Behavioral Economic Analyses of Reinforcement in the Experimental Analysis of Human Behavior

by

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Abstract

Title: Behavioral-Economic Analyses of Reinforcement in the Experimental Analysis of Human Behavior

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Evidence-based advances in the field of Behavior Analysis have begun to demonstrate ways in which behavioral-economic methods may provide a coherent understanding of responding and consumption of reinforcers. This dissertation extends the literature to behavioral-economic analyses of programmed video reinforcement in the experimental analysis of human behavior (EAHB), as well as a novel reinforcement arrangement for reduction of in-session duration. Three aims served to guide this study: (a) demonstrate the feasibility and utility of behavioral-economic assessments of reinforcement in EAHB, (b) extend economic predictions of unit price to video reinforcement arrangements, and (c) evaluate the utility of an exponential model of demand for indexing essential value of reinforcement in EAHB. Across three experiments, investigators first arranged for analyses of responding and consumption under single-schedule arrangements for each
reinforcer; a second concurrent-schedules arrangements for both reinforcers followed. Finally, three economic predictions of unit price were assessed under choice arrangements for access to video alone. Investigators analyzed data using an exponential model of demand to calculate essential value of reinforcers across experiments. Findings from Experiments 1 and 2 supported the utility of applying behavioral-economic methods within EAHB contexts, demonstrating adherence to established models of demand and work output (i.e., total responding). Findings from Experiment 3 supported economic predictions of unit price, with some noted deviations. Across all experiments, the exponential model of demand provided a good fit to obtained data.
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Behavioral economics
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Dedication

I would like to dedicate this dissertation to all of the family and friends who have stood by me, provided endless encouragement, and tolerated so much craziness throughout this long, long process.
Introduction

Behavior Analytic researchers have begun to explore the utility of integrating principles, procedures, and analyses common to this field with those developed within the relatively new area of inquiry known as Behavioral Economics (Bickel & Madden, 1999; Delmendo, Borrero, Beauchamp, & Francisco, 2009; Hursh & Roma, 2014; Madden, Bickel, & Jacobs, 2000). Recent developments from behavioral economics toward establishing demand profiles and analyzing demand for, or consumption of, commodities across unit price values have advanced behavior analysts’ ability to quantify the value of reinforcers in individual organisms. This dissertation aims to extend behavioral-economic analyses of demand within the experimental analysis of human behavior (EAHB) to the methodological practice of providing contingent audio-visual (i.e., video) reinforcement, as well as a novel reinforcement contingency of reduced experimental session duration.

The primary researcher conducted three related experiments designed to 1) establish and analyze demand curves for each reinforcer under single-schedule reinforcement arrangements, 2) analyze demand for these reinforcers under concurrent-schedules arrangements, and 3) evaluate economic predictions of unit
price for video alone under choice arrangements varying response requirement and duration of video access. Additional analyses were conducted utilizing an exponential model of demand, originally developed by Hursh and Silberberg (2008), and subsequently extended by Hursh (2014a, 2014b) and Hursh and Roma (2015). Hursh and colleagues designed the exponential model of demand to quantify the essential value of reinforcers according to changes in elasticity of demand across unit price values.

Although a number of well-established methods and measures exist to empirically evaluate the efficacy of such reinforcer arrangements (Bickel, Marsch, & Carroll, 2000; Hursh & Silberberg, 2008; Madden, Smethells, Ewan, & Hursh, 2007; Nevin 1992; Nevin & Grace, 2000; Silberberg, Warren-Boulton, & Asano, 1987), there exists a dearth of evidence directly assessing the effectiveness of these reinforcers at maintaining or strengthening behavior. Additionally, conditions that may alter the efficacy of these reinforcement arrangements with human volunteers have not been systematically investigated. This lack of empirically validated reinforcement arrangements represents a critical limitation within EAHB literature. Moreover, reinforcement procedures employed by investigators in EAHB may have unforeseen effects on behavior (Buskist & Johnston, 1988). Further identification and evaluation of reinforcers and the conditions contributing to or
limiting their reinforcing efficacy is necessary to improve understanding of responding in EAHB contexts.

In this dissertation, I first provide a comparison of traditional and behavioral-economic measures of reinforcer efficacy and parameters of reinforcement, followed by an assessment of reinforcement in EAHB. I then describe a study consisting of three related experiments, employing behavioral-economic analyses aimed at extending our current understanding of reinforcement in EAHB. Included is a description of general methods employed across all three experiments, as well as specific methods and results of each of the three experiments. I conclude with a discussion of conclusions based on findings, and future directions for behavioral-economic assessments of reinforcement in EAHB and other behavior-analytic contexts.

**Behavioral Economics**

Hursh, Madden, Spiga, DeLeon, and Francisco (2013) described behavioral economics as the application of microeconomic theory to the study of consumption in individuals, and the extension of operant conditioning to demand for commodities or reinforcers. Reinforcement arrangements within EAHB typically incorporate contrived reinforcers such as points for which participants are instructed to respond (Doolan & Bizo, 2013; Jessel & Borrero, 2014). Investigators may also program for the accumulation of tokens within session. Points or tokens
are later exchanged for back-up reinforcers such as money or goods or immediately consumable primary reinforcers such as food, drug, or audio/video stimuli (Hackenberg & Pietras, 2000; Kangas & Hackenberg, 2009; Locey, Pietras, & Hackenberg, 2009). Behavioral economics provide investigators the means to empirically evaluate the efficacy of these reinforcement arrangements.

**Measures of Reinforcer Efficacy**

Attempts to establish the reinforcing efficacy of contingent stimuli often rely on measures of the behavior-maintaining or behavior-strengthening properties of those stimuli (Bickel et. al, 2000). Three measures commonly employed to assess these properties over the previous five decades include a) peak response rates maintained by access to the reinforcer (Skinner, 1932a, 1932b); b) choice among concurrently available reinforcers (Baum & Rachlin, 1969; Herrnstein, 1961, 1970; Miller, 1976; Shwartz, Silberberg, Casey, Paukner, & Suomi, 2016); and c) progressive-ratio (PR) breakpoint, measured as maximum schedule value completed to obtain the reinforcer under systematically increasing schedule requirements (Hodos, 1961; Roane, 2008). More recently, investigators have begun to evaluate alternative conceptual frameworks for assessing effects of properties of reinforcement on behavior. Two increasingly popular approaches include 1) behavioral momentum theory (Nevin, 1992; Nevin & Grace, 2000) and 2)
behavioral economic theory (Hurst & Silberberg, 2008; Madden et. al, 2007; Silberberg, et. al, 1987).

Each of the aforementioned measures and methods for assessing relative reinforcing efficacy of contingent stimuli may be prone to limitations. However, findings produced from studies directly comparing traditional behavior-analytic methods and measures with those of behavioral-economics have increasingly led many to suggest the latter may produce more coherent conclusions across experimental arrangements (Bickel & Madden, 1999; Bickel et al., 2000; Hursh, Raslear, Shurtleff, Baum, & Simmons, 1988; Hursh & Roma, 2015; Hursh and Silberberg, 2008; Roma, Hursh, & Hudja, 2015; Schwartz et al., 2016). Hursh and Silberberg (2008) suggested that data obtained via behavioral-economic methods and analyzed using quantitative models of behavior may bring investigators closer to establishing a single measure, termed essential value, capable of indexing reinforcers according to relative effects on responding and consumption.

Investigators in the area of behavioral economics typically plot consumption (i.e., number of reinforcers earned) as a function of price (response requirement to produce a reinforcer). The price of a given reinforcer will often be presented as a cost-benefit ratio; by extension, unit price represents price per one “unit” of the reinforcer. Determination of what constitutes one unit may vary across stimuli and context. A plot of consumption as a function of price is known as a demand curve,
and the degree to which consumption may be sensitive to changes in price (i.e., changes along the demand curve) is termed \textit{elasticity of demand}. Investigators can calculate the essential value of a reinforcer by obtaining behavioral-economic measures derived from demand curves and applying them to an exponential demand equation originally developed by Hursh and Silberberg (2008):

\[
\log Q = \log Q_0 + k (e^{-\alpha Q_0 C} - 1)
\]

By applying data making up a demand curve to the exponential demand equation developed by Hursh and Silberberg (2008), investigators established a parameter indexing essential value according to rate of change in elasticity of demand (Foxall, 2015; Hursh & Roma, 2015; Hursh & Silberberg, 2008; Oliveira-Castro, Foxall, Yan, & Wells, 2011).

Behavioral-economic methodology and measures are not completely independent of the three traditional measures of reinforcer efficacy, including maximum rate of responding, choice among concurrent options, and breakpoint (Bickel et al., 2000; Bickel & Madden, 1999). Rather, traditional measures and the methods employed to obtain them, have informed behavioral-economic methodology and nomenclature. By extension, behavioral-economic methodology has allowed investigators of operant behavior analysis to ask different questions, approach questions from an alternative perspective, and expand upon or generate
novel answers (Bickel et al., 2000). For example, Bickel, Marsch, and Carroll (2000) summarized findings from multiple studies demonstrating that traditional measures leading to discrepant conclusions regarding reinforcer efficacy are actually associated with different aspects of the same demand curve. In doing so, these authors demonstrated how behavioral-economics may provide for more systematic interpretation of findings across variations in experimental arrangements.

Bickel and Madden (1999) compared within-participant measures of PR breakpoint, response rate, and preference (i.e., choice) with measures of elasticity of demand and $P_{max}$ in human participants responding for cigarettes and money. $P_{max}$ identifies the point on a demand curve at which slope is equal to -1, signifying the price at which consumption shifts from being inelastic to elastic. The value of $P_{max}$ also corresponds with the price associated with the greatest response output; a measure of response rate referred to as $O_{max}$. During the initial phase of Bickel and Madden (1999), money and cigarettes were available within sessions under single-schedule arrangements (i.e., one of the two were available per session) contingent on completing PR schedule requirements systematically increased across sessions; these procedures allowed for consumption of multiple reinforcers under each schedule arrangement throughout a given session. During a second study phase, money and cigarettes were available under concurrent-schedule arrangements (i.e.,
participants could choose to work for either) at fixed-ratio (FR) response requirements which maintained responding during the first phase (Bickel & Madden, 1999).

Bickel and Madden (1999) initially analyzed data for traditional measures of responding. Across single-schedule PR and concurrent-schedule FR conditions measures of rate, breakpoint, and preference indicated inconsistencies in relative reinforcing efficacy of cigarettes and money. In general, Bickel and Madden (1999) suggested 1) cigarettes maintained higher breakpoints than money in all participants; 2) both money and cigarettes were equally effective at maintaining similar peak response rates; and, 3) under concurrent schedules participants preferred (i.e., chose) money at lower response requirements, yet reversed preference with increased response requirements.

Bickel and Madden (1999) subsequently conducted behavioral-economic analyses of the same data set, previously described according to traditional measures. Behavioral-economic analyses revealed that intensity of demand (i.e., greatest consumption at low price) was higher for money than for cigarettes. However, demand for money was also more elastic than demand for cigarettes such that demand for cigarettes decreased at a slower rate as price increased (i.e., demand was less sensitive to price). In other words, the demand curves crossed as response requirements increased. Congruent with these findings, P$_{\text{max}}$ values for
money were lower than those for cigarettes. That is, the highest rates of responding and consumption were observed at lower prices for money than for cigarettes (Bickel & Madden, 1999).

Bickel and Madden (1999) then compared results from the traditional measures of reinforcer efficacy with those from the behavioral-economic analysis and found that PR breakpoint was strongly positively correlated with $P_{\text{max}}$ (Pearson correlation coefficient $r = 0.98$) and inversely related to average elasticity (Spearman Rank Order correlation coefficient $r = 0.79$). A secondary analysis of these data conducted by Bickel et al. (2000) found that $O_{\text{max}}$ was positively correlated with peak response rate (Pearson correlation coefficient $r = 0.93$). Analyses comparing the relative positions of demand curves under single-schedule arrangements with choice under concurrent schedules revealed the crossing demand curves were consistent with reversal of preference across price changes. That is, the preferred reinforcer at a given price under concurrent-schedules arrangements was associated with greater consumption at that price under single-schedule arrangements. Bickel and Madden (1999) proposed that PR breakpoints are related to behavioral-economic analyses of $P_{\text{max}}$ and elasticity, maximum response rates are related to $O_{\text{max}}$ values, and choice of reinforcers at a given price are correlated with relative positions on demand curves obtained under single-schedule arrangements.
Bickel and Madden (1999) supported and extended previous findings comparing measures of PR breakpoint, consumption, and P\textsubscript{max} values with primates. Broadly, Rodefer and colleagues (Rodefer & Carroll, 1996, 1997; Rodefer, DeRouche, Lynch, & Carroll, 1996) described three separate studies in which male rhesus monkeys worked under varying conditions of food restriction and satiation for access to water, saccharin, PCP, and ethanol (specific combinations varied across studies). Concurrent- and single-schedules across the three studies consisted of PR-schedule requirements increasing non-systematically within daily sessions. Across all studies, lip to drink-spout contact closed an electrical circuit to register responses. Following completion of an active schedule requirement a 10-minute reinforcement period went in effect. Reinforcement consisted of 40 fluid deliveries from the respective drink spout (containing tap water; or dilutions of saccharin, PCP, or ethanol, depending on study conditions) under an FR\textsubscript{1} schedule of lip to spout contact. Findings were consistent and complementary across the three studies. That investigators have drawn consistent conclusions from findings with both human and non-human subjects lends further support to the utility of behavioral-economic assessments across arrangements (Rodefer & Carroll, 1996, 1997; Rodefer, DeRouche, Lynch, & Carroll, 1996).

Results from Rodefer & Carroll (1996) demonstrated that rate of responding and PR breakpoint increased for both PCP and ethanol under food-restriction
conditions. A follow-up study (Rodefer et al., 1996) extended these findings under similar conditions, revealing increases in $P_{\text{max}}$ for both PCP and ethanol under food restriction conditions. Findings from these two studies in combination suggest a strong link between measures of PR breakpoint, response rate, and $P_{\text{max}}$. Further support for the link between these three measures is provided via findings from the third of this series of studies (Rodefer & Carroll, 1997). Rodefer and Carroll measured PR breakpoint and $P_{\text{max}}$ under similar concurrent PR schedules for self-administered PCP and water or saccharin. Measures of $P_{\text{max}}$ and PR breakpoint for PCP both significantly decreased when concurrently-available saccharin replaced water, suggesting a link between these measures. Taking into account findings from the three studies combined, Rodefer and Carroll (1997) suggested that $P_{\text{max}}$ is analogous to response rate and breakpoint measures of reinforcer efficacy. These findings combined with those of Bickel and Madden (1999) and Bickel et al. (2000) support the use of behavioral-economic measures of responding to assess the efficacy of various contingent stimuli as reinforcers.

**Parameters of Reinforcement**

In demonstrating that traditional measures of reinforcer efficacy relate to different aspects of a demand curve, investigators in the area of behavioral economics bring behavioral scientists closer to a coherent model by which to measure effects on responding and consumption. However, decades of empirical
data produced within the science of behavior analysis have demonstrated that
different schedule parameters (e.g., ratio or interval requirements; Ferster &
Skinner, 1957) and parameters of reinforcement (e.g., magnitude, quality, rate,
delay, etc.) also interact in many ways to influence overall responding and
consumption of reinforcers (Hodos, 1961; Hursh, Raslear, Shurtleff, Bauman, &
Simmons, 1988; Neef, Shade, Miller, 1994). Studies assessing responding under
varying unit price and cost-benefit ratio arrangements within the behavioral-
economic literature further support these conclusions (Delmendo et al., 2009;
Madden et al., 2000). Findings from these studies suggest unit price may provide
for one coherent measure by which to assess responding and consumption when
manipulating both schedule parameters (i.e., cost) and parameters of reinforcement
(i.e., benefit).

Delmendo et al. (2009) assessed the extent to which changing cost-benefit
arrangements while controlling for unit price of reinforcement affected responding
and consumption in typically developing children. Specifically, investigators tested
two predictions of economic theory related to unit price: 1) overall consumption
will decrease as unit price increases, and 2) overall consumption will be similar
under different cost-benefit components when unit price values are equal. That is,
participants would obtain fewer reinforcers as response-requirement per reinforcer
increases; and total number of obtained reinforcers would be similar under equal
price per reinforcer, even with changes in the response-to-reinforcer ratio components. Throughout experimental conditions, four typically developing children completed academic tasks commensurate with their respective age and skill level (Delmendo et al., 2009). Following identification of preferred edible items, a reinforcement effect was demonstrated via a reinforcer assessment consisting of two conditions: baseline and reinforcement. During baseline conditions therapists presented each participant’s respective academic task and participants could freely engage with the activity. Reinforcers were not present or available during baseline conditions. Reinforcement conditions were similar to those of baseline with the exception that therapists kept individually identified reinforcers visible, delivered according to an FR 1 schedule of task completion. Participants moved on to the experimental demand evaluation following demonstration of higher rates of responding under reinforcement conditions and return to little or no responding with reversal to baseline.

Each participant in Delmendo et al. (2009) completed two series of demand evaluations. During Series 1, one reinforcer (i.e., one bite of preferred edible) was delivered contingent on completion of a predetermined FR-schedule requirement; during Series 2, FR schedules produced two reinforcers. During each session, participants were told how many responses were required to produce reinforcement. Sessions continued until one of two criteria was met: 1) the
participant stated “I’m done,” or 2) three minutes elapsed without responding. Each
series consisted of prearranged increasing FR requirements across sessions.
Schedule requirements arranged during Series 2 (for two reinforcers) were two-
times those arranged during Series 1 (for one reinforcer), resulting in equivalent
series of unit-price values.

Delmendo et al. (2009) conformed to the hypotheses that participant
responding was consistent with the two economic predictions of unit price. As unit
price increased, participants tended to obtain fewer reinforcers; that is, consumption
decreased at higher prices. Additionally, consumption did not differ under different
cost-benefit components at similar unit-price values. These findings lend further
support toward the assertion that analyzing data through the lens of behavioral
economics can provide alternative interpretations to findings obtained by way of
more traditional behavior-analytic arrangements and measures. Furthermore,
Delmendo et al. (2009) indicated that behavioral-economic predictions and
hypotheses might help to further guide the efforts of behavior analysts.

Behavioral-economic predictions regarding effects of reinforcement
arrangements on responding and consumption should be considered with caution,
however. Despite supporting results reported by Delmendo et al. (2009),
behavioral-economic predictions may not always hold true. Madden, Bickel, and
Jacobs (2000) tested three predictions of unit price regarding consumption and
response output in a choice context: 1) when plotted on logarithmic coordinates, total consumption summed across concurrent sources of reinforcement should be a positively decelerating function of unit price and total response output should be a bitonic function of unit price; 2) total response output and consumption should be determined by unit price value, independent of cost-benefit ratio components; and 3) when identical reinforcers are available at the same unit price across concurrent sources, consumption should be equal between sources. Four adult cigarette smokers (two males and two females) consented to participate in exchange for $10 per hour, as well as experimenter provided cigarettes. Sessions were scheduled 3 hours per day 5 days per week throughout the duration of participation. During all sessions participants worked alone in a room equipped with an experimental response panel and a computer with monitor. The room also contained newspapers, magazines, and a radio with which participants could engage at any time. Instructions provided to participants prior to each session specified response requirements and number of cigarette puffs to be earned on each response option. Target responding consisted of pulling one of three plungers, located horizontally on the response panel. During experimental sessions, FR response requirements were programmed on the center and right plungers; completing an FR 5 on the left plunger switched contingencies between the center and right plunger. On the computer screen, the words LEFT, CENTER, and RIGHT appeared in their respective positions corresponding to the three available response plungers. Below
each word a number indicated how many cigarette puffs had been earned by completing response requirements on the respective plunger during the current session (Madden et al., 2000).

Madden et al. (2000) assessed responding under both equal and unequal unit price conditions through multiple concurrent-schedules and unit price arrangements. Each concurrent-schedules unit price arrangement was presented to a given participant throughout the duration of one session, varying arrangements across sessions. Under unequal unit price conditions, concurrent-schedules arrangements consisted of (a) a fixed number of puffs available at high and low FR values, (b) more or fewer puffs available at the same FR value, and (c) different puff amounts and FR values across response options. During equal unit price conditions, concurrent-schedules consisted of alternatives with different numbers of puffs, and symmetrical differences in response requirements. Three combinations of puff amounts (i.e., three vs. six, three vs. nine, or six vs. nine) varied such that each was assessed at all unit-price values (Madden et al., 2000).

Madden et al. (2000) confirmed the first stated prediction of unit price: consumption of cigarette puffs decreased as a function of increasing unit price, and response output was a bitonic function of unit price under the programmed choice arrangements. Findings also supported the second prediction of unit price: overall cigarette-puff consumption summed across concurrently available alternatives was
affected by unit-price variations, but was not systematically affected by differences in cost-benefit components. These finding presented by Madden et al. (2000) support those of Delmendo et al. (2009), and extended the conclusions to responding within a choice context.

Support for the third prediction of unit price tested by Madden et al. (2000) was less clear; the third prediction of unit price stated that equal consumption should be observed across equal unit-price options. This prediction suggested that unequal consumption would be observed when unit price was unequal across options (i.e., participants will allocate greater responding to the lower unit price option). This aspect of the third prediction was supported by findings that participants tend to choose more puffs over fewer when FR is held constant, and smaller FR values over larger when number of puffs is held constant. However, during some unequal unit price conditions choice-responding indicated near-indifference when low unit price was associated with few puffs over a large number of puffs at higher unit price. Additionally, under conditions of equal unit price, systematic deviations from indifference appeared such that participants allocated responding to the option associated with more puffs and higher FR at low unit-price values. Conversely, the option associated with fewer puffs and lower FR was preferred at high unit price values. These systematic deviations from expected responding suggest that response output and consumption under choice
arrangements are sensitive to relative cost-benefit components beyond the effects of unit price, at least at extreme low or high values (Madden et al., 2000).

Despite some deviation from outcomes predicted by the economic concept of unit price, Madden et al. (2000) further confirmed that analyses of traditional behavior-analytic measures and arrangements from a behavioral-economic perspective are viable and useful. Analyses of variations in reinforcer magnitude and reinforcement-schedule arrangements as single unit-price expressions may bring “order […] to data that otherwise appear disorderly” (Madden et al., 2000, pg. 56). Analyses of response-output and consumption as a function of traditional measures of response requirement and reinforcer magnitude may yield inconsistent or unsystematic findings. The behavioral-economic model offers a more consistent and systematic account by combining response requirement and reinforcer magnitude into one measure: Unit price. Analyses of responding and consumption as a function of unit price have been shown to yield orderly findings (Madden et al., 2000).

**Essential Value of Reinforcers**

Evidence provided by the previously cited body of literature suggests that analyzing and interpreting data using behavioral-economic methods brings behavior scientists closer to developing a coherent model by which to measure reinforcer efficacy. Traditional behavior-analytic measures of responding may in
some cases lead to discrepant conclusions. However, behavioral-economic
measures derived from a single demand curve produced from the same data as the
traditional measures can bring order to the findings. Additionally, analyzing
responding and consumption according to unit-price value across cost-benefit ratios
may produce more systematic results, as opposed to varying schedule parameters
and parameters of reinforcement in isolation.

In a reanalysis of behavioral-economic measures of consumption reported
by investigators across multiple studies employing a variety of experimental
arrangements, Hursh and Silberberg (2008) outlined how investigators may
establish a single index of reinforcer value by inputting behavioral-economic
measures into an exponential demand equation, indicated by Equation (1):

$$\log Q = \log Q_0 + k (e^{-\alpha Q_0 C} - 1) \quad (1)$$

Within this equation, $\alpha$ represents the primary variable by which reinforcer
value is to be indexed. Specifically, $\alpha$ measures rate of change in the exponential,
or the rate of decreasing consumption with price increases. The variable $Q$
represents consumption, or obtained reinforcers. By extension, $\log Q_0$ represents
the logarithm of consumption when price is zero (i.e., free access). The variable $k$
specifies the range of the dependent variable in logarithmic units. Generally, the
value of $k$ will be set to a constant across comparisons, given the value $k$ merely
specifies the range of data. Elasticity of demand will be jointly determined by \( k \) and \( \alpha \). However, given that \( k \) is set to a constant, changes in elasticity are determined by the value of \( \alpha \). Finally, \( e \), is a mathematical constant representing the base of the natural logarithm, approximately equal to 2.71828. With obtained values for consumption, \( Q \), and range, \( k \), entered into the exponential demand equation, we have nearly obtained the essential value of the reinforcer based on exponential change in elasticity, \( \alpha \), along the demand curve (Hursh & Silberberg, 2008).

Before the essential value of a given reinforcer can be identified, investigators must account for price variations in experimental arrangements. In the Hursh and Silberberg (2008) exponential demand equation, \( Q_0C \) represents standardized price designed to eliminate scalar differences in the reinforcer. The value \( Q_0C \) expresses total cost required to defend maximal consumption, \( Q_0 \), as a function of \( C \), the FR per reinforcer (i.e., unit price). In other words, if the commodity differs in size (e.g., magnitude of reinforcement), differences in the exponent may reflect differences in responding required to defend maximum consumption obtained under free conditions, \( Q_0 \), as well as difference in essential value of the reinforcer. By standardizing the price at \( Q_0C \), we can isolate overall sensitivity to changes in unit price as a measure of elasticity expressed by \( \alpha \).

Obtaining \( \alpha \) indicated by a demand curve for a given reinforcer provides investigators with a measure of decreasing levels of consumption across increases
in unit price. As such, α returns as a negative value inversely proportional to essential value (abbreviated EV in recent extensions of the exponential model; Hursh, 2014a, 2014b; Hursh & Roma, 2015). Hursh (2014a, 2014b) and Hursh and Roma (2015) recently extended the exponential model of demand to account for varying values of k, range of consumption, in establishing EV as the inverse of α across experimental arrangements and a variety of reinforcers. This formula is given in Equation (2):

$$EV = \frac{1}{(100 \times \alpha \times k^{1.5})}$$  \hspace{1cm} (2)

The value of EV provided in Equation (2) is linearly related to $P_{\text{max}}$, the price at which demand elasticity equals -1 and overall responding is maximal. This value of $P_{\text{max}}$ is an estimate defined for demand in normalized units of consumption expressed as a percent of $Q_0$, or maximal consumption ($Q_0 = 100\%$), with price in normalized units of cost per 1%-unit consumption ($C \times Q_0 / 100$). Finding the near-exact value of $P_{\text{max}}$ expressed in units of $C$ requires accounting for variations in the value of $k$ by replacing the constant 100 in Equation (2) with $Q_0$ and adjusting for $k$:

$$P_{\text{max}} = \frac{m}{(Q_0 \times \alpha \times k^{1.5})},$$  \hspace{1cm} (3)

where $m = 0.084k + 0.65$
Analyzing data for responding and consumption obtained across unit price values provides investigators the means to establish a demand curve for a given reinforcer. Inputting measures derived from the demand curve into the exponential model of demand allows investigators to establish $\alpha$, a single value representing degree of sensitivity of consumption to changes in unit price. Calculating the inverse of $\alpha$ adjusted for varying range of consumption across reinforcers and experimental arrangements provides a standard measure of essential value of a given reinforcer, $EV$ (Hursh, 2014a, 2014b; Hush & Silberberg, 2008).

**Assessment of Reinforcement in EAHB**

Measures derived from behavioral-economic demand curves in combination with the exponential model of demand proposed by Hursh and Silberberg (2008), and subsequently expanded by Hursh (2014a, 2014b) and Hursh and Roma (2015), represent a viable option for indexing $EV$ of reinforcement. However, the vast majority of laboratory experimental arrangements under behavioral-economic conditions have programmed for primary reinforcers (i.e., food and drugs) with non-human animal subjects. Drugs, money, or hypothetical goods are commonly used for research involving human participants. A dearth of evidence exists to evaluate potentially less potent primary or conditioned reinforcers in EAHB (Kangas & Hackenberg, 2009).
Identification of effective reinforcers which may be provided within EAHB arrangements represents a critical problem to investigators. Galizio and Buskist (1988) suggested that different reinforcement histories, extra-experimental access to reinforcement, and relevant participant characteristics are important considerations in designing methodologically sound EAHB studies in which reinforcement is to be provided. Additionally, Galizio and Buskist emphasized that investigators in EAHB must frequently arrange for extra-experimental incentives in order to recruit and retain participants, potentially confounding within-session reinforcement procedures.

Buskist and Johnston (1988) concluded that many of the informal practices of investigators in EAHB, such as arranging within session reinforcement, may have unknown and possibly significant effects. These authors further suggested that investigators should be encouraged to report and describe all procedures related to the selection and incorporation of such methodological arrangements with as much rigor as other aspects of experimental design. Furthermore, Buskist and Johnston advised researchers to empirically evaluate the behavioral effects of these methodological arrangements in order to improve overall understanding of human behavior in experimental contexts.

Unfortunately, little progress has been made in the standardization of EAHB reinforcement methodology (Kangas & Hackenberg, 2009). Within-session
reinforcement in EAHB will often involve the accumulation of points or tokens presumed to function as reinforcers in themselves (Doolan & Bizo, 2013), established as reinforcers through competitive contingencies (Jessel & Borrero, 2014), or later exchangeable for backup reinforcers (e.g., money, food, preferred items, or activities). In recent years, contingencies arranging access to preferred video have frequently been described in EAHB (Andrade & Hackenberg, 2012; Charlton & Fantino, 2008; Forzano, Michels, Sorama, Etopio, & English 2014; Hackenberg & Pietras, 2000; Lagorio & Hackenberg, 2010; Lociey, Pietras, & Hackenberg, 2009; Macaskill & Hackenberg, 2013; Navarick, 1996, 1998). Under these arrangements, participants typically select from an experimenter-provided array of available videos. The use of video within an EAHB paradigm has been suggested as a potential analogue to immediately consumable primary reinforcement with non-human animals.

Navarick (1996) described video reinforcement as “an immediately consumable (intrinsic) positive reinforcer” (pg. 540). Navarick later elaborated with a description of intrinsic reinforcers as stimuli that reinforce behavior in a particular setting and in the absence of a specified backup reinforcer. In discussing discrepant findings under delay-discounting procedures, Navarick suggested that differences in sensitivity to delay-of-reinforcement observed across human and non-human subjects may be methodological in origin resulting from a lack of functional
equivalence between reinforcement procedures. That is, discrepant findings may
occur due to programming of conditioned reinforcers with humans (e.g., points or
tokens) and primary (i.e., intrinsic) reinforcers with non-human animals. Navarick
hypothesized that the immediately-consumable nature of video as a reinforcer
would serve to narrow this methodological gap between human and non-human
animal studies.

Navarick (1996) tested hypotheses regarding the nature of video
reinforcement assessing human responding under a delay-discounting procedure.
Thirty-nine undergraduate students participated in the Navarick delay-discounting
study. Participants responded to access videos of popular television shows in five
different categories: exercise shows, disco dancing, fashion shows, cartoons, and
travel/nature shows. Participants were seated alone in an unlit room containing a
response panel, behind which sat a VHS videocassette player. A color TV monitor
sat atop a video cart positioned near the response panel. The response panel
contained two back-lit response keys illuminated individually or simultaneously to
indicate available options. A top row of three lights served as additional stimuli to
indicate when responding was available. Navarick randomly assigned participants
to experimental groups in which standard or minimal instructions were provided
prior to sessions. All instructions informed participants to respond for access to
video by pressing response buttons according to the visual stimuli provided by
response panel lights. Standard instructions provided to participants further informed participants that the button they choose may affect the duration of the video segment, as well as the delay to onset of video. Minimal-instruction participants did not receive this additional information. Each 90 min session was divided into four trials. Video-segment and delay durations were varied across trial periods. Between trial periods participants could choose to switch videos or continue watching the same video (Navarick, 1996).

Overall, Navarick (1996) demonstrated that participants prefer longer video segments to shorter when delay is constant, and shorter delay over longer delay when video duration is held constant. Furthermore, many participants reliably made choices to hasten the delivery of shorter video segments when longer delays preceded longer video segments. Responding such as this is commonly referred to as impulsivity. These results are inconsistent with those commonly obtained using points as reinforcers in delay discounting tasks with human participants. When responding for points, human participants typically demonstrated self-controlled responding (cf. Hyten, Madden, & Field, 1994). However, effects observed on key-pressing responses for video were consistent with those observed in non-human studies programming for primary reinforcement, in that participants demonstrated more impulsive responding. Navarick also observed a substantial amount of switching between videos following sets of trials. Navarick suggests this switching
may call into question the reinforcing efficacy of the videos. Navarick concluded by suggesting the continued refinement of research methods employing “intrinsic” reinforcers such as video is essential to advance human operant research (Navarick, 1996).

Navarick (1998) extended previous findings obtained from humans responding for access to video under conditions similar to those previously reported (Navarick, 1996). Following exposure to a delay-discounting task, Navarick assessed the predictive value of individual differences in choice responding during a second session. Follow-up sessions occurred days after the first session and included a reversal to test reliability of observed preferences. Participants responded for an “intrinsic positive reinforcer” (Navarick, 1998, pg. 666) in the form of animated cartoon videos. Participants recruited from Introductory Psychology classes indicated an interest in viewing cartoon videos in an experiment prior to recruitment. Investigators provided course credit to participants as incentive for participation. All participants agreed to participate in two 1.5-hr sessions on separate days. Investigators informed participants they would receive full credit for the first session regardless of completion, but participants had to arrive for the second session to receive remaining credit (Navarick, 1998).

Under conditions in which immediate access to video resulted in a relatively short video segment (10 s), nearly all subjects demonstrated self-controlled
responding for the delayed, larger (25 s) video segment (Navarick, 1998). However, when the duration of the small video segment was increased slightly (15 s), individual differences in responding became apparent. These individual differences between participants were consistent within participants across sessions. Possible explanations for observed individual differences provided by Navarick include a) variations in participants’ ability to discriminate delay and video durations, b) different participant histories with exposure to delay of reinforcement, and c) different histories of conditioned reinforcement with video. Navarick further suggested future research should aim to identify variables responsible for these differences.

In the time since Navarick (1996, 1998) introduced the use of video reinforcement, others have extended its use in EAHB. Locey, Pietras, and Hackenberg (2009) assessed species-specific differences in delay sensitivity observed in basic behavioral research. Specifically, this Locey et al. study investigated the possibility that species differences in responding may reflect differences in procedures employed to study choice in humans and non-human animals. Locey et al. designed procedures with humans to closely approximate procedures commonly employed with non-human animals.

Locey et al. (2009) exposed participants to contingencies across many sessions, until stable trends in contingency-shaped choice responding were
observed. These extended exposure procedures differed from prior studies in which human participants are generally exposed to brief sessions, with instructions and/or prompts provided across contingencies. Additionally, whereas prior studies have commonly employed hypothetical or instructed reinforcing outcomes (e.g., points or symbols; “get as many points as possible”) with humans, the Locey et al. study aimed to more closely approximate “real outcomes” (e.g., food) commonly provided to non-human animals. As stated by Locey et al.:

Perhaps the lack of delay sensitivity in humans reflects the use of weak reinforcers (if indeed, the consequences functioned as reinforcers at all). What is needed for a comparative analysis are studies with human subjects that use actual and meaningful reinforcers. Therefore, in the present study humans’ choices produced access to video clips (2009, pg. 16).

Locey et al. (2009) cited prior research demonstrating that video access functions as a reinforcer for both children (e.g., Dogget, Gans, & Stein, 2000) and adults (Hackenberg & Pietras, 2000; Navarick, 1996, 1998). Locey et al. further assert video reinforcers are more like consumable reinforcers (e.g., food; water) arranged with non-human animals in that video reinforcers are consumed as they are earned. This is in contrast to reinforcers that accumulate over time and across trials (e.g., tokens; money). Participants in the Locey et al. study participated in one 45-min session per-day, Monday through Friday. Each participant received $1.50
flat wage, plus $4.00 per session if the experiment was completed in its entirety (Locey et al., 2009).

Findings reported by Locey et al. (2009) were inconsistent with much of the prior research involving human participants, demonstrating self-controlled responding for delayed points or tokens. However, findings were consistent with similar research involving non-human animals, demonstrating impulsive responding for immediately-consumable reinforcers. These findings suggest procedural variations may be responsible for observed response patterns. Locey et al. concluded that the “consumable-type” reinforcer (i.e., access to video) enhanced delay sensitivity, bringing results more in line with research involving other animals. Locey et al. compared these findings with similar studies employing choice procedures for access to video clips (Hackenberg & Pietras, 2000) and other consumable-type reinforcers such as juice (Forzano & Logue, 1994), as well as escape from aversive noise (Stockhorst, 1994).

Locey et al. (2009) further suggested important considerations when programming for video reinforcement. For example, the reinforcing efficacy of video depends on a specific conditioning history prior to the experiment. Individual differences in conditioning are likely to result in differential reinforcing efficacy. Additionally, reinforcing efficacy of video clips is likely to depend in part on continuity, duration, and inter-clip interval. Based on these considerations, Locey et
al. (2009) recommended that further research assessing variables affecting the reinforcing efficacy of video access would enhance its use as a methodological tool.

**Behavioral-Economic Analyses in EAHB**

Evaluations of reinforcer efficacy using procedures derived from the science of behavioral economics have demonstrated that traditional behavior-analytic measures (e.g., response rate, choice, and breakpoint) relate to various aspects of demand curves (Bickel & Madden, 1999; Bickel et al., 2000; Rodefer & Carroll, 1996, 1997; Rodefer et al., 1996). Furthermore, when the effects of varying parameters of reinforcement such as magnitude of reinforcers and response requirements are analyzed as collective measures of unit price, coherent patterns of responding emerge from data which may otherwise appear non-coherent (Delmendo et al., 2009; Madden et al., 2000).

Applying findings from prior studies of behavioral-economic measures to the development of quantitative models of behavior has proven fruitful in bringing behavioral scientists closer to a coherent model by which to measure reinforcer efficacy, or value. However, the majority of research developing these models has focused on responding for primary reinforcers in non-human animals; or responding for money, drugs, and contrived reinforcers in humans. Some investigators have begun to assess the use of video reinforcement when assessing
responding in human participants as a potential analogue to primary reinforcers in non-human animals. However, there remains a dearth of studies investigating video reinforcement in humans from a behavioral-economic analysis. Further research is required to identify and evaluate reinforcers within EAHB in order to enhance behavioral scientists’ use of these methodological tools. Additionally, empirical evaluations of the conditions under which EAHB reinforcers may be more or less effective are warranted.

The current study was guided by three aims. The first aim was to further assess consumption of reinforcers in EAHB through behavioral-economic methods and measures under two reinforcement arrangements: Access to video and reduction of in-session duration. The second aim was to extend prior research assessing economic predictions of unit price via a choice procedure for video alone (Madden, Bickel, & Jacobs, 2000). The third aim was to further evaluate the utility of the exponential model of demand for indexing EV of the current reinforcers within the context of EAHB (Hursh & Silberberg, 2008; Hursh, 2014a, 2014b; Hursh & Roma, 2015).

Previous findings from unpublished data obtained in our lab suggested undergraduate students participating in research in exchange for course credit frequently forgo watching earned video in favor of terminating participation early (Chastain & Harvey, 2016). Undergraduate students completed multiple-choice
arithmetic problems for access to pre-selected video utilizing a progressive ratio reinforcement schedule. During test conditions, participants chose to either immediately watch earned video, or continue working and save earned video time. Participants who chose to save earned video could later choose to either watch the earned video(s) or forgo access to accumulated video. Analyses of video-consumption data revealed a majority of participants ($M = 74.6\%$) chose to skip- and-save large portions of earned video segments. Of that majority, a large portion of participants (66%) chose to forgo consuming accumulated video following completion of all schedule requirements. These findings suggest responding may have been under the control of alternative extra-experimental contingencies rather than preprogrammed video reinforcement. In light of these preliminary findings, the current study included a novel reinforcement arrangement in the form of access to reduction of total session duration. In line with the first aim of this study, investigators assessed reduced session time as reinforcement individually via single-schedule arrangements, and under choice arrangements with concurrently available video.

The primary investigator developed a computer program specifically for the current study. The program arranged all stimuli presentations and collected all data in real time. Experiment 1 assessed responding for access to video and reductions in session duration under single-schedule arrangements incorporating...
progressively-increasing FR requirements within session across trials. Experiment 2 assessed responding for both reinforcers under concurrent-schedules (i.e., choice between reinforcers) arrangements and progressively increasing FR requirements. Experiment 3 extended evaluations of economic predictions of unit price to responding for access to video under choice arrangements incorporating a variety of FR-video duration ratios. Primary dependent variables of interest were level of consumption of reinforcers (i.e., number of reinforcers earned) and response output as a function of unit-price and cost-benefit arrangements, and choice among reinforcer options. Investigators calculated unit price for duration of access to video as number of responses (response requirement) per second of reinforcement (magnitude; 30 s, 60 s, and 90 s). Calculating unit price and consumption according to duration allowed for consistent analyses across varying durations of uninterrupted video, rather than multiple discontinuous clips of fixed duration. The experimental program also recorded data on rate of responding.
General Method

Participants

Investigators recruited participants via the Sona Research Participation System (Sona) from a pool of students enrolled in undergraduate psychology courses at Florida Institute of Technology (FIT). The primary investigator created and posted a project title, basic participation information, and available participation times to be viewed by potential participants on-line. To complete the on-line registration process, participants were required to register for two sessions occurring within two calendar weeks of each other. Participants received 2-hours’ worth of participation points (5 credits) toward one undergraduate course for each experimental session completed.

Consent

During the informed consent process, a lab staff member instructed participants to leave any personal belongings (e.g., backpack, books, phone, watch, etc.) outside of session. Prior to initiating the first session with a participant the lab member reviewed the informed consent form with the participant and provided a general overview of session procedures. The lab member confirmed participants had registered for two separate sessions scheduled to occur on two separate days.
for two hours each. Prior to initiating a session, the lab member prompted the participant to confirm he or she could complete the full two-hour session. In the event that a participant was not available for the full two hours the session could be rescheduled for a later date. This occurred one time throughout the study.

Prior to initiating the first session with any participant a lab member informed participants they would need only the computer mouse to respond throughout session. The lab member provided a description of the apparatus (described in detail below) and target response, and provided an opportunity for the participant to ask questions prior to initiating session. The lab member attempted to address all questions without revealing specifics regarding experimental hypotheses. In the event that the lab member was unable to answer questions to the satisfaction of participants, sessions could be rescheduled by having the participant contact the primary investigator. This did not occur throughout the study. All participant questions and comments, and any lab member responses, were informally logged by lab members to be reviewed by the primary investigator.

**Setting**

Participants completed all sessions in a laboratory spaces (2.7 m by 4.1 m) located in the Harris Commons building at FIT. Participants sat at a table (1.2 m wide x 0.6 m deep) equipped with a computer, keyboard, external mouse, and headphones. Portable framed-fabric partitions separated tables such that
participants running simultaneously could not see each other or adjacent computers. During all sessions one research team member was assigned to monitor lab operations. Researcher team members were free to exit or move about the room as necessary while remaining unobtrusive to participants. Though it was possible researcher team members might occasionally be positioned such that they could see or be seen by an individual participant, no pre-planned human observation of sessions occurred.

**Apparatus**

The primary investigator developed a computer program, specifically for this study, using Microsoft Visual Basic® software in Visual Studio® 2013. The experimental apparatus was identical across all experiments with condition-specific differences in investigator-provided instructions, trial durations, and reinforcement arrangements during program runtime. The program presented all experimental conditions and recorded all data in real time. All experimental stimuli and response options appeared within a single graphical frame, approximately 26.5 cm wide by 16 cm high. Investigators programmed for one frame size to contain all experimental stimuli rather than adjusting to the entire monitor screen in order to control for variations in screen dimensions. Throughout all sessions the graphical frame appeared centered midway across and to the top two-thirds of the computer monitor.
**Procedures**

Participants completed multiple fixed-duration trials throughout each session. Trials consisted of multiple opportunities to contact reinforcement under different unit-price and cost-benefit arrangements, specific to each experiment. Figure 1 depicts a concurrent-schedules experimental-trial screen. Single-schedule trials differed in that only one response option was present within the graphical frame, randomly assigned to either side across trials. During all experimental trials, participants responded by positioning the mouse cursor over a response button and clicking with the left mouse button. Response buttons (approx. 2.1 cm squared) appeared at randomly generated positions for each discrete response within the respective response frame (approx. 10.6 cm squared). Within each response button a label indicated the reinforcer available for responding on that option. Investigators selected this discrete response form to provide for low effort on the part of the participant while requiring the participant to actively attend to and interact with the experimental program in order to emit a correct response. Additionally, this response allowed for completion of multiple FR requirements (i.e., multiple opportunities to access reinforcement) within a trial.

Throughout each trial, immediately above each response frame a text box (approx. 10.6 cm wide x 2 cm high) indicated the response requirement and reinforcer programmed for the relative response option. A ribbon centered at the
top of the graphical frame (approx. 23.8 cm wide x 1.6 cm high) displayed a
centered digital clock counting down the time remaining in session. To either side
of the clock a text box displayed number of responses completed for the respective
response option in the response frame below.

During single-schedule video and concurrent-schedules choice sessions,
Windows Media Player® software displayed earned digital video clips within the
experimental graphical frame (Figure 2). The actual size of the video image varied
depending on the dimensions of the original video, maximized within the graphical
frame while maintaining original height-to-width ratio. Video clips played in
sequence such that a given video clip initiated where the previous video clip
terminated. Session-time reduction reinforcement (Figure 3) included a blackout
from responding while displaying a countdown clock labeled “Wait:” centered to
the top two-thirds portion of the graphical frame. The session clock remained in
place at the top of the graphical frame throughout the blackout period. All mouse
and keyboard functions were unavailable during video reinforcement and blackout
periods to prevent participant interference with programmed timers and video
controls.

At the outset of each session, and between all trials, the experimental
program displayed an instruction screen (Figure 4) containing a text box (approx.
18.5 cm wide x 9.3 cm high) with condition specific instructions. Clicking a “Begin
Session” button (approx. 6.6 cm wide x 2.1 cm high) positioned immediately below the instruction text box allowed participants to initiate the next trial. During inter-trial instructions, the session timer remained in place above the instruction text box. Total session duration continued to count down during all presentations of the instruction screen.

The experimental program displayed a video-selection screen to participants (Figure 5) prior to any session in which video reinforcement was to be available. A text box positioned at the top of the graphical frame (approx. 25.5 cm wide x 1.7 cm high) displayed the text “Please select the video you would like to view.” Positioned horizontally immediately below the text box, five image boxes (approx. 3.4 cm wide x 5.1 cm high) displayed available videos. Participants could select any video or change a previous selection by clicking on a video image. Clicking a “Continue” button (approx. 4.3 cm wide x 1.8 cm high) located below video selection options confirmed the selected video and presented a dialog box to initiate sessions.

**Data Analyses**

The experimental program collected raw data on all stimulus presentations and changes, as well as participant responses. At the start of each participation session, the experimental program created a Comma Separated Values (CSV) file in which to record raw data in real time. The experimental program recorded data
on participant responses and stimulus presentation, rounded to 1/100th of a second according to the internal computer clock. Real-time data collection ensured that data were recorded and saved on a continuous basis. The primary investigator developed data summary macros using Visual Basic for Applications software in Microsoft Excel® to organize and summarize raw data for subsequent analyses. The primary investigator conducted all data analyses using templates created specifically for exponential demand analyses (Hursh & Roma, 2014) with GraphPad Prism 6.0®, and behavioral-economic and EV analyses (Kaplan & Reed, 2014) within Microsoft Excel®.
Experiment 1

The aim of Experiment 1 was two-fold: 1) extend previous studies of behavioral-economic analyses of responding and consumption to access to video as reinforcement in EAHB under single-schedule arrangements, and 2) extend behavioral-economic assessments of reinforcement in EAHB to a novel reinforcement arrangement, reduction in session duration under single-schedule arrangements. Throughout Experiment 1 participants completed two experimental sessions across two lab visits, one session during each visit. Session arrangements included one-of-two programmed reinforcers within each session: 30 s video clips (video condition) or 5 s reduction in session duration (time condition) plus 30 s blackout period (controlling for response-unavailable time during video presentation). These values allowed for multiple reinforcement opportunities per trial while ensuring adequate overall time to complete all trials in each session. Arranging 5 s reductions from total session time insured participants could contact multiple time reinforcement opportunities while maintain adequate total session time to complete all programmed trials. During each session a single-schedule of reinforcement arranged for one of the two programmed reinforcers available across all trials. The experimental program randomized order of reinforcer presentation
such that participants might access video during Session 1 and time during Session 2, or vice versa.

Method

Participants

Ten participants (six males; four females) completed participation in Experiment 1. Across participants in Experiment 1, two initial FR response requirements (FR2 and FR8; explained in detail below) were implemented such that five participants experienced one initial value and the remaining five participants experienced the alternative initial value. Four additional participants did not complete the second session of Experiment 1 and were excluded from final data analyses.

Procedures

Instructions. At the start of each session the experimental program displayed instructions to the participant indicating what reinforcer would be available. For example, prior to the initial trial of the video reinforcement condition instructions indicated:

During this session you will have the opportunity to click on a 'Watch Video' button for opportunities to watch segments of your selected video. The number of button clicks required to watch video and the number of
seconds of video available will be written over the button frame. You may choose to work as much or as little as you like to watch the video. A clock centered at the top of the window will display the total time remaining in this session. Click the 'Begin Session' button to start the first trial.

**Progressive-ratio schedules.** To provide for concise description throughout this study, PR schedules will refer to response requirements systematically increased within session across fixed-duration trials (for a review of PR schedules, see Roane, 2008). A PR schedule arranged for increasing ratio values across seven 15-minute trials within each session of Experiment 1. Ratio values doubled across trials such that response requirements were twice that of the immediately preceding trial. Five participants (Low UP group; 102, 103, 104, 105, and 106) completed schedule requirements beginning at FR2 and progressing through FR128. Following limited variability in responding across trials within the first five participants, investigators increased initial response requirements for subsequent participants. The final five participants (High UP group; 109, 110, 111, 112, and 113) completed schedule requirements beginning at FR8 and progressing through FR512.

Following completion of seven 15-min trials in a session (totaling 105 minutes of the 120-minute session), the experimental program initiated an eighth trial under the next response requirement in the PR sequence (i.e., 256 or 1024) for
the duration of remaining session time according to the digital session timer. Responding and consumption during this partial trial was not included in final analyses. The purpose of this trial was merely to ensure participants did not access additional reduction of total session duration beyond programmed reinforcement arrangements. For example, if following completion of seven trials (including initial and inter-trial instruction), 10 minutes remained on the session timer, the participant would be exposed to a final 10-minute trial rather than leaving the experimental setting early.

**Reinforcement.** Within each trial, following completion of an FR-schedule requirement responding was not available for a 30 s period. During this period either a) an earned video clip automatically initiated and played for the full 30 seconds (video; Figure 2) or, b) a 30 s blackout screen appeared (time; Figure 3). Upon initial presentation of the blackout screen a text box positioned directly under the session timer indicated session reduction value earned (i.e., “-05 s”). During the first 1 second of the blackout period this value sequentially reduced, with concomitant reductions from the session clock. Throughout the blackout period a black-and-white countdown timer display centered on a dark red background. The 30 s blackout period controlled for potential effects of response unavailable during 30 s video periods.
**Data Analysis**

The primary investigator first analyzed data for rate of responding within participants across FR trials. The primary investigator additionally analyzed data obtained in Experiment 1 to construct demand curves using an Exponential Model of Demand Analysis Template developed for such analyses in GraphPad Prism 6.0® (Hursh & Roma, 2014). The output of these analyses included best-fit estimates from Equation 1 for $Q_0$, $\alpha$, and $k$. This template design additionally provided testing for statistically significant differences in values across groups and individuals via an extra sum-of-squares F test (Brunstein & Paul, 2016). The template provided for extra sum-of-squares testing in one of two ways: Testing for differences between a single unshared parameter across two models, constructed from different data sets; or testing whether one curve, constructed from different data sets, best represent all models across multiple variables (Hursh & Roma, 2014; GraphPad Software, n.d.). The current study individually tested for differences across single parameters for $Q_0$ and $\alpha$ within Experiments 1 and 2.

The primary investigator applied obtained best-fit $Q_0$, $\alpha$, and $k$ values as input within a Microsoft Excel® template designed to calculate $P_{\text{max}}$, $O_{\text{max}}$, and EV adjusted for varying range of consumption across qualitatively different stimuli according to Equations 2 and 3 (Kaplan & Reed, 2014). Finally, the primary investigator plotted work functions (i.e., changes in total responding across unit
price arrangements) as actual work output and predicted work output for each participant, graphed according to participation group.

Prior to analyzing data to construct demand curves for consumption of programmed reinforcers it was necessary to determine a method for handling any trials in which consumption did not occur. Zero values are undefined within logarithmic transformations. As such zero values cannot be directly plotted on logarithmic scales. Multiple methods for handling zero-consumption occurrences have been suggested (Hursh, 2016; Hursh & Roma, 2015; Hursh & Silberberg, 2008; Koffarnus, Franck, Stein, & Bickel, 2015; Madden, Bickel, & Jacobs, 2000), though no consensus solution has yet been reached. Across the current series of experiments and data analyses the primary investigator followed recommendations proposed by Hursh (2016) and previously described by other investigators (Madden, Bickel, & Jacobs, 2000), suggesting data remain unadulterated with no-consumption trials excluded from logarithmic transformations (see General Discussion of the current dissertation for further discussion of this topic). In line with this recommendation, the Exponential Model of Demand Analysis Template (Hursh & Roma, 2014) automatically excluded all zero-value and empty cells.

Reed (2016) suggested development of best-fit models of demand constructed using Equation 1 must control for any constraints on $Q_0$ naturally occurring within an experimental arrangement. Absent these pre-arranged
constraints on best-fit models it may be possible for model estimates of $Q_0$ to predict values beyond those which may be feasibly or practically achieved. For example, in the case of Experiment 1 during video conditions, participants were exposed to multiple 15-min trials, each consisting of a given FR-schedule requirement for access to 30 s video clips. It would therefore not be possible for $Q_0$ to exceed 30 video clips, or 900 total seconds of video (i.e., the total session duration). Given that unconstrained consumption of reinforcement was not directly assessed, it may be possible for an individual model to predict unconstrained consumption greater than 30 video clips, or 900 seconds of video. The Exponential Model of Demand Analysis Template (Hursh & Roma, 2014) includes built-in model-constraint options for such considerations. Data analyses conducted within Experiment 1 included constraints on $Q_0$ set to 30 video clips or 900 s (which ever was appropriate to a given analysis) under video reinforcement conditions, and 30 reinforcement-blackout periods or 150 s of session reduction under time conditions.

**Results**

**Response rate**

Figure 6 depicts rate-of-responding within-participants across FR-trials for both video and time conditions. Investigators calculated rate as average responses per minute (RPM) by dividing total responding by total response-available time within each FR trial. Total response available time included any time in which the
Experimental response frame was present (i.e., excluding video playback and blackout periods, and instruction presentations).

Within Low UP group, all participants initially decreased rates of responding from the first trial (FR2) to the second trial (FR4) under both video and time conditions. Participants 103 and 104 subsequently displayed stable response rates across remaining trials within both reinforcement conditions. Participant 106 engaged in a similar pattern of responding within the video condition. Under the time condition this participant’s responding continued on a decreasing trend during the final three trials (i.e., FR 32, 64, and 128). Participant 105 ceased all responding under FR8 – 128 within the video condition, and under FR32 – 128 within the time condition. Response rates exhibited by participant 102 deviated from those of other participants in that responding within the time condition generally remained high and stable, while responding within the video condition increased markedly across the final two trials (i.e., FR64 and 128).

Within High UP group (initial FR8) response patterns were generally similar to those observed in participants 103, 104, 105, and 106. Participants 111 and 114 engaged in generally stable rates of responding across FR8 – 128 trials followed by decreased rates under FR256 and 512 within both reinforcement conditions. Participant 112 engaged in similar patterns of responding under video reinforcement, but maintained responding across all trials under the time condition.
Participant 113 engaged in generally decreasing rates of responding across conditions. The exception to this general pattern of responding was a brief increase within the sixth trial (FR256) of the video condition followed by no responding throughout the final trial. Participant 110 response rates were generally stable across all trials within both reinforcement conditions.

Taken together, these findings demonstrate participants engaged in initially-high rates of responding at very low schedule values (i.e. FR2 within Low UP group) for both access to video and reduced within-session time. Rate of responding tended to decrease moderately with small increases in schedule requirements, and subsequently stabilize across multiple trials. Data from participant 105 was an exception to this pattern in that responding generally did not stabilize, and dropped out during earlier trials.

Findings from High UP group generally showed stable levels of responding across multiple trials under schedule requirements corresponding to those of Low UP group. However, four out of the five High UP group participants either decreased responding or ceased responding all together for one or both reinforcers at high schedule values. These findings suggest the reinforcing efficacy of the programmed reinforcers decreased as response requirements increased.
Demand and Essential Value

Testing unit price methodology. The primary investigator conducted analyses to develop best-fit exponential demand models across both video and time reinforcement conditions according to two possible cost-benefit ratios: (a) responses per second of reinforcement (second) and (b) responses per reinforcement period (Sr period). In other words, the two models represented consumption under unit price per second of reinforcement, or unit price per reinforcement period. These models directly compare conclusions drawn from variations in unit-price calculation methodology under time-based reinforcement arrangements. The primary investigator conducted this analysis to demonstrate the feasibility of developing exponential demand models for duration based reinforcers according to either number of responses per second or responses per reinforcement period. It was expected that similar conclusions should be drawn from models developed according to second and Sr period unit price ratios.

Table 1 displays values for models constructed by plotting within-group consumption averaged across participants for each unit price value. While it would be desirable to display comparison values for all participants individually, such a table would be prohibitively large and has thus been excluded from presentation. However, conclusions drawn from presented group-average data are representative
in that all individual models showed symmetrical demand curves across unit-price methodology.

As seen under “Diff” columns in Table 1, differences in $Q_0$ and $P_{\text{max}}$ estimates are apparent across second and Sr period models under all reinforcement arrangements. These differences are expected as a result of direct proportional differences in unit-price calculation methodology. For example, a cost-benefit ratio of 2:1 for video clips (i.e., Sr period) was always approximately equal to 30 times the cost-benefit ratio for 1 s of video, \textasciitilde0.067:1. Of primary interest, despite expected differences in $Q_0$ and $P_{\text{max}}$ estimates, little-to-no difference is estimated across all other measures. Again, these findings are expected with direct proportional differences in unit price calculations. Though $Q_0$ and $P_{\text{max}}$ estimates differ, the shape and position of the relative demand curves should not change in any significant way beyond slight variations due to rounding differences.

Due to small differences in calculated exponential demand measures, likely resulting from averaging and rounding across data sets, slight variations unit price models were found in $\alpha$ and $O_{\text{max}}$ under Low UP group video reinforcement (Table 1). No such differences were observed in models constructed across all participants individually (data not presented). Despite this small variation in final calculated measures, findings displayed within Table 1 demonstrate the feasibility of
developing exponential demand models for duration-based reinforcers according to either unit price methodology: Responses per second or responses per Sr period.

**$Q_0$ and $k$ values.** The primary investigator conducted a series of extra sum of squares $F$-tests to compare expected $Q_0$ and $\alpha$ values across group averages for both video and time reinforcement. Differences in $\alpha$ values are expected to occur across groups as a result of decreases in consumption proportionally-greater across higher unit price values. That is, greater $\alpha$ values should occur within High UP group if demand indeed became more elastic at higher unit prices, as predicted by established behavioral-economic models. Even with expected differences in estimated values of $\alpha$, best-fit models across groups should not predict differences in expected $Q_0$. That is, although increased elasticity of demand is expected to occur at higher unit price values, predicted unconstrained consumption should not differ across groups if levels of consumption are determined by unit price alone. Such findings are important in demonstrating no extraneous differences in consumption across groups.

Figure 7 displays exponential demand models within reinforcement conditions across Low UP and High UP groups. Results from extra sum of squares $F$-tests did reveal significant differences in $\alpha$ across groups for video consumption, $F(1, 9) = 31, p < .01$ (Low UP group $\alpha = 0.00011$; High UP group $\alpha = 0.00024$). Extra sum of squares $F$-tests also revealed significant differences in $\alpha$ for time
consumption, $F(1, 9) = 13, p < .01$ (Low UP group $\alpha = 0.00016$; High UP group $\alpha = .00024$). These findings support the hypothesis that demand for both video and time reinforcement becomes more elastic across greater unit price values. Further extra sum of squares $F$-tests revealed no significant differences in $Q_0$ for video consumption, $F(1, 9) = 1.2, p = 0.301$ (Low UP group $Q_0 = 27$; High UP group $Q_0 = \sim 30$); or for time consumption, $F(1, 9) = 0.7, p = 0.423$ (Low UP group $Q_0 = 24$; High UP group $Q_0 = 22$). These findings suggest expected unconstrained consumption of each programmed reinforcer would be similar across groups.

Recommendations from previous investigators suggest the exponential model of demand is best fit to consumption data averaged within unit price values and plotted across unit price changes (Hursh & Roma, 2015; Hursh & Silberberg, 2008). Additionally, best-fit values for $k$, range of consumption, are fixed within experimental arrangements (and often within a given lab setting) for each reinforcing stimulus (Hursh, 2016; Reed, 2016). Equation 2 subsequently provides for quantitative comparisons (EV) across qualitatively different reinforcers by adjusting for variability in $k$ when calculating inverse of $\alpha$, essential value. Demand models described previously for comparison across group average consumption provided for best-fit $k$ values of video and time reinforcement. Consistent with these models the primary investigator conducted all subsequent Experiment 1
analyses of video and time exponential demand models with $k$ equal to 1.5 and 1.2, respectively.

**Exponential demand.** The primary investigator constructed exponential demand models for each participant’s individual consumption data, as well as consumption averaged across all participants. Within Experiment 1, participants were exposed to two different reinforcement arrangements across sessions. In one session, participants worked to earn access to 30 s video clips; in the alternative session, participants earned 5 s reduced session time plus 30 s blackout period. The 30 s blackout period within the time condition was included to control for responding unavailable during video conditions. Thus for every 5 s time reduction earned a participant was required to wait 30 s before the next opportunity to respond. As such, directly comparing consumption of video and time according to unit price per second was not possible under the current arrangement. Therefore, the primary investigator constructed all demand models according to unit price per reinforcement period (i.e., FR schedule requirement).

Figures 8 and 9 display graphs depicting consumption of video and time respectively. Each graph contains inset $Q_0$, $\alpha$, and $R^2$ values corresponding to each model. Table 2 provides adjusted EV, $P_{\text{max}}$, and $O_{\text{max}}$ values calculated according to Equations 2 and 3 for each model. Data obtained from one participant (105) did not allow for development of an exponential demand model within the video condition.
due to zero consumption following the second trial. Therefore, Table 2 contains no adjusted EV, \( P_{\text{max}} \), and \( O_{\text{max}} \) values for this session. Figure 10 displays obtained and predicted work output (i.e., total responding), depicted by individual data points and model curve respectively. Measures were derived from consumption data across video (left column) and time (right column) conditions for all participants in Low UP group (top panels) and High UP group (bottom panels).

Within Low UP group, consumption data for video in Participants 103, 104, and 106 demonstrate systematically decreasing consumption (Figure 8). In line with these observations, Table 2 indicates values for EV derived from these demand curves are fairly consistent across the three participants (range 45.36 – 38.88), with \( P_{\text{max}} \) falling near the maximum schedule value assessed (range 121.14 – 103.84). Consistent with these \( P_{\text{max}} \) estimates, work output for video in participants 103, 104, and 106 increased steadily until leveling off between the sixth and seventh trials (Figure 10).

Video consumption observed in Participant 102 (Figure 8) also conform to observed response rates in that this participant initially demonstrated a slight decline in consumption, followed by relatively stable consumption across the final three trials. In line with these findings, EV (77.76) and \( P_{\text{max}} \) (250.94) calculated for video in participant 102 were the highest observed (Table 2). Consistent with these
findings work output in participant 102 maintained on an increasing trend across all trials (Figure 10).

High UP group participants experienced somewhat higher unit price values than Low UP group, beginning at FR 8 and continuing through FR512. As seen in Figure 6, consistent with Low UP group, High UP group participants tended toward stable response rates through FR128. However, response rates subsequently decreased to a greater degree in the final two trials. Consistent with these findings, consumption of video in High UP group participants decreased to a greater degree than observed within Low UP group.

Two participants from High UP group (110 and 114) consumed reinforcement across all video trials, completing only one schedule requirement each during the final trial (Figure 8). Participants 111 and 112 each consumed only one video reinforcer during the fifth trial; participant 111 again consumed one reinforcer during the sixth trial, while 112 consumed none. Data obtained from participant 113 indicate consumption decreased quickly across trials. This participant consumed only one video reinforcer during the sixth trial, and zero reinforcers during the final trial.

Consistent with these findings, work output functions for video in High UP group participants were initially higher than those observed under equivalent unit
price in Low UP group (Figure 10). Work output functions in High UP group also initially increased, though at a lower level than those observed of Low UP group. Interestingly, work output in High UP group participants began to level off, and subsequently decrease, at lower unit price value than those of Low UP group. As would be expected based on these findings, EV (range 18.14 – 28.65) and \( P_{\text{max}} \) (range 42.58 – 82.18) values for video across High UP group participants were consistently lower than for Low UP group (Table 2).

As a whole, data obtained for consumption of reinforcement within the time condition were similar to those observed for video. Minor within-participant variation was observed. Data for participants 103 and 104 were highly consistent with those obtained under video conditions. Participant 102 initially demonstrated greater stability in levels of time consumption than those observed for video, though consumption decreased during the final two trials. Consistent with findings from video conditions, participant 102 demonstrated higher EV for time (63.39) than all other participants.

Consumption of time (Figure 9) in participant 106 decreased to a greater degree than observed for video. Participant 106 completed criteria for time reinforcement only once during the sixth trial, and not at all during the seventh trial. In line with these findings, Equation 2 reveals an estimated EV of only 8.55 for time in participant 106 (Table 2). Similarly, data for participant 105 show
consumption within the time condition decreased dramatically across trials, though this participant did continue responding across more trials than observed under video conditions. Though no EV for video could be calculated for participant 105, Equation 2 revealed EV of only 1.33 for time in this participant.

Within High UP group under time conditions, participant 110 maintained levels of consumption fairly consistent with those of video, though slightly less elastic in that the lowest level of consumption observed was two rather than one. Consistent with this observation, Equation 2 provides an EV estimate of 44.75 for time, as compared to 28.65 for video. Participants 111, 112, and 113 similarly maintained slightly higher levels of time consumption than those observed for video. Indeed, participants 112 and 113 continued consuming reinforcement in the time condition across all trials, as compared to only the first five and six trials, respectively, in the video condition. These levels of consumption resulted in EV of time at 36.23 compared to 18.14 for video in participant 112. Participant 113 showed a negligible difference in EV across reinforcers (video = 18.14; time = 19.02). Participant 114 consumed fewer reinforcers resulting in lower EV under time conditions (EV = 19.02) than video conditions (EV = 25.92).

Data from Low UP and High UP groups show similar work output functions for reduced session time (Figure 10). Across participants, work output tended to increase slightly across the first few trials. During later trials (i.e., higher
unit price values) work output began to stabilize and/or decrease across participants. These work output functions would be expected under conditions in which programmed reinforcers transition from inelastic to elastic with increases in unit price.

As previously noted, the exponential model of demand is most often applied to consumption data averaged across data sets, or averaged across multiple exposures to each unit price variation (Hursh, 2016; Hursh & Roma, 2015; Hursh & Silberberg, 2008). Within EAHB arrangements, it is likely that investigators face limited resources when considering experimental design. For example, when recruiting undergraduate research participants, as in the current study, many students may agree to participate to the extent that they will earn course credit for doing so. As such, participants may be available for very few sessions occurring for limited duration. Under such constraints, it may not be feasible to construct within-participant demand models through repeated exposure to conditions. Additionally, investigators are unlikely to assess reinforcers individually across all participants prior to initiating a given experimental condition. As such, within EAHB arrangements, investigators could benefit from understanding and predicting potential reinforcement effects, as indicated across multiple participants.

Figures 8 and 9 included exponential demand models constructed for average consumption across all participants within each unit price for video and
time, respectively. Additionally, the bottom most row of Table 2 provides values of EV, $P_{\text{max}}$, and $O_{\text{max}}$ for consumption averaged across all participants, provided by Equations 2 and 3. When comparing demand curves and exponential demand values for video and time within the current arrangement, models suggest unconstrained consumption of video ($Q_0 = 29$) may be higher than for time ($Q_0 = 26$). However, variations in $\alpha$ (video = 0.00019; time = 0.00024) suggest consumption of time reinforcement may persist to a slightly greater degree under single-schedule arrangements. Consistent with these findings, estimated values for EV (video = 30.24; time = 31.70), $P_{\text{max}}$ (video = 80.76; time = 95.04), and $O_{\text{max}}$ (video = 713.87; time = 715.01) under the current reinforcement arrangements were all slightly higher for time than for video. However, observed differences were negligible.

**Experiment 1 Discussion**

Decreasing response rates with concomitant decreases in consumption in Low UP group participants suggest demand became slightly more elastic with increases in unit price. However, caution is warranted in making such conclusions prima facie due to increasing proportion of allotted trial duration required to satisfy increasing response requirements. Participants who maintain stable rates of responding in later trials must naturally consume fewer reinforcers within the allotted trial time. For example, data obtained from participant 104 demonstrate
remarkably stable response rates across trials 3 through 7. This participant’s responding stabilized at approximately 100 RPM under both video and reduce time reinforcement components. As such, within the sixth trial (FR 64) this participant was accessing one reinforcer following a response run of approximately 40 s. Transitioning into the seventh trial (FR 128) while maintaining a constant rate of responding would thus result in access to reinforcement following approximately 80 s of responding. In other words, in the time it took participant 104 to complete one schedule requirement in the seventh trial, this participant could have both completed a schedule requirement AND watched a resulting 30 s video clip within the sixth trial. Without increasing rate of responding, defense of consumption could not be achieved.

In the event that the current data represent ceiling effects in response rates, defense of consumption would be nearly impossible to achieve under increasing response requirements. However, all participants within Low UP group did decrease rate of responding to some degree across sessions. Additionally, during the final two trials one participant (102) dramatically increased responding under the video reinforcement condition and successfully defended stable levels of consumption. These findings support the conclusion that demand for these reinforcers indeed became more elastic with increases in unit price for the remaining Low UP group participants.
Data from High UP group lend further support to the conclusion that demand for video and reduced time became more elastic at higher unit price values. All participants in High UP group demonstrated either relatively stable (110 and 112) or decreasing response rate with increases in unit price, thus resulting in reduction of consumption proportionally greater than unit price increases. Similarly, across-groups visual analyses of demand curves constructed from average consumption data revealed greater reductions in consumption at FR64 and 108 within High UP group. These data suggest behavioral momentum effects related to greater density of reinforcement within Low UP group increased response persistence under increasing unit price values. These findings also demonstrated that reduction in consumption within High UP group were not due to time constraints alone.

Findings demonstrate increased elasticity of demand at high unit price values. Additionally, examination of EV estimates across participants and reinforcement conditions revealed values consistent with combined observations from response rate analyses, $Q_0$ and $\alpha$ estimates, and variations in $k$ across reinforcers. Taken together, findings from Experiment 1 support the utility of behavioral-economic and exponential demand analyses in EAHB.
Experiment 2

Findings from Experiment 1 support the utility of behavioral-economic and exponential demand analyses of responding and consumption of reinforcers in EAHB. Experiment 1 assessed responding and consumption under single-schedule arrangements for either access to video or reduced in-session duration. The aim of Experiment 2 was to extend analyses from Experiment 1 to consumption of reinforcers under concurrent-schedules arrangements. Throughout Experiment 2 participants completed two experimental sessions across two lab visits, one session during each visit. Session arrangements included both 30 s video clip(s) and 5 s reduction(s) from session time plus 30 s blackout period within each trial. In

Method

Participants

Three participants from Experiment 1 (104, 106, and 113) volunteered to attend a third session under Experiment 2 concurrent-schedules arrangements. Each of these participants completed an FR sequence identical to the sequence he or she experienced during single-schedule arrangements within one concurrent-schedules session. Data from these participants’ sessions provided for direct comparison of responding and consumption across reinforcers under single- and concurrent-
schedules arrangements. Eleven novel participants (eight males; three females) completed participation in Experiment 2. Table 1 displays initial response requirements arranged for each participant across Sessions 1 and 2 (further explained below). Three additional participants did not complete the second session of Experiment 2 and were thus excluded from final data analyses.

**Procedures**

Instructions provided to participants throughout Experiment 2 were similar to those previously described in Experiment 1 (Figure 4), with the exception that both programmed reinforcers were described within one instruction frame. The experimental program implemented reinforcement procedures for each reinforcer identical to those previously described in Experiment 1.

Arrangement of PR sequences within session occurred as described in Experiment 1. Throughout Experiment 2 both initial FR response requirements arranged within Experiment 1 (i.e., FR2 and FR8) were employed such that a given participant might experience both PR sequences across sessions, or one PR sequence replicated across both sessions (Table 1). This design allowed for replications across multiple FR values while also providing for exposure to all FR arrangements among a subset of participants.
During each session concurrent-schedules of reinforcement arranged for the two programmed reinforcers available across response options (Figure 1). Clicking one response option resulted in the alternative response option becoming deactivated until the current schedule requirement was completed. The experimental program randomized placement of the two response frames upon initiation of each new response opportunity. That is, at the start of each trial and following each reinforcement period either video or reduced session time might be available in the left response frame, with the other reinforcer available in the right response frame.

**Data analysis**

Experiment 2 arranged for exposure to PR sequences across sessions in four related designs, with initial FR values beginning at either FR2 or FR8 during a given session. For organization purposes while conducting analyses and describing results, Experiment 2 participants were grouped and referenced according to the order of initial FR values to which they were exposed: Both PR sequences with an initial FR2 (group 2-2); both initial FR8 (group 8-8), Initial FR8 during Session 1 and FR2 during Session 2 (group 8-2); and Initial FR2 in Session 1 and FR8 in Session 2 (group 2-8).

As in Experiment 1, the primary investigator first analyzed data obtained within Experiment 2 for rate of responding within participants across FR trials.
This analysis additionally included proportion of responding allocated across reinforcer options. The primary investigator then conducted analyses of exponential demand in similar manor as described for Experiment 1. Best-fit values of $Q_0$, $\alpha$, and $k$ provided for input within Equations 2 and 3 to calculate $P_{\text{max}}$, $O_{\text{max}}$, and EV. The primary investigator then plotted work functions as actual work output and predicted work output for each participant, graphed according to participation group.

As described in Experiment 1, the primary investigator let data remain unadulterated with no-consumption trials excluded from exponential demand analyses and logarithmic transformations (Hursh, 2016; Madden, Bickel, & Jacobs, 2000). Additionally, within Experiment 2 participants had the option of working for either of the two programmed reinforcers across multiple opportunities within each FR trial. As described in Experiment 1, within a 15-min trial it would not be possible for maximum consumption to exceed 30 obtained reinforcement periods. Therefore, data analyses conducted within Experiment 2 again constrained $Q_0$ to consumption of 30 reinforcers (Reed, 2016). Related to this constraint on $Q_0$, under concurrent-schedules arrangements consumption of each reinforcer is inextricably tied to consumption of the other reinforcer in that total unconstrained consumption must be allocated across options. At $Q_0$, increasing consumption of one reinforcer must necessarily result in decreasing consumption of the other (i.e., one cannot
consume both reinforcers simultaneously). Therefore, the primary investigator conducted initial exponential demand analyses comparing models across groups by averaging total consumption of reinforcers (both video and time) across unit price values.

**Results**

**Response Rate and Choice**

The primary investigator initially analyzed participants’ average rate of responding across FR trials. As in Experiment 1, rate of responding was calculated for RPM by dividing total responses to a given response option by the total duration the respective response option was available. Throughout Experiment 2 responding to one option rendered the alternative option unavailable for the remainder of the current-schedules requirement. As such, following the first response within a schedule requirement only the selected response option was counted towards response-rate calculations. Throughout this analysis the primary investigator additionally analyzed allocation of responding across reinforcer options (i.e., choice).

Figure 11 displays rate and proportion of consumption across reinforcer options in the three participants who formerly completed Experiment 1. Participant 104 engaged in rates of responding nearly identical to those observed during Experiment 1 sessions. That is, across the first three trials participant 104 engaged
in decreasing rates of responding, followed by stable levels of responding across all remaining trials. Throughout all concurrent-schedules trials participant 104 responded exclusively for video with only one exception occurring during the first trial.

Overall rate of responding in participant 106 (Figure 11) under concurrent-schedules arrangements was similar to those observed in Experiment 1 across single-schedule sessions. Participant 106 initially responded at high rates across both reinforcement options during the first trial (FR2), allocating two-thirds of responding to the video option. Across the next three trials participant 106 engaged in responding at steadily decreasing rates while allocating responses almost exclusively to time. During the fifth trial participant 106 engaged in nearly equivalent rates of responding across response options, allocating choice equally to both reinforcers. During the sixth trial participant 106 allocated responding exclusively to video, and subsequently ceased responding in the final trial (FR128). Interestingly, when compared with data obtained during Experiment 1 under single-schedule arrangements, concurrent-schedules response rates and allocation of choice within FR32 and FR64 trials were strikingly similar. Under identical response requirements across single-schedule sessions responding for video maintained while responding for time declined, and eventually ceased during the final session.
Participant 113 experienced PR-schedule requirements beginning at FR8 (Figure 11). Rate of responding in participant 113 across concurrent-schedules trials was similar to responding observed during Experiment 1 across single-schedule sessions. Allocation of choice among reinforcers observed in participant 113 across concurrent-schedules trials was variable. Initially, during the FR8 trial participant 113 allocated consumption of reinforcement at nearly equal proportions for both video and time. During the second trial participant 113 responded exclusively to the video option, reverting back to nearly equal proportions during the third trial. During the fourth and fifth trials this participant responded exclusively for video and time, respectively. No responding occurred during the final two trials (FR256 and 512).

Figures 12 – 15 display response rates and proportion of choice across reinforcers for participants within groups 2-2, 8-8, 8-2, and 2-8, respectively. Session 1 data are depicted in the left column of each graph, with Session 2 data presented in on the right. Within group 2-2 (Figure 12), participant 208 responded at high and stable rates across trials and sessions, with the exception of the first trial of Session 2 during which rate of responding greatly increased. Across trials and sessions participant 208 allocated responding exclusively for video across trials and sessions, again with the exception of the first trial of Session 2 during which time was selected once.
During Session 1, participant 209 (Figure 12) engaged in responding at decreasing rates across trials, nearing stability during the final three trials of Session 1. Throughout Session 1 across all trials, participant 209 allocated responding primarily for video, accessing time at relatively small proportions within each trial. During the final trial of Session 1 (FR128) participant 209 initiated responding for time but ceased responding before completing the schedule requirement, thus not accessing time reinforcement during this trial. Response patterns observed in participant 209 throughout Session 2 were similar to those observed during Session 1. Exceptions include nearly equal choice proportions across reinforcers during the second trial, and an absence of responding for time during the fifth (FR32) and seventh (FR128) trials.

Participant 210 (Figure 12) engaged in stable overall-rates of responding across all trials during both sessions. Interestingly, this participant allocated choice of reinforcers nearly exclusively toward video during the first five trials of Session 1. The during the final two trials of Session 1, participant 210 exclusively responded for time. During Session 2 participant 210 continued responding for time almost exclusively with the exception of the first trial, in which video was selected approximately one-third of choice opportunities.

Within group 8-8 (Figure 13), participant 202 engaged in nearly stable rates of responding across trials and sessions, with a slight decreasing trend observed
within sessions. Across the first five trials of Session 1, participant 202 allocated choices at higher proportions for video than for time reinforcement. During the sixth trial of Session 1 (FR256) participant 202 reversed choice allocating nearly two-thirds of responding to time. During the final trial of Session 1 this participant allocated choice equally across reinforcers. Participant 202 showed similar patterns of responding during Session 2, with the exception that exclusive responding for video was observed during the third, fifth, and sixth trials.

Data from participant 203 (Figure 13) show slightly decreasing rates of responding across the first six trials of Session 1, with responding dropping out during the seventh trial. Throughout Session 1 participant 203 responded almost exclusively for video across the first five trials, with the exception of some limited choice allocated to time during the first and fifth trials. During the sixth trial (FR256) participant 203 allocated choices equally across reinforcers. At the start of the seventh trial (FR512) participant 203 initiated responding for time, but subsequently stopped responding without completing any FR-schedule requirements. Participant 203 allocated choice during Session 2 exclusively to video reinforcement with the exception of the second trial, in which a very small portion of choice opportunities were allocated to time. During the fifth trial participant 203 initially began responding for video, but ceased all responding after accessing one reinforcer. Interestingly, during the sixth and seventh trials of
Session 2 participant 203 initiating responding for time and video, respectively, but ceased responding prior to completing any schedule requirements. As such, this participant contacted no reinforcement during the final two trials of Session 2.

Data obtained from participant 205 (Figure 13) were similar to those described for participants 203. Throughout Session 1, rate of responding continued along a slightly decreasing trend, with more pronounced decline observed following the sixth trial. Throughout Session 1 participant 205 allocated choice primarily to video. Indeed, during the fifth (FR128), sixth (FR256), and seventh (FR512) trials participant 205 chose video exclusively. During the first four trials of Session 2 participant 205 engaged in response rates similar to those observed during Session 1. However, responding during the final three trials of Session 2 decreased significantly, with no reinforcement obtained during the fifth (FR128) and seventh (FR512) trials. During the first trial of Session 2 participant 205 chose time on nearly two-thirds of choice opportunities. Proportion of reinforcer selection reversed during the second trial in favor of video. Thereafter participant 205 continued to choose video to the near exclusion of time across trials.

Participants in group 8-2 (Figure 14) experienced two different PR sequences across sessions. Session 1 initiated at FR 8 and Session 2 initiated at FR2. Data from participant 204 show similar trends in overall response rates across both sessions, progressing on a decreasing trend across trials. During the first and
second trials of Session 1 participant 204 allocated responding primarily for video, with only a small proportion of choice opportunities going to time. Preference then reversed during the third through the sixth trials, with choice of time proportionally higher than video. During the seventh trial (FR512) participant 204 again reversed preference responding exclusively for video. During Session 2 participant 204 allocated the greatest proportion of choice opportunities to time across all trials. Indeed, choice for time was exclusive throughout the fifth (FR32), sixth (FR64), and seventh (FR128) trials. Incidentally, these three trials corresponded to FR values presented during the third, fourth, and fifth trials of Session 1, in which choice of reinforcer switched in favor of time.

Participant 213 (Figure 14) engaged in fairly stable rates of responding across sessions and trials with the exception of the first trial in Session 2 (FR2) during which RPM increased significantly. Participant 213 chose video exclusively across sessions and trials with the exception of one choice opportunity allocated for time during the first trial of Session 1 (FR8). Data obtained from participant 215 (Figure 14) were somewhat unique for two reasons. First, during Session 1 (FR8 – 512) participant 215 chose time exclusively across all trials. However, during Session 2 (FR2 – 128) participant 215 reversed preference, selecting video exclusively across all trials. Data obtained from participant 215 were also unique in that rate of responding increased within Sessions 1 and 2 across trials. During the
final three trials of Session 1 (FR 128 – 512) response rates observed in participant 215 were nearly three times higher than those observed in any other participants. The one notable exception to this observation was participant 102 from Experiment 1. Participant 102 was the only participant from Experiment 1 observed to defend levels of reinforcer consumption throughout the video condition, engaging in dramatically higher rates of responding within FR64 and FR128 trials.

Finally, participants within group 2-8 (Figure 15) were also exposed to two different PR sequences. Session 1 initiated at FR 2 and Session 2 initiated at FR8. Within Session 1 across trials participant 206 engaged in response rates on a generally decreasing trend. During the first four trials of Session 1 (FR2, 4, 8, and 16) participant 206 allocated choice primarily toward video, with only a small proportion of time selected during the first and fourth trials. During the final three trials of Session 1 (FR32, 64, and 128) participant 206 reversed preference, selecting time nearly exclusively. During Session 2 participant 206 responded on a generally decreasing trend across the first through fourth trials, increasing rate of responding during the fifth trial. Responding dropped to low-to-zero rates across the final two trials of Session 2 (FR256 and 512).

Participant 207 (Figure 15) engaged in overall rates of responding within Session 1 on a slight decreasing trend across trials. Throughout Session 1 participant 207 allocated responding primarily to video. Video was exclusively
selected during the fifth and sixth trials of Session 1. Similar responding was observed in participant 207 throughout Session 1 with the exception that no response requirements were completed during the final two trials (FR256 and 512).

**Demand and Essential Value**

*Q₀ and k values.* As described previously in Experiment 1, the primary investigator conducted extra sum of squares F-tests to compare expected Q₀ and α values across group average consumption of reinforcement. To reiterate, while variations in α across groups are to be expected under conditions in which groups are exposed to different unit price ranges, these differences should not translate into expected differences across estimated Q₀ values. For example, group 2-2 participants were exposed to a maximum of FR128 across both sessions, while group 8-8 participants were exposed to two trials exceeding this value (i.e., FR256 and FR512) during each session. If it was the case that consumption of reinforcement decreased at levels proportionally greater than concomitant price increases at high unit price values, investigators should expect variations in estimated α values across these two groups. However, best-fit models across groups should not predict differences in expected Q₀. While increased elasticity of demand was expected to occur at higher unit price values, predicted unconstrained consumption should not differ across groups.
Figure 16 displays exponential demand models for consumption of reinforcement across the four participant groups. Results from extra sum of squares $F$-tests did reveal significant differences in $\alpha$ across groups, $F(3, 21) = 55, p < .0001$ (group 2-2 $\alpha = 0.00014$; group 8-8 $\alpha = .00016$; group 8-2 $\alpha = .000082$; group 2-8 $\alpha = .00016$). These results suggest that group 8-2 demand was slightly less elastic than the remaining groups. Extra sum of squares $F$-tests applied to $Q_0$ revealed no significant differences in consumption of reinforcement across groups, $F(3, 21) = 0.63, p = 0.301$ (group 2-2 $Q_0 = 27$; group 8-8 $Q_0 = 26$; group 8-2 $Q_0 = 27$; group 2-8 $Q_0 = 29$). These findings suggest unconstrained consumption of reinforcement was similar across groups.

As described in Experiment 1, establishing comparable exponential demand models within an experimental arrangement across participants or groups requires that investigators determine a best-fit value of $k$, range of reinforcer consumption, as a fixed parameter within the exponential model of demand. Demand models described for comparison across group average reinforcer consumption provided for a best-fit $k$ value across all groups. Consistent with this estimated value, the primary investigator conducted all subsequent Experiment 2 analyses of video and time exponential demand models with $k$ equal to 1.7.

**Exponential demand.** The primary investigator constructed exponential demand models for individual participant consumption data, as well as
consumption averaged across all participants. Within Experiment 2, participants were exposed to concurrently-available reinforcement options across all trials. Consistent with Experiment 1, the primary investigator constructed all demand models according to unit price per reinforcement period (i.e., FR schedule requirement).

Figure 17 displays graphs of consumption of both video and time within each participant. Graphs contain inset $Q_0$, $\alpha$, and $R^2$ values corresponding to each reinforcer. Table 4 provides adjusted EV, $P_{\text{max}}$, and $O_{\text{max}}$ values calculated according to Equations 2 and 3 for each model. Data obtained from participants 104, 208, and 213 did not allow for calculation of exponential demand models of time reinforcement due to zero consumption across multiple trials. Table 4 therefore contains no adjusted EV, $P_{\text{max}}$, and $O_{\text{max}}$ values corresponding to time for these participants. Figure 18 displays actual and predicted work output calculated from consumption data across video (left column) and time (right column) reinforcers for all participants within each group.

Within the group of participants carried over from Experiment 1, participant 104 consumed time reinforcement on only one choice opportunity (Figure 17). Video consumption in this participant remained high across unit price values. Consistent with this finding, $P_{\text{max}}$ of video in participant 104 was estimated at 120.17, nearly the highest unit price value assessed in this participant (Table 4).
Participant 106 allocated consumption of reinforcers variably across unit price values resulting in an inverted demand curve for video and low EV (8.35) and $P_{\text{max}}$ (30.04) for time.

Participant 113 data reveal this participant demonstrated highly variable consumption across trials, consuming two time reinforcers during the first and third trials and one during the fifth trial (Figure 17). This participant did not consume any time reinforcement during the second, fourth, sixth, or seventh trials. With a $Q_0$ value of only 4.8 and an $\alpha$ of 0.0011, estimated EV and $P_{\text{max}}$ were 5.78 and 198.95, respectively (Table 4). The unusually high $P_{\text{max}}$ estimate was obtained as a result of artificially low elasticity. Under this demand model, estimated $P_{\text{max}}$ is expected to occur at consumption of only 0.71 reinforcers. Although estimated $P_{\text{max}}$ was unusually high for this participant, the low EV of 5.78 lends credibility to the proposition that EV may be a more reliable index of reinforcer value.

Within group 2-2, participant 208 consumed time reinforcement on only one choice opportunity at low unit price (Figure 17). Video consumption in this participant remained high across all unit price values, with $P_{\text{max}}$ of video equal to 120.17 (Table 4). Exponential demand models for participant 209 reveal fairly stable levels of consumption predicted across reinforcers, with video consumed at much higher levels than time. However, due to variability in time consumption across unit prices the exponential model for this reinforcer resulted in very poor fit
Exponential demand models for the final participant in group 2-2, participant 210, reveal consistent levels of consumption across reinforcers at relatively low price with $Q_0$ estimates of 15.0 for video and 13.8 for time. However, consumption of time continued across greater unit price values, resulting in higher EV for this reinforcer (time = 37.60; video = 12.53).

Within group 8-8 participant 202 consumed much more video at low unit price values ($Q_0 = 24.0$) than time ($Q_0 = 2.0$). Consumption of video decreased quickly with increases in unit price, resulting in $P_{\text{max}} = 106.22$ and $\text{EV} = 32.23$. Variable consumption of time across unit price values in participant 202 resulted in a poor fit of the exponential demand model, with $R^2 = 0.52$. Participant 203 in group 8-8 also initially consumed more video at low unit price values ($Q_0 = 22.5$) versus time ($Q_0 = 2.5$) with consumption of video decreasing rapidly across unit price increases. Similar to the exponential demand model previously described for participant 113, the corresponding model for participant 203 estimates an unusually high $P_{\text{max}}$ value of 202.79. However, as was the case with participant 113, this $P_{\text{max}}$ value is somewhat deceptive in that predicted consumption at this price would be roughly 0.5 reinforcers. Again in this case EV (4.10) provides for a better index of low reinforcer value for time in participant 203. Exponential demand models for both video and time in participant 205 demonstrate initially high levels of consumption at low unit price (video $Q_0 = 18.0$; time $Q_0 = 19.9$). Demand for time
however appears to be much more elastic than demand for video in that consumption of video persists across greater unit price values (video $P_{\text{max}} = 90.13$; time $P_{\text{max}} = 10.44$). Consistent with these observations EV estimates for participant 205 are actually greater for video (EV = 20.51) than for time (EV = 2.51).

Within group 8-2, participant 204 consumed both reinforcers at somewhat variable levels across unit price values resulting in reduced fit of the exponential demand models (video $R^2 = 0.63$; time $R^2 = 0.78$). Participant 204 initially consumed video at higher levels than time with $Q_0$ values estimated at 30.0 and 15.0, respectively. However, consumption of video decreased to a much greater degree than that of time with unit price increases, resulting in much lower EV of video (3.47) than time (26.54). Participant 213 consumed high levels of video across sessions to the near exclusion of time. As such, no exponential demand model could be constructed for time. Consumption of video in this participant remained fairly high across unit price values, providing the highest EV of video across all participants (EV = 53.08). Data obtained from participant 215 demonstrate high and stable rates of consumption for both video and time. Recall that this participant also engaged in increasing rates of responding within sessions across trials. In line with these observations, Equations 2 and 3 provide for relatively high values of EV (video = 34.70; time = 63.54) and $P_{\text{max}}$ (video = 137.27; time = 359.06) in this participant.
Group 2-8 included two participants, 206 and 207. Participant 206 initially consumed high levels of video at low unit price values with consumption decreasing rapidly across unit price values. Consistent with these observations the exponential model for video in participant 206 estimates $Q_0$ at the maximum value of 30.0, with low $P_{\text{max}}$ (10.82) and EV (4.10) suggesting limited value across unit price increases. Due to the very low levels of time consumption at low unit price in participant 206, followed by high levels of consumption at higher unit price values, the exponential demand model constructed for time reinforcement was a very poor fit ($R^2 = 0.04$). However, as might be expected given the increasing consumption of time at higher unit price values, the model did predict relatively high EV (45.12) and $P_{\text{max}}$ (419.89) values for this reinforcer. Participant 207 consumed video reinforcement to the near exclusion of time across sessions. Exponential model constructed for this participant reveal high levels of initial consumption of video ($Q_0 = 27$) declining slowly across unit price increases. Estimated EV for video in this participant was relatively high (32.23) with $P_{\text{max}}$ estimated at 94.42.

As discussed in Experiment 1, when considering potential reinforcement arrangements within the context of EAHB investigators seldom enjoy the luxury of limitless resources and boundless time in which to individually identify and assess reinforcers for a given participant. It is therefore of value to investigators to understand likely effects of reinforcement across multiple participants in EAHB
arrangements. The primary investigator therefore applied the exponential model of demand to levels of consumption averaged across all Experiment 2 participants for both video and time. These models suggest that participants will consume more video than time at low unit price values under the current arrangements (video $Q_0 = 21.0$; time $Q_0 = 6.2$). However, demand for video became elastic to a greater degree with unit price increases resulting in lower estimated $P_{\text{max}}$ for video (94.42) than for time ($P_{\text{max}} = 279.93$). Despite the greater $P_{\text{max}}$ for time, higher initial levels of video consumption combined with converging levels across reinforcers at high unit price values resulted in greater estimated EV for video (32.23) than for time (5.31).

Figure 18 display graphs depicting work output across all participants. In general, participants exposed to lower unit price values tended to demonstrate monotonic work functions increasing steadily across unit price increases. These patterns of responding are expected given relative inelasticity of demand. However, those participants exposed to greater unit price values tended to demonstrate bitonic work functions. Total responding in these participants increased initially at lower unit price values prior to leveling and subsequently decreasing at high unit price. These patterns of responding would be expected as demand becomes more elastic in the face of increasing unit price.

It should be noted that work functions produced from group 2-8 data may be slightly deceiving. Recall that the current data analysis procedures did not adjust
for zero consumption values. Participants within group 2-8 responded across all trials during Session 1 (i.e., through FR2 – 128). However, within Session 2 these participants responded only through the fifth trial. When exposed to response requirements exceeding those of Session 1 (i.e., FR256 and 512) these participants ceased responding altogether. In excluding zero-consumption data, this procedure gives the appearance of monotonic work functions across unit price values contacted within Session 1. However, zero-consumption data across the two highest unit price values during Session 2 would suggest dramatically decreasing work functions (near zero output).

**Experiment 2 Discussion**

General trends in response rate across participants completing concurrent-schedules arrangements (including three participants carried over from Experiment 1) showed that nearly all participants decreased overall rate of responding to some degree with increases in response requirement. Participant 215 being the notable exception to this trend, showing increasing rate of responding markedly across PR requirements within both Sessions 1 and 2. Of the 14 total participants (11 novel; three from Experiment 1) eight participants demonstrated preference for video reinforcement, selecting this option to a greater proportion of time across sessions. Three participants demonstrated preference for time reinforcement, choosing this option a greater proportion of opportunities across session over video. The
remaining three participants did not show clear preference for either video or time as determined by proportion of choice allocation.

In considering the escalated response rates in participant 215, it is important to note that this participant accessed reinforcement at higher levels within each session than all other participants. As a result, within Session 1, while responding exclusively for time this participant accumulated a total of 10 min and 10 s of session reduction. Additionally, informal session logs collected by lab members report that this participant demonstrated some difficulty with the English language, asking multiple questions regarding the on-screen instructions prior to initiating session. Indeed, closer inspection of raw data obtained during Session 1 revealed this participant spent nearly 15 min on the initial instruction screen prior to initiating session. Taken in combination with the escalated levels of reinforcer access (and concomitant session reductions), the final trial of Session 1 presented to participant 215 was cut short by approximately 10 min. Following some consideration, the primary investigator decided not to exclude these data from analyses on the grounds that they represent such unique levels of responding. That this participant was able to respond at increasing rates within session across trials seems important enough to warrant presentation. Despite the fact that consumption of time was artificially reduced during the final trial of Session 1 due to trial duration being cut short, this participant nevertheless achieved the highest EV
observed across participants for time reinforcement \( (EV = 63.54) \). This finding lends additional support to the proposition that EV calculated from the exponential model of demand may provide for a reliable index of reinforcer value across experimental arrangements.

Exponential demand models constructed from consumption data averaged across participants provided higher EV for video than for time under Experiment 2 concurrent-schedules arrangements. These findings are interesting when compared to those of Experiment 1. Recall from Experiment 1 that estimated EV and \( P_{max} \) were greater for time than for video under single-schedule arrangements. While participants in Experiment 1 tended to consume more video \( (Q_0 = 29.00) \) than time \( (Q_0 = 26.00) \) at low unit price values under single-schedule arrangements, consumption of time persisted to a greater degree with increases in unit price value. This general pattern of consumption held true under concurrent-schedules arrangements. However, as previously discussed consumption of both reinforcers under concurrent-schedules arrangements are inextricably tied in that increased consumption of one reinforcer must result in decreased consumption of the other at \( Q_0 \). Therefore, greater levels of video consumption at low unit price values resulted in much lower levels of time consumption at low unit price values. Under the current experimental arrangements average consumption of video and time converged at higher unit price values, but did not reverse. Thus the demand curve
constructed for video remained higher than that for time across unit price values, producing greater EV for video than for time.
Experiment 3

Experiments 1 and 2 extended the application of behavioral-economic methods and measures to the assessment of reinforcement and consumption in EAHB. Experimental arrangements assessed participants’ consumption of video and reduced session duration reinforcement under PR-schedule requirements (i.e., increasing unit price). Experiment 3 further extends previous behavioral-economic investigations of reinforcement arrangements (Madden, Bickel, & Jacobs, 2000) by assessing three economic predictions of unit price in humans responding for video access alone under choice arrangements. Three predictions of unit price include: 1) total consumption (i.e., video duration watched) summed across concurrent schedules should be a positively decelerating function and total response output should be a bitonic function of unit price; 2) total consumption and response output should be determined by value of unit price ratio, independent of cost-benefit components; and 3) when a reinforcer is available at the same unit price across all sources of reinforcement, consumption should be equal between sources independent of cost-benefit ratio. Experiment 3 assessed these predictions across multiple unit price cost-benefit arrangements for varying duration of video.
Method

Participants

Experiment 3 final analyses included data obtained from 20 participants (15 males; five females). Four participants did not complete the second session of Experiment 3 and were excluded from final data analyses. Additionally, the primary investigator discovered an error had occurred within the pre-experimental settings of Session 2 for one participant; this data set was also excluded from analyses.

Procedures

At the start of each session the experimental program displayed instructions similar to those described for Experiment 1 (Figure 4). Exact instruction text was presented as follows:

"During this session you will have the opportunity to watch segments of your selected video. Throughout all trials you will be able to earn access to video clips on either the LEFT or RIGHT response option. The number of button clicks required to watch video and the number of seconds of video available will be written over each button frame. The amount of work required to earn video on each option may change for each trial. During each trial, you may work as much or as little as you want for each option. Click the 'Begin Session' button to start the first trial."
Concurrent-schedules. Investigators modeled concurrent-choice and unit-price arrangements after those arranged by Madden, Bickel, and Jacobs (2000). Table 5 presents all concurrent-schedule arrangements randomized across sessions and trials. Across two lab visits, participants completed two experimental sessions; one session during each visit. Within each session, eleven 10-min trials consisted of concurrent FR schedules for access to video reinforcement. Prior to initiating Session 1, the experimental program randomized unit price and cost-benefit arrangements such that each comparison (Table 2, Trials 1–22) was presented once across sessions. Concurrent-schedules arrangements assessed participant responding under both unequal and equal unit price arrangements. Investigators calculated unit price values for video according to the range achieved during Experiment 1 under the initial-FR8 sequence. Three video durations (30s, 60s, and 90s) were incorporated across trials and cost-benefit ratios.

Investigators assessed preference across unequal unit price under three overarching arrangements: a) fixed video duration obtained at high versus low FR values (Table 2, Trials 1 & 2), b) fixed FR value for longer versus shorter video duration (Table 2, Trials 3 & 4) and c) video duration and FR value both varying between alternatives (Table 2, Trials 5–9). Responding between high versus low FR (a) and longer versus shorter video duration (b) was assessed at the lower and upper ranges of unit price achieved during Experiment 1, initial-FR8 sequence.
These arrangements tested for systematic variations in preference for lower FR or longer video duration at high versus low unit price. During all other unequal trials, concurrent-schedules arrangements incorporated unit price values at a ratio of 1:2 across response options. Unit price values during these trials corresponded to the three middle values achieved during the Experiment 1 PR sequence.

During equal-unit-price trials, participants chose between response alternatives with different video duration (30s vs. 60s, 30s vs. 90s, or 60s vs. 90s) and different response requirement resulting in equivalent unit price values (Table 2, Trials 10 – 22). Investigators selected to include throughout these trials five unit-price values from the range achieved during the Experiment 1 PR sequence. Unit-price values corresponded to FR 8, FR 32, FR64, FR128, and FR512.

**Data Analysis**

Experiment 3 extended previous investigations of economic predictions of unit price to the consumption of video reinforcement. Across two sessions, investigators arranged for exposure to 22 concurrent-schedules arrangements assessing choice and consumption of video across multiple unit prices and cost-benefit components.

Similar to Experiments 1 and 2, the primary investigator conducted analyses of exponential demand utilizing the Exponential Model of Demand Analysis
Template previously described (Hursh & Roma, 2014). Experiment 3 provided participants response-contingent access to three possible durations of video across response requirements and trials. Access to video at all durations occurred as one continuous, uninterrupted video clip. In order to standardize calculation of consumption across trials and unit-price arrangements the primary investigator calculated consumption as total seconds-of-video consumed within a trial.

As previously described, Experiment 3 arranged for assessment of choice and consumption under concurrent-schedules of both equal and unequal unit price. Within unequal unit-price arrangements it was possible that participants might respond to both response options throughout the duration of the trial. When this occurred, the primary investigator calculated within-trial obtained unit price by dividing total responses by total seconds of video consumed. Within equal unit-price arrangements obtained unit price was always the prearranged unit price value regardless of response allocation. The primary investigator calculated consumption of video under each obtained unit price value averaged across trials.

The primary investigator conducted all analyses of consumption within Experiment 3 under the constraint that $Q_0$ could not exceed the total duration of a given trial. As such, $Q_0$ for all models could not exceed 600 total seconds. Also consistent with Experiments 1 and 2, construction of exponential demand models excluded no-consumption trials (Hursh, 2016; Madden, Bickel, & Jacobs, 2000).
Prior to conducting analyses of individual consumption data the primary investigator first determined a within-experiment fixed value of $k$, range of consumption, for application to all exponential models by constructing an exponential demand model of average consumption across all participants. The best-fit exponential demand model constructed for average consumption across all participants provided a good fit to the data, explaining a large portion of variance ($R^2 = 0.98$, $Q_0 = 527$, $\alpha = 0.00014$, $k = 2$). Individual best-fit values of $Q_0$, and $\alpha$, provided for calculation of $P_{\text{max}}$, $O_{\text{max}}$, and EV as described by Equations 2 and 3.

The primary investigator plotted work functions as actual work output and predicted work output for each participant. Additionally, the primary investigator analyzed and plotted proportion selection across response options during equal and unequal unit price arrangements, as well as sensitivity to high versus low response requirements and longer versus shorter video durations.

**Results**

**Economic predictions of unit price**

The first economic prediction of unit price states that consumption of a reinforcer should be a monotonic function of unit price such that consumption decreases as unit price increases. Additionally, work output should be a bitonic function of unit price such that increases in unit price initially produce increased
responding at lower unit price values, with subsequent decreases in responding at
greater unit price as demand becomes elastic.

In an effort to provide for visual analyses of individual data across all 20
Experiment 3 participants without significant decrements in graph size and
readability, the primary investigator divided participants into groups of four across
five separate figures. Figures 19 through 23 present exponential demand models
and work output functions for all participants. Each figure presents individual data
for four participants, grouped in sequential order by participant number. The left
column of each figure depicts consumption and exponential demand models, with
inset values of $Q_0$, $\alpha$, and $R^2$ provided. The right column depicts actual work output
and predicted output.

The left columns of Figures 19-23 show that for all participants,
consumption of video was a positively decelerating function of unit price. That is,
across all participants, consumption of video decreased as unit price of video
increased. Equation 1 provided a good fit across individual consumption data
despite variations in level of consumption and slope of demand (average $R^2 = 0.93$,
$SD = 0.043$). The Right columns of Figures 19-23 show that work output tended to
increase with increases in unit price at lower unit price values across all
participants. Though specific price varied across participants, for each participant a
price was eventually reached at which point work output began to decrease.
The second economic prediction of unit price states that total amount of a reinforcer consumed is determined by unit price, independent of cost-benefit components of the unit price ratio. Experiment 3 tested this prediction via assessment of consumption across four equal-unit-price conditions (see Table 5). Equal unit price trials consisted of concurrent-schedules in which FR-schedule requirement (cost) and video duration (benefit) varied across response options. The experimental arrangement assessed consumption of video under each equal unit price value across three trials varying cost-benefit options.

Figure 24 depicts consumption of video in total seconds across equal unit price trials. For all participants, consumption of video tended to be very similar across trials of equal unit price consisting of different cost-benefit components. Consumption at the highest unit price value assessed differed slightly in that 15-of-20 participants consumed small amounts of video during at least one of the three trials, but not all trials. Four participants consumed no video across all three trials in which the highest unit price value was assessed. Only one participant (323) consumed video across all three trials in which the highest unit price value was assessed. As a whole, similar consumption across cost-benefit components of equal unit price value support the second economic prediction of unit price.

The second economic prediction of unit price, that consumption is determined by unit price independent of cost-benefit components, predicts that
consumption across response options within a given equal unit price trial should show indifference. That is, if consumption is determined by unit price independent of cost-benefit components, participants should not show preferential consumption across concurrently-available equal-unit-price options. The primary investigator assessed this aspect of the second prediction of unit price by calculating average proportion of consumption across response options during equal unit price trials. Figure 25 displays proportion of consumption allocated to either the smaller FR-schedule requirement for shorter video duration (left) or the larger FR-schedule requirement for longer video duration. The top graph shows that participants consumed approximately equal proportions across response options when consumption is averaged across all unit price values. As previously described, Experiment 3 arranged for assessment of consumption at four equal unit price values. The middle graph of Figure 25 shows proportion of consumption allocated to the smaller and the larger FR requirements across the two highest equal unit price values assessed. The bottom graph of Figure 25 shows proportion of consumption allocated to the smaller and larger FR requirements across the two lowest equal unit price values assessed. These data revealed participants did in fact display preferential responding across response options under equal unit price arrangements. When unit price was low, participants preferred to respond on the relatively-larger FR requirement for longer video duration; however, when unit price was high, participants switched preference to the relatively-smaller FR
requirement for shorter video duration. The second economic prediction of unit price does not account for such preferential responding.

The third economic prediction of unit price states that individuals should prefer lower unit price over higher among response alternatives. Experiment 3 assessed this prediction by exposing each participant to nine trials in which unit price varied across concurrent options. All participants demonstrated preferential consumption of the lower unit price alternative across the majority of these trials (mean = 7.05; range = 5 to 9). The primary investigator analyzed and graphed all consumption data by averaging consumption of video across participants, within respective unequal trial arrangements. Consumption is plotted as average proportion consumption across response alternatives. Figure 26 depicts proportion of consumption across alternatives when options included either matched FR requirements for different video duration (90 s or 30 s; unit price ratio 1:3), or matched video duration (30 s) across different FR requirements (unit price ratio 1:2). Figure 26 shows that, under high unit price arrangements all participants exclusively consumed video on the lower unit price option. Some small deviation from this pattern occurred under lower unit price arrangements.

Figure 27 depicts proportion of consumption across response alternatives when both video duration and FR requirements varied within a trial. Across all trials in which both cost and benefit components of the unit price ratio varied, unit
price was always presented at a ratio of 1:2. Figure 27 shows that participants tended to consume proportionally more video on the lower unit price, with some deviations. Unlike matched unequal unit price arrangements, exclusive consumption on the lower unit price option across all participants was not observed under any of the arrangements assessed. The greatest deviation from predicted consumption occurred under FR128 for 60 s (unit price 2.13) versus FR384 for 90 s (unit price 4.27), with only 76% of all consumption occurring on the lower unit price option. Within this arrangement, 12 participants demonstrated exclusive consumption of lower unit price video, while three participants demonstrated exclusive consumption on the higher unit price option. The third economic prediction of unit price does not account for such deviations.

Following assessments of the three economic predictions of unit price, the primary investigator conducted secondary analyses of EV, P_{max}, and O_{max} from Equations 2 and 3 across all participants. Table 6 presents these data for all participants, and for the exponential demand model constructed from average consumption across all participants. Across all participants, average EV = 28.13 (SD = 4.51), ranging from 20.80 to 37.61. When calculating unit price as number of responses per second of video, average P_{max} = 4.90 (SD = 1.01), ranging from 3.31 to 7.05. Video reinforcement appears to function as a reinforcer under the current arrangements, maintaining high levels of responding and consumption across unit
price values. Additionally, findings demonstrate the utility of applying the exponential model of demand to the analysis of a time-based reinforcer, calculating unit price as responses per second of access.

**Experiment 3 Discussion**

Experiment 3 extended previous assessments of economic predictions of unit price to participants responding for access to video within an EAHB arrangement. The first prediction of unit price states that consumption should decrease with increases in unit price for reinforcement. Additionally, work output should initially increase across unit price increases until a price is reached at which point work output begins to decrease. Findings from Experiment 3 support this prediction across all participants.

The second prediction of unit price states that level of consumption should be determined by unit price, independent of cost-benefit components. Again, findings from Experiment 3 supported this prediction in that consumption across equal-unit-price trials presenting varying cost-benefit arrangements at the same unit price tended to be very similar. However, findings also indicated that this prediction did not hold when analyzing within-trial consumption across response alternatives. Under low unit price values participants consumed proportionally greater amounts of video on the higher FR-longer video duration option. Conversely, under high unit price, participants consumed proportionally greater
amounts of video on the lower FR-shorter video option. The second economic prediction of unit price does not account for such preferential consumption. These findings replicate and extend those of previous investigators assessing consumption of cigarettes in adult smokers (Madden, Bickel, & Jacobs, 200).

The third economic prediction of unit price states that individuals should prefer the lower unit price option across unequal unit price alternatives. Findings from Experiment 3 support this prediction in that participants consumed proportionally greater amounts of video on the lower unit price option across multiple unit price arrangements. However, some deviation from this prediction occurred under lower unit price arrangements when either FR requirements or video duration were matched within a trial. Similarly, deviations occurred under arrangements in which both components of the cost-benefit ratio varied within a trial.
General Discussion

Investigators employed behavioral-economic methods and measures toward assessment of responding and consumption of reinforcers within EAHB arrangements across three experiments. The primary investigator analyzed data using an exponential model of demand across all experiments. Experiments 1 and 2 included analyses of participants’ rate of responding across reinforcers and response requirements. Experiment 1 extended previous behavioral-economic research using within-session single-schedule PR reinforcement arrangements to develop demand curves for reinforcers. Investigators assessed participants’ consumption of response-contingent access to video, as well as a novel reinforcement arrangement of in-session reductions in session duration. Experiment 2 extended procedures from Experiment 1 to concurrent-schedules reinforcement arrangements assessing consumption across both programmed reinforcers. Experiment 3 extended previous research assessing economic predictions of unit price to the assessment of consumption of video under choice arrangements.

Experiment 1

Findings from Experiment 1 generally indicated rate of responding across participants tended to decrease when response requirements increased. Decrements
in rate of responding were often less pronounced across higher FR values until responding ceased. Findings similarly indicated that consumption under both video and time reinforcement arrangements generally decreased in relation to corresponding increases in unit price. These findings may suggest consumption became constrained under fixed trial duration at higher unit price values. In order to maintain consumption (i.e., inelastic demand) under these arrangements, participants must increase rate of responding and total work output across trials. Analyses of work output, according to constructed exponential demand models, showed that total work output initially tended to increase with increases in unit price at lower unit price values. For nearly all participants a price was eventually reached after which work output either began to decrease or ceased entirely.

Experiment 1 findings support the utility of applying behavioral-economic methods and measures within EAHB contexts. Exponential models and demand curves plotted to double logarithmic scales provided for a clearer assessment of responding and consumption across unit price values, and extended application of the exponential model of demand to duration-based reinforcement within EAHB experimental arrangements. Models constructed using the exponential model of demand generally provided for good fit and accounted for large portions of variance across individual data sets. Individual calculations of EV (indexing the value of a given reinforcer) provided for a more consistent measure of reinforcer
value than might be provided by analyses of rate of responding, maximum consumption, or $P_{\text{max}}$ alone.

**Experiment 2**

Rates of responding observed during Experiment 2 resembled patterns observed during Experiment 1 across participants and reinforcers. Similarly, consumption of both video and time reinforcement decreased with increases in unit price, while total work output decreased or ceased following initial increasing trends at low unit price values. Interestingly, initial elevated levels of video reinforcement consumption in many participants suppressed consumption of time reinforcement at low unit price values under concurrent-schedules arrangements. However, consumption of video frequently decreased with increases in unit price until consumption across both reinforcers became more similar. Rarely did exponential demand models for video and time cross such that time was consumed at greater levels than video. Consistent with these findings, calculated values of EV for video and time across participants under concurrent-schedules arrangements most often indicated higher value for video than time. These models and measures provided a much clearer assessment of reinforcer consumption and work output than more traditional measures for rate of responding and proportion of choice.
Experiment 3

Findings from Experiment 3 support previous findings described by investigators assessing economic predictions of unit price (Madden, Bickel, & Jacobs, 2000). The first economic prediction of unit price states that consumption of a reinforcer will decrease with increases in unit price. Concomitant with decreases in consumption, work output will initially increase at low unit price values prior to reaching a point at which work output begins to decrease, or cease entirely. Findings across all Experiment 3 participants (as well as the majority of Experiment 1 and 2 participants) support the first prediction of unit price.

The second economic prediction of unit price states that total consumption will be determined by unit price independent of cost-benefit ratio components. Findings from Experiment 3 generally support this prediction, with notable deviations. Experiment 3 arranged for assessment of video consumption across multiple trials under equal unit price and different cost-benefit components. Findings indicate total video consumed was similar across trials of equal unit price, despite differences in cost-benefit components. These findings are consistent with the second economic prediction of unit price.

Further analyses revealed responding and consumption within equal-unit-price trials inconsistent with the second economic prediction of unit price. These analyses revealed preferential responding across equal unit price response options.
Participants allocated a large proportion of responding to the larger of two available FR-schedule requirements for longer duration of video access at low unit price values. Conversely, participants allocated a large proportion of responding to the smaller FR requirement for shorter duration of video access at high unit price values. Economic predictions of unit price do not account for such preferential responding across concurrently available options of equal unit price value.

Interestingly, these findings replicate patterns of preferential consumption previously described in adults working for discrete reinforcers (Madden et al., 2000).

Observed within-trial deviations from predicted indifference across response options at very high unit price values may indicate discrimination of potential time constraints. That is, participants may have preferentially responded to the lower of two FR requirements in an effort to ensure completion of the FR requirement within the 10-min trial duration at very high unit price values. However, this hypothesis is less likely under the lower of the two “high” unit price values assessed (i.e., 4.267 responses-per-second of video).

Response requirements were presented at three different FR values for three different durations of video (i.e., FR128 = 30 s, FR256 = 60 s, and FR384 = 90 s) across trials arranging for the lower-of-two high unit prices. Participants could complete multiple response requirements throughout the 10-min duration of these
trials. Participant-allocated consumption to the smaller of two FR options (and thus shorter video clips) under these conditions supports previous findings demonstrating discounted valuation of delayed video in college students (Locey et al., 2009; Navarick, 1996, 1998) under self-control paradigms. Findings described by previous investigators demonstrated participants chose the longer of two available video clips when delay to video was either relatively short or held constant across concurrent options. However, choice switched to shorter video durations when delay to onset of longer video clips increased across trials. Larger FR values seemingly represented longer delay to onset of video in the context of the current experimental arrangements; however, this interpretation is tentative. Further investigation is warranted to determine the extent to which larger FR requirements and longer delay to video onset are analogous.

Participants allocated large portions of consumption to the higher FR requirement and longer video duration within low-unit-price trials. That participants preferentially allocated consumption toward higher FR requirements and longer video durations under low unit price may lend support to previous hypotheses regarding continuity of time-based reinforcers (DeLeon et al., 2014; Locey et al., 2009; Navarick, 1996, 1998). As previously described, Navarick (1996, 1998) and Locey et al. (2009) demonstrated preference for longer video durations in college students under equal delay to onset. Locey et al. suggested
continuity of video might represent an important dimension of such reinforcing stimuli. Importance of continuity may provide for an alternative to strict magnitude-based interpretations of preference in time-based reinforcement.

Extending from EAHB contexts to children with intellectual and developmental disabilities working for activity- or time-based reinforcers (e.g., games, puzzles, music, videos, etc.), DeLeon et al. (2014) described findings indicating participants preferred to continue working for accumulated reinforcement over more immediate access to shorter duration of reinforcement. Providing accumulated longer-duration access rather than distributed shorter-duration access increased reinforcing efficacy under these arrangements. DeLeon and colleagues (2014) additionally observed that participants oftentimes preferred accumulation procedures to those arranging for more immediate access despite inherent increases in delay to onset of reinforcement. Similarly, within equal low-unit-price trials continuity of video (i.e., longer duration) may have increased efficacy of reinforcement sufficiently to overcome relatively-small increases in delay to onset due to increased FR requirements under the current experimental arrangements. Again, these interpretations are tentative, requiring further investigation.

The third prediction of unit price states that individuals will prefer the lower of concurrently-available unit price options. Findings from Experiment 3 support
this prediction. Experiment 3 arranged for assessment of video consumption across multiple trials under unequal unit prices and different cost-benefit components. Unequal trials arranged for concurrent availability of reinforcement at a unit price ratio of 1:2 across response options. Assessment of video consumption averaged across all participants revealed large proportions of consumption allocated to smaller unit price options across all unequal unit price trials. This pattern of preferential consumption was most pronounced under arrangements in which either duration of video clips or FR-schedule requirements were matched across options. Some deviation from lower-unit-price preference occurred across all unmatched arrangements. Participants demonstrated slightly more pronounced deviations from predicted consumption under arrangements in which the higher unit price option resulted in longer durations of video. These findings provide further support to previous hypotheses suggesting continuity of time-based reinforcers as an important consideration (DeLeon et al., 2014; Locey et al., 2009; Navarick, 1996, 1998).

Findings showing deviation from strict preference for lower unit price under matched low-unit-price conditions and across unmatched conditions might represent discrimination errors on the part of some participants. It may be assumed that participants could discriminate the lower of the available unit price options with little error when price differences were more pronounced (e.g., under high
unit-price arrangements), whereas discrimination was less likely when prices were relatively less discrepant (e.g., under low unit-price arrangements). For example, all participants consumed video exclusively on the lower unit price option when available response options included FR256 for 30 s of video vs. FR512 for 30 s of video under matched arrangements. If deviation from preference for lower unit price is interpreted as an “error” in discrimination, such large FR requirements for equal duration of video may have facilitated errorless responding. Conversely, participants consumed on average 14.5% of video on the higher unit price option (the largest discrepancy observed across unequal trials) when available response options included FR128 for 60 s of video vs. FR384 for 90 s of video. Discrimination of price difference may be more “difficult,” in that errors are more likely to occur, under arrangements such as these. Interpretation of deviation from expected lower-price preference as an error in responding is merely hypothetical under the current experimental arrangement. Future research might support or refute such interpretations via parametric analyses of consumption across high, moderate, and low unequal price levels.

**Future Directions**

Limitations inherent in the current experimental arrangements are worth noting. Investigators assessed consumption of reinforcers under multiple unit price values across 15-min trials within Experiments 1 and 2; Experiment 3 assessed
consumption across 10-min trials. These relatively-low duration trials may represent confounding constraints on consumption of reinforcers. Behavior analysts specializing in behavioral economics have suggested sessions must be of extended duration and baseline conditions must provide for unconstrained consumption if investigators are to obtain valid measures from which to derive demand curves (Hursh et al., 2013). Indeed, these investigators suggested changes in consumption should not be confounded by extraneous variables such as caps on total reinforcers available or limited session durations as consumption is assessed under varying unit price values.

Despite these assertions, in practice consumption across unit price values must always contact some limitation on time. That is, though it could reasonably be presumed that additional consumption of a reinforcer will occur with indefinite observation duration, in order to manipulate unit price values investigators must place some cap on duration of access to reinforcement under any given unit price value. Hursh et al. (2013) suggested investigators could reasonably conduct studies of consumption in non-human animals under session durations of 11 hours. Such extended session durations at any unit price value are impractical when evaluating consumption in human participants.

Others have successfully assessed consumption of reinforcers in non-human animal and human participants under reduced session duration (Bickel & Madden,
Additionally, experimental arrangements described by Bickel and Madden (1999) and Madden et al. (2000) did not include evaluations of baseline unconstrained consumption in adult humans. These investigators reported demand profiles successfully obtained under 3-hour session durations across multiple days and weeks. However, as participants in these studies volunteered to participate in exchange for extra-experimental monetary compensation, it is unclear if similar results might be obtained in EAHB settings with undergraduates volunteering in exchange for course credit.

Other investigators have suggested arrangement of PR schedules to assess consumption under varying unit price values. These investigators suggested such arrangements may expedite constructing demand curves in human participants (Reed et al., 2013). While arrangements of PR schedules have been conceptualized as including a variety of designs (DeLeon, Iwata, Goh, & Worsdell, 1997; Hodos, 1961; Tustin, 1994), the most commonly reported arrangements involve increasing requirements within sessions across trials of fixed reinforcer access (Roane, 2008). Though similar to unit price evaluations, these PR arrangements constrain both reinforcer access and time under each unit price. Therefore, PR schedule arrangements (i.e., within sessions, across trials) may lack validity as a method for evaluating demand curves across unit prices. The current arrangements alleviated
some of these constraints allowing for multiple schedule completions within fixed
trial duration, analogous to increasing unit price across sessions.

Synthesis of behavioral-economic unit-price evaluations and PR-schedule
arrangements may represent additional valid and efficient means for constructing
demand curves in human participants. For example, within-session PR schedules at
fixed unit price values (i.e., with symmetrical increases in reinforcement) in
combination with across session unit price increases might quickly assess
consumption with limited constraint on reinforcer access. This suggestion
represents just one potential strategy for efficiently developing demand curves in
human participants. Future research will reveal additional arrangements.

While not directly constraining availability of reinforcers within and across
trials, short-duration trials arranged throughout this study likely constrained access
to reinforcers to some degree. These constraints appear more pronounced at high
unit price values as FR schedules required proportionally more time to complete a
trial or entailed increased response rates. The first economic prediction of unit price
theorizes total work output should initially increase in defense of consumption with
increases in unit price. The current experimental arrangement did not allow for
increased total duration of responding, but participants could increase rate of
response if consumption was to be defended. Maintaining a steady rate of
responding with increasing unit price would result in decreasing consumption
approximately proportional to unit price increases under these arrangements. However, decreasing response rates – with concomitant decreases in work output – at higher unit price values suggest many of the current participants did not contact individual maximum consumption during these trials. That is, participants obtained more reinforcement by maintaining (or increasing) rate of responding across trials. Previous findings regarding correlations between $O_{\text{max}}$ and peak response rate support these conclusions (Bickel et al., 2000; Bickel & Madden, 1999). Future research should investigate the degree to which within-session and within-trial changes in response rate may be predictive of changes in demand elasticity.

Analyzing consumption of reinforcers across unit price values must necessarily involve some constraint on time, total reinforcers available, and effort or response requirements. These constraints are likely to be more pronounced when evaluating consumption in human participants. Future research might systematically evaluate which, if any, of these constraints represents the best option for efficiently developing demand curves in humans. Additionally, investigators must determine what values, or methods for determining individualized values of these constraints, might be incorporated in demand evaluations. Indeed, it may be the case that unconstrained consumption in humans actually decreases total consumption in some circumstances (Ariely, Gneezy, & Haruvy, 2008). Evaluation of such effects of constraint, or lack thereof, on consumption represents a crucial
area for future research to continue developing behavioral-economic methodology
with human participants.

As previously described within the current study data-analysis description, prior to analyzing data obtained for evaluation of consumption of a given reinforcer investigators must determine how to handle zero consumption under any unit price. Multiple methods for handling such no-consumption data have been suggested (Hursh, 2016; Hursh & Silberberg, 2008; Hursh & Roma, 2015, Koffarnus, Franck, Stein, & Bickel, 2015; Madden, Bickel, & Jacobs, 2000), each presenting with relative pros and cons.

One common approach to analyzing data sets containing no-consumption trials involves replacing zero values with small non-zero values such as 1 or 0.1, depending on actual levels of consumption observed across participants. However, even small differences in replacement values can have dramatic effects on resulting demand curves. Differences in chosen values can thus result in disproportionately large effects on estimations of elasticity and demand intensity (Koffarnus et al. 2015). Alternatively, analyses may be restricted to consumption averaged across large groups of participants, thus reducing the likelihood of obtaining zero consumption at any one unit-price value. This approach may not be ideal when investigators are interested in evaluating individual consumption, or between-subject variability.
More recent suggestions for incorporating zero-consumption values into demand evaluations involve altering all data points by some fixed value. For example, all data points might be increased by “1” such that no-consumption trials are then evaluated as logarithmic transformations of “1” rather than being excluded as “0” values. While this approach allows for inclusion of more data points in the exponential model of demand, increasing consumption by fixed values at each unit price necessarily misrepresents work output in that more work output is artificially included at higher unit price values. Another means of altering all data equally to allow for inclusion of zero values involves exponentiation, or raising the function by a power of 10 (Koffarnus et al. 2015). This approach assumes mathematical similarity across models resulting in return of the same results given no zero-consumption values in the data set. However, some investigators suggest this assumption may not hold true and exponentiation may in fact alter outcomes by altering presumed error within the model fit (D. D. Reed, personal communication, May 9, 2016). Based on preliminary evaluations indicating such occurrences, Reed suggested forgoing exponentiation of the exponential model of demand until further direct evaluations are reported.

Similarly, investigators may also handle no-consumption, zero values by simply excluding them from data analyses using the exponential model of demand. This approach has been recommended by Hursh (2016) and demonstrated by others.
(Madden, Bickel, & Jacobs, 2000). Recall the current study analyzed data in line with this recommended approach. One limitation to this method of excluding zero values is the skewing of demand curves and estimated elasticity at higher unit price values if consumption ceases quickly. This is less of a concern when low consumption values have been recorded prior to consumption extinguishing entirely. Despite this potential limitation, Hursh (2016) recommends this method of analysis on the grounds that “zero data” may not necessarily represent zero consumption at a given unit price value.

As an example, consider Experiments 1 and 2 of the current study in which within-session, across-trial PR schedules arranged for geometric increases in response requirements times 2. If under a given FR requirement (i.e., unit price), a participant consumed one reinforcer followed by zero consumption at the next FR requirement, this may indicate the participant would be willing to consume some quantity of the reinforcer between zero and one at the current unit price. That is, given the option, the participant might be willing to complete half of the FR requirement (as in the previous trial) for a smaller magnitude of reinforcement. Alternatively, a drop to zero consumption could indicate the need for a more refined analysis of unit prices falling between the terminal and previous unit price values.
Rather than artificially adulterating data through addition or exponentiation, future research may investigate methods for fine-tuning unit price evaluations when no-consumption trials are indicated. Investigators may wish to adjust unit price evaluations in a participant- or consumption-specific manner under conditions in which data can be analyzed in real time. If a participant consumes zero reinforcement within a given trial the experimental program could simply adjust the unit price of the subsequent trial to a value somewhere between the terminal and previous values. Alternatively, the experimental program might track inter-response intervals for some maximum value, at which point the current trial immediately terminates and a new, lower unit price trial begins.

Finally, investigators might arrange for reversed unit price progressions such that unit price values systematically decrease rather than increase as a means of establishing maximum unit price values. Investigators could arrange initial high unit price values at which participants are unlikely to consume reinforcement. Unit price values would then begin to decrease incrementally at fixed time intervals, and participants could choose to begin responding when a price is reached at which they are willing to consume reinforcement. Within EAHB contexts assessing consumption in undergraduates volunteering for course credit, incremental progression of unit price decreases could be timed such that zero would occur following all allotted session time if a participant chose not to respond. In these
cases, waiting for very small unit price values would also translate to greater delay in reinforcement onset and less total reinforcement available while also ensuring participants do not artificially reduce total session duration through not responding. These suggested methods represent untested considerations toward evaluating demand for reinforcers in EAHB. There are presumably innumerable different arrangements by which unit price evaluations may produce demand curves in such contexts. Future methodological evaluations will elucidate best-practice arrangements.

Another potential limitation within the current experimental arrangement relates to selection of reinforcers. Across experiments participants selected from an array of five available videos. This array was neither extensive nor based on pre-trial preference assessment(s). Investigators made an effort to include relatively recent and / or highly rated viewing options. However, it is likely that at least some participants did not prefer any of the available videos. For these participants, the provided array may more closely resemble a forced-choice rather than an indication of preference (see Tullis et al., 2011 for a review of choice and preference in applied contexts). Limited consumption of video reinforcement in participants might then indicate revealed preference for none of the available videos. Identification of preferred videos prior to participation in demand evaluations would likely result in greater consumption of those videos across unit price values.
Alternatively, developing experimental arrangements with more extensive pre-trial video arrays, or online-streaming of video, may increase the likelihood of participants contacting preferred video options, thereby increasing consumption across unit price increases.

Limitations related to the second reinforcer (i.e., reduction of in-session time) arranged within this study also merit discussion. Experiments 1 and 2 provided for a novel reinforcement contingency in the form of 5 s reductions from total in-session duration with accompanying 30 s blackout periods from responding (i.e., time). This reinforcement arrangement was provided following previous findings from unpublished data suggesting undergraduate participants will frequently forgo watching earned video in favor of terminating experimental participation early (Chastain & Harvey, 2016). These findings were produced from experimental arrangements in which the total reduction of in-session time was directly proportional to the amount of video earned and not watched. Experiments 1 and 2 did not arrange for symmetrical durations of video and time.

Across Experiments 1 and 2 a 5 s time value was arranged in order to insure total session duration was long enough for participants to complete seven total experimental trials (i.e., 105 min) while allowing for instruction-presentation periods (variable total duration). Had participants been permitted to consume time at maximum efficiency across all seven trials (for example, under continuous FR1,
accounting for blackout periods) a total of 17 min and 30 s would have been subtracted from total in-session time. However, total in-session time reductions became more constrained as unit price increased under the current geometric PR-schedules. As an example, participant 215 obtained the highest amount of time reinforcement accessed by any one participant across Experiments 1 and 2. This participant contacted time reinforcement periods on a total 122 occasions for a total of 610 s (i.e., 10 min and 10 s) reduction of in-session time. These data demonstrate that the current reinforcement arrangements provided adequate total session time for participants to complete all seven experimental trials without significant reduction of in-session duration.

In arranging time reinforcement such that total session duration would remain long enough to complete all trials, investigators deviated from previous arrangements suggesting preference for time over video reinforcement. It is reasonable to hypothesize that increasing time values would increase consumption of this reinforcer during single-schedule arrangements, thus altering exponential demand models and derived EV measures. Similarly, increasing time values would likely increase consumption of this reinforcer under concurrent-schedules arrangements, thereby decreasing consumption of video. Future research is warranted to investigate these hypotheses. Likewise, methodological advancements will follow from further analyses of exponential demand models derived from unit
price for seconds of video and time reinforcement directly, rather than reinforcement periods obtained. Inclusion of blackout periods controlling for response-unavailable time prevent such analyses of the current data.

**Conclusions**

Despite these limitations, the current study extends and supports previous investigations demonstrating the utility of behavioral-economic arrangements for the assessment of responding and consumption in EAHB contexts. This series of studies additionally provides an example for directly assessing the efficacy or value of reinforcers provided within EAHB arrangements. Experiment 3 extends and supports previous findings assessing economic predictions of unit price in humans responding for video reinforcement. And finally, findings across all three studies demonstrate the utility of applying exponential model of demand analyses to the consumption of time-based reinforcers across single-schedule, concurrent-schedules, and unit-price choice arrangements.

Extending behavioral economic analyses and exponential analyses of demand within EAHB contexts offers essential tools for translating and advancing findings from the non-human animal literature to responding and consumption in human participants. In translating these theoretical platforms and quantitative models of behavior into controlled experimental settings with human participants, investigators come closer to understanding how such models may be utilized within
applied contexts. Understanding how behavioral-economic and quantitative models may be utilized to assess and predict responding in applied settings will provide clinicians, educators, policy makers, and care providers the means to achieve many socially and individually significant gains across populations and contexts.
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Figure 1. Concurrent-schedule trial screen

Screen shot of experimental response screen presented across experiments. Throughout Experiment 1, single-schedule arrangements, only one response frame and button was visible, randomly presented on either the left or right across schedule requirements. Throughout Experiments 2 and 3, concurrent-schedule arrangements, both response frames were visible and response options were randomized to the left and right options. Following each response, the selected yellow response button randomly generated at a new location within the respective light-grey response frame. Throughout all experiments a session clock (center top) counted down remaining session duration. Response counters positioned above each response frame incrementally counted each response made to the respective response button. Active schedule requirements and available reinforcement were provided immediately above each response frame.
Figure 2. Video playback screen

Screen shot of video screen presented during response contingent video access. All video expanded to maximum size within the video frame while maintaining the original aspect ratio of the video file.
Figure 3. Time reduction and blackout screen

Screen shot of blackout screen presented during response-contingent in-session time reductions. At initial presentation a time-reduction box displayed immediately below the session clock. During the first 1-2 s of the blackout period the time-reduction value incrementally reduced the indicated time from the session clock. Throughout the blackout period a “Wait:” clock counted down time remaining in the blackout period. The Session clock continued counting down remaining session time throughout the blackout period.
Figure 4. Instruction screen

Screen shot of instruction screen presented at the start of session and between all trials. Actual instruction text varied across initial instruction screen and inter-trial screen according to experimental arrangements.

Note: during the initial instruction screen the session timer was not visible.
Screen shot of video-selection screen presenting array of available videos prior to all sessions in which experimental arrangements provided for video reinforcement. Participants selected videos by positioning the mouse pointer over a video option and clicking the left mouse button. The yellow text boxes and green “CONTINUE” button appeared following an initial selection. Participants were free to change selections as many times as they like until clicking the “CONTINUE” button.
Figure 6. Experiment 1 responses per minute

Rate of responding in responses per minute in each participant across reinforcers (arranged individually across sessions). Open squares depict responding for in-session time reductions while closed circles depict responding for video access. Individual participant numbers are indicated top-left of each graph.
Exponential demand models for average consumption within Low UP group are indicated by closed circles, and within High UP group by closed squares. The left graph displays models for average consumption of video within Low UP group, $R^2 = 0.97$, $Q_0 = 27$ and $\alpha = .00011$; and High UP group, $R^2 = 0.98$, $Q_0 = ~30$ and $\alpha = .00024$. The right graph displays models for reduced time within Low UP group, $R^2 = 0.9$, $Q_0 = 24$ and $\alpha = .00016$; and High UP group, $R^2 = 1$, $Q_0 = 22$ and $\alpha = .00024$.

Note: X- and Y-axes presented as logarithmic scales.
Figure 8. Experiment 1 single-schedule video demand

Exponential demand models constructed for consumption of video in each Experiment 1 participant, and for consumption averaged across all participants. Participant numbers are presented center-top of each graph. Values of $Q_0$, $\alpha$, and $R^2$ corresponding to each model are inset bottom-left within each graph.

*Note:* X- and Y-axes presented as logarithmic scales
Exponential demand models constructed for consumption of in-session time reductions in each Experiment 1 participant, and for consumption averaged across all participants. Participant numbers are presented center-top of each graph. Values of $Q_0$, $\alpha$, and $R^2$ corresponding to each model are inset bottom-left within each graph.

Note: X- and Y-axes presented as logarithmic scales.
Figure 10. Experiment 1 work output functions.

Obtained and predicted work output for all Experiment 1 participants, graphed according to group participation. Left graphs depict work output for access to video. Right graphs depict work output for in-session time reductions. Top graphs present data for Low UP group; bottom graphs present data for High UP group.
Figure 11. Experiment 2 response rates across prior Experiment 1 participants.

Rate of responding in responses per minute and proportion of selection across reinforcer options in three participants completing one concurrent-schedules session, following completion of Experiment 1 participation. Open squares depict responding for in-session time reductions; closed circles depict responding for access to video (left axis). Light-grey bars indicate proportion consumption of video; dark-grey bars indicated proportion consumption time reductions (right x-axis).
Figure 12. Experiment 2 group 2-2 response rates.

Rate of responding in responses per minute and proportion of selection across reinforcer options in group 2-2 participants. Left graphs depict responding during Session 1; right graphs depict responding during Session 2. Open squares depict responding for in-session time reductions; closed circles depict responding for access to video (left axis). Light-grey bars indicate proportion consumption of video; dark-grey bars indicated proportion consumption time reductions (right x-axis).
Figure 13. Experiment 2 group 8-8 response rates.

Rate of responding in responses per minute and proportion of selection across reinforcer options in group 8-8 participants. Left graphs depict responding during Session 1; right graphs depict responding during Session 2. Open squares depict responding for in-session time reductions; closed circles depict responding for access to video (left axis). Light-grey bars indicate proportion consumption of video; dark-grey bars indicated proportion consumption time reductions (right x-axis).
Figure 14. Experiment 2 group 8-2 response rates.

Rate of responding in responses per minute and proportion of selection across reinforcer options in group 8-2 participants. Left graphs depict responding during Session 1; right graphs depict responding during Session 2. Open squares depict responding for in-session time reductions; closed circles depict responding for access to video (left axis). Light-grey bars indicate proportion consumption of video; dark-grey bars indicated proportion consumption time reductions (right x-axis).
Figure 15. Experiment 2 group 2-8 response rates.

Rate of responding in responses per minute and proportion of selection across reinforcer options in group 2-8 participants. Left graphs depict responding during Session 1; right graphs depict responding during Session 2. Open squares depict responding for in-session time reductions; closed circles depict responding for access to video (left axis). Light-grey bars indicate proportion consumption of video; dark-grey bars indicated proportion consumption time reductions (right x-axis).
Figure 16. Experiment 2 group-averaged exponential demand

Exponential demand models for average consumption within group 2-2 are indicated by closed circles; group 8-8 consumption indicated by closed squares; group 8-2 consumption indicated by open circles; group 2-8 consumption indicated by open squares. Best-fit $k = 1.7$ across all models is indicated top-right.

*Note:* X- and Y-axes presented as logarithmic scales.
Figure 17. Experiment 2 concurrent-schedules exponential demand.

Exponential demand models constructed for video consumption (open circles) and time reductions (open squares). Participants are presented horizontally according to group participation as indicated top-right of all left-column graphs. 

Note: X- and Y-axes presented as logarithmic scales.
Figure 18. Experiment 2 actual and predicted work output

Obtained and predicted work output across video and time reinforcement in all participants, graphed according to group participation, as indicated top-left corner of all right-column graphs. Left graphs depict work functions for access to video; right graphs depict work functions for in-session time reductions. 

*Note:* X- and Y-axes presented as logarithmic scales.
Figure 19. Experiment 3 Demand and Work 1

Exponential demand models and work output constructed for consumption of access to video (s) in four participants. Unit price was calculated as responses per second of video. Values of $Q_0$, $\alpha$, and $R^2$ for each model inset bottom left corner. Exponential demand is displayed on left graphs; work output displayed on right graphs.

Note: X- and Y-axes presented as logarithmic scales.
Exponential demand models and work output constructed for consumption of access to video (s) in four participants. Unit price was calculated as responses per second of video. Values of $Q_0$, $\alpha$, and $R^2$ for each model inset bottom left corner. Exponential demand is displayed on left graphs; work output displayed on right graphs.

*Note:* X- and Y-axes presented as logarithmic scales.
Figure 21. Experiment 3 Demand and Work 3

Exponential demand models and work output constructed for consumption of access to video (s) in four participants. Unit price was calculated as responses per second of video. Values of $Q_0$, $\alpha$, and $R^2$ for each model inset bottom left corner. Exponential demand is displayed on left graphs; work output displayed on right graphs.

*Note*: X- and Y-axes presented as logarithmic scales.
Figure 22. Experiment 3 Demand and Work 4

Exponential demand models and work output constructed for consumption of access to video (s) in four participants. Unit price was calculated as responses per second of video. Values of $Q_0$, $\alpha$, and $R^2$ for each model inset bottom left corner. Exponential demand is displayed on left graphs; work output displayed on right graphs.

*Note:* X- and Y-axes presented as logarithmic scales.
Figure 23. Experiment 3 Demand and Work 5

Exponential demand models and work output constructed for consumption of access to video (s) in four participants. Unit price was calculated as responses per second of video. Values of $Q_0$, $\alpha$, and $R^2$ for each model inset bottom left corner. Exponential demand is displayed on left graphs; work output displayed on right graphs.

Note: X- and Y-axes presented as logarithmic scales.
Total video (s) consumed within equal unit price trials across all Experiment 3 participants. The Y-axis indicates within session unit price values in ascending order from left to right. Dark-grey bars indicate consumption within sessions arranging for 30 s vs 60 s video clips; light-grey bars indicate consumption within sessions arranging for 30 s vs 90 s video clips; white bars indicate consumption within sessions arranging for 60 s vs 90 s video clips.
Figure 25. Experiment 3 consumption across equal unit price options

Proportion of consumption averaged across all participants within Experiment 3. Left bars indicated consumption on the smaller of the two FR-schedule requirements; right bars indicate consumption on the larger of two FR requirements. The top graph depicts consumption averaged across all equal unit price trials. The middle graph depicts consumption averaged across only the two (of four) highest unit price values assessed; bottom graph depicts consumptions averaged across only two lowest unit price values.
Figure 26. Experiment 3 unequal unit price: matched

Proportion of consumption averaged across all Experiment 3 participants across matched unequal unit price trials. Matched trials arranged for 90 s and 30 s video clips available on equal FR requirements; or 30 s video clips available on unequal FR requirements (1:2 ratio). The Y-axis indicates FR-schedule values arranged across each response option. Duration of video access available on each response option is indicated by labels positioned within bars (light-grey; lower unit price) or above bars (dark-grey; higher unit price).
Proportion of consumption averaged across all Experiment 3 participants and unequal unit price trials arranging for varied video duration and FR-schedule requirements. Unit price was always arranged on a ratio of 1:2 across options. The Y-axis indicates FR-schedule values arranged across each response option. Duration of video access available on each response option is indicated by labels positioned within bars (light-grey; lower unit price) or above bars (dark-grey; higher unit price).
Table 1. Experiment 1 Comparison of Exponential Demand Values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Video</th>
<th>Time</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Second</td>
<td>Sr Period</td>
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<tr>
<td></td>
<td>Low UP Group</td>
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</tr>
<tr>
<td>Q₀</td>
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<td>29.00</td>
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<tr>
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</tr>
<tr>
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</tr>
<tr>
<td>Oₘₐₓ</td>
<td>1127.90</td>
<td>1152.42</td>
</tr>
</tbody>
</table>

“Second” columns contain value estimates for unit-price-per-second access. “Sr Period” columns contain value estimates for FR-per-reinforcement period. “Diff” columns contain difference across Second and Sr Period columns. Despite expected differences in Q₀ and Pₘₐₓ values across Second and Sr Period models, little-to-no difference is indicated in k, α, R², EV, and Oₘₐₓ values.

*Constrained value
Table 2. Experiment 1 Adjusted EV, P\textsubscript{max}, and O\textsubscript{max} Values.

<table>
<thead>
<tr>
<th>Participant</th>
<th>Video ((k = 1.5))</th>
<th>Time ((k = 1.2))</th>
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</thead>
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<tr>
<td></td>
<td>EV</td>
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<tr>
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<td>105</td>
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<tr>
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<tr>
<td>114</td>
<td>25.92</td>
<td>71.70</td>
</tr>
<tr>
<td>All</td>
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<td>76.51</td>
</tr>
</tbody>
</table>

EV, P\textsubscript{max}, and O\textsubscript{max} values calculated as described by Equations 2 and 3 of the exponential model of demand. Columns to the left of center present values calculated from demand models for access to video; columns to the right of center present values calculated from demand models for in-session time reductions. Models were constructed using separate best-fit values of \(k\) for video (\(k = 1.5\)) and time (\(k = 1.2\)) according to models comparing group averages.
Table 3. Experiment 2 Initial Schedule Requirements

<table>
<thead>
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<th>Participant</th>
<th>Session 1</th>
<th>Session 2</th>
</tr>
</thead>
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<tr>
<td>204</td>
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<tr>
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<td>209</td>
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</tr>
<tr>
<td>210</td>
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<td>2</td>
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</table>

Values indicate first FR-schedule requirement of the PR sequence within a given session across participants.
Table 4. Experiment 2 Adjusted EV, $P_{\text{max}}$, and $O_{\text{max}}$ Values.

<table>
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<tr>
<th>Participant</th>
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<th>Omax</th>
<th>EV</th>
<th>Pmax</th>
<th>Omax</th>
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<td>n/a</td>
<td>n/a</td>
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<td>67.60</td>
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<td>84.79</td>
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<td>787.32</td>
<td>5.31</td>
<td>279.93</td>
<td>129.68</td>
</tr>
</tbody>
</table>

**ALL**    | 20.51| 77.25 | 501.02| 11.87| 151.49| 290.07|

EV, $P_{\text{max}}$, and $O_{\text{max}}$ values calculated as described by Equations 2 and 3 of the exponential model of demand. Columns to the left of center present values calculated from demand models for access to video; columns to the right of center present values calculated from demand models for in-session time reductions. Models were constructed using best-fit value of $k = 1.7$ according to models comparing group averages.
Table 5. Experiment 3 Concurrent-schedules Arrangements

<table>
<thead>
<tr>
<th>Trial</th>
<th>Unit Price*</th>
<th>Video duration (s)</th>
<th>Fixed ratio</th>
<th>Unit price (R/s)**</th>
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<td>Left</td>
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<td>24</td>
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<td>22</td>
<td>E</td>
<td>30</td>
<td>90</td>
<td>64</td>
</tr>
</tbody>
</table>

Trial order was randomized such that each unit price cost-benefit arrangement was presented one time across sessions and trials. Unequal unit price trials are presented with lower unit price values on the left. During program runtime, the experimental program randomized unit-price values across left and right response options prior to initiating each trial. During equal unit price trials, cost-benefit components were randomized across response options.

*E – equal; U – unequal

**Unit price = Response requirement (R) / video duration (s)
Table 6. Experiment 3 EV, P<sub>max</sub>, and O<sub>max</sub> of Video

<table>
<thead>
<tr>
<th>Participant</th>
<th>EV</th>
<th>P&lt;sub&gt;max&lt;/sub&gt;</th>
<th>O&lt;sub&gt;max&lt;/sub&gt;</th>
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</table>

EV, P<sub>max</sub>, and O<sub>max</sub> values calculated as described by Equations 2 and 3 of the exponential model of demand. Models were constructed using best-fit value of \( k = 2 \) according to an exponential demand model constructed for average consumption across all participants.