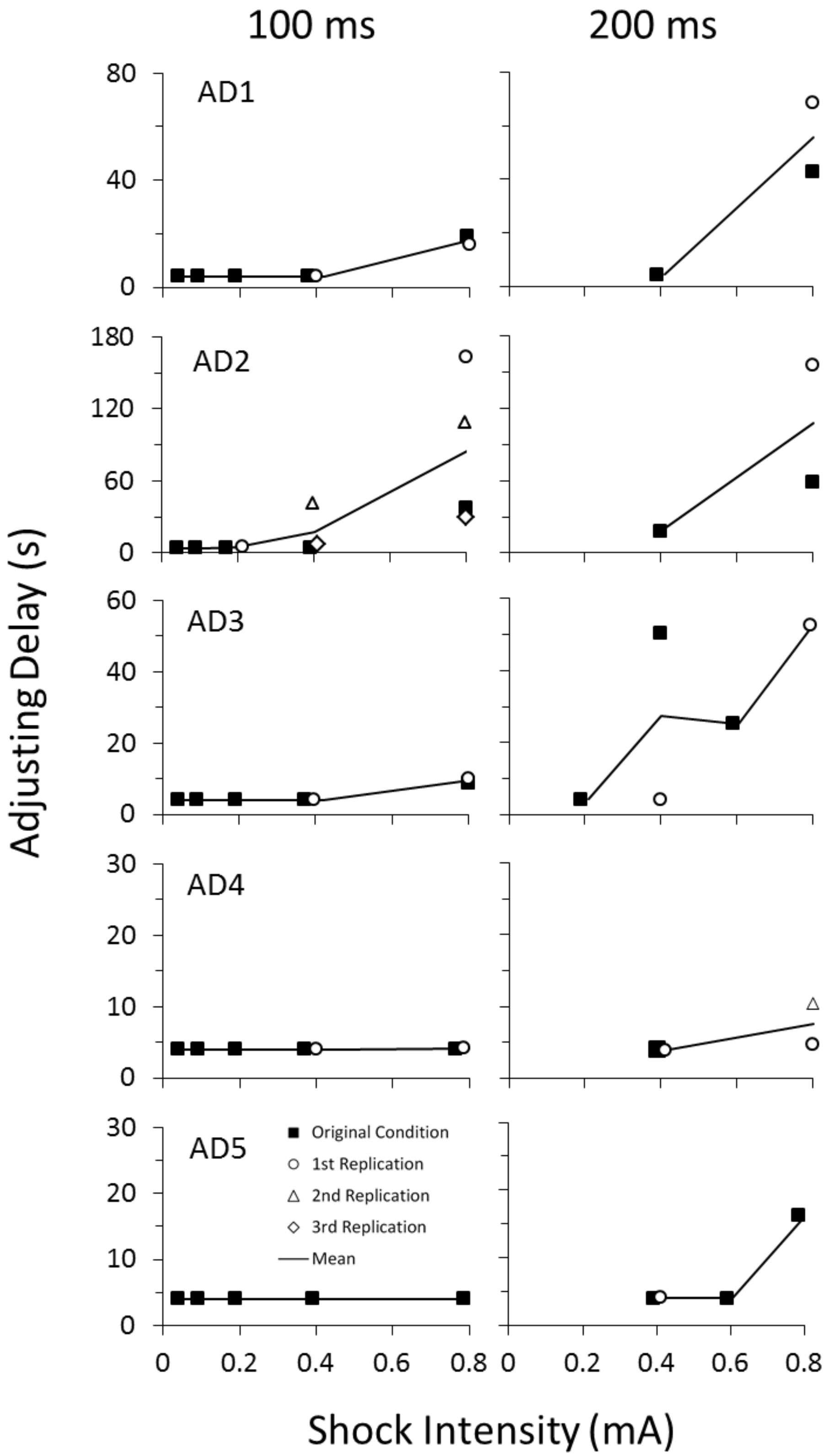

Figure 1. Stable adjusting delays from all conditions, shown as a function of shock intensity. Left panels show delays from conditions in which shock lasted 100 ms; right panels show delays from conditions in which shock lasted 200 ms.

shocks lasted 200 ms, all rats showed disruption of predominant choice of the multiple pellets and delayed shock option, with mean adjusting delays of 55.8, 107.5, 52.6, 7.6, and 16.2 s for Rats AD1, AD2, AD3, AD4, and AD5, respectively. Furthermore, for four of five rats, obtained adjusting delays tended to be higher when 0.8-mA shocks lasted 200 ms vesus 100 ms, showing the effect of shock duration (AD2's data showed some exceptions).

Overall, Figure 1 shows that adjusting delay was a positive function of shock intensity and shock duration. As the delayed shock was made more intense, it needed to be further delayed to obtain indifference. As the shock was made to last longer, it also needed to be further delayed to obtain indifference.

Whereas the summary data in Figure 1 report the delays at which responding met stability criteria, it is also worth examining block-by-block delay adjustments within conditions, as these adjustments reveal patterns of responding not evident in the stable adjusting delays. Block-by-block delay adjustments provide information about all choices made in a condition. Each increase in delay indicates that two consecutive free choices of 1 pellet occurred in the prior block; a decrease in delay indicates two choices of multiple pellets and shock in the prior block; and no delay adjustment indicates one choice of each option. Figure 2 shows the block-by-block adjusting delays for all 0.8-mA conditions testing shocks of 100-ms duration, and Figure 3 shows the same adjustments for all 0.8-mA conditions testing shocks of 200-ms duration. These figures highlight conditions testing 0.8-mA shocks because this is the only shock intensity that consistently resulted in indifference (versus exclusive responding on one lever). As such, these conditions allow examination of patterns of responding that *precede* indifference. From left to right, the conditions are listed in relative order of presentation (however, other shock intensities were tested in between these conditions), and an arrow marks the beginning of each condition's

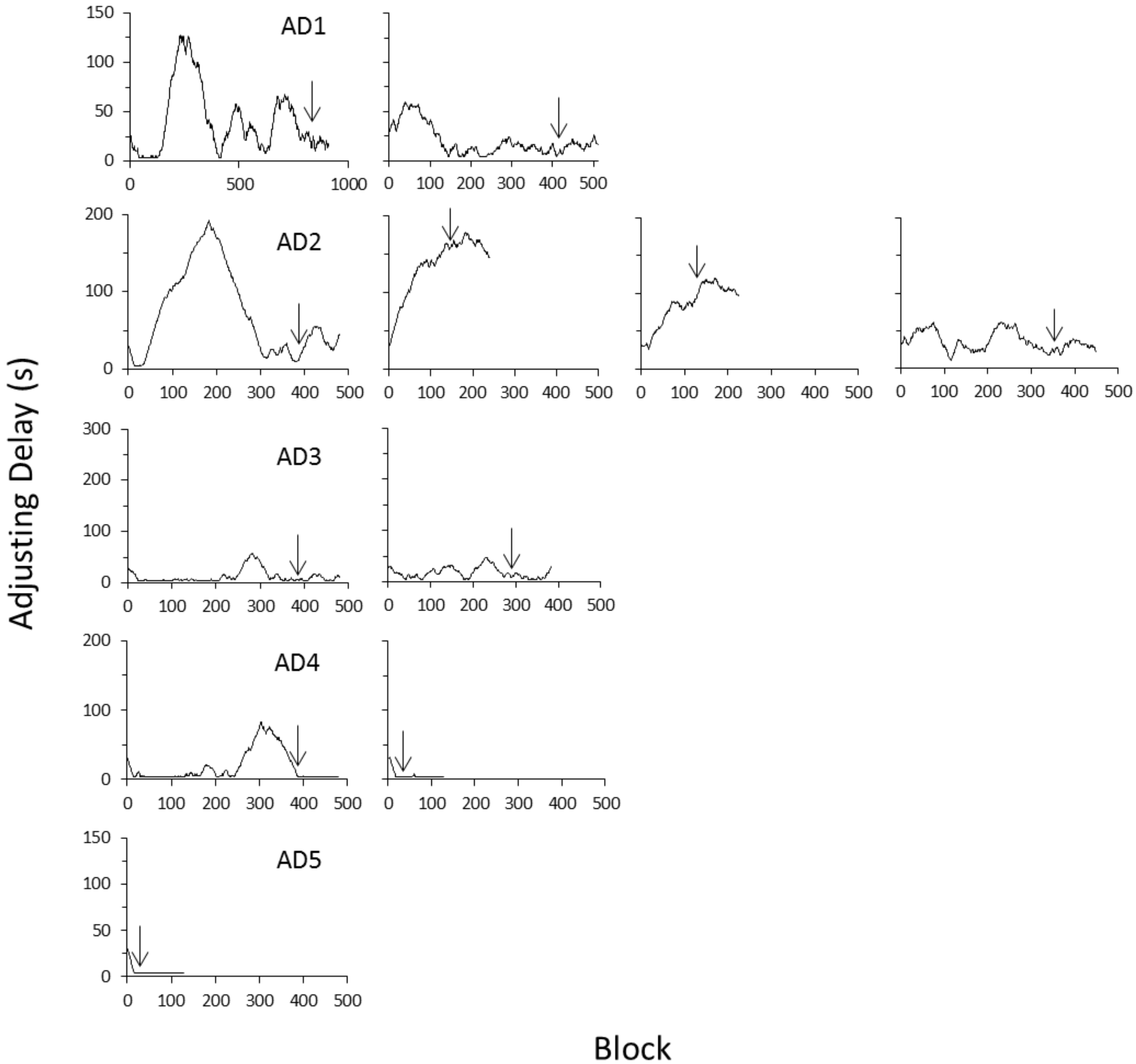

Figure 2. Adjusting delays over blocks, from all 0.8-mA conditions in which shock lasted 100 ms. A vertical arrow marks the beginning of the stable period.

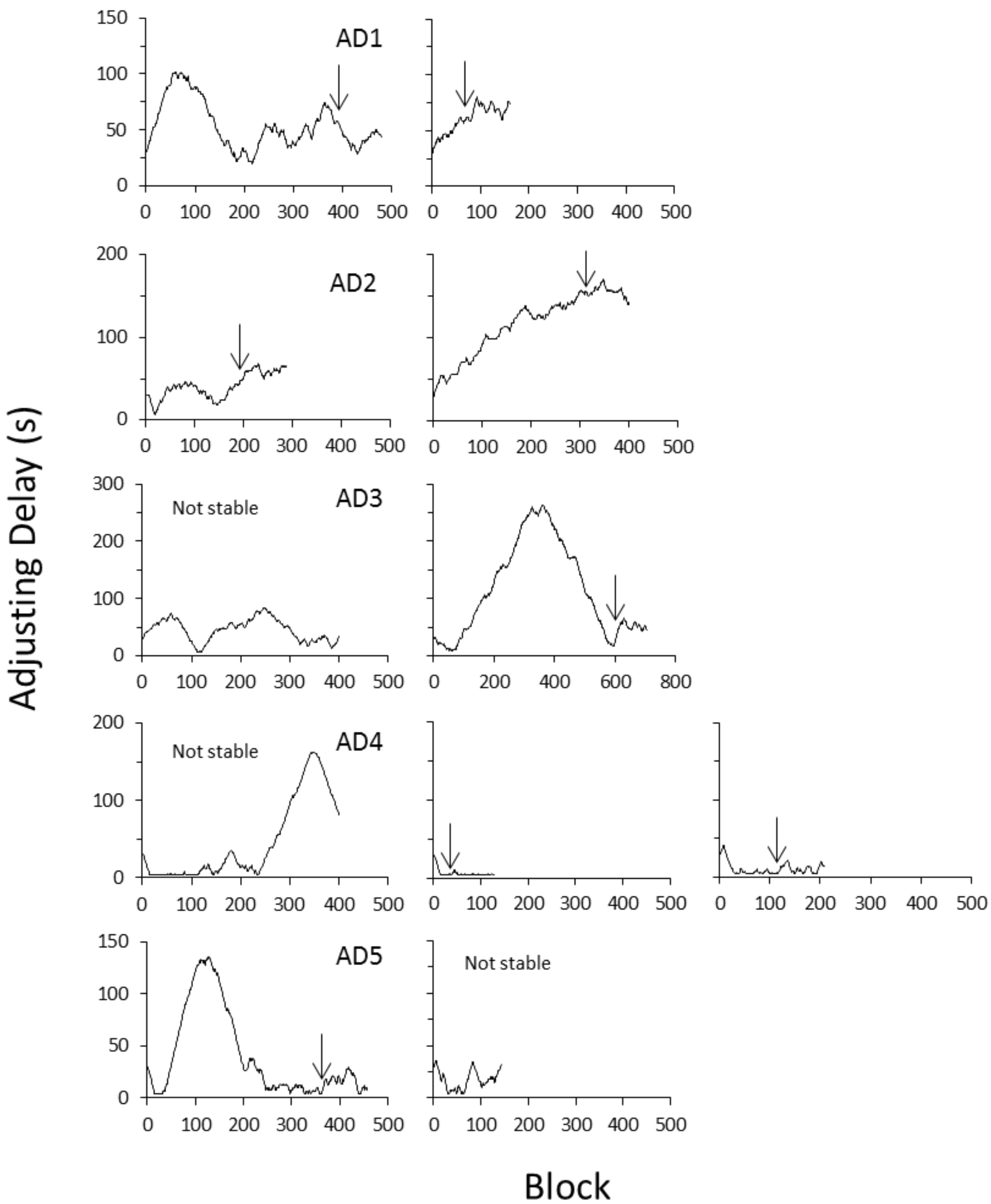

Figure 3. Adjusting delays over blocks, from all 0.8-mA conditions in which shock lasted 200 ms. A vertical arrow marks the beginning of the stable period. Conditions marked "Not stable" did not retroactively meet the modified stability criteria.

stability period. Conditions marked “Not stable” were conducted before the stability criteria were modified; these data did not retroactively meet the modified criteria but are included to highlight patterns of responding.

Figures 2 and 3 reveal that delays do not adjust directly to their ultimate terminal value and stabilize thereafter. Rather, some conditions are characterized by a prominent peak in adjusting delays, at delays far surpassing the ultimate stable delay (e.g., AD2’s first 0.8-mA condition with shocks of 100-ms duration in Figure 2; AD3’s second 0.8-mA condition with shocks of 200-ms duration in Figure 3). These peaks indicate a prolonged period of predominant choice of 1 pellet leading up to the peak, followed by a prolonged period of predominant choice of multiple pellets and shock after the peak. To facilitate description, one such condition (AD5’s original 0.80-mA condition with shocks of 200-ms duration) is enlarged and presented in Figure 4. Various locations on the adjusting-delay function are labeled with letters “A” through “F,” and a dotted line runs through the stable adjusting delay of 16.2 s. The period of ascending delays leading up to the peak, indicating predominant choice of 1 pellet, occurs from points “A” to “C” (blocks 31 to 108, approximately 5 sessions). Of the 156 choices made over these blocks, the 1-pellet option was chosen 142 times (91.0%). The period of descending delays following the peak, indicating predominant choice of multiple pellets and shock, occurs from points “D” to “F” (blocks 130 to 201, 4.5 sessions). Of the 144 choices made over these blocks, the multiple pellets and shock option was chosen 127 times (88.2%). This selected condition from rat AD5, and other conditions in Figures 2 and 3, show that indifference is often preceded by prolonged periods of responding almost exclusively for one option, followed by a reversal in choice whereby the other lever is predominantly chosen.

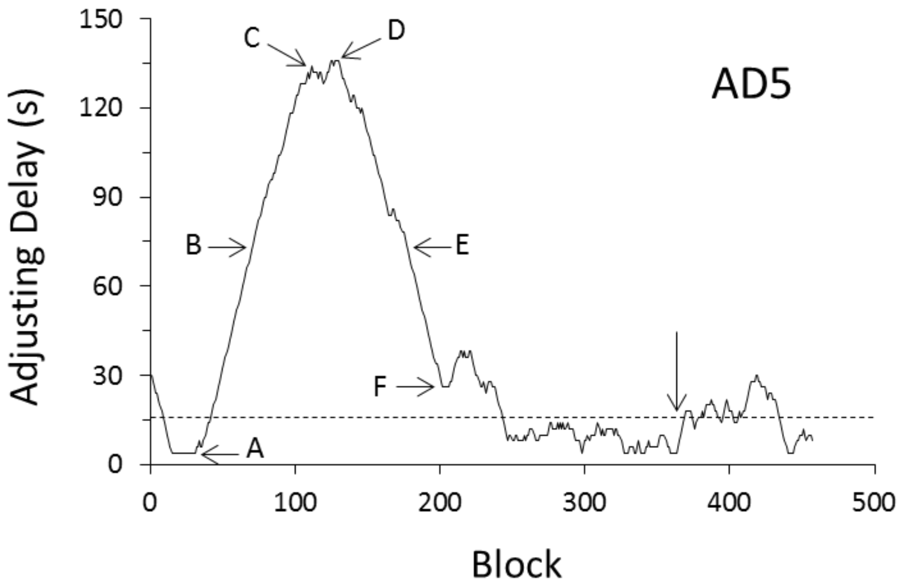

Figure 4. Delay adjustments from AD5's original 0.8-mA condition in which shock lasted 200 ms. A vertical arrow marks the beginning of the stability period, and the horizontal dotted line represents the stable adjusting delay of 16.2 s. Various locations on the adjusting-delay line are marked with letters to facilitate description (see Results section of text).

These "peaked reversals" are important because they indicate that the rat behaves drastically differently between repeated presentations of the *exact same* choice contingencies. It appears that how the rat responds to choice contingencies of certain parameters (shock intensity, duration, and delay) depends on choices offered and choices made in the recently preceding blocks. This is evident when points "B" and "E" are compared in Figure 4. In the blocks that occurred at points "B" and "E," the delay to shock was set at 74 s, and shock intensity and duration were held constant (as they were throughout this condition). The rat was presented with the exact same choice situation yet responded in a polar-opposite manner between the two blocks. In the block at point "B," the 1-pellet option was chosen twice; in the block at point "E," the multiple pellets and shock option was chosen twice.

Although the immediate contingencies are the same between these blocks, what differ are the choices offered and the choices made in the recently preceding blocks. In the 40 blocks leading up to point “B” (from point “A”), the rat was presented with shorter shock delays (relative to 74 s) and had predominantly chosen 1 pellet (77 times, or 96.3%). In the 47 blocks leading up to point “E” (from point “D”), the rat was presented with longer shock delays (relative to 74 s) and had predominantly chosen multiple pellets and shock (78 times, or 83.0%). This same polar difference in choice is observed as equivalent delays are traced along the ascending and descending arms of the peak. The rat responds to the same long range of delays one way the first time they are experienced (choosing 1 pellet); the second time, the delays are treated completely differently (choosing multiple pellets and shock). In this procedure, the determinants of choice over multiple blocks clearly include more than just shock and delay parameters. Recent behavioral history appears to significantly impact choice. This type of responding is also observed in any other conditions in Figures 2 and 3 that feature a distinguishable peak in delays.

Figure 4 also shows that choice at the ultimate stable delay appears to depend on how many times the choice situation has already been encountered. The dotted indifference line intersects the adjusting-delay function three times before the stable period. The blocks that occur close to these intersections represent blocks in which the rat was presented with shock delay at or near the ultimate stable adjusting delay (i.e., the indifference point). However, even though the rat was offered an option featuring an adjusting delay that was at or near the ultimate indifference point for that condition, the rat predominantly chose one lever – behavior not consistent with indifference. It was not until repeated exposure to delays around this ultimate stable value that the rat began to choose both levers a similar proportion of the time. Similar patterns of responding can be identified in other 0.8-mA conditions in Figures 2 and 3 (e.g., AD1's original condition with 100-ms shocks).

Figures 2, 3, and 4 highlight that indifference is not obtained simply by presenting the rat with the ultimate stable adjusting delay. Rather, multiple instances of contacting this delay are often required, sometimes accompanied by wide swings in choice, before the rat exhibits indifference.

Examining response allocation is one way to compare the reinforcing value of two separate consequences in a choice situation; another way is by examining response latency. Latency, as a measure of response strength, is inversely related to the value of the consequence of responding (Mackintosh, 1974, pp. 143-144): Consequences of high reinforcing value maintain relatively short latencies. In the present experiment, over the stable six sessions per condition – when indifference is reached and the two choice alternatives are presumably equal in value – it might be expected that the latency to respond to produce 1 pellet (a single-valence response) should equal the latency to respond to produce multiple pellets and shock (a dual-valence response). The opposite case would be if there is a difference in the allocation of choice between the two alternatives, which would indicate unequal value between them. As such, differential allocation should be accompanied by differences in response latency between the alternatives.

To quantify such differences in latency, sign tests were performed on latencies from forced-single-valence and forced-dual-valence trials, over the 96 stable blocks of each condition. The sign test is a non-parametric statistical test, and in the present experiment it examines whether, for each block, latencies were shorter on the forced-single-valence trial or the forced-dual-valence trial. This comparison is done by subtracting the forced-dual-valence latency from the forced-single-valence latency in each block. Positive differences are assigned a plus sign and indicate that latency was shorter in the forced-dual-valence trial. Negative differences are assigned a minus sign and indicate that latency was shorter in the forced-single-valence trial. Differences of zero ("ties") are not included in the analysis. Pluses and minuses are tallied over the 96 blocks, and the resulting tally is compared against the binomial distribution to determine whether a statistically significant number of the 96 blocks featured shorter latencies in one trial type over another. (See Siegel, 1956 for a more detailed description of the sign test.)

This analysis was conducted with forced-choice trials (versus free-choice trials) because every block always contains one forced-choice response on the single-valence lever, leading to 1 pellet, and one forced-choice response on the dual-valence lever, leading to multiple pellets and a delayed shock. Over the six stable sessions of each condition, this resulted in 96 obtained latencies of each response type. With one of each response per block, it is possible to conduct a block-by-block comparison of latencies between the two responses. Such a comparison would not always be possible by examining latencies in *free-choice* trials, as the rat can respond exclusively on one lever in the free-choice trials.

Table 2 displays forced-choice latency data, stable adjusting delays, and the results of sign tests for conditions with shocks of 100-ms duration. Lower p-values from sign tests result from a greater disparity in the number of pluses and minuses obtained in the analysis (i.e., a predominance of one trial type producing shorter latencies). As such, very low p-values are not consistent with the notion of indifference. To facilitate interpretation, only p-values less than .05 are included in the table. Values greater than .05 are represented by a dashed line, and for these conditions it is not possible to reject the null hypothesis of indifference.

Table 2

Forced-choice latency data (25th, 50th, 75th percentile), stable adjusting delays, and results of sign tests from the 96 stable blocks of each condition with 100-ms shock. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$.

Rat	mA	Stable	Single-Valence			Dual-Valence			Sign Test		
		Delay (s)	25th	50th	75th	25th	50th	75th	+	-	p
AD1	0.05	4.0	0.75	1.33	2.11	0.58	0.66	0.73	78	18	< .001
	0.1	4.0	1.34	1.75	2.55	0.58	0.69	0.85	86	10	< .001
	0.2	4.0	0.98	1.17	1.57	0.59	0.64	0.71	90	6	< .001
	0.4	4.0	0.88	1.08	1.34	0.61	0.66	0.75	87	9	< .001
	0.8	19.3	0.75	0.99	1.24	0.75	1.04	1.48	38	57	---
	0.4	4.2	0.66	0.78	1.04	0.60	0.69	0.92	63	33	.003
	0.8	16.0	0.66	0.74	0.94	0.61	0.69	1.04	51	43	---
AD2	0.05	4.0	1.13	1.23	1.68	1.30	1.39	1.48	49	47	---
	0.1	4.0	1.12	1.42	2.23	1.23	1.30	1.35	59	37	.032
	0.2	4.0	1.12	1.28	1.58	1.26	1.30	1.36	49	46	---
	0.4	4.0	1.29	1.66	2.41	0.98	1.19	1.36	78	17	< .001
	0.8	37.5	1.19	1.32	1.46	0.62	1.12	1.58	61	35	.011
	0.8	163.6	1.00	1.31	1.54	1.02	1.19	1.35	58	37	.04
	0.2	5.1	0.80	1.08	1.42	0.81	0.98	1.17	59	36	.024
	0.4	41.2	0.80	1.05	1.51	0.67	0.97	1.35	58	38	---
	0.8	109.0	1.00	1.26	1.87	0.96	1.19	1.68	51	44	---
	0.4	7.1	0.85	1.11	1.36	0.72	1.01	1.52	52	44	---
	0.8	29.9	1.00	1.40	1.80	0.77	1.10	1.67	58	38	---
AD3	0.05	4.0	1.31	1.53	1.85	0.72	0.75	0.82	93	3	< .001
	0.1	4.0	1.23	1.58	2.11	0.64	0.72	0.78	95	1	< .001
	0.2	4.0	1.00	1.28	1.72	0.62	0.69	0.73	95	0	< .001
	0.4	4.0	1.00	1.23	1.73	0.61	0.70	0.73	91	5	< .001
	0.8	8.7	0.70	0.81	1.20	0.66	0.76	1.28	45	51	---
	0.4	4.1	0.73	0.86	1.48	0.58	0.64	0.78	79	16	< .001
	0.8	10.0	0.70	0.80	1.08	0.66	0.76	1.34	51	43	---
AD4	0.05	4.0	1.47	1.67	2.25	1.05	1.14	1.25	89	7	< .001
	0.1	4.0	1.36	1.55	1.77	0.76	0.80	0.86	93	3	< .001
	0.2	4.0	1.30	1.47	1.79	0.75	0.81	0.86	94	2	< .001
	0.4	4.0	1.17	1.31	1.61	0.70	0.75	0.78	96	0	< .001
	0.8	4.1	0.81	0.92	1.14	0.66	0.72	0.87	78	18	< .001
	0.4	4.0	1.11	1.31	1.67	0.59	0.62	0.67	92	4	< .001
	0.8	4.2	0.96	1.13	1.41	0.58	0.65	0.72	82	14	< .001
AD5	0.05	4.0	1.28	1.65	1.97	0.61	0.66	0.70	95	1	< .001
	0.1	4.0	1.05	1.46	1.83	0.66	0.69	0.73	92	3	< .001
	0.2	4.0	1.35	1.50	1.82	0.61	0.66	0.72	93	3	< .001
	0.4	4.0	1.03	1.38	1.67	0.60	0.62	0.69	95	1	< .001
	0.8	4.0	0.80	1.15	1.49	0.66	0.72	0.84	79	16	< .001

From Table 2, a relation is evident between stable adjusting delay and the plus and minus tallies of the sign test. When adjusting delays stabilized at or near 4 s due to limits of the procedure (when choices were allocated predominantly to the dual-valence lever; see reporting on Figure 1), there are relatively more plus signs, and these conditions tend to be accompanied by p-values less than .05. A greater number of plus signs indicates that more blocks contained a shorter latency in the forced-dual-valence trial versus the forced-single-valence trial. Exceptions to this pattern occur at two of AD2's five conditions with adjusting delays at or near 4 s (the 0.05- and 0.2-mA conditions).

Alternatively, at conditions in which an indifference point was obtained (indicated by adjusting delays *above* the range of 4 to 6 s), the disparity between the number of pluses and minuses is generally reduced. In some cases, the number of pluses and the number of minuses are close to equal (e.g., AD3's 0.8-mA conditions). This approaching of equalization indicates that, for these conditions, there was not a predominance of one trial type consistently producing shorter latencies. With relatively equalized plus and minus tallies, these conditions typically produced p-values that failed to be significant at the $p < .05$ level. Values failed to be significant at all conditions of AD1 and AD3 with adjusting delays above the 4-6 s range and at four of six such conditions for AD2. For AD4 and AD5, no conditions with shocks of 100-ms duration yielded adjusting delays above 6 s (i.e., no indifference points were obtained).

This relation between stable adjusting delay and the number of blocks with shorter latencies in the dual-valence trial is represented visually in Figure 5. The top panel shows data from conditions with 100-ms duration shock (data from Table 2); the bottom panel shows data from conditions with 200-ms duration shock. Individual bars show the mean number of blocks out of 96 in which latency was shorter in the dual-valence trial. Means were calculated from the

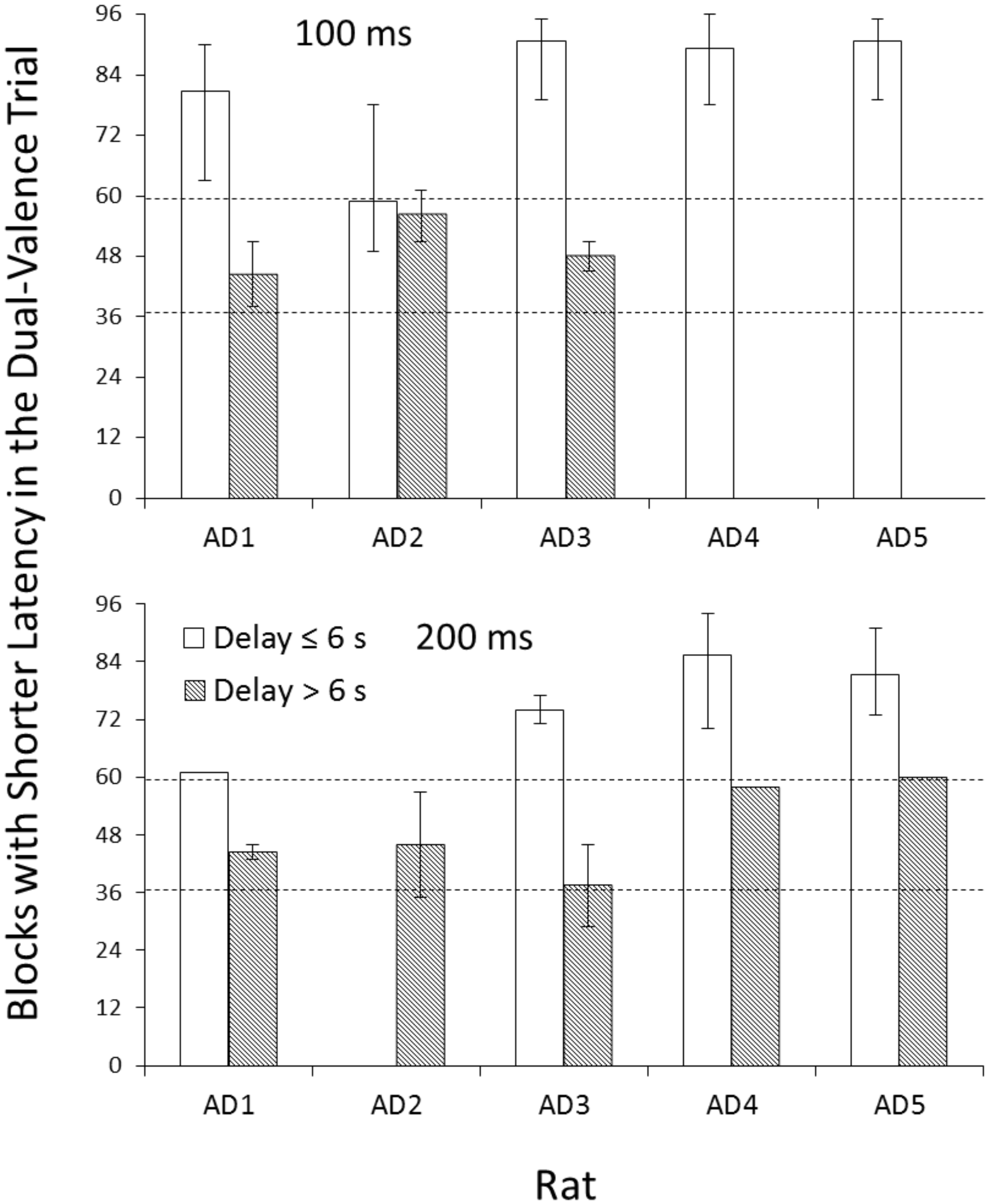

Figure 5. The mean number of stable blocks in which latency from the forced-dual-valence trial was shorter than latency from the forced-single-valence trial. Vertical bars above and below each mean represent the maximum and minimum number of such blocks from each condition. Unfilled bars represent conditions that yielded adjusting delays less than or equal to 6 s (not indifference points). Filled bars represent conditions that yielded adjusting delays above 6 s (indifference points). Dotted lines indicate the range of blocks (above 59 or below 37) that reach statistical significance at $p < .05$ according to the sign test.

number of plus signs resulting from each condition's sign test. The white bars represent conditions that yielded a stable adjusting delay less than or equal to 6 s (i.e., not an indifference point), and the filled bars represent conditions that yielded a stable adjusting delay greater than 6 s (i.e., an indifference point). Vertical lines above and below each mean represent the maximum and minimum number of blocks across all conditions used to calculate the mean. The dotted horizontal lines show the two ranges of blocks (59 blocks or more; 37 blocks or less) that should occur with $p < .05$ according to the binomial distribution, assuming a hypothetical probability of .5 (i.e., assuming indifference and therefore an equal number of plus and minus tallies).

In Figure 5, white bars generally extend into the range of statistical significance whereas filled bars generally fall into the middle range with p-values greater than .05. This shows that conditions failing to yield an indifference point (white bars) also tended to feature an extreme number of blocks with a shorter latency in the forced-dual-valence trial. These shorter latencies in the forced-dual-valence trial imply higher reinforcing value of the multiple pellets and shock consequence. These latency data are consistent with response allocation in these conditions, which occurred almost exclusively to the multiple pellets and shock consequence, driving delay down to 4 s. In these conditions, shock delayed by 4 s was not sufficient to overcome the relatively larger value of multiple pellets versus 1 pellet. Alternatively, conditions that yielded adjusting delays that can reasonably be called indifference points as determined by response allocation (filled bars) tended to feature a more equalized number of blocks with shorter latency in either trial type. This result is consistent with the notion of indifference, as equal value between alternatives. Latency data reported in the bottom panel of Figure 5, from each condition with shocks of 200-ms duration, are displayed in Table 3. Inspection of Table 3 reveals the same relation between adjusting delay and plus and minus tallies that is evident in Table 2.

Table 3

Forced-choice latency data (25th, 50th, and 75th percentile), stable adjusting delays, and results of sign tests from the 96 stable blocks of each condition with 200-ms shock. Plus and minus signs were calculated by subtracting the forced-dual-valence latency from the forced-single-valence latency, and the right-most column shows the corresponding p-values. Missing p-values indicate that the test results were not significant at $p < .05$.

Rat	mA	Stable Delay (s)	Single-Valence			Dual-Valence			Sign Test		
			25th	50th	75th	25th	50th	75th	+	-	p
AD1	0.8	43.0	0.99	1.28	1.80	1.11	1.51	2.39	43	53	---
	0.4	4.5	0.72	0.82	1.08	0.66	0.73	0.98	61	34	.008
	0.8	68.6	1.07	1.75	5.60	1.17	1.66	3.58	46	50	---
AD2	0.8	59.2	1.02	1.44	2.81	0.98	1.51	8.10	46	50	---
	0.4	18.0	0.92	1.41	2.06	0.78	1.08	1.87	57	38	---
	0.8	155.8	1.03	1.83	2.68	1.24	3.53	7.75	35	61	.011
AD3	0.4	50.2	0.73	0.96	1.43	0.78	1.10	1.38	46	50	---
	0.2	4.4	0.86	1.15	1.42	0.67	0.80	1.01	77	19	< .001
	0.6	25.2	0.67	0.76	0.94	0.72	0.89	1.14	38	57	---
	0.4	4.4	0.76	1.10	1.40	0.66	0.73	0.90	71	24	< .001
	0.8	52.6	0.71	0.93	1.24	0.97	1.26	1.54	29	65	< .001
AD4	0.4	4.0	1.00	1.23	1.48	0.56	0.59	0.62	94	2	< .001
	0.8	4.7	0.79	0.95	1.14	0.61	0.70	1.02	70	25	< .001
	0.4	4.0	1.13	1.45	1.65	0.61	0.66	0.72	92	4	< .001
	0.8	10.5	0.75	0.87	1.11	0.66	0.73	0.97	58	38	---
AD5	0.4	4.0	1.19	1.40	1.77	0.66	0.72	0.81	91	5	< .001
	0.8	16.2	0.89	1.05	1.24	0.69	0.83	1.20	60	36	.019
	0.4	4.3	0.81	1.11	1.32	0.64	0.69	0.83	80	15	< .001
	0.6	4.1	0.84	1.20	1.61	0.70	0.76	0.85	73	22	< .001

Although in Figure 5 there are some exceptions to the overall trend, the exceptions are rare when examined across all conditions used to calculate the means. Of the 36 conditions that yielded adjusting delays less than or equal to 6 s (not indifference points), only 2 conditions failed to produce significant p-values. Both conditions were from AD2. Of the 20 conditions that yielded adjusting delays greater than 6 s (indifference points), only 5 conditions produced significant p-values. Considering the relatively small number of exceptions, this trend is robust.

In sum, at shock intensities sufficient to yield an indifference point, there is likely not to be a substantial difference in latencies between forced-single-valence and forced-dual-valence responses. Results of the adjusting-delay data and the latency data support the conclusion that indifference, or something close to it, was achieved when delays adjusted above the 4-6 s range. At these indifference points, neither choice alternative was valued substantially more than the other, by indices of response allocation or latency to respond.

Discussion

This procedure is a viable means of studying choice between a small immediate reinforcer versus a larger immediate reinforcer and a delayed aversive event. Rats chose between 1 pellet and multiple pellets followed by a delayed shock. The delay was increased or decreased based on the rat's choices until stability criteria were met. Each condition tested a different combination of shock intensity and shock duration. Overall, stable delay was a positive function of shock intensity and duration. When shock was made more intense, it needed to be further delayed to achieve indifference between 1 pellet and multiple pellets followed by a delayed shock. When shock lasted longer, it also needed to be further delayed to achieve indifference. When rats were indifferent, latencies between each response type did not differ substantially. When rats were not indifferent and instead predominantly chose multiple pellets and shock, latencies were significantly shorter for this response type.

The present study has provided some indication of which combinations of shock intensity and shock duration are behaviorally active in this procedure and which tend to be ineffective at altering choice. Shocks of 0.4 mA or less, even delayed by only 4 s, were typically not sufficient to degrade the reinforcing value of 2 pellets to approach that of 1 pellet. That most shock intensities were behaviorally inactive was somewhat surprising. Casual visual observation of sessions with 0.4-mA shock revealed that rats would often jump, yelp, or scurry in response to shock administration. Shocks of 0.4 mA or less have produced suppression in other studies using shock with rats, but it is important to acknowledge that they are typically tested with longer durations such as 500 ms (e.g., Baron, 1965; Church, Raymond, and Beauchamp, 1967; Cohen, 1968). With the relatively short shock durations of 100 and 200 ms used in the present study, shock intensity had to be increased relatively highly, to 0.8 mA, to reach behaviorally active shocks.

Future studies should aim to identify the optimal parameters of shock intensity and shock duration for use in this procedure. Shocks of 0.8-mA intensity and 100- or 200-ms duration were generally sufficient to disrupt exclusive choice of multiple pellets and shock, but they also generated some very long latencies and periods of predominant choice of 1 pellet that produced extreme delays well above the ultimate indifference point. Raising duration of 0.8-mA shocks to 400 or 500 ms may prove to be intolerable for the rat, especially considering that this procedure requires regular contact with shock via every forced-choice trial to progress through a session – plus regular contact with shock in free-choice trials in order for stability criteria to be met. Whether or not such shocks are intolerable is an empirical question and can be answered in future studies. Perhaps shocks that are moderately intense and moderately long (e.g., a 0.4-mA shock lasting 500 ms) will prove to be ideal.

Even though most 100-ms shocks failed to disrupt exclusive choice of multiple pellets and shock, caution should be exercised in outright dismissing any parameters of shock intensity or duration from use in future studies. With new manipulations (e.g., drugs or exteroceptive stimuli), some of these parameters may prove to be behaviorally active. Still, unless a future study has a specific empirical or conceptual basis for expecting behavioral activity from 100-ms shocks less than 0.4 mA, a good starting point is probably with shocks of 0.4 mA or greater.

Regarding starting points, how the rat is introduced to shock, and the particular sequence of shocks used, may prove to be important and consequential components of the procedure. This study's main procedure began with a no-shock baseline to verify that 2 (or 3) pellets would indeed be chosen predominantly over 1 pellet. Because these baseline sessions were the rats' first instances of contact with the procedure, this may have generated a stronger likelihood of responding on the dual-valence-lever (due to larger reinforcer magnitude) even once shock was introduced, rather than if shock had been contacted from the outset. Future studies might explore if and how choice is affected if the no-shock baseline is bypassed.

Punishment studies have shown that fading up the intensity of a punisher can reduce its effectiveness and that, instead, more abrupt, discriminable changes in intensity are ideal for obtaining suppression (cf. Azrin & Holz, 1966). After the no-shock baseline, the sequence of shocks administered in the present study featured a gradual increase from 0.05 mA to 0.8 mA. This sequence may have reduced the suppressive effect of 0.4-mA shocks, for instance. The increasing sequence of shocks was chosen as a conservative approach so as not to achieve full suppression with no recovery or only partial recovery (indifference requires a maintenance of responding rather than full suppression). It is unknown at the present time whether a rat would continue to respond for multiple pellets and shock if the no-shock baseline were skipped and its first contact with the procedure began with a 0.8-mA condition.

In addition to the behavioral inactivity of certain shock parameters, another unexpected result was the path taken by adjusting delays in 0.8-mA conditions, before stability was reached. Multiple 0.8-mA conditions were characterized by periods of predominant choice of 1 pellet that drove delays to maximums well above the ultimately obtained indifference point (see Results section and Figures 2 and 3). Following these maximum delays, choice tended to reverse so that the multiple pellets and shock option was predominantly chosen. Nothing approximating the magnitude of these peaks can be found in adjusting-delay data reported in Mazur (1987) or Mazur (1988). A crucial difference, though, is that the present study includes aversive consequences and Mazur's studies include only positive reinforcers (disregarding any aversiveness of delay).

The aversive component to the present study, and the notable peaks in adjusting delays, beg consideration that respondent processes might be meaningfully contributing to choice. It seems possible that, once shock delays are adjusted sufficiently upward, the shock no longer exerts any suppressive effect and the rat continues to avoid the shock in free-choice trials due to persisting effects of respondent aversion that took hold when the delay was brief. Inspection of some panels in Figures 2 and 3 reveals that, before some of the periods of increasing delays leading to peaks, delays were actually adjusted downward close to or at 4 s. Contact with intense 0.8-mA shock at such a brief delay may have been so aversive that the dual-valence lever became a conditioned aversive stimulus, taking on aversive properties of the shock (similar to how one instance of food poisoning can elicit nausea and avoidance with subsequent exposure to the offending food item). Furthermore, the relatively small delay-adjustment increment of 2 s may have resulted in excessive exposure to these shocks of short delay (e.g., 4, 6, 8, and 10 s), thereby strengthening respondent aversion. It is possible that the respondent relationship between the lever and shock was not sufficiently extinguished until a sufficient number of blocks elapsed – likely at blocks occurring near the peak delay. Considering the above, the prolonged periods of choosing 1 pellet predominantly over multiple pellets and shock may have been driven more by the length of time to achieve extinction of the respondent relationship and less by operant contingencies relating to reinforcer magnitude and shock delay. Because dual-valence-lever assignment was maintained for each rat throughout the entire experiment, respondent processes may have persisted, waxed and waned, and/or strengthened across conditions.

In addition to the potential for shock aversiveness to change over the course of the experiment due to respondent conditioning, habituation may also have occurred. In Figures 2 and 3, inspection of 0.8-mA conditions for Rats AD4 and AD5 reveals that replication conditions produced delays – stable adjusting delays *and* the overall range of delays – substantially lower than delays produced in the original conditions. With the importance of keeping motivational operations constant throughout this procedure – in order to isolate the effects of shock delay, intensity, and duration on choice – it is important to determine the long-term constancy of shock aversiveness.

Refinements to the Procedure

As the experiment progressed, it became necessary to add the trial-duration yoking requirement and to modify the stability criteria. Here, these refinements are discussed and additional recommendations are made for future experiments.

Before the yoking requirement was added, the procedure was liable to produce substantial differences in trial duration between the two consequences. Originally, a single-valence trial (a trial in which the single-valence lever was pressed) always lasted 60 s. However, it was possible for a dual-valence trial (a trial in which the dual-valence lever was pressed) to last more than 60 s if shock delay became sufficiently long to extend trial duration beyond 60 s. Prior to addition of the yoking requirement, this situation occurred only for Rats AD1 and AD2. The maximum delay reached for AD1 before addition of the yoking requirement was 116 s. This delay, plus the 15-s post consequence period, resulted in a dual-valence-trial duration of at least

131 s (plus the initial latency to respond). AD2's maximum delay before the yoking requirement was 166 s, which resulted in a dual-valence-trial duration of at least 181 s.

When trials for one consequence (1 pellet) last 1 min and trials for the other consequence (multiple pellets and shock) last 3 min, this creates *unintended* differences in reinforcement density between the trial types. Problematically, these differences serve to undermine the *intended* difference in reinforcement density. For instance, with AD2 it was intended that reinforcement density from dual-valence trials (2 pellets per unit time) would be double the density obtained from single-valence trials (1 pellet per unit time), or a ratio of 2:1. However, when dual-valence trials were extended to 3 min, reinforcement density changed to 2 pellets per 3 min, or 0.67 pellets per min. With density for single-valence trials still at 1 pellet per min, the ratio of reinforcement density between dual-valence and single-valence trials then became 0.67:1 – substantially lower than the intended 2:1 ratio. With a 0.67:1 ratio, the rat can maximize its reinforcement by choosing 1 pellet every minute, rather than 2 pellets every three minutes, *and* the rat will avoid more shocks. With this incentive to continue choosing the 1-pellet option, there is good reason to believe the rat would continue doing so, further increasing the delay to shock, thereby further increasing the problematic difference in reinforcement density and perpetuating a cycle. This situation is clearly a significant departure from the choice situation originally intended and was in need of correction.

The yoking requirement was added to correct this oversight in the original design of the procedure. By yoking all single-valence-trial durations to the last dual-valence-trial duration, the intended reinforcement-density ratio was closely preserved throughout the experiment. An analysis can be conducted to determine how close the yoking requirement came to maintaining the intended reinforcement-density ratio over a given session, versus the ratio in sessions prior to addition of the yoking requirement. For a given session, the number of pellets obtained from each trial type (single-valence or dual-valence trials) is summed to form session totals. These pellet totals are then, respectively, divided by the total time spent in each trial type (summed trial durations). Finally, the resulting rates of pellets per min are compared as a ratio of dual-valence reinforcement density to single-valence reinforcement density. For AD2's session prior to addition of the yoking requirement, single-valence responses produced 40 pellets over 40 min, or 1 pellet per min. Dual-valence responses produced 48 pellets over 70.1 min, or 0.685 pellets per min. This session's ratio of reinforcement density between dual-valence and single-valence trials was unacceptably 0.685:1 (the intended ratio is 2:1). For AD2's first session with the yoking requirement, single-valence responses produced 40 pellets over 126 min, or 0.317 pellets per min. Dual-valence responses produced 48 pellets over 75.8 min, or 0.633 pellets per min. This session's ratio of reinforcement density between dual-valence and single-valence trials was 0.633:0.317, or 1.99:1 – virtually identical to the intended ratio of 2:1.

Although the yoking requirement does a great job of preserving the intended reinforcement-density ratio within and across sessions, there are practical and conceptual considerations for modifying it in future iterations of the procedure. The yoking requirement has no known drawbacks when response latencies are reasonably short (on the order of a few seconds or less), but when latencies on dual-valence trials are unusually long (e.g., 10 min), this latency is included in the yoked trial duration. In sessions that included many dual-valence trials with long response latencies, the duration of these latencies gets artificially replicated across multiple single-valence trials throughout the session (due to yoking), and it was not unusual for the session to terminate prematurely at the maximum 5-hr limit.

Session durations of 5 hrs are potentially troublesome. First, a 5-hr session from one rat will disrupt the running schedule of other rats run in the same chamber. This changes the scheduled running time of these other rats, increasing their food-deprivation time beyond the intended 22 hrs or so. Second, for the rat whose session lasts 5 hrs, the duration of food deprivation for the upcoming day's session is decreased to approximately 18.5 hrs because feeding takes place later than it should. Less time without food will presumably reduce choice of 2 pellets relative to 1 pellet, especially when 2 pellets are followed by shock. Considering that 5-hr sessions typically occurred when the rat predominantly chose 1 pellet and delays were thereby driven up to the aforementioned "peaked reversals," a reduction in motivation for choosing 2 pellets may have contributed to these periods of predominant choice of 1 pellet.

Perhaps more problematically, inclusion of latencies into trial-duration yoking has the potential to create drastic differences between the post-response periods of single-valence trials and dual-valence trials. With the yoking requirement, no changes are imposed on duration of the post-response period in dual-valence trials. A press on the dual-valence lever always results in immediate delivery of multiple pellets, followed by the programmed shock delay for that block and the 15-s post-consequence period. However, a press on the single-valence lever results in immediate delivery of 1 pellet plus whatever remaining time is necessary to equal the trial duration of the previous dual-valence trial. If the previous dual-valence trial contained a 10-min latency, this 10-min period is injected into the remaining duration of the single-valence trial (plus any other time required to equal the previous dual-valence-trial duration). This unusually long period following delivery of 1 pellet, of no experimental events, can be conceptualized as a timeout period. When one response (producing multiple pellets and shock) is followed by a relatively brief post-response period on the order of 2 min and another response (producing 1 pellet) is followed by a relatively long post-response period on the order of 10 or 20 min, this represents a significant departure from the choice situation originally intended. The rat might wait 10 min before making a forced-dual-valence response (presumably driven by the aversiveness of the shock) but still choose this alternative in a free-choice trial because single-valence responses have recently resulted in a 10-min period without the opportunity to respond for food.

An alternative way to program trial-duration would be to use the default 60-s rule when shock delay is 44 s or less and to equate the post-response periods of all trials in a block when delay is 46 s or greater. When the programmed shock delay for a particular block is 44 s or less, the default trial duration would last 60 s and at least 15 s following the completion of the consequence, whichever occurred later, regardless of latency. When the programmed shock delay for a block is 46 s or greater, the post-response period would last the programmed delay plus 15 s – again, regardless of latency. In this way, the only differences in the consequence following either choice concern reinforcer magnitude and presence/absence of a shock – not duration. Any departures from the intended reinforcement density, due to long latencies, would result from the rat's behavior and *not* from imposition of the procedure.

Ultimately, how to arrange trial-duration yoking likely comes down to a tradeoff between preserving the intended reinforcement-density or preserving the intended choice contingencies, in addition to any considerations regarding 5-hr sessions. Future experiments with either approach to trial duration should clarify which concern is more important.

The need also arose to modify stability criteria. It became apparent that the original stability criteria could be met despite recent sessions in which one alternative was predominantly chosen – behavior not consistent with the concept of indifference. This outcome was possible because stability was determined by examining adjusting delays only; proportion of choice for each alternative was not included. In Figure 3, AD4's original 0.8-mA condition with shocks of 200-ms duration highlights what was liable to occur. The plotted delays on either side of the distinguishable peak are almost perfectly symmetrical. Because part of the stability criteria compares the mean delay across the last three sessions to the mean delay across the previous three sessions and stipulates that they cannot differ by more than 10%, this averaging process deemed AD4's data stable – even though the steep increases and decreases in delay on either side of the peak indicate predominant choice of one alternative. The other conditions labeled "Not stable" in Figure 3 also met the original stability criteria due this averaging process despite predominant choice of one alternative in three of the last six sessions ("predominant" as determined by the binomial distribution; see Method section).

To ensure that indifference was decided not only by examining mean delays but also by allocation of choice, criteria were added that focused on proportion of choices for each alternative over the last six sessions. At least five of these six sessions were required to meet a criterion of choice allocation: Of the 32 free-choice trials, the proportion of choices for one alternative could not exceed 22 or be below 10. Plus, there could be no monotonic trend in these six calculated proportions.

These additional criteria brought the stability criteria more in line with the concept of indifference, but they can be further improved. Part of the criteria examining adjusting delay specify that, when each half-session mean delay is calculated, neither the minimum nor the maximum half-session mean can occur within the last six half-sessions (the last three sessions). However, the entire period examined to determine indifference occurs over the last twelve half-sessions (last six sessions), and the indifference point is calculated as the mean delay over these last twelve half-sessions. If these last twelve half-sessions are the entire period to be deemed stable, the criteria should be modified to specify that neither the minimum nor maximum half-session mean delay can occur over the last *twelve* half-sessions, rather than just the last six.

The prohibition against a monotonic trend in the proportion of free-choice trials for either alternative over the last six sessions should also be amended. Such a six-session trend was never observed (in an otherwise stable period) in the present study. However, a five-session monotonic trend was observed. Like a six-session trend, conceptually a five-session trend is unacceptable and incompatible with indifference. The monotonic-trend criteria should be changed to prohibit such a trend over at least five consecutive sessions out of the last six. Limiting the number of sessions with a monotonic trend to four still may not interfere with identification of indifference points.

Lastly, no recordings were made of head pokes into the food trough, but these should be recorded in future iterations of the procedure to ensure that pellets are claimed before shocks are administered. During casual visual observation of some trials, it appeared that rats may have sometimes assumed a “frozen” stance after a dual-valence lever press, perhaps as a pre-potent response before shock administration, and that pellets may have been claimed after shock was received. Recording the time point of head pokes relative to lever presses and shocks should serve to verify that pellets were infrequently claimed after the shock.

This procedure will likely undergo further refinements over time. Other changes to the procedure might include different delay-adjustment increments (e.g., 6 s rather than 2 s) or the addition of exteroceptive stimuli such as cue lights, houselight changes, and tones. Perhaps utilizing optimal parameters and procedural arrangements will result in more reliable identification of stable adjusting delay across replications or with fewer swings in choice.

Conceptual Considerations

The present study's results are consistent with what would be expected to occur based on the punishment literature (see Introduction section), but at this point, it is unclear how these results fit with the existing delay-discounting literature. This procedure was developed with the aim of reproducing some of the choice situations experienced by humans in which one choice is called "impulsive," "maladaptive," or "socially undesirable." The present procedure's analogue for this undesirable option *might* be the large immediate reinforcer plus a delayed aversive event. But the rationale for deeming this choice "impulsive" seems to be less clear than the rationale for classifying the small immediate reinforcer impulsive in the traditional delay-discounting model. This is because in the traditional model a subject can maximize reinforcement by repeatedly choosing the larger delayed option. Failing to do so by choosing the small immediate option is viewed – objectively – as suboptimal choice (less reinforcement is obtained). A conceptual framework for the current procedure is still nascent, and at least so far, there is no objective conceptual basis for classifying the large reinforcer and delayed aversive event option as impulsive – other than that this option produces an aversive event that the subject might otherwise avoid. In this light, and for the present time, it may make more sense to conceptualize this option simply as maladaptive or, even more conservatively, as an analogue for socially undesirable choices.

Future studies with this procedure should explore some of the same manipulations and correlations that have been examined with the traditional delay-discounting model. Examples include the administration of drugs that have been shown to alter the proportion of impulsive choices made in rats (e.g., Evenden & Ryan, 1996 with d-amphetamine) or studies that have found correlations between level of impulsivity and a variety of outcomes in humans, including drug abuse, gambling, and obesity (see Odum, 2011). Whether results turn out to be consistent or inconsistent with the traditional delay-discounting model, it should be telling either way. Confirmation of these relations may indicate that this procedure is measuring a similar behavioral process as the traditional procedure and that one option really *should* be deemed impulsive or maladaptive. After all, there may be multiple different choice situations that can justifiably be labeled impulsive. Disconfirmation may indicate that this procedure is measuring something different altogether. Regardless of how this procedure fits conceptually with popular attempts of operationalizing impulsivity, there should be applied significance in identifying ways of decreasing choice of the larger reinforcer and delayed aversive event option.

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