Published in final edited form as:

Behav Processes. 2011 May ; 87(1): 100–105. doi:10.1016/j.beproc.2011.01.010.

The Role of Context in Risky Choice

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Abstract

Human choice behavior was assessed in a concurrent-chains schedule, where two equal initial links (IL) each led to a distinct terminal-link (TL). One TL was associated with a fixed ratio schedule of reinforcement, while the other was associated with a bi-valued mixed ratio schedule of reinforcement, whose arithmetic mean equaled the Fixed TL schedule. The fixed component (FR50; FR25; FR5) was arranged to be equal to the alternative mixed component in each condition (FR1/99; FR1/49; FR1/9), and choice behavior was measured by proportion of responses to each IL. In addition, the IL duration varied across conditions (VI 30s; VI 15s; FI 1s). Preference for the mixed option was observed with longer durations (e.g. when IL = VI 30s and TL = FR1/99). Participants were relatively indifferent in other conditions, though the results suggested a monotonic increase in preference as either durations or programmed efforts increased. It is concluded that both choice and the conditioned reinforcement value of the mixed option are contextually based, so that the value of a stimulus correlated with an immediate reward (i.e. FR 1) is enhanced the greater the temporal context in which the FR1 is embedded.

Keywords

choice behavior; reinforcement; preference; delay-reduction theory; concurrent-chains; context

Risky-choice behavior is of great interest to researchers in many fields most notably behavioral psychology and economics, where a choice is made between two options, one certain and the other uncertain. Much work has been done with humans on decision-making under uncertainty, for example Prospect-Theory (Kahnemann & Tversky, 1979) while behavioral studies have addressed this issue with non-human subjects (Fantino, 1967; Sherman & Thomas, 1968; Rider, 1983). While there is no standard definition, the term “risky choice” in the current experiment is empirically defined as a choice between two options, one fixed and the other variable (in terms of the reinforcement schedule parameters, not reinforcer amount). Results from behavioral studies involving human choice between fixed vs. variable options have differed in their results, where there is some evidence that humans prefer the variable option (Locey, Pietras, & Hackenberg, 2009), the fixed option (Kohn, Kohn & Staddon, 1992) and also evidence indicating that they are indifferent (Weiner, 1966). In particular, the immediacy by which a variable schedule will provide reinforcers seems to be an important determinant of choice (Locey et al, 2009). It is hypothesized that the reinforcing value of a stimulus (when paired with an immediate reward) is relative to its context; meaning that the value of a stimulus (as measured by

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choice) depends not only on its correlation with immediate reward, but also on its relative immediacy or discriminability from surrounding stimuli and their contingencies.

Behavioral experiments have studied risky choice by offering the choice between two routes to reinforcement, one fixed and the other variable, in terms of time-based delay (Cicerone, 1976; Locey, Pietras, & Hackenberg, 2009) or response requirement (Fantino, 1967; Sherman & Thomas, 1968; Rider, 1983). Results from non-human studies have consistently found strong preference for the “variable” outcome, when overall reinforcement rate was held constant between the two outcomes.

It has been suggested that a major controlling variable in preference for the variable option is the presence of short-delay reinforcers, as discussed by Locey et al (2009). However, the surrounding context is of great import in determining the potency of the stimulus paired with short-delay reinforcement, and even the term “short-delay” can be said to be relative to the surrounding temporal context, where the term “context” is used to refer to the surrounding program values.

Research on choice between fixed vs. variable delay/effort in non-humans has determined fairly conclusively that the variable option is preferred to an equivalent fixed schedule of reinforcement. There is a large body of research on choice behavior using the concurrent-chains procedure (see Fantino & Logan, 1979), where preference for different alternatives to reward can be assessed. Two major contextual variables in a concurrent-chains schedule are duration of the initial links, and the schedule values of the terminal links. One early study found that when choosing between a fixed interval and a variable interval schedule with the same mean value, pigeons prefer the terminal-link option leading to the variable schedule (Herrnstein, 1964).

Fantino (1967) utilized a concurrent-chains schedule to determine choice between a fixed ratio (FR) vs. a “mixed ratio” (MR) requirement using pigeons. A FR schedule is a schedule of intermittent reinforcement providing reinforcement upon completion of a fixed number of responses. In this case, the MR consisted of a randomly alternating bi-valued ratio schedule, where no exteroceptive stimuli indicate which ratio value is in effect. The terminal links were programmed as either a FR schedule or a MR schedule of reinforcement. Upon completion of food intake the initial links resumed, beginning the next trial. Choice behavior is measured by the proportion of responses to each initial-link stimulus, where greater responding toward one stimulus indicates preference (and therefore greater conditioned reinforcing value) for its corresponding terminal-link.

Fantino (1967) exposed pigeons to a concurrent-chains schedule where one terminal-link was a MR schedule of values 1/99, 10/90, or 25/75, and the other terminal-link was the arithmetic mean, FR 50. In all three conditions, birds preferred the initial-link associated with the MR terminal-link. This demonstrates that the MR stimulus had a greater conditioned reinforcing value. In fact the 1/99 MR was preferred even when the FR was as low as FR 20. The current study is similar to Fantino (1967) with the use of the concurrent-chains design and attempts to clarify how the conditioned reinforcement value of a stimulus paired with immediate reinforcement (i.e. FR1) in humans is a function of context, by manipulating initial-link and terminal-link values.

Research on choice between fixed and variable outcomes has also involved temporal delay of reward. For example, one experiment had rats choose in a Y-maze, between a constant delay of 15s to food, and a delay of either 0s or 30s (Pubols, 1962). Rats strongly preferred the arm associated with the variable delay to reinforcement. A study involving pigeons sought to determine whether constant or variable delay to food reward was preferred (Cicerone, 1976). Birds consistently preferred the variable delays, especially when the range

of possible mixed values was greater (e.g. 2/14s delay rather than 6/10s). One argument for this is that variable schedules inevitably contain shorter-delay (or shorter-effort) reinforcers than the equivalent fixed schedules.

Additional support for this conclusion comes from Sherman & Thomas (1968), where a multiple schedule was arranged consisting of 9 fixed-ratios, each associated with a different stimulus leading to food reward. Pigeons could complete a given FR within the multiple schedule, or by pecking a 2nd key could switch to a variable-ratio (VR) schedule consisting of the same 9 ratios. Results revealed consistent switching behavior toward the VR schedule, although this did not maximize rate of reinforcement. However, when single-response reward opportunities were removed on the variable schedule, subjects decreased their switching to this schedule.

In one of the earliest human studies (Weiner, 1966), participants were offered a choice to switch from a FR to an equal VR schedule (or vice versa) of reinforcement where participants watched videos. Results did not show preferential switching behavior from either schedule to the other, suggesting that participants were indifferent to fixed vs. variable ratio schedules. A more recent experiment by Locey et al (2009) studied how human participants made choices for delayed access to video clips. In the initial experiment all participants preferred the variable-delay schedule vs. the fixed-delay schedule. In a second experiment, two alternatives were again made available, this time each associated with a variable-time schedule of delay, however one of the alternatives was programmed to have a higher probability of short-delay reinforcers. As was hypothesized, participants preferred the alternative with higher probability of short-delay reinforcers even though reinforcement rate was equated in both alternatives. This finding is consistent with the conclusion that short-delay (or short-effort) reinforcement is a potent contributor to choice in these tasks.

The current study assessed choice behavior for mixed vs. fixed ratio schedules in the context of a concurrent-chains schedule with humans. The two contextual variables manipulated were a) duration of initial-link and b) absolute size of the terminal-link ratio requirement. It was hypothesized that the longer the initial or terminal links, the more salient the FR1 outcome, and the more likely preference would occur for the mixed outcome.

Method

Participants

496 undergraduates from the University of California, San Diego participated in the experiment. Each participated in one experimental session which consisted of a 40-trial choice task. Compensation for participating in the experiment consisted of course credit in undergraduate psychology courses.

Apparatus

The experimental chamber was a sealed room with four isolated computer stations. There were no windows or decorative items on the walls. One-inch thick wood panels partitioned the four computer stations. A standard computer monitor, keyboard, and a mouse were in front of the participants. Most incidental stimuli were removed from the room.

Procedure

Participants were led individually into the experimental chamber, contingent on relinquishing: backpacks, cell phones, food or any other distracting stimuli. Experimenters instructed participants to refrain from speaking to others during the experiment and

experimenters periodically patrolled to maintain internal validity. Instructions given to participants were as follows:

The goal of this task is to finish as quickly as you can. Use the mouse to click on the buttons. In the center of the screen will be a progress bar, which represents the time remaining in the task.

You may click however you like, but it is your job to determine how to use the buttons to reduce the progress bar. Once the progress bar is empty, the task will be complete and you will be notified.

The experiment made use of concurrent-chains schedules of reinforcement, consisting of two equal, independent variable-interval initial links each of which produced a terminal-link stimulus corresponding to a ratio schedule of reinforcement. At the beginning of each trial the two identical white keys at the top of the screen were illuminated. Participants responded freely to either initial link stimulus, where a change over delay of 2s for initial-link responding was programmed. Upon completion of the interval schedule, a response to either initial-link key produced the terminal-link stimulus corresponding to that option, along with a ratio schedule of reinforcement. A pictorial representation of the concurrent-chains schedule is available in Figure 1. One terminal-link key was programmed with a bi-valued Mixed (FR) schedule and the other terminal-link key was programmed with a constant FR schedule where the means of the two schedules were equal. The location of the terminal-links was randomly assigned with a 0.5 probability across subjects. A trial was completed when the response contingency in the terminal-link was fulfilled, followed by two events: (1) illumination was removed from current key; (2) The area around the progress bar flashed yellow and the progress bar decreased. The inter-trial interval was 2s.. Regardless of which condition the participant experienced, 40 trials were required to complete the experiment and obtain compensation. There were seven conditions in the experiment: (1) *VI30sMean50*: initial link of Variable Interval (VI) 30 second where one terminal-link consisted of a Fixed Ratio 50 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR99 (n=70); (2) *VI30sMean25*: initial link of VI 30s where one terminal-link consisted of a FR 25 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR49 (n=69); (3) *VI30sMean5*: initial link of VI 30s where one terminal-link consisted of a FR 5 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR9 (n=69); (4) *VII15sMean50*: initial link of VI 15s where one terminal-link consisted of a FR 50 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR99 (n=70); (5) *FII1sMean50*: initial link of FI 1s where one terminal-link consisted of a FR 50 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR99 (n=70); (6) *FII1sMean25*: initial link of FI 1s where one terminal-link consisted of a FR 25 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR49 (n=71); (7) *FII1sMean5*: initial link of FI 1s where one terminal-link consisted of a FR 5 while the other was a bi-valued Mixed Ratio schedule of FR1 and FR9 (n=77); Table 1 also indicates the interval and ratio values for each condition.

Results

Choice was measured as the proportion of responding on the initial-link key corresponding to the mixed option compared to overall initial-link responses. For example, if during the initial link, 200 responses were made to the initial-link key corresponding to the mixed schedule and 100 responses were made to the initial-link key corresponding to the constant schedule, then the choice proportion for the mixed ratio key would be $200/(200+100)=0.67$. The 40 trials were subsequently divided into eight-five trial blocks in which the means of the choice proportions of the five trials, within each block, were taken.

A factorial design was implemented in the analysis of our two dependent variables: (1) *Last 5* - Proportion of initial link responses for the mixed fixed ratio schedule over the last five trials, and (2) *Last 25* - Proportion of initial link responses for the mixed fixed ratio schedule over the last 25 trials. Since analysis results were strikingly similar for both of the above dependent variables, results were primarily presented for *Last 5*, and only for *Last 25* where different. Means and standard errors are given in Tables 2 and 3.

Results of dependent variable *Last 5* were contrasted with indifference. Thus, a significant outcome indicates preference for the mixed schedule. Of the seven conditions studied, four indicated that participants significantly prefer the mixed outcome: *VI30sMean50* [$t(69)=3.81$, $p<0.01$], *VI30sMean25* [$t(68)=2.01$, $p<0.05$], *VI15sMean50* [$t(69)=2.30$, $p<0.05$], and *FII1sMean25* [$t(70)=2.04$, $p<0.05$]. Results from *VI30sMean5*, *FII1sMean50*, and *FII1sMean5* conditions were found to be non-significant, indicating that participants were indifferent in these conditions.

The effect of holding the initial links constant while varying terminal link values was analyzed. A comparative analysis of data for dependent variable *Last 5* given independent variables *VI30sMean50*, *VI30sMean25* and *VI30sMean5* was conducted using a one-way ANOVA, which was found to be non-significant [$F(2,205)=2.06$, $p>0.05$]. A different outcome was observed for dependent variable *Last 25*, where a one way ANOVA indicated a significant main effect [$F(2,205)=3.12$, $p<0.05$]. Furthermore, a Post Hoc Tukey HSD Test revealed statistical significance between the means of *Last 25* given *VI30sMean50* and *VI30sMean5* with $p<0.05$, indicating significantly greater preference for the mixed option in the former. Graphical representations of choice proportions in *VI30sMean50*, *VI30sMean25* and *VI30sMean5* conditions can be seen in Figure 2.

When initial link was *FII1s*, analysis of dependent variable *Last 5* using a one way ANOVA show a non-significant main effect [$F(2,215)=1.00$, $p>0.05$]. Graphical representations of choice proportions in conditions *FII1sMean50*, *FII1sMean25* and *FII1sMean5* can be seen in Figure 3.

The effect of varying the initial link while holding the terminal link constant was analyzed. Data for dependent variable *Last 5* for conditions *VI30sMean50*, *VI15sMean50* and *FII1sMean50* was analyzed using a one-way ANOVA, where a significant main effect was found [$F(2,207)=3.36$, $p<0.05$]. Post Hoc Tukey HSD tests revealed that participants in *VI30sMean50* condition preferred the mixed option to a greater extent than those in the *FII1sMean50* condition ($p<0.05$), but not between the other conditions. Graphical representations of choice proportions in *VI30sMean50*, *VI15sMean50* and *FII1sMean50* can be seen in Figure 4.

Discussion

In the current experiment participants were given the choice between two concurrently available schedules with identical mean rates of reinforcement. Several non-human experiments have shown significant preference for the variable alternative over the fixed alternative when the two are equated (Fantino, 1967, Sherman & Thomas, 1968; Cicerone, 1976; Rider, 1983). In generalizing the results to humans, the experiment sought to discover what contingencies facilitate these patterns in choice behavior.

A schedule was considered to produce preference for the mixed alternative if dependent variable *Last 5* differed from indifference with $p<0.05$. As the results indicate, *Last 5* in conditions *VI30sMean50*, *VI30sMean25*, *VI15sMean50*, and *FII1sMean25* all indicated preference for the mixed option. Although not all conditions were shown to produce preference for the mixed schedule, one interesting thing to note in Figures 2, 3, and 4 is the

general increasing trend of preference for the mixed alternative toward the end of the session for all conditions. It is possible that increasing the number of trials per session could reveal more pronounced preference over time. Another explanation for the increase in preference over time across groups is that fatigue may play a role in the potency of immediate reward (FR1) in the mixed schedule - fatigue may be said to increase across trials, thus from an 'effort-saving' point of view the FR1 can potentially increase in potency.

As seen in Figure 2, given long initial-link duration (VI30s), manipulation of the number of mean contingent responses to reinforcement directly affects the proportion of responses toward the initial link associated with the mixed alternative. In *VI30sMean5*, *VI30sMean25* and *VI30sMean50* conditions, the proportion of responses for the mixed schedule begins at indifference and increases to a 2:1 ratio as the contingencies of the terminal link increase in response requirement across conditions. It is speculated that as the mean contingent number of responses increases, the FR1 component of the mixed schedule becomes more salient/discriminable, and its corresponding stimulus increases in conditioned reinforcing value. For instance, in *VI30sMean5* at any given time responding to the fixed ratio schedule only requires five contingent responses, while responding to the mixed ratio schedule requires either one or nine contingent responses to reinforcement; the advantage of the immediate reward (FR1) is only four fewer contingent responses. This conclusion is supported by the fact that indifference was observed in *VI30sMean5* and *FII5Mean5* participants. Greatest preference was observed in *VI30sMean50*, where the FR1 has 49 fewer contingent responses than the FR50, making the FR1 far more salient/discriminable in this condition.

For groups with the greatest terminal-link response requirement (i.e. FR50 vs. FR1/99), initial-link duration had a significant effect on the proportion of responses to the initial-link key leading to the mixed schedule. Participants in the *VI30sMean50* condition preferred the mixed alternative to a significantly greater extent than those in the *FII5Mean50* condition. This result stands in contrast to findings which showed that when you increase initial-link delay in a concurrent-chains schedule, preference for the shorter terminal link decreases (Goldshmidt & Fantino, 2004). However, the same experiment showed that preference for the variable schedule increased as mean terminal-link values increased; a finding which is consistent with the results from the present study. On a related note, self-control research has shown that when the choice between a smaller-sooner reward and a larger-delayed reward is moved further in time, choice will favor the latter (Navarick & Fantino, 1976). However, the current study did not employ differential outcomes for choosing either alternative; both terminal-link options led to equal reinforcement (decrease in progress-bar).

Whereas previous human research has varied as to whether humans prefer variable vs. fixed options (Weiner, 1966; Kohn et al, 1992; Locey et al, 2009), the current findings show preference for the mixed option with human participants in the majority of conditions and did not show preference for the fixed option. However, this preference was shown to depend both on the contingencies themselves (MR vs. FR) as well as the context in which the schedules occurred. In particular, there must be sufficient contrast between the fixed and mixed options so that the FR1 component of the mixed option is sufficiently salient. These results are consistent with Locey et al. (2009) as well as studies with non-human participants (see Fantino, Navarro, and O'Daly, 2005 for a review) and also support the growing emphasis on the role of contextual variables in choice (e.g. Fantino, 2001; O'Daly, Meyer, and Fantino, 2005).

Unlike most experiments which investigate the etiologies of risky decision-making, the current experiment employed a time and effort based negative reinforcement as opposed to monetary reinforcement. There are two rationales for the choice of reinforcer: (1) By utilizing negative reinforcement which is in this case the reduction of effort, the results are

more generalizable to risky choices concerning temporal variables; and (2) We contend that whereas monetary reinforcers are compromised by wealth effects - the value of a monetary reward may be influenced by a participant's wealth - effort-based reinforcers are not. The nature of the reinforcer is an issue discussed by Locey et al (2009), which questions the usage of non-consumable reinforcers such as 'points' or hypothetical money, versus consumable ones such as food or access to video clips. Although the current study utilizes reduction of effort or time as the reinforcer, it can certainly be considered a "consumable" one being that participants "consume as they earn". This is perhaps an important influence in the agreement of our results with those of Locey et al (2009) in human preference for the variable option.

In the current study, longer initial-link duration and larger terminal-link response contingencies were associated with greater preference for the mixed outcome. The condition which contained a long initial link plus high response effort in terminal link (*VI30sMean50*) led to the highest preference for the mixed alternative. In the *VI30sMean50* condition, immediate reward (FR1) in the mixed schedule was associated with the greatest reduction in effort from other schedule parameters, so that stimulus can be said to be highest in salience/discriminability. Indeed, compared to all other conditions *VI30sMean50* produced the highest preference for the mixed option.

Preference for the mixed option increased monotonically as absolute response effort increased across conditions (that is, from FR1/9 to FR1/49 to FR1/99). The stimulus associated with immediate reward may be more salient/discriminable when the alternative terminal-link schedule provides a significantly longer delay/effort in comparison (this refers to FR1 vs FR 50, as opposed to FR1 vs FR5). For conditions where the initial link was VI 30s, a monotonic increase in preference was observed for the mixed option across conditions (Figure 2). This result is in agreement with nonhuman studies which found that preference for variability increased as terminal-link schedule values increased (McSweeney, Kowal, & Murphy, 2003; Goldshmidt & Fantino, 2004).

Delay-Reduction Theory (DRT) (Fantino, 1969) states that choice is a function of a reduction in delay to reinforcement between the initial link and terminal link. In light of the present study, this key tenet of DRT might be extended to say that choice is a function of reduction in *effort* between initial and terminal link. Even though terminal-link options were equal on average and neither option maximized overall reward, the value of the stimulus associated with immediate reward was shown to vary as other parameters vary. Participants' choice of the mixed option was greatest when initial and terminal-link schedule values were greatest (i.e. *VI30sMean50*), thus in this condition the immediate reward (FR1) in the mixed schedule offered the greatest reduction of effort compared to other conditions. Results indicated indifference in *VI30sMean5* and *F11sMean5* conditions, where the salience/discriminability of immediate reward could be said to be lower. In these two conditions the FR1 is associated with very little reduction of effort compared to other schedule values. While results can be interpreted alongside qualitative predictions made by DRT, it is a delay-based model which makes predictions based on VI terminal links, whereas ratio schedules comprised the current experimental setup. While preference for short delays is well described by hyperbolic discounting models (Mazur, 1984), the model is also inapplicable with ratios. It was "designed for single-response choice situations, and attempts to apply this equation to results from concurrent-chain procedures are bound to fail" (Mazur, 1984, p. 435). Also, since terminal link options had equal average values, DRT and other quantitative models predict indifference between the two options across trials (Fantino, 1969; Mazur 1984).

The argument has been raised that humans are risk averse in single trial vs. maximizers in multiple-trial gambles (Keren & Wagenaar, 1987). However, these researchers gave explicitly described information to subjects - recent research suggests that humans behave differently when choices are made based on explicitly described information compared to experience-based decision making (Hertwig, Barron, Webber, and Erev, 2004). In the current study human participants were not given information regarding schedule values, thus their decision making process was based on experience. Moreover, in the current study neither option could be considered more optimal, given that terminal-link values were equal on average.

Overall the findings lend support to the conclusion that the conditioned reinforcement value of a stimulus paired with immediate reward is a function of other stimuli present in the choice environment which are mediated through the contextual manipulation of delay/effort. Thus, the context in which immediate reinforcement (FR1) occurs is influential in determining choice. The role of context has been emphasized in autoshaping and conditioned suppression procedures as well as choice behavior (for a discussion, see Fantino, 2001). The present results suggest that contextual variables influence whether or not humans prefer mixed to fixed outcomes: when the most immediately rewarding outcome (in the mixed option) is embedded in a relatively more impoverished context, choice for the mixed option will be evident. This conclusion is consistent with qualitative versions of delay reduction and hyperbolic value added models of choice (e.g., Mazur, 2001).

References

- Cicerone RA. Preference for mixed versus constant delay of reinforcement. *Journal of the Experimental Analysis of Behavior*. 1976; 25(2):257–261. [PubMed: 16811909]
- Fantino E. Preference for mixed- versus fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior*. 1967; 10:35–43. [PubMed: 16811303]
- Fantino E. Choice and rate of reinforcement. *Journal of the Experimental Analysis of Behavior*. 1969; 12:723–730. [PubMed: 16811396]
- Fantino, E. Conditioned reinforcement: Choice and information. In: Honig, WK.; Staddon, JER., editors. *Handbook of operant behavior*. Prentice-Hall; Englewood Cliffs, NJ: 1977. p. 313-339.
- Fantino E. Context: A central concept. *Behavioural Processes. Special Issue: The longer view: 20th century quantitative analyses of behavior*. 2001; 54:95–110.
- Fantino E, Navarro A, ODaly M. The science of decision-making: Behaviors related to gambling. *International Gambling Studies*. 2005; 5(2):169–186.
- Goldshmidt J, E. Fantino E. Economic context and pigeons' risk-taking: an integrative approach. *Behavioural Processes*. 2004; 65:133–154. [PubMed: 15222962]
- Green L, Fristoe N, Myerson J. Temporal discounting and preference reversals in choice between delayed outcomes. *Psychonomic Bulletin & Review*. 1994; 1(3):383–389.
- Herrnstein RJ. Aperiodicity as a factor in choice. *Journal of the Experimental Analysis of Behavior*. 1964; 7:179–182. [PubMed: 14130099]
- Hertwig R, Barron G, Weber E, Erev I. Decisions from experience and the effect of rare events in risky choice. *Psychological Science*. 2004; 15:534–539. [PubMed: 15270998]
- Keller, FS.; Schoenfeld, WN. *Principles of psychology*. Appleton-Century-Crofts; New York: 1950.
- Kohn A, Kohn W, Staddon J. Preference for constant duration delays and constant sized rewards in human subjects. *Behavioral Processes*. 1992; 26:125–142.
- Locey ML, Pietras CJ, Hackenberg TD. Human risky choice: Delay sensitivity depends on reinforcer type. *Journal of Experimental Psychology: Animal Behavior Processes*. 2009; 35(1):15–22. [PubMed: 19159159]
- Mazur J. Tests of an Equivalence Rule for Fixed and Variable Reinforcer Delays. *Journal of Experimental Psychology: Animal Behavior Processes*. 1984; 10:426–436.

- Mazur J. Hyperbolic value addition and general models of animal choice. *Psychological Review*. 2001; 108:96–112. [PubMed: 11212635]
- McSweeney, Kowal; Murphy. The effect of rate of reinforcement and time in session on preference for variability. *Learning & Behavior*. 2003; 31(6):225–241. [PubMed: 14577547]
- Navarick D, Fantino E. Self-control and general models of choice. *Journal of Experimental Psychology: Animal Behavior Processes*. 1976; 2:75–87.
- ODaly M, Meyer S, Fantino E. Value of conditioned reinforcers as a function of temporal context. *Learning and Motivation*. 2005; 36:42–59.
- Rachlin H, Green L. Commitment, choice and self-control. *Journal of the Experimental Analysis of Behavior*. 1972; 17(1):15–22. [PubMed: 16811561]
- Rider DP. Choice for aperiodic versus periodic ratio schedules: A comparison of concurrent and concurrent-chains procedures. *Journal of the Experimental Analysis of Behavior*. 1983; 40(3):225–237. [PubMed: 16812346]
- Sherman JA, Thomas JR. Some factors controlling preference between fixed-ratio and variable-ratio schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*. 1968; 11(6):689–702. [PubMed: 16811316]
- Weiner H. Preference and switching under ratio contingencies with humans. *Psychological Reports*. 1966; 18:239–246. [PubMed: 5908485]

Figure 1.
A diagram representing the concurrent chains procedure used for the experiment.

Figure 2. The proportion of responses to the initial link associated with the mixed ratio terminal link across the last 25 trials, holding the initial link constant at VI30s and varying the terminal link values.

Figure 3.

The proportion of responses to the initial link associated with the mixed ratio terminal link across the last 25 trials, holding the initial link constant at FI1s and varying the terminal link values.

Figure 4. The proportion of responses to the initial link associated with the mixed ratio terminal link across the last 25 trials, varying the initial link duration and holding the terminal links constant at FR50 while the mixed option was FR1 and FR99.

Table 1

List of Experimental Conditions

Condition	Initial Link	Fixed option	Mixed option
VI30sMean50	VI 30s	FR 50	Mixed FR 1 FR 99
VI30sMean25	VI 30s	FR 25	Mixed FR 1 FR 49
VI30sMean5	VI 30s	FR 5	Mixed FR 1 FR 9
VI15sMean50	VI 15s	FR 50	Mixed FR 1 FR 99
FI1sMean50	FI 1s	FR 50	Mixed FR 1 FR 99
FI1sMean25	FI 1s	FR 25	Mixed FR 1 FR 9
FI1sMean5	FI 1s	FR 5	Mixed FR 1 FR 9

Table 2

Mean proportion of Initial-Link responses toward the Mixed schedule of *Last5* and *Last 25* given *VI30sMean50*, *VI30sMean25* and *VI30sMean5*.

VI 30s Initial Links			
Mixed TL		Trials 36–40	Trials 16–40
1/99	Mean	0.645	0.612
	N	70	70
	s.e.	0.038	0.03
1/49	Mean	0.572	0.546
	N	69	69
	s.e.	0.036	0.025
1/9	Mean	0.545	0.523
	N	69	69
	s.e.	0.034	0.023

Table 3

Mean proportion of Initial-Link responses toward the Mixed schedule of *Last5* and *Last 25* given *FII*sMean50, *FII*sMean25, *FII*sMean5 and *VI*15sMean50.

IL value	Mixed TL		Trials 36–40	Trials 16–40
FI 1s	1/99	Mean	0.506	0.477
		N	70	70
		s.e.	0.039	0.029
	1/49	Mean	0.576	0.532
		N	71	71
		s.e.	0.037	0.028
	1/9	Mean	0.514	0.474
		N	77	77
		s.e.	0.038	0.028
VI 15s	1/99	Mean	0.587	0.544
		N	70	70
		s.e.	0.038	0.029