EFFECTS OF DELAY TO REINFORCEMENT AND INTER-TRIAL INTERVAL ON FIXED-RATIO SCHEDULE PERFORMANCE

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ABSTRACT

A delay to reinforcement has been found in previous studies to influence the effectiveness of a reinforcer. As the delay duration increases, response rates decrease and post reinforcement pause durations increase. The present study tested whether it was the increase in time between the effective response and delivery of reinforcement, or, the increases in intervals between reinforcers that devalue the reinforcer. This study also compared the ability of two demand equations and MPR to predict response rates when effort required was changed. The effects of varying delay to reinforcement and intertrial interval on behaviour was examined while the time available for responding was kept constant.

There were four conditions; 4-s ITI, 4-s delay, 16-s ITI and 16-s delay, and 6 hens responded under each of these conditions in an ascending geometric series of fixed ratio (FR) values. It was shown that hens generally responded at a faster rate in the ITI conditions than the equivalent delay conditions and peak response rates were seen highest in the 16-s ITI condition in accordance with the demand data. The data was described well by both the demand equations and the MPR equation. While there were inconsistencies among the parameters, there was a moderately strong positive relationships between the parameter values of a_s and α in the 16-s ITI (r = .51, p = 0.29) and delay (r = .44, p = .44) conditions.

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To my Nana, I got it done!

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Introduction

Both experimental and applied research has documented the effects that schedules of reinforcement have on behaviour. Depending on the type of schedule in effect, a subject’s rate and pattern of responding changes. In fixed-ratio (FR) schedules, a reinforcer is delivered after every n^{th} response since the last reinforcer was delivered (Fester & Skinner, 1957). The time elapsed between the delivery of reinforcement differs depending on how quickly the required FR responses are emitted (Fester & Skinner, 1957). The rate of reinforcement therefore is directly related to the rate of responding; the faster the rate of responding, the greater the reinforcement rate. FR schedules are characterized by a pause in responding following the delivery of a reinforcer. This pause is then followed by an increased high steady rate of target behaviour until the FR requirement is met. Behaviours under FR schedules were initially described in detail by Fester and Skinner (1957), who examined pigeons’ behaviour under many different FR conditions, finding that performance declined as the FR value increased. Since then, performance under FR schedules has become a widely researched area.

Through providing the initial detailed descriptions of behaviour under FR schedules, Fester and Skinner (1957) illustrated the main features of this reinforcement schedule. Typically, pigeons were exposed to one particular schedule until performance was judge stabled. Conditions used included transitions from continuous reinforcement to low FRs, low FRs to high FRs and extinction after FRs, as well as records of final performances on FR 20 and FR 200 and the effects of drugs on FR performance. The pattern of responding was typically described as being a short period of high responding which followed by a period of low rate responding with a subsequent acceleration which continued to increase until the FR requirement was reached (Fester & Skinner, 1957). Cumulative records indicated that responding was characterized by brief pauses during the responding time, before the final acceleration of rate preceding the terminal rate of the schedule. Pause length after reinforcement increased as the FR value increased (e.g., FR 120 & FR 200).

While these findings mentioned above provided the basis for examination of performance under FR schedule, more recently data analysis practices have shifted away from the reliance on cumulative records. Systematic manipulations of FR schedules have been used to describe performance in terms of averages of total session data in shorter fixed time sessions. It is more common practice today to use mean post-reinforcement pause (PRP) (time from last reinforcer till first response), running response rates (responses per minute, excluding PRP time and reinforcement time), and the overall response rate (responses per minute, excluding reinforcement time) as a means of examining and measuring the effects of FR schedule value on performance (Mazur, 1983).

Research examining the relationship between the FR ratio requirement and the response rates has produced mixed results (Crossman, Bonem & Phelps, 1987). Overall response rates have been reported by some to be inconsistent among subjects (e.g., Powell, 1968) or to be bitonic, initially increasing across small FRs, then decreasing as the FR value increases further (e.g., Crossman et al., 1987; Mazur, 1983). However, more recently it has been suggested that overall response rates under FR schedules may be influenced by factors other than solely the FR value. For example, the length of the session or the amount of food that is available to the subject outside of the experimental session have been also argued to influence responding. Foster, Blackman, and Temple (1997) found that while the overall response rate decreased with increasing FR requirement, when session time was lengthened and the only access to food was during the experimental session, overall response rates generally increased with the increasing FR requirement. Collier, Johnson, and Morgan (1992) had previously also found that in experimental conditions, where the rats' entire daily intake was gained during the experiment session regardless of body weight, rats' responded faster for smaller pellets than in conditions where they had access to the pellets outside the experimental sessions. Similar mixed findings have been reported in regards to the relationship between running response rates and FR size (Crossman et al., 1987), however, generally results have shown that increases to the FR ratio decreases the average running response rate (e.g., Felton & Lyon, 1966; Foster et al., 1997; Harris, 2010).

Research detailing the relationship between the FR value and the PRP has shown more consistent results compared to those found for response rates. The period of zero responding after the delivery of the reinforcer is known as the 'post-reinforcement pause' (PRP; Felton & Lyon, 1966). Fester and Skinner (1957) originally reported that as the FR value increased, so too did the length of the PRP. Studies following on from this looking at the relationship between the FR value and PRP have provided further support for this through using more systematic research methods (e.g., Bizo & Killeen, 1997; Felton & Lyon, 1966; Harris, Foster, Levine, & Temple, 2012; Powell, 1968). Felton and Lyon (1966) recorded the duration of the PRP for four pigeons while varying the FR schedule value (FR 25 to FR 150). The experimental sessions were terminated after 50 reinforcers were gained. Results supported pervious findings, such as Ferster and Skinner (1957), showing a consistent and stable increase of the PRP duration as the value of the FR schedule increased. Powell (1968) used a similar procedure to that of Felton and Lyon (1966) but used smaller sequential changes in the FR value size (e.g., FR 15 to FR 20). His results showed that even with smaller increases of the FR value, the PRP duration increased as the FR size increased. More recent research has also extended on these original findings such as Bizo and Killeen (1997) who looked at PRP in relation to models of reinforcement and found that the PRP duration increased as the amount of work was required increased (FR value).

Subsequent studies have identified a number of different variables which affect the duration of the PRP during FR schedules. These variables include, but are not limited to, reinforcer magnitude (e.g., Powell, 1969), the size of the reinforcer (e.g., Felton & Lyon, 1966), the amount of response effort required (e.g., Alling & Poling, 1995) and the delay time between the last required response for the FR ratio and the delivery of the reinforcer (e.g., Morgan, 1972).

Delay

The effect of delayed reinforcement on schedule performance has been investigated using a number of different species, pigeons (Lydersen & Crossman, 1974), hens (Harris et al., 2012), rats (Kirshenbaum, Szalda-Petree, & Haddad, 2003) and monkeys (Ferster & Hammer, 1965). When reinforcement is delayed, a period of time is introduced between an effective response and the delivery of reinforcement (e.g., Sizemore & Lattal, 1978). Typically, in delayed reinforcement research, variable interval (VI) schedules have been used (e.g., Chung & Herrnstein, 1967). However, more recently, studies have selected a variety of different schedules of reinforcement, other than VI schedules, to further the research of delay effects on reinforcement (e.g., Differential Reinforcement of

Other Behaviour (DRO) and FR schedules) through looking at the effects on response rates, PRP, and consumption rate. Additionally, research has also investigated the difference between using signalled and unsignalled delays on performance within the schedules of reinforcement (e.g., Schaal, Schuh & Branch, 1992; Williams, 1976). Regardless of species, schedules, or specific manipulations, these studies have shown that imposing a delay reduces the effectiveness of reinforcement and delayed reinforcement is associated with lower rate of responding and increased PRPs.

The effect of delayed reinforcement on the duration of the pause following reinforcement during experiments is a general finding and has been shown in a range of different schedules including VI and FR schedules of reinforcement (e.g., Chung & Herrnstein, 1967; Morgan, 1972; Pierce, Hanford, & Zimmerman, 1972). Pierce et al. (1972) investigated the effects of different delay procedures and different delay durations on PRP and the response rates of albino rats. Pierce et al. (1972) found that regardless of the delay procedure, as delay duration increased, so too did PRP duration.

Response rates have also been found to be directly influenced by delay duration. Using a range of schedules including VI (e.g., Chung & Herrnstein, 1967; Pierce et al., 1972), DRO (e.g., Azzi, Fix, Keller, & Rocha e Silva, 1964) and differential reinforcement of low rates (DRL) (e.g., Richards, 1981), response rates have been found to decrease with increases in delay duration. A two-key procedure, in which the delay to reinforcement was held constant on one key and varied on the other (the experimental key), was used to investigate the effects of delay on response rates using pigeons (Chung & Herrnstein, 1967). Four pigeons were required to respond on a VI schedule on either the left key, which provided reinforcement after a delay of 8 s, or the right key on which the delay to reinforcement was varied 1 to 30 s. For two other pigeons, the left key had a constant delay to reinforcement of 16 s, and the right key the delay varied from 2 to 30 s. As the delay to reinforcement on the experimental key was increased, the relative frequency of responding to that alternative increased. These results lead to the conclusions that the relative frequency of responding matched the relative immediacy of reinforcement. Similar findings have been reported by Sizemore and Lattal (1978), Richards (1981) using VI and DRL, Pierce et al. (1972), and Harris et al. (2012) with hens using FR schedule of reinforcement.

Research has also found that the effect of a delay on responding depends on whether the delay is signalled or unsignalled. Some researchers have focused on the effect of delay in the presence of the same stimulus, known as an unsignalled delay (e.g., Williams, 1976). Others have used signalled delays where the delay interval is correlated with a stimulus change (such as blackouts; Lydersen & Crossman, 1974) for the duration of the delay. Generally, unsignalled delayed reinforcement is associated with decreased response rates (e.g., Sizemore & Lattal, 1978; Williams, 1976). While typically responding during the delay has no effect on the delay or response rates; a resetting delay may be used in which responding during the delay acts to extend the delay period. During a resetting delay, any response made during the delay duration restarts the delay. This is in contrast to a non-resetting delay where any response made during the delay has no effect on the delay or reinforcer. Response rates under unsignalled resetting delays have been reported to be greatly lower than response rates under unsignalled non-resetting delays of the same duration (e.g., Dews, 1960).

A VI schedule was used to examine the effects of different unsignalled delay durations (3, 5, 8, and 15 s) on response rates by Williams (1976). During the delay procedure, the first peck after a reinforcer was scheduled would start a delay timer and the reinforcer would be delivered on completion of the delay interval. The delay was unsignalled and did not reset with additional responses during the delay. Williams showed that unsignalled delays between the response and the reinforcer substantially reduced the rate of responding across delays that ranged from 3 s to 15 s.

Similar to unsignalled delays, research on signalled delays has also reported response rates decrease as the signalled delay increases (e.g., Schaal, et al., 1992). Signalled delays have been found to result in a more stable pattern of responding, and reduce the response rate less than an equivalent unsignalled delay (e.g., Richards, 1981; Richards & Hittesdorf, 1978; Williams, 1976). For example, Richards (1981) examined the differences between the effect of signalled and unsignalled delays to reinforcement of between 0.5 s to 10 s. Richards reported that unsignalled delays of 5 s and 10 s resulted in larger decreases in response rate than the equivalent signalled delays, which only produced moderate decreases in response rates. This finding was confirmed later by Reilly and Lattal (2004) in their Experiment 2 which examined the effects of delay on response rates through using a progressive-delay procedure. The procedure used a VI schedule and either signalled or unsignalled delays to reinforcement. Their results also showed that response rates were higher when delays to reinforcement were signalled, than when the delays to reinforcement were unsignalled (Reilly & Lattal, 2004).

There have only been a handful of studies on the effects of delayed reinforcement in FR schedules. Azzi et al. (1964) examined the effects of delayed reinforcement during FR schedules using continuous reinforcement (FR 1) through increasing unsignalled resetting delays. They found both a clear decrease in rate of responding and an increase in the PRP duration as the delay to reinforcement duration increased. In a second condition, responding was found to be faster and more stable when a 20-s or a 30-s delay was signalled compared to when it was not signalled. These findings are consistent with studies with other schedules (e.g., Reilly & Lattal, 2004) showing that the effect of delay to reinforcement on responding is greater when the delay is unsignalled than when it is signalled.

While Azzi et al. (1964) found comparable results to those studies using different schedules of reinforcement, during a FR 1 schedule, Morgan (1972) stressed the importance of arranging response requirements beyond FR 1 to better understand the effects of delay to reinforcement upon rates of responding after the pause. A FR 9 schedule was used to examine the effects of three signalled delays to reinforcement; 0.75 s, 3 s, and 12 s. Their results showed that the PRP duration increased as the delay to reinforcement increased. Topping, Johnson, and McGlynn (1973) also examined the effects of delay to reinforcement on PRPs for rats responding under one of three FR schedules (10, 75 and 150). The delayed reinforcement duration was systematically manipulated between 0 s and 180 s. They also found that PRP duration increased as the delay to reinforcement increased. However, unlike Azzi et al. (1964), neither Morgan (1972) nor Topping et al. (1973) found any consistent effects of delay to reinforcement on rates of responding.

There are several potential reasons for the discrepant findings. Firstly, in each study, different FR values and delay intervals were used as well as the type of delay. Azzi et al. (1964) used resetting delays while Morgan (1972) and Topping et al. (1973) used a non-resetting delays. As previously mentioned, studies have found that resetting delays, such as used by Azzi et al. (1964), have more of an effect on response rates than non-resetting delays. Furthermore, it appears that Azzi et al. (1964) included the delay duration in their calculation of the overall response rate. Morgan (1972) and Topping et al. (1973) on the other hand did not include the delay interval in their calculation of the overall response rate. By including the delay in the calculation of the response rate, consumption rate would decrease with increasing delay, regardless of the subjects' behaviour. If the delay duration was excluded from the analysis perhaps Azzi et al. (1964) may have observed similar findings to Morgan (1972) and Topping et al. (1973).

Overall, the effects of delayed reinforcement on behaviour under increasing FR schedules seemed unclear. More recently however, Harris et al. (2012) used hens to further the research on the effects of delay to reinforcement on FR performance. In a series of conditions, hens responded to gain 3-s access to wheat following a range of delay values (0, 4, 8, 16, & 32 s) under increasing FR schedules. Time available for responding was kept constant at 40 mins, to ensure that the period of time in which the hens could respond was the same regardless of the duration of the delay. Harris et al. (2012) found at each ratio requirement, with an increased delay duration, response rate and total consumption rates decreased and PRP duration increased at the larger delay durations, consistent with the findings reported by Azzi et al. (1964).

Intertrial interval

Not only has delayed reinforcement been found to influence behaviour, but so too has an intertrial interval (ITI). Over the years, time has become to be thought of as a contextual stimulus influencing behaviour by changing the temporal context and influencing behaviour accordingly (Bouton, Westbrook, Corcoran & Maren, 2006). As previously mentioned, studies have found introducing a delay increases the time to the reinforcer and effects responding. An ITI refers to the time between successive trials when there are no scheduled experimental events and response operand and stimulus lights are usually turned off. The difference between a delay and an ITI is where the additional time passage occurs in the sequence of events. Studies looking at the way time influences behaviour have investigated the effects of ITI's is largely during learning and memory procedures such as discrimination training (e.g., Williams, 1998), autoshaping (Kaplan, 1984) and matching-to-sample (e.g., Thomas, 1979) using different reinforcement schedules including FR schedules.

The effect of the temporal variable ITI has been examined during discrimination learning. Williams (1998) used rats to study the effects of an ITI in a simple conditional discrimination task, where a tone or a light signalled whether the right or left lever, correspondingly, was correct. Results reported that as the ITI duration increased, the rate of learning also increased, an opposite effect from that seen in earlier studies of serial reversal learning. This study was replicated by Ploog and Williams (2010) but used an ITI in conjunction with a delay (e.g., 4 s or 40-s ITI followed by a 0 s of 2-s delay before reinforcement delivery). While Ploog and Williams (2010) results were the reverse effect reported by Williams (1998) their findings were consistent with previous studies of ITI in serial reversal learning (e.g., Williams, 1971) showing that reversal learning is faster with shorter ITIs than larger ones (Ploog & Williams, 2010).

Another area of research which has examined the effects of an ITI is matching-to-sample and delayed matching-to-sample. Matching-to-sample is a procedure of responding, where subjects are to correctly choose between stimuli presented, which one corresponds in some way to a sample stimulus (Thomas, 1979). A number of studies which have used an ITI during such a procedure have reported greater accuracy and higher acquisition rate with the use of a ITI, as opposed to no ITI (e.g., Holt & Shafer, 1973; Thomas, 1979), and with longer ITI’s (e.g., Roitblat & Scopatz, 1983; Spetch & Rusak, 1989).

Research on the effect of an ITI during delayed matching to sample tasks has found similar results, reporting a direct relationship between the ITI duration and accuracy on the tasks. Studies using pigeons (e.g., Roberts & Kraemer, 1982) have shown that the percentage of accurate choices increase as the ITI duration increases. Roberts and Kraemer (1982) examined the effects of ITI on pigeons’ performance during a delayed matching to sample task while varying the delay and ITI duration. With decreases in delay, and increases in ITI duration, accuracy increased. These findings were later support by Spetch and Rusak (1989), who went on further to examine the effects of within-session variations of the ITI and delay. Conclusions from these studies have suggested that accuracy with memory tasks is better with spaced practice (e.g., using ITI’s) than massed practice (Roberts & Kraemer, 1982) and the temporal variable ITI, directly influences behaviour.

The effects of an ITI on matching tasks are similar to those effects this variable has on autoshaping tasks. Several experiments which have looked at the effect of ITI on the rate of acquisition and maintenance of autoshape pecking have found them to be directly affected by the length of the an ITI (e.g., Perkins, Beavers, Hancock, Hemmendinger, Hemmendinger, & Ricci, 1975). Regardless of the procedure, an ITI has been found to be a variable which has an effect on an animal's behaviour. While the present study will not be using the ITI for the same purpose that it has been used for in the previously mentioned studies, the ITI will simply be used as a place holder of time.

The reduce effectiveness of the reinforcer could be due to either the increase of time between the effective response and the delivery of reinforcement or due to the increase in intervals between the reinforcers. This author could not find research which clarified which of these two explanations contributes most to the reduced effectiveness of the reinforcer. Thus, an aim of the present study was to explore which explanation is more likely to account for the reduced effectiveness of the reinforcer. While delayed reinforcement has been previously mentioned to reduce the value of the reinforcer, an ITI will be used to determine if it is the increase in intervals between the reinforcers which devalues the reinforcer instead of the increase time between the effective response and the delivery of reinforcement which is produced by the delay.

Behaviour Economics

Two major purposes of experimental research are to describe and explain behaviour (Church, 1997). The ability in which to do so is followed by the ability to predict and control behaviour. The application of economic concepts to the analysis of behaviour has generated significant interest over the past 15 years (Foster et al., 1997). In behaviour economics the subject is the consumer and price relates to the amount of work required to gain access to a commodity (reinforcer) (Lea, 1978). When demand for a commodity is investigated, the experimenter manipulates the effort required for that commodity, while monitoring the consumption rate. The term demand refers to the change in the quantity of a commodity consumed, as a function of the change in price of that particular commodity (Hursh, 1980). Typically, FR schedules are used in those investigations as this particular schedule defines the exact number of responses (price) required before the commodity is delivered (Hursh, 1984).

The degree to which the consumption rate changes as a function of a change in price is known as the elasticity of the demand function (Hursh, 1980). When consumption is measured across different prices, consumption (number of reinforcers obtained at each price) is graphed logarithmically as a function of the log schedule size to give the demand function (Lea, 1978). Typically demand functions show a decrease in consumption of a commodity as the price increases (Hursh, 1980). It is the slope of this demand curve which gives the measure of elasticity and is used to determine the importance of different reinforcers (Hursh, 1980). A demand curve which has a slope shallower than negative 1.0 is said to show inelastic demand. To show inelastic demand, subjects would maintain a relatively steady level of consumption and would show an increase in response expenditure as price increases (Hursh, 1980). A shallow decreasing demand curve reflects a highly valued reinforcer, where the subject will continue to work hard for the reinforcer as price increases (Foster, Sumpter, Temple, Flevill & Poling, 2009). A slope which is steeper than negative 1.0, shown by a steeply decaying curve, is called elastic demand (Hursh, 1980). A steeply declining demand curve suggests that the benefits of obtaining a reinforcer, is not justified by the increasing cost it and therefore, the reinforcer is valued less. Consumption is highly sensitive to price shown by large decreases in consumption (response rate) due to increases in price (FR schedule) (Hursh, 1984).

The economic system used during an experiment has been argued to influence the elasticity of demand (Hursh, 1980). The economic system may be open or closed. A closed economy is where subjects only have access to the commodity during the experimental session. If the subject is working for food as the commodity, their entire daily intake must be gained during the experimental session. The food consumption is solely dependent on the subject's interaction with the schedule of reinforcement (Hursh, 1980). An open economy refers to subjects having access to the commodity after the experimental session as well as during it in these procedures. The subject's total consumption of food is not purely a result of the experimental session but controlled by the experimenter (Hursh, 1980), for example, by maintaining subject's body weight at 80% with additional food. Hursh (1980) argued that closed economies resulted in more inelastic demand functions, while open economies resulted in elastic demand functions. His argument was based on research which found, subjects responding under closed economies minimise changes in consumption by increasing their rate of responding, along with increases in the response requirement, while subjects under open economies maintained a relatively constant rate of consumption (Hursh, 1980).

More recently, it has been argued that other factors may have actually influenced the results found by Hursh (1980). Closed economy experimental sessions are typically long, ensuring that subjects are able to obtain all the food it requires, while open economy experimental sessions are typically short, resulting in supplementary food (Foster et al., 1997). Foster et al. (1997) noted this difference and examined the demand for food in hens in closed and open economies. The hens were maintained at 80% of their free-feeding body weights through the addition of supplementary food during open economies. During closed-economy sessions, the hens had to obtain their entire daily food intake within both long (24-hr) and short experimental (40-min) sessions. Results showed demand was elastic during open-economy sessions and inelastic during long closed-economy sessions in agreement with pervious findings. When the hens' were exposed to short closed economy sessions however, the demand was more elastic, leading to the suggestion that session length may be more influential on demand than economy type.

The elasticity of a demand curve may not always remain continuous across the different prices, changing from inelastic to elastic with increases in price (Hursh, 1984). This means that the slope of the function on the log-log coordinates decrease from a value greater than -1 to value which is less than -1. This change produces a curvilinear demand function (Hursh, 1980). This type of demand curve has been reported to be common among experiments which have used animals (Hursh, 1984). Hursh, Raslear, Shurtleff, Bauman, and Simmons (1988) proposed the following equation to describe this type of data

$$\log Q = \log L + b(\log P) - a P \tag{1}$$

where *Q* represents the total consumption (reinforcers obtained) per session, *P* is the unit of price (for this experiment with FR the response requirement is the *P)* and *L, b,* and *a* are the fitted parameters. *L* estimates the level consumption at the minimal price (e.g., FR 1); the larger the *L* value (when the consumption is measured on a common scale) the more of that commodity is consumed at the minimal price. The parameter, *b,* is the initial elasticity at the minimal price, and *a* is the degree of the rate of change (or acceleration) of the slope with the increase in price (Hursh et al., 1988). These two parameters are required to describe the elasticity of the function. When the function is inelastic over low prices but shifts to being elastic as the price increase, a and b are used to find the price associated with maximal response output (Foster et al., 2009) The price which is associated with maximal response output is termed P_{max} and is the price at which the demand changes from being inelastic to elastic (Hursh et al., 1988). The equation for P_{max} is (Hursh & Winger, 1995);

$$P_{max} = (1 + b) / a \qquad (2)$$

where a and b are as defined above. P_{max} is used as a measure for the comparison of the value of different commodities. The higher the P_{max} value, the higher the price at which the demand changed from inelastic to elastic. The greater the value of P_{max} , the greater the expenditure of resources as price increases.

While the P_{max} value defines the maximal response output, it only provides one single point on the demand curve. More recently, Hursh and Silberberg (2008) suggested an alternative equation to the Hursh et al. (1988) which uses a single parameter, Alpha (α), to measure how steeply the demand curve declines across the entire demand curve as price increases.

$$\ln Q = \ln Q_0 + \mathrm{k} (e^{-\alpha P} - 1) \qquad (3)$$

where Q_0 estimates the highest level of consumption at minimal price, comparable to the L parameter in Equation 1, while P and Q are as in Equation 1. The parameter k specifies the range of consumption, and α, the rate constant, represents how consumption changes as the price increases. Hursh and Silberberg (2008) refer to α as specifying the ‘essential value’ of a commodity (or the reinforcer), while k is a scaling parameter. k is set to the same constant across comparison so that changes in elasticity may be determined by changes in the parameter α. The value of α is inversely related to the value of a reinforcer.

Therefore, the larger the α value, reflecting increasing elasticity, the less the essential value of a reinforcer and the steeper the demand curve. One of the main characteristics of α is that it is unaffected by the scalar properties of a reinforcer such as magnitude or quantity (Hursh & Silberberg, 2008).

Hursh and Silberberg (2008) concluded that this Equation 3 is superior to the Hursh et al. (1988) nonlinear equation (Equation 1), because not only did it reflect the 'value' of a commodity but was able to do it using one single parameter α to scale elasticity of demand (Hursh & Silberberg, 2008). While α values are inversely related to value, P_{max} , which is derived from α, has been argued to be a more intuitive measure of essential value and is inversely proportional to α. As previously mentioned, P_{max} not only is the price at which the slope of demand curve is -1 but also describes the price at which peck responding occurs.

As previously mentioned, delayed reinforcement can alter a reinforcers value and therefore its effectiveness, leading to decreases response rates. Harris (2010) used hens to investigate the effect of a signalled delay to reinforcement on FR performance and the demand for food. Functions were fitted using both Hursh et al. (1988) and Hursh and Silberberg (2008) exponential equations. Harris (2010) found both equations fitted the data well, but neither case did any of the parameters vary systematically with delay. The only consistent finding was that the initial consumption was largest when there was no delay and smallest in the condition with the largest delay. Her results did suggest a decreasing effect of delay to reinforcement with increases in the response requirement (Harris, 2010).

Behaviour economics has not only been used when investigating the effects of delay on responding but also to investigate the demand for a certain reinforcer when an ITI is manipulated. Silberberg, Warren-Boulton and Asano

(1987) looked at the effects of consumption in a discrete-trail choice procedure with monkeys. In their first experiment, monkeys' earned their daily food by choosing between a small food pellet and a large, bitter-tasting pellet. When income was high, a circumstance arranged by having a short interval between trials, monkeys met their food requirements by consuming small pellets almost exclusively. On the other hand, when the number of trials per session was reduced by lengthening the ITI, their consumption of the large, bitter pellet increased while their consumption of the small pellets decreased. Later, Hastjarjo, Silberberg and Hursh (1990) replicated this study using rats and found similar results. Like Silberberg et al. (1987), this study also used the choice between a smaller amount of better tasting food and a larger amount of bitter tasting food but manipulated the number of trials per session. From their results, it appears that as less favoured of two outcomes became more accessible it became either more or less acceptable, conditional on the way accessibility was manipulated (Hastjarjo et al., 1990).

MPR

Another model which aims to describe and predict animals' response rates while responding under different schedules is the Mathematical Principles of Reinforcement (MRP, Killeen, 1994). MPR is a general theory of operant behaviour proposed by Killeen (1994), which identifies three factors which affect the control of behaviour by reinforcement. Reinforcement increases behaviour, as the rate of reinforcement increases, the number of responses that each reinforcer can influence decreases (Killeen, 1994). The three main principles are; arousal, constraint and coupling. Firstly, reinforcers activate behaviour which is described by the parameter known as specific activation. Constraint is the second factor which refers to the limits to responding such as the time it takes to emit a response. The third factor is known as coupling, which defines the strength of the association between a reinforcer and a response class (Killeen, 1994). The three factors are represented by three parameters, which are feature in the fundamental equations of Killeen's theory.

The animal's arousal itself cumulates with increases in the frequency of reinforcement (Killeen & Sitomer, 2003). This arousal which cumulates from feeding is defined by the parameter known as *specific activation* (a_s) (Killeen, 1994). Due to using the symbol *a* in the Hursh et al.'s (1988) nonlinear demand equation, for purposes of this the present study, specific activation known as (*a*) will be referred to as (a_s). Specific activation is the measure of motivation and is the integral of the exponential decay curve of responses per reinforcer when exposed to multiple presentations of incentives (Killeen & Sitomer, 2003). It represents the number of seconds of responding which is activated by each incentive (or reinforcer). The duration of activation provides a guide of the effectiveness or 'incentive value' of the reinforcer. While it may seem likely that the delivery of an incentive would increase the activity of a subject, research has found many influencing factors of specific activation including the animal's level of saturation (e.g., Killeen, 1995), size of reinforcer (e.g., Bizo & Killeen, 1997) duration for which the reinforcer is presented (e.g., Bizo & Killeen, 1997) and what type of economy system is, open or closed (e.g., Zeiler, 1999).

In 1978, Killeen, Hanson and Osborne examined the relationship between behavioural activation and incentive value. During the first experiment, food deprived pigeons were fed once in an activity enclosure where their activity was recorded, then returned to home cages after 30 minutes. Activity was the highest immediately following food delivery then decreased as time since the food was delivery increased. The second experiment investigated what happened to the pigeons’ activity when the rate of feeding was increased to various fixed time schedules (FT 30 s and FT 50 s). Results revealed that the pigeons’ activity increased at a level much greater than found in the first experiment. The findings from both experiments suggest that rate of feeding directly affects the rate of activity, with the arousal of the birds directly associated to the frequency of food delivery (Killeen et al., 1978).

Later, it was noted that the rate of responding was not exclusively a function of the rate of reinforcement (Killeen et al., 1978). The second principle, *constraint,* refers to the limits (or factors), unrelated to arousal or specific activation, which may cause response rates to fall short of the theoretical curve (Killeen & Sitomer, 2003). While responses may be elicited at a rate defined by the first principle, this second principle of MPR states that responses may be prompted faster than they can be performed (Killeen & Sitomer, 2003). Competition from other responses, and the time taken to make a response, influence the rate at which responses are emitted (Killeen, 1994). Inter-response time (IRT) refers to the minimum response duration an organism is physically able to produce. This time is taken from the start of one response to the start of the next (Killeen & Sitomer, 2003).

The third principle, *coupling*, describes the relationship between the reinforcer and a response class. This third factor of MPR determines the likelihood of a response from that response class being emitted (Killeen & Sitomer, 2003). When a response is emitted, it has an effect on the memory of a certain strength which decays over time. The memory trace of a response is strengthened when another response of the same class is emitted (Killeen, 1994). During a FR schedule, all target responses must be emitted before reinforcement is delivered. As the FR requirement increases, the effect of each reinforcer contacts more responses, and so the response rate is seen to be increasing. However, at the same time, the level of arousal decreases. Therefore, MPR predicts an inverted U change in response rate as a function of ratio requirement (Killeen, 1994). Once the number of responses has saturated the memory, responding is governed only by arousal, and is depicted in the downward part of the inverted U (Killeen, 1994). Coupling is represented by the parameter β (a factor of constraint represented by δ), lambda (λ) is the rate at which response traces decay. When using FR schedules, the following equation is used,

$$B = \frac{c.}{\delta} - \frac{n}{\delta as} \qquad \text{where } a_s > 0,\ \beta > 0, \text{ and } \delta > 0 \qquad (4)$$

where *c.* is the coupling coefficient for the ratio schedules in force, B refers to the rate at which responses are emitted, n is the FR value, δ is the parameter which expresses the minimum inter-response time, and parameter a_s is the number of target responses that a reinforcer can maintain (Killeen & Sitomer, 2003).

There are several different versions of MPR, with one equation including the additional parameter epsilon (ε). The addition of this parameter is to reflect the degree to which memory of a target response is erased between responses (Killeen & Sitomer, 2003).

$$C_{FRn} = 1 - \varepsilon\, e^{-\lambda\delta n} \qquad (5)$$

Values for ε can vary between 0 and 1, with 0 representing total recall, and 1 complete erasure. In Equation 5, coupling is expressed as a factor of λ and includes ε (Killeen & Sitomer, 2003).

The four graphs in Figure 1 illustrate the hypothetical effects of a change in each of the four parameters of Equation 4. In each of the graphs, the continuous line shows the baseline function and the dotted lines illustrates the change function; (i) a change in δ alters the peck function, (ii) a change in a_s alters the slope of the function, (iii), a change in ε shortens the ascending portion of function and raises the peck, (iv) a change in λ alters the slope of the ascending limb of the function.

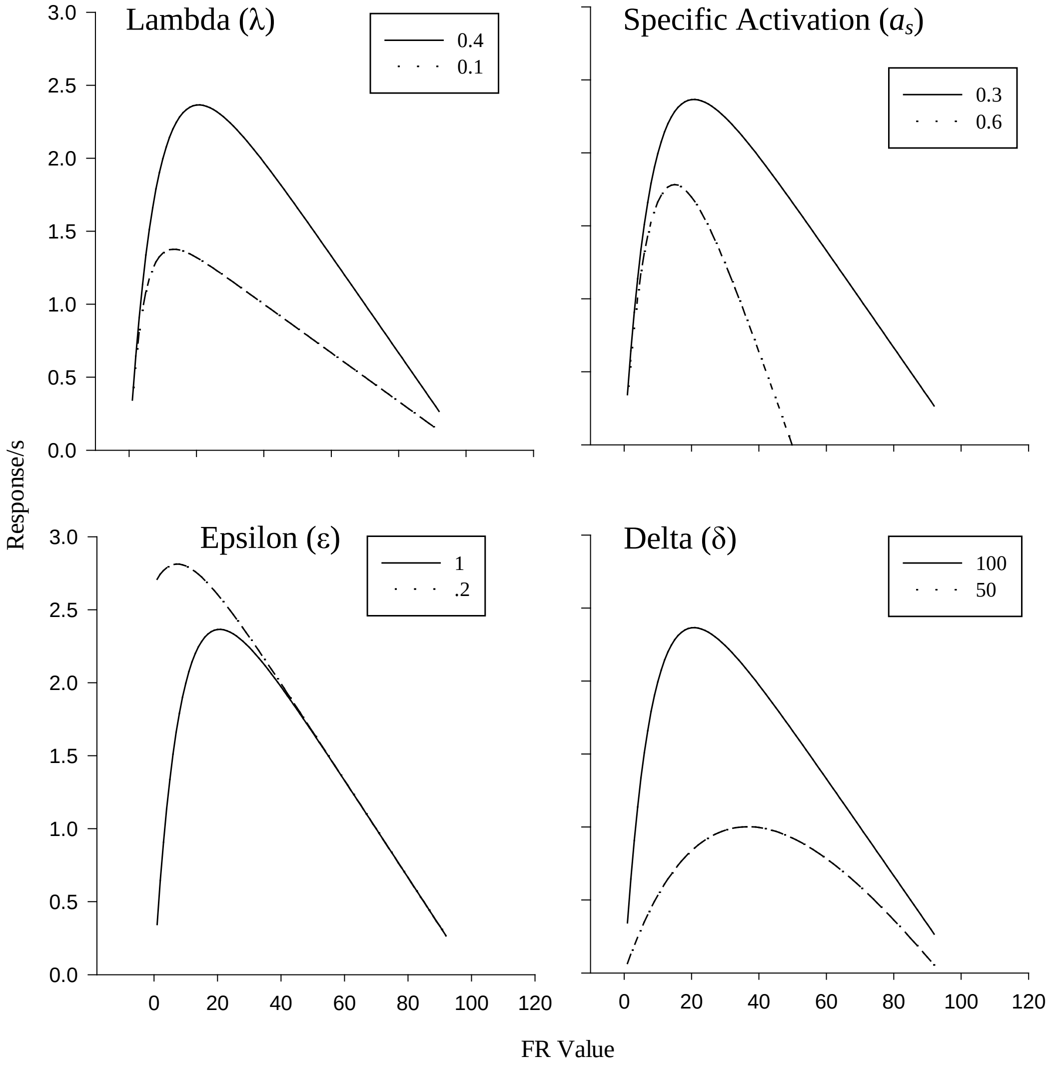


Figure 1: Theoretical FR functions representing the effects of changes to λ (top left side), a_s (top right side), ε (bottom left side), and δ (bottom right side).

The ability of this model to accurately make predictions was tested by Bizo and Killeen (1997) using FR and VR schedules with pigeons and known preferred foods. Bizo and Killeen (1997) reported estimates of a_s were higher for the most preferred food (popcorn) and lower for the least preferred (millet) as predicted. Longer access to a food reinforcer also produced higher estimates of a_s than shorter access to the corresponding food. Furthermore, results showed that different reinforcers had different estimates of a_s. This suggests that specific activation values may be used as a measure of reinforcer effectiveness sensitive to the manipulation in size and quality of the reinforcer while δ is affected by response-force requirements (Bizo & Killeen, 1997).

Thus, behaviour under FR schedules has been described in several different ways through using different models relating to the consumption of reinforcers at each FR value. An aim of the present study was to compare these methods over the same data set with hens for measuring the relative values of reinforcement. Overall, the existing data suggest that the effectiveness of a reinforcer is reduced by adding a delay between the last effective response and the delivery of the reinforcer (e.g., Azzi et al., 1964: Morgan, 1972). Thus, the addition of a delay should effect the parameters of MPR, and both behavioural economic models; Hursh et al. (1988) equation and Hursh and Silberberg’s (2008) equation with changes to the FR value. The delay has the effect of increasing the time between the reinforcement. As previously mentioned, ITI also increases the total session duration, therefore it is predicted that it should also affect the parameters of MPR, and both behavioural economic models but to a lesser extent than the delay to reinforcement.

The present study used two delay and ITI durations to determine the effect of each on responding. Previous research suggests that for a reinforcer with a delay, consumption might be reduced across all FR values, including the small FR values, compared with consumption of one with an ITI or no delay. Also, the larger the delay, the larger this effect would be. Additionally, based on Hursh and Silberberg's assumptions regarding the parameter α, there should be no changes to this parameter if the delay has similar effects on the essential value of the reinforcer as do changes in does with drugs or quantity with food. It might also be expected that consumption will decrease faster, demand functions would be more elastic, and that P_{max} would be smaller for reinforcers with a delay. It is also expected that if the delay to reinforcer devalues the reinforcer more than the ITI, longer delays should produce smaller estimates of a_s for MPR and lower rates of responding. Likewise, it is expected that values for ε would be higher and closer to 1 during the delay conditions than in the equivalent ITI conditions. It is expected that the faster response rates would be seen in the ITI conditions than the equivalent delay conditions and the slowest response rate would be in the 16-s delay condition.

Method

Subjects

Six domestic laying Gallus Domesticus hens (number 31 through to 36) were housed individually in wire cages (500-mm long x 510-mm wide x 420-mm high), in a ventilated room which was lit on a 12 hours light; 12 hours dark cycle (6 am – 6 pm). Hens were weighed daily and they were maintained at 85% ± 5% of their free-feeding weights through post-session feeding of commercial layer pellets. Water was freely available in the wire cages and grit and vitamin supplements were provided on a weekly basis. At the beginning of the experiment, 31-33 had no prior experience on simple schedules of reinforcement, while 34-36 did have some experience on progressive ratio schedules.

Apparatus

The experiment chamber was located in a room with other experimental chambers and measured 640-mm long x 450-mm wide x 580-mm high. The interior was painted white with an operant response key and food magazine mounted on the right hand wall. The food magazine was located behind an opening (115-mm x 70-mm) centred 105-mm above the floor. The operant response key was a frosted transparent perspex response key (30-mm in diameter) which was positioned 390-mm from the floor and lit red with a 28-V multi-chip LED (light-emitting diode) bulb. The force requirement to activate the response key was approximately 0.2 N which resulted in an audible beep. When activated, a light above the magazine was illuminated and the magazine was raised to allow 2-s timed access to wheat.

All experimental events were controlled and recorded by a Dell PC computer running Med-PC IV software. The data at the end of each experimental session was manually recorded into a data book as well as being recorded by the computer software.

Procedure

In a series of conditions, the hens responded to gain 2-s access to wheat following completion of a FR schedule which included either an ITI or a delay to reinforcement. For all series, the hens proceeded through a geometric progression of FR values (FR 1, 2, 4, 8, 16, 32, 64, 128, 256, 512, 1024 & 2048) until no reinforcers were delivered in a session. If no reinforcers were delivered, that FR value was re-presented in a second session, and if no reinforcers were obtained in that session, the series was deemed to be ended. However, if a reinforcer was delivered, the next FR value in the sequence was initiated in the following session. Following the completion of each FR series, the hens' responded on a FR 20 schedule of reinforcement and either the delay or ITI for the particular condition they were completing before proceeding onto the next series of the condition. Following the completion of a condition each hen then responded on a FR 20 for 6 sessions with the relevant delay or ITI for the coming condition in effect.

Training. Hens' 31, 32, 33 key response required shaping by successive approximations procedure. They first had magazine training before being hand shaped to key peck where a reinforcer was manually delivered after every response for the first 30 reinforcers. This was completed in two sessions. Once they were responding consistently to the lit response key, each hen then completed six sessions that ended after 20 reinforcers were delivered according to a FR 20 schedule.

All hens completed 15 sessions on a FR 20 which ended after a key time of 40 minutes (2400 s).

Experimental conditions. The experimental sessions lasted for a total of 40 min of key time (total session time minus the reinforcer delivery time and delay and ITI time), to ensure that each hen had the same available period of time in which they could respond regardless of the duration of the delay or ITI. For each hen, a session was conducted every day that they were in their specified weight range. For the lower FR values, this was every second to third day due to the large numbers of reinforcers obtained.

Condition 1 involved the hens being exposed to the geometric series of FR values with a 4-s ITI. After the ITI, the response key was illuminated and the hens were required to respond to the specific ratio requirement by pecking at the response key before reinforcement was delivered.

In Condition 2, hens were exposed to the same geometric series of FR values but with a delay to reinforcement of 4 s. Similar to the first condition, the response key was illuminated and the hens were required to respond to a specific ratio requirement by pecking at the response key before there was a black out period of 4 s followed by the reinforcement. Immediately following the delivery of reinforcement, the next component of the experiment started.

Condition 3 was the same as Condition 1 except the ITI was 16 s.

Condition 4 was the same as Condition 2 except the delay to reinforcement was 16 s.

Data collection. Data collected included the FR size, delay length or ITI length, time to first response, between ratio pause times, run time, key time, and total number of responses and number of reinforcers obtained. Also recorded was the total session time, mean eating time (time head was in magazine during reinforcer access), and amount of post feed (if required based on the number in which the hen received during the experiment).

Table 1.1.
The order of experimental conditions, together with the highest FR schedule completed in each series of each condition for each hen.

Condition	Series	Hen					
		31	32	33	34	35	36
Condition 1: 4-s ITI	1	512	256	1024	512	256	512
	2	1024	1024	512	512	512	256
	3	1024	512	1024	512	512	512
Condition 2: 4-Delay	1	1024	256	1024	512	256	1024
	2	1024	256	2048	512	256	512
	3	1024	512	1024	512	512	1024
Condition 3: 16-s ITI	1	512	512	2048	2048	512	2048
	2	1024	512	1024	1024	512	2048
	3	512	256	512	1024	256	2048
Condition 4: 16-s Delay	1	512	128	2048	512	512	
	2	1024	512	1024	1024	512	
	3	512	512	1024	1024	256	

Results

This experiment exposed six hens to two different types conditions; ITI or delay to reinforcement. The hens’ responding was reinforced according to a geometrically ascending series of FR values, from FR 1 to FR 2048. Each condition was repeated three times. Data from all series and all conditions were analysed and presented in Appendix 2 along with the raw data. The data from the three series of each condition were averaged; overall response rates, running response rates and post reinforcement pause. In all figures, delay and ITI time was excluded when calculating response and consumption rates.

Hursh et al. (1988) Nonlinear Demand Functions

Presented in Figure 2 are the natural logarithms of the consumption data (the numbers of reinforcers obtained at each FR value in each session of 40-mins key time) for each hen for each condition. The lines were fit using Hursh et al. (1988) nonlinear equation (Equation 1). The parameter estimates derived from these fits are presented in Table 2, together with the P_{max} value (FR value at which maximal responding is predicted), as calculated by Equation 2. The Equation 1 fitted the data well (accounting for over 91% of the variance for all but 2 cases). In all cases, consumption rate decreased as the FR increased with the demand being curvilinear as shown by the functions in Figure 2.

For all hens, the largest initial demand (ln L values) occurred in the 4-s ITI condition. The largest initial demand value was also larger in the ITI condition than the corresponding delay condition. There were no other consistent patterns across all six hens. The smallest initial demand occurred in the 16-s delay condition shown in Table 2 for all but two hens; 32 and 34. For three of the six hens the ln L values decreased across the four conditions. For four of the six hens, the largest initial slopes (*b* values) was in the 4-s ITI condition and for all but one case, the ITI condition produced a larger initial slope than the corresponding delay condition. For Hen 35 only, the largest initial slope was during 16-s ITI condition and the 4-s delay condition had a larger initial slope than the 4-s ITI condition. In the 4-s ITI condition, 5 hens had the lowest P_{max} value in the 4-s ITI condition and three of the six hens had the largest P_{max} value in the 16-s ITI condition. There were no other consistent patterns across conditions in the rate of change of elasticity (*a* values) or P_{max}.

Hursh and Silberberg (k set as largest consumption data)

The exponential equation (Equation 3) suggested by Hursh and Silberberg (2008) was fitted to the data and the parameter values and measures of fit are given in Table 3. The values of ln Q_0 and α both change with changes to the *k* value, thus the same *k* value was used for the fit for each hen across the four conditions when the parameters were compared. For the present data the values of *k* value were obtained (as suggested by Hursh in the electronic tool referenced in the Hursh & Silberberg, 2008, p. 192, paper) by using the maximum range of consumption across all four conditions for each hen through setting the *k* estimator on the spread sheet to method 1. These *k* values ranged from 2.98 to 3.92. The parameters of these lines, ln Q_0 (initial consumption), and α (essential value) are presented in Table 3, together with %VAC and P_{max} values. The natural logarithms of the number of reinforcers are plotted against the natural logarithms of the FR value price together with these fitted functions (Figure 3). The lines fitted to consumption data accounted for over 90% of variance in 13 out of 23 cases, was between 85 and 89 for 8 cases and below 80 for 2 cases.

The α values generally increased between the 4 s and 16 sec conditions and were larger for both 16 sec ITI and delay conditions than delay and ITI 4 sec conditions for all cases. For all hens the α value was largest in the delay conditions than when an equivalent ITI conditions. For all six hens, ln Q_0 decreased consistently with increases in the duration of the ITI and the delay with the lowest value in the 16-s delay condition with the exception of 34. For all six hens, both the 4 s and 16-s delay conditions had lower ln Q_0 values than the equivalent ITI condition. The P_{max} value, calculated using the Hursh electronic tool, generally increased for all hens when the time was increased from 4 s to 16 s for both the delay and ITI conditions. It was higher for the delay conditions than the corresponding ITI conditions. For all but two cases, the P_{max} value was higher in the delay conditions than the equivalent ITI condition (Hens 34 & 35).

Table 2.

The parameters a, b, and ln L for Hursh et al. (1988) nonlinear equation (Equation 1) fitted to the natural logarithms of the mean consumptions data from all conditions. Also shown are the FR values at which maximal responding is predicted (P_{max}) and %VAC.

Hen	ITI	Delay	ln *L*	*a*	*b*	*se*	% VAC	P_{max}
31	4	0	5.75	0.0027	-0.6976	0.42	96.7	111
31	0	4	4.43	0.0034	-0.3455	0.22	97.6	194
31	16	0	4.41	0.0065	-0.3644	0.30	95.4	98
31	0	16	3.81	0.0045	-0.3242	0.57	78.9	150
32	4	0	7.28	0.0040	-0.9199	0.40	97.1	20
32	0	4	5.28	0.0269	-0.2566	0.29	97.7	28
32	16	0	6.16	0.0063	-0.7060	0.25	98.6	46
32	0	16	5.33	0.0077	-0.5473	0.30	97.4	59
33	4	0	6.20	0.0045	-0.5486	0.36	97.0	99
33	0	4	6.20	0.0041	-0.3897	0.15	1.00	151
33	16	0	5.73	0.0030	-0.4941	0.24	97.9	171
33	0	16	4.54	0.0052	-0.2618	0.21	98.2	142
34	4	0	5.69	0.0094	-0.5375	0.13	1.00	49
34	0	4	4.77	0.0100	-0.4359	0.28	97.8	57
34	16	0	5.45	0.0031	-0.5024	0.24	98.1	160
34	0	16	5.05	0.0042	-0.4922	0.21	98.7	121
35	4	0	6.00	0.0218	-0.5012	0.36	97.0	23
35	0	4	5.29	0.0080	-0.6490	0.34	96.0	44
35	16	0	5.27	0.0004	-0.7788	0.41	94.8	621
35	0	16	5.00	0.0024	-0.7399	0.19	98.9	109
36	4	0	5.42	0.0111	-0.3248	0.19	98.8	61
36	0	4	4.95	0.0048	-0.3336	0.30	96.7	140
36	16	0	4.95	0.0048	-0.3336	0.42	91.6	140

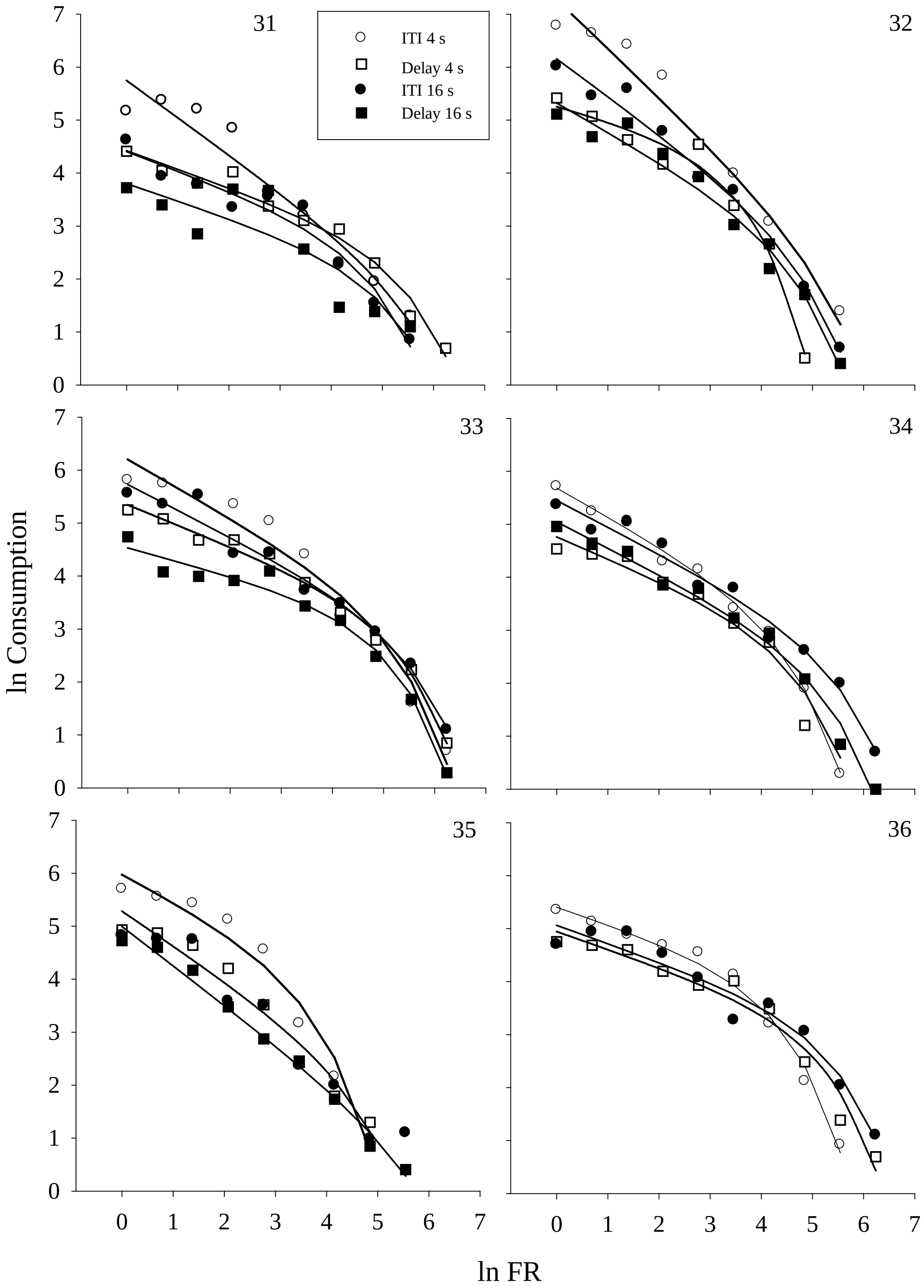


Figure 2. The natural logarithms of the consumption data, plotted against the natural logarithms of the FR size for each condition and each hen. The data are means of the series of each ITI and delay condition. The lines were fitted using Hursh et al.'s (1988) nonlinear equation (Equation 1).

Table 2.

The parameters ln Q_0 *,* α *and k for Hursh and Silberberg's (2008) exponential equation (Equation 3) and the values of k derived from the fit of Equation 3 to the max range of consumption data from all four conditions of each hen. Also shown is the predicted maximal response rate (*P_{max}*) corresponding to the FR value*

Hen	ITI	Delay	ln Q_0	k	α	%VAC	P_{max}
31	4	0	4.812	2.83	0.0000314	86.4	48
31	0	4	3.843	2.83	0.0000347	90.7	114
31	16	0	3.913	2.83	0.0000601	89.9	61
31	0	16	3.345	2.83	0.0000790	73.4	82
32	4	0	6.313	3.44	0.0000119	89.9	23
32	0	4	5.064	3.44	0.0000406	96.3	23
32	16	0	5.245	3.44	0.0000227	88.8	35
32	0	16	4.604	3.44	0.0000360	90.7	42
33	4	0	5.475	3.02	0.0000134	93.2	54
33	0	4	4.697	3.02	0.0000166	92.1	95
33	16	0	4.880	3.02	0.0000141	85.5	93
33	0	16	4.120	3.02	0.0000277	95.6	101
34	4	0	5.046	2.98	0.0000332	94.2	34
34	0	4	4.246	2.98	0.0000496	92.2	50
34	16	0	4.606	2.98	0.0000200	86.6	87
34	0	16	4.308	2.98	0.0000340	93.0	69
35	4	0	5.677	2.98	0.0000371	97.9	16
35	0	4	4.646	2.98	0.0000685	87.9	24
35	16	0	4.213	2.98	0.0000571	75.0	45
35	0	16	4.012	2.98	0.0000770	82.8	41
36	4	0	5.068	2.82	0.0000282	98.4	41
36	0	4	4.461	2.82	0.0000249	95.0	86
36	16	0	4.441	2.82	0.0000170	92.4	129

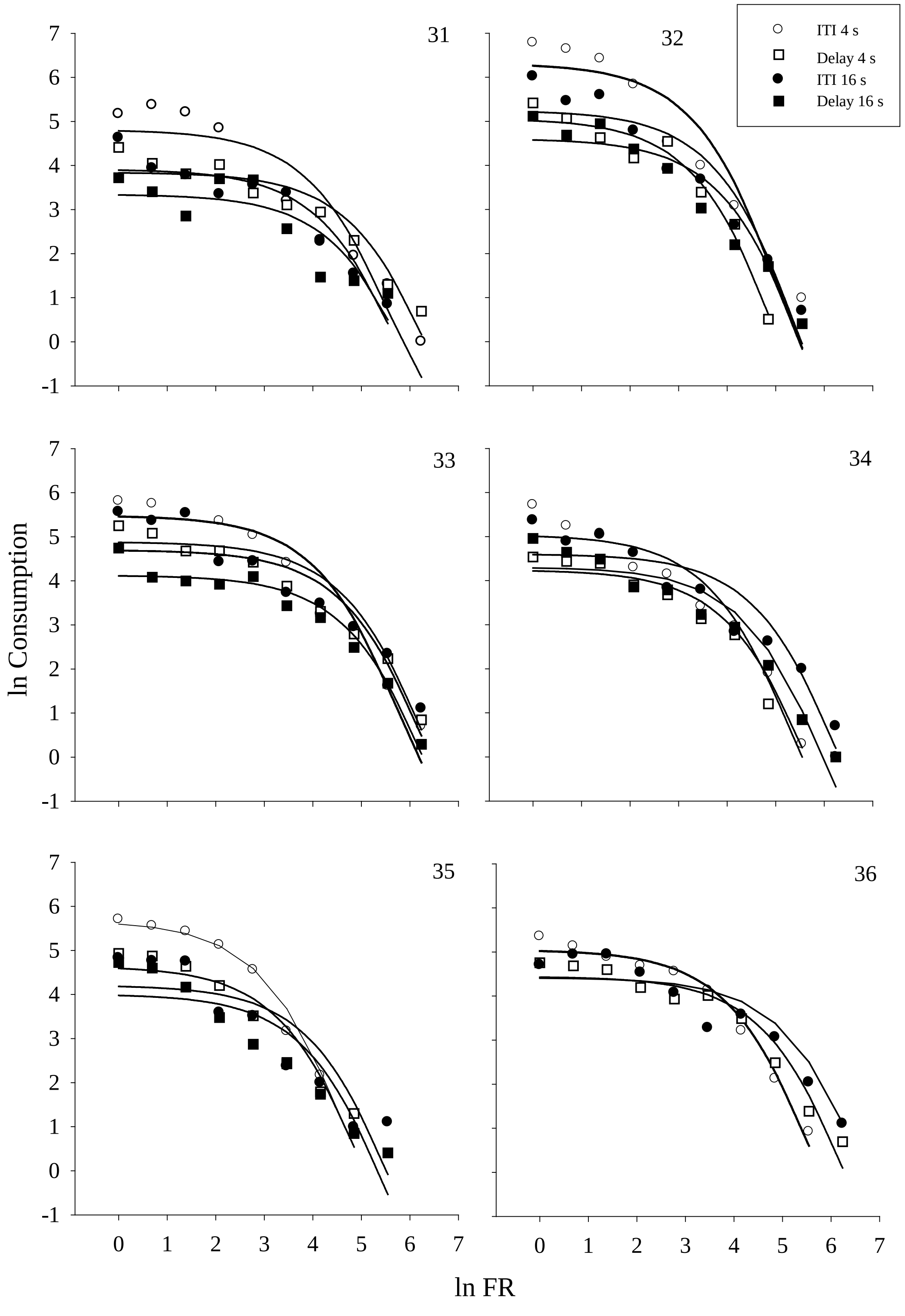


Figure 3. The natural logarithms of the consumption data, plotted against the natural logarithms of the FR size for each condition and each hen. The data are means of the series of each condition. The lines were fitted using Hursh and Silberberg’s (2008) exponential equation (Equation 3).

MPR

Figure 4 shows that typically, response rates increased with increases in ratio value up to a point, usually around FR 32 or 64, before decreasing at the larger FR values. Comparing the data points for the across the four conditions, hens responded at a lower rate during the 4-s delay condition (with the exception of Hen 31). For three of the hens (Hens' 33, 34, and 36) the 16-s ITI condition showed the highest rate of responding at higher FR values. The smooth curves through the data were fitted using Equation 4, represent the predictions of MPR. Parameter estimates of a_s, δ, ε and λ were obtained from the best fit of Equation 4 to the data for the individual hens' averages across all series in each conditions. The variation in the FR values at which hens stopped responding for each condition is captured by the model's estimate values for a_s. These values, as well as the parameter estimates for δ, λ, ε, and R^2 for the averages of each condition are compared in Table 4. In Table 4, it can be seen that the estimates for a_s are inconsistent across hens and across conditions but generally larger in the delay conditions then in the ITI conditions. Hen 31 had the same as value for the 4-s ITI condition and the 16-s delay condition. Likewise, the estimates for δ generally increased as the blackout time increased from 4 s to 16 s in both the delay and ITI conditions, and were generally higher for the delay conditions than the equivalent ITI condition. Estimates for λ were mostly higher in the ITI conditions than the corresponding delay duration conditions and were highest in the 4-s ITI condition. There were minimal differences seen in the values of ε across all conditions and all hens.

Table 4.

The estimated values of α_s, λ, δ and ε, along with R^2 for each fit of Equation 4 for each hen for responding across all conditions.

Hen	ITI	Delay	a_s	λ	δ	ε	R^2
31	4	0	4096.00	0.140	2.822	1.00	0.65
31	0	4	2225.95	0.016	1.678	0.95	0.94
31	16	0	1440.21	0.025	2.993	1.00	0.87
31	0	16	4096.00	0.025	4.274	1.00	0.57
32	4	0	582.26	0.664	1.246	1.00	0.59
32	0	4	279.45	0.072	2.028	1.00	0.67
32	16	0	646.37	0.203	2.318	1.00	0.76
32	0	16	812.67	0.085	3.349	1.00	0.90
33	4	0	1071.63	0.166	1.037	1.00	0.90
33	0	4	1502.13	0.030	0.952	0.90	0.94
33	16	0	1274.50	0.024	0.811	0.85	0.90
33	0	16	1832.89	0.027	1.449	0.99	0.96
34	4	0	686.64	0.044	2.050	0.79	0.88
34	0	4	1086.29	0.044	3.926	1.00	0.83
34	16	0	1624.20	0.016	1.150	0.82	0.86
34	0	16	1168.12	0.024	2.096	0.91	0.94
35	4	0	261.51	0.184	2.037	1.00	0.69
35	0	4	492.07	0.084	4.699	1.00	0.79
35	16	0	4096.00	0.078	5.401	1.00	0.55
35	0	16	781.64	0.007	4.989	0.65	0.77
36	4	0	570.06	0.081	1.381	1.00	0.86
36	0	4	1179.55	0.044	1.267	1.00	0.90
36	16	0	2167.39	0.024	0.914	0.90	0.88

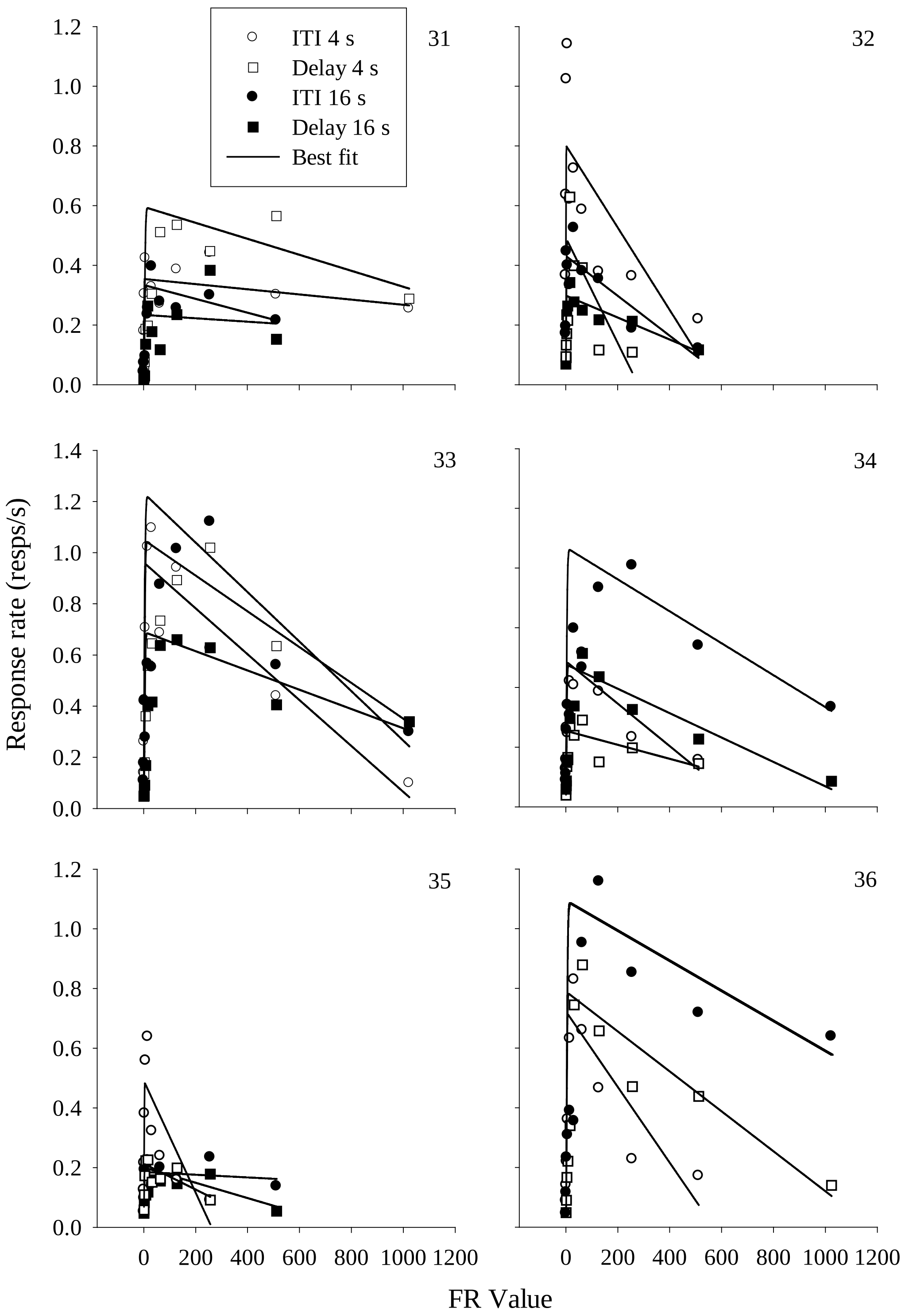


Figure 4. Mean response rates for each session are plotted as a function of the FR value for responding on the key. The curves are drawn by the MPR equation predictions

Mean Overall Response Rates

The mean total response rates (per s) for each hen and for each condition are shown in Figure 5. The total response rates were calculated by dividing the total number of responses at each FR by the key time (which excludes the reinforcement time and delay/ITI time). Generally, the total response rates increase across small to mid FR values, and then decrease across the large FRs. For Hens 32, 33, 34, and 35 the total response rates peaked at the higher FR values in the 16-s ITI condition in accordance with the demand data in which some hens were found to have the largest values of P_{max} in the 16-s ITI condition. Hen 31 and 36 total response rates were overall higher in the 4-s ITI condition at the lower FR values but were highest at the higher FR values in the 4-s delay condition. Across all hens and all conditions, the total response rates tended to increases across the small to mid FR values, then decrease across large FRs.

Mean Running Response Rates

Figure 6 presents the mean running response rates (per s) for each hen and for each condition. The running response rates at each FR were calculated by dividing the total number of responses by the run time (which excludes reinforcement time, PRP time and delay or ITI time), and are plotted for each condition. It should be noted, it is not possible to calculate running response rates for the FR value of 1. Generally, as the either the delay or ITI condition duration increased from 4 s to 16 s, the running response rates tended to decrease. In most cases the running response rates tended to decrease as the FR value increase, although in few cases (Hens 31, 33, 34) there were slight increases during the higher FR values before it decreased again. Hen 33 showed a more inconstant pattern of response during all four conditions.

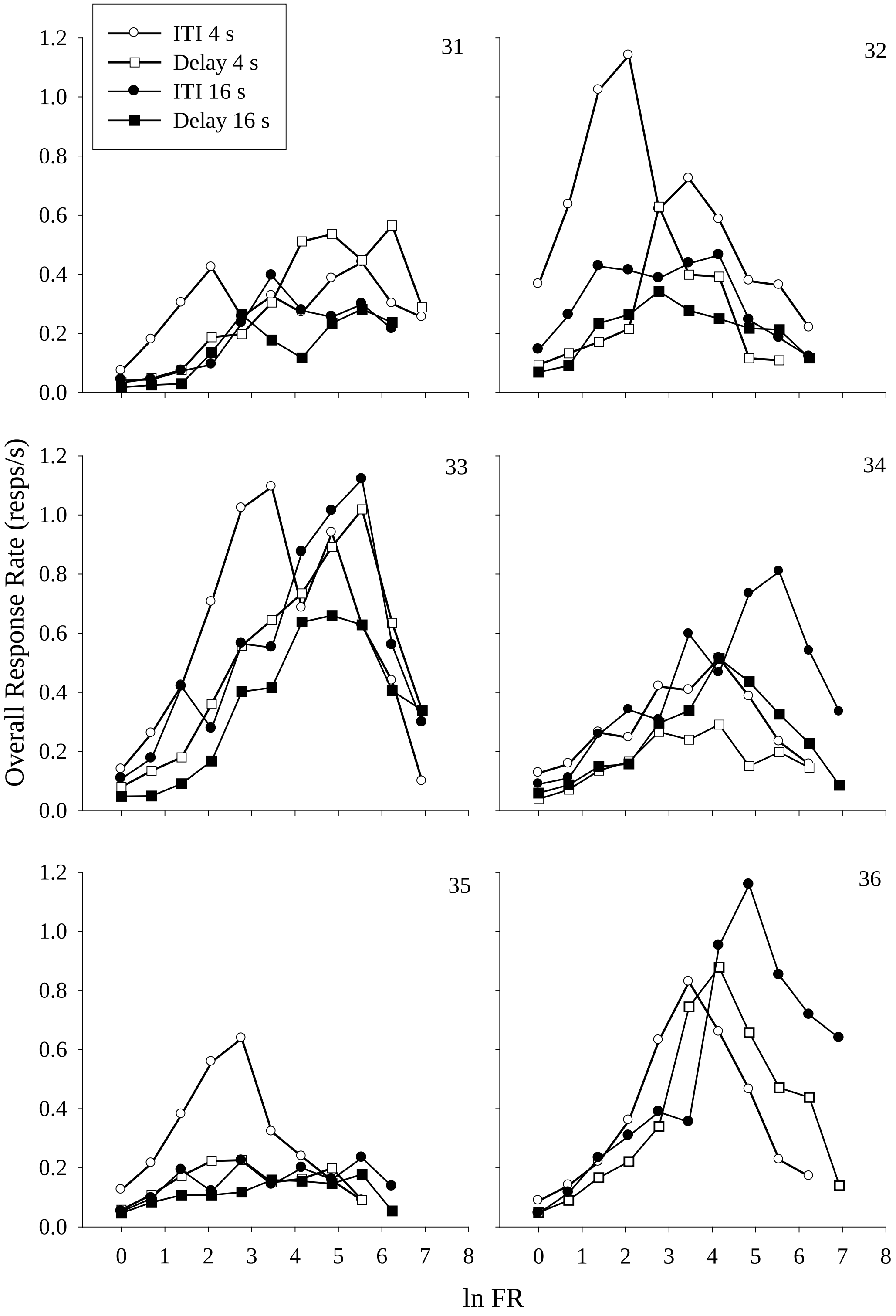


Figure 5. The overall response rates (per s), plotted for each ITI and delay condition for each hen. The data are means of the series of each ITI and delay condition.

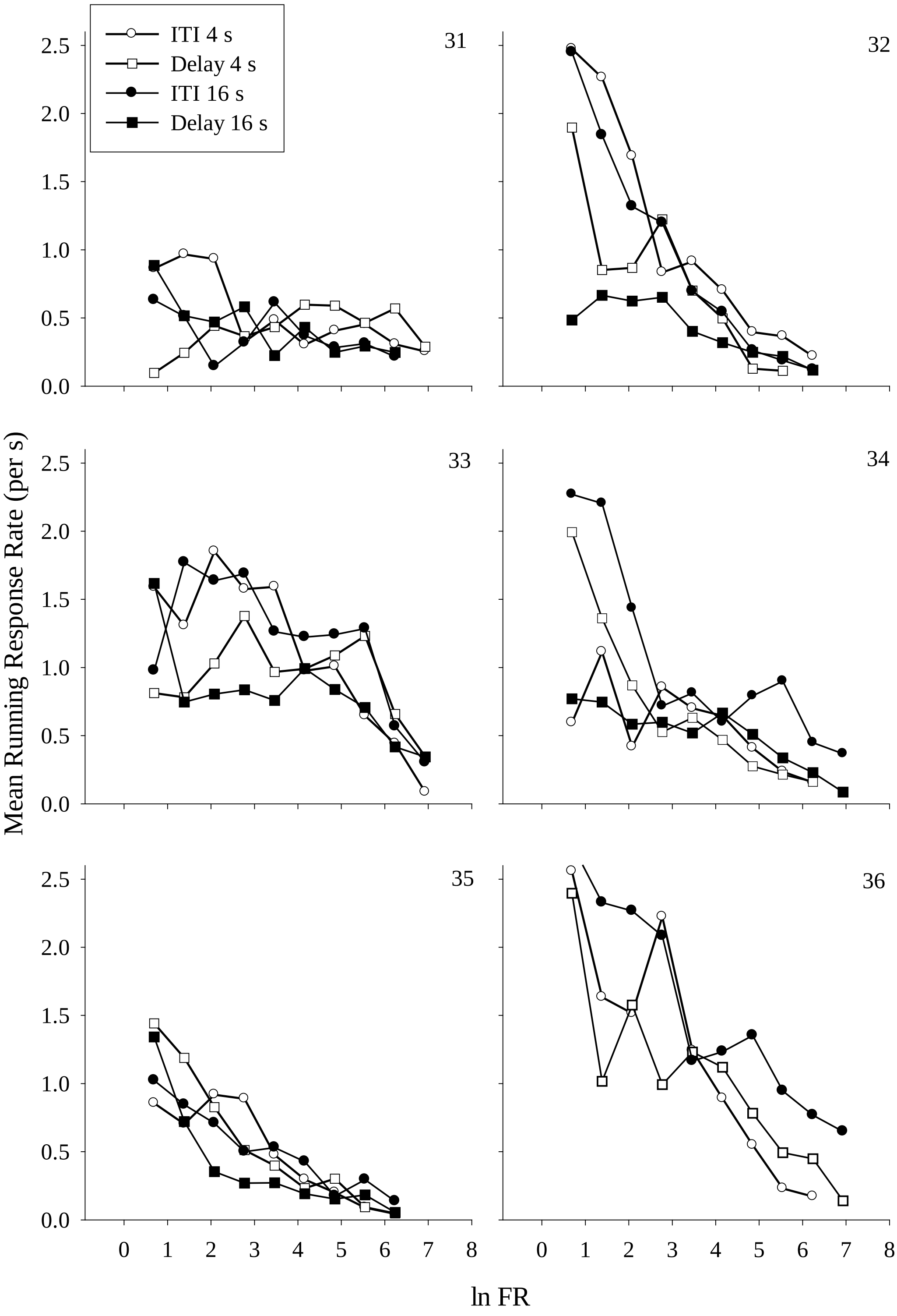


Figure 6. The running response rate (per s), plotted for each ITI and delay condition for each hen. The data are means of the series of each ITI and delay condition.

For all hens the delay 16-s condition produced the steepest declining running response rate as the FR value increases.

Post reinforcement pauses

Figure 7 presents line and scatter plot graphs of the post reinforcement pause durations (y axis, frequency of particular pause durations, plotted against the natural logs of the FR values) from the mean of all series for each condition of each hen. Several data points lie beyond the graph axes; these PRP typically occurred at the larger FR values where few reinforcers were obtained. Analysis of the session data suggest that the hen either pauses for a long duration after a reinforcer before responding again or the hen stopped responding all together mid-way through the session after receiving a reinforcer. These values are displayed numerically alongside the relevant graphs (Hens 31, 32, 34 & 35)

Generally the PRP durations in the 16-s delay or ITI condition were longer than those in the 4-s delay or ITI condition. However for three hens (32, 34, & 35) the PRP increased dramatically during the 4-s delay at the higher FR values before steeply declining again for Hen 31 and 35. Hens 32 and 34 did not show this steep decline due to the way the data was averaged across sessions. Additionally, the PRP for each condition increased as the FR value increased to a point, and then decreased at the larger FR values for all hens excluding 33. Hen 33 showed an increase in PRP in the 4-s delay and 16-s ITI condition at the highest FR value. For Hens’ 32 and 36, during the ITI 4-s condition the PRP duration tended to remain relatively constant or increase only slightly as the FR increased.

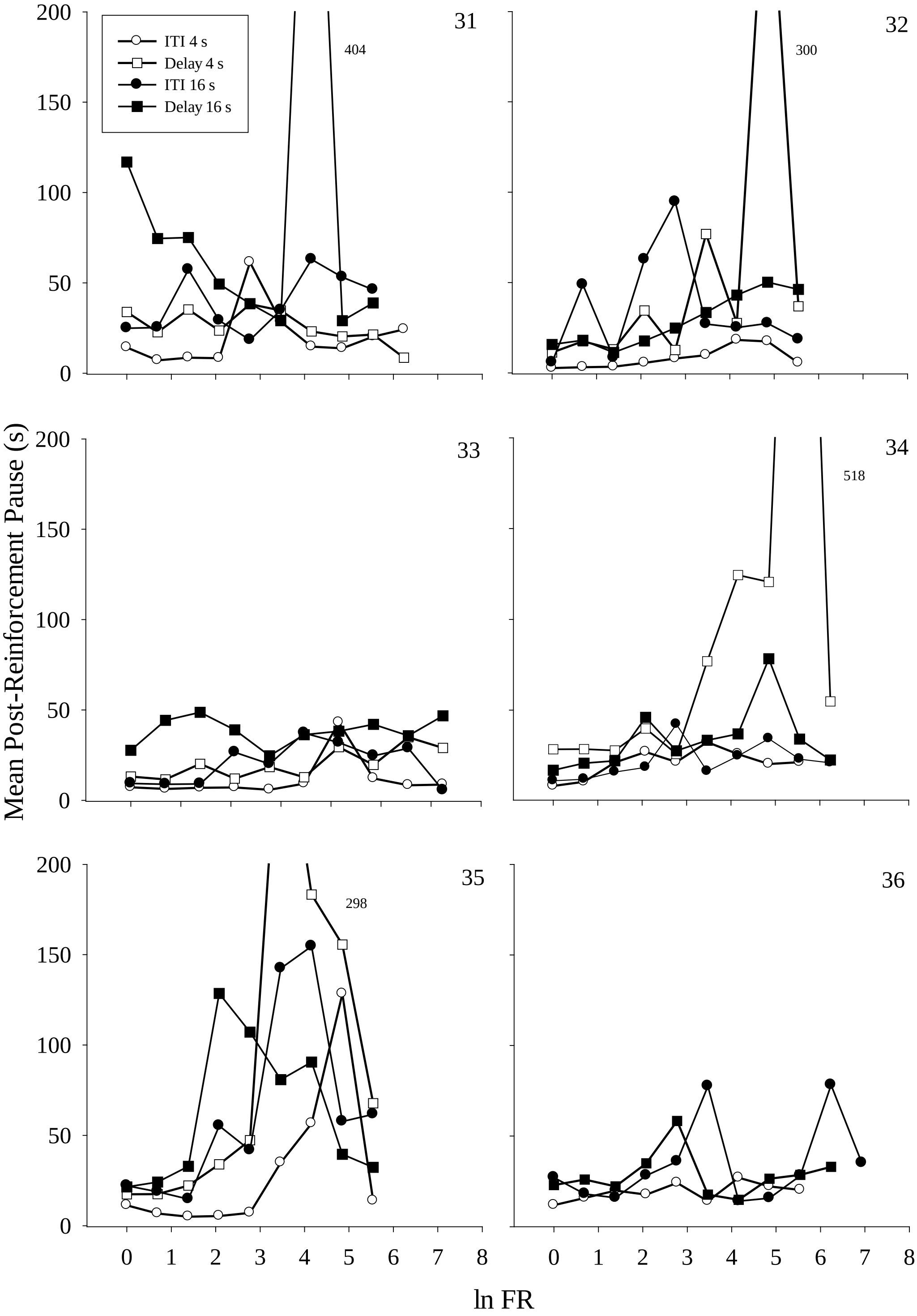


Figure 7. The mean post reinforcement pause durations, plotted for each ITI and delay condition for each hen and for each FR. The data are means of the series of each ITI and delay condition. Data points that lie beyond the axes are displayed numerically (FR, pause duration) alongside the relevant graphs.

Eat Time

Figure 8 presents the mean eating time (in s) at each FR value from the mean of all series for each condition of each hen. Eat time is the total duration that each hen's head was in the magazine for when it was raised was divided by the number of reinforcers obtained during that particular session. Generally, the mean eat time was shortest across all FR values for both ITI conditions. For Hens 32 and 35 there was a clear difference between eat times with the delay and ITI conditions. For four of the six hens, the delay conditions also recorded the highest eat time at the higher FR values.

Blackout Pecks

Although details are not presented here (presented in Appendix F) the rate of blackout pecks per reinforcer was obtained by dividing the number of pecks by the number of reinforcers obtained at that FR value. Exanimation of the rates of black out pecks showed that throughout all experimental conditions (across both the delay and ITI conditions and FR values) rates of blackout pecking was very low (in most cases fewer than one peck per reinforcer). What is interesting to note is that more blackout pecks occurred during the ITI conditions at the higher FR values, ITI 16 s showing the most across all hens.

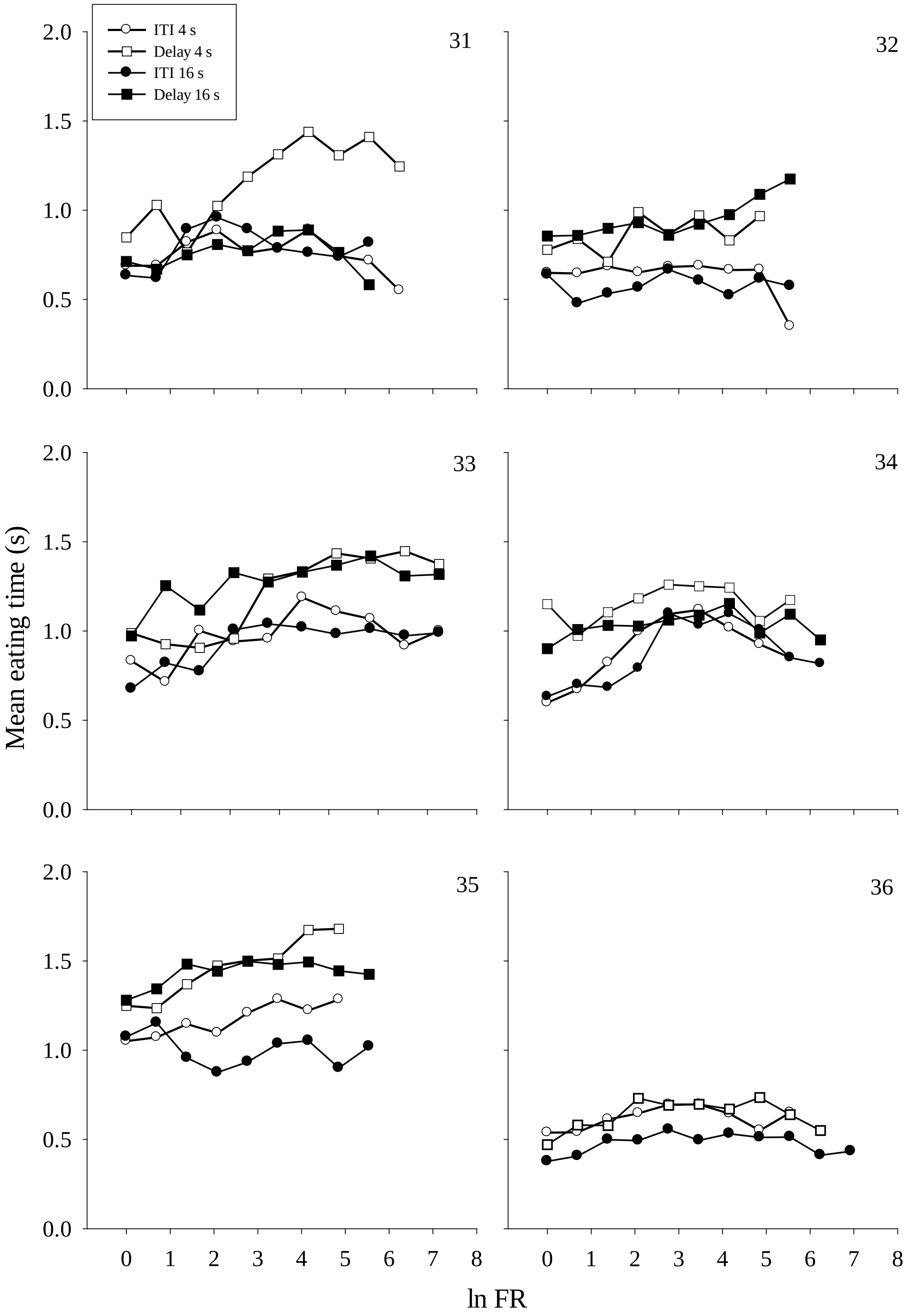


Figure 8. Mean eating time (in s) at each FR value plotted for each condition and for each hen. The data are means of the series of each ITI and delay condition.

Discussion

This experiment examined the effects of delayed reinforcement and ITI on hens’ performance under increasing FR schedules. In previous research (e.g., Azzi et al., 1964; Harris, 2010; Pierce et al., 1972) delayed reinforcement has been shown to devalue the reinforcer. One aim of the present study was to determine whether it was the increase in time between the effective response and the delivery of reinforcement or increases in intervals between reinforcers which devalues the reinforcer. Hens’ responded to a geometrically ascending series of FR values with either a; 4-s ITI, 4-s delay, 16-s ITI, or a 16-s delay. It was found that when an ITI was used instead of the equivalent delay condition (e.g., ITI 4 s and delay 4 s), the response rate was higher and the PRP was lower. When the delay or ITI increased in duration from 4 s to 16 s, PRP increased and response rates decreased. Therefore, while the ITI had an effect on response rates, it appears it is the time between the effective response and the delivery of reinforcement made by the delay which devalued the reinforcer most.

The finding of a reduction in response rates (overall and running) with increase of the delay duration is consistent with the majority of previous delayed reinforcement research (e.g., Harris, 2010; Sizemore & Lattal, 1978). Research investigating the effect of delayed reinforcement on performance in FR schedules has provided mixed findings concerning changes in overall and running response rates. Not only were response rates found to be affected by the delay and ITI duration, but the effect depended on the size of the FR value. Consistent with the present study findings, Azzi et al. (1964) and Harris (2010) found reduced overall rates of responding with increases in the delay. In comparison to these findings, Morgan (1972) and Topping et al. (1973) reported no effect of signalled non-resetting delayed reinforcement on rates of responding. Because Azzi et al. (1964) used unsignalled resetting delays it is surprising to note that the present study findings are more similar to Azzi et al. (1964) than to Morgan (1972) and Topping et al. (1973). Furthermore, Azzi et al. (1964) also used the delay duration in their calculation of overall response rates which meant overall response rates would still decrease even if the running response rates remained the same at each delay (Harris, 2010). However, Topping et al. (1973) did not provide any response data, it was simply stated that response rates did not change consistently with delay interval and Morgan (1972) did not compare response rates to a condition which had no delay. Similar conclusions to the present study, like Harris (2010), may have been drawn if Morgan (1972) and Topping et al. (1973) had presented the full data.

Response rates in the present study were affected by not only the increase in duration of the delay but also the ITI. While there was no research to support this, it was the prediction that by adding more time to the experimental session, responding would decrease, but to a lesser extent than with the delay. It was therefore also predicted that response rates would be lower in the delay conditions than the ITI conditions. This was confirmed by the present results. An unexpected finding that was evident was overall response rates in the delay condition were often lower than the equivalent ITI condition, however, they peaked at higher FR values. Figure 5 shows that for Hen 31, for FRs 64 through to 1024, responding in the 4-s delay condition was faster than the other three conditions.

Consistent with previous research (e.g., Crossman et al., 1987; Mazur, 1983), response rates generally increased with increases in FR value up to a point, usually around FR 64, before decreasing at the larger values. Harris (2010) also reported overall response rates generally increased across the small to mid FR values then either remained constant or decreased across the large FR values showing the bitonic pattern. An unexpected finding was that the 16-s ITI conditions gave peaks at higher FR values than in the other conditions (Hens' 33, 34, and 36). It should be noted that the delay or ITI time was excluded from the key time (the time available for responding) and key time was always held constant (40 minutes). Therefore, changing the condition from ITI to delay and increasing it from 4 to 16 s did not restrict the time in the session available for responding. All the hens had the same opportunity at each FR value to maintain the same level of consumption they had obtained at the 4 s conditions as the 16 s conditions. If the delay or ITI duration was part of the calculation then results would show a decrease in response rate with increasing ITI or delay, regardless of the hens' behaviour. The present procedure made it possible to see changes that result from changes in the hens' behaviour, rather than the delayed reinforcement or ITIs.

Previous research investigating the effect of delayed reinforcement on performance under FR schedules has found that the length of PRP tends to increase with increases to the delay duration (e.g., Harris, 2010; Harris et al., 2012; Morgan, 1972; Topping et al., 1973). This was also found in the present experiment (see Figure 7). As the delay or ITI duration was increased from 4 s to 16 s, the PRP duration increased (with one exception; Hen 34). PRPs were often variable and showed extremely long pauses for four of the six hens. The variability is possibly due to the hen stopping responding mid-session (but after a reinforcer) for an uncharacteristically long duration before they started to respond again. The PRP duration was calculated by dividing the total cumulative PRP duration (time taken to respond following the delivery of reinforcement), at each FR, minus the time to the first response at the start of the session, divided by the total number of reinforcers obtained (Harris, 2010). When these uncharacteristically long pauses occur (outliers), it influences the mean and therefore presents a problem when mean PRP durations are used to reflect pause length.

Baron and Herpolsheimer (1999) pointed out that interpretations of average values are simplest when the variation among session, or individuals, is relatively small and non-systematic, representing the individual scores faithfully. However, because of the statistical properties of the mean, makes it particularly susceptible to distortion by extreme values. In regards to the present study, this is clearly seen in Figure 7. The present experiment averaged the PRP duration across the three series of each condition. Because of this, while most of the data from individual subjects are regarded as acceptable, the extremely long pauses in some series clearly affected the means, leading to less accurate interpretation of patterns. Harris (2010) reported both the mean and median data, reporting that both types of analysis showed generally the same effect but the median reported it tidier and trends more visible to see. The present study also analysed the data medians but found that although in some instances the data appeared more orderly, the same general effect could be seen with presenting the means.

Another aim of the present study was to compare two demand equations and MPR using the same set of data obtained. The two different demand equations were fitted to the data; Hursh et al., (1988) nonlinear model given by Equation 1 (Figure 2 and Table 2) and Hursh and Silberberg's (2008) exponential model given by Equation 3 (Figure 3 and Table 3). All data was described well by both equations with the %VAC being higher than 85% for all but one case for Hursh et al., (1988) and all but three for Hursh and Silberberg's (2008) models, respectively. The predictions of MPR from Equation 4 also provided a fair description of response rates across FR values with mean R_2 values ranging from 0.55 to 0.94. Consumption data was used for the demand equations while response rates were used for the MPR fits.

While these two types of models cannot be directly compared, both models include parameters that are meant to reflect the value of the reinforcer. In MPR, specific activation provides the value of reinforcer as a number of responses a single reinforcer will support, while Hursh and Silberberg's (2008) equation's the parameter alpha (α) provides the essential value. A correlation between methods of analysis and the a_s and α values of the 4s and 16s data sets revealed moderately strong positive relationships between the parameter values in the 16-s ITI ($r = .51$, $p = 0.29$) and delay ($r = .44$, $p = .44$) conditions. There was a weak positive correlation found between the parameter values in the 4-s ITI condition and a moderately strong but negative correlation for the 4-s delay condition ($r = -0.52$). This demonstrates that between the two methods of analysis there were minimal differences in the 16-s conditions, however, in the 4-s condition there was more variability in parameter values possibly suggesting more impact of the delay or ITI at shorter durations.

For all hens', as the schedule requirement increased, the demand for the reinforcer tended to decrease. Equation 1 described the trend of observed demand well, with the lowest percentage of variance account for by the fitted lines being 79%. All but two were above 95% which matches Hursh et al. (1988)'s findings and similar to Foster et al. (1997). All functions showed mixed elasticity. For all hens', the parameter *b*, showed that demand was inelastic initially at the lower FR values and all the '*a*' values were small and positive, indicating that demand functions become more elastic as the FR increased as shown in Figure 2. The P_{max} values were calculated by Equation 2 showed the ratio value where, as the schedule requirement increased, the slope of the demand function grew steeper than -1, changing from inelastic to elastic demand. Generally, the P_{max} value was lower in the ITI conditions than in the delay condition. As previously mentioned, P_{max} not only shows the point at which demand shifts from inelastic to elastic, but also the point of maximal responding (Foster et al. 2009). Therefore this result was not predicted as it was predicted that with a higher response rate in the ITI conditions, the P_{max} values would also be higher. However, the 16-s ITI condition had the highest P_{max} for four hens.

While the P_{max} value indicates preference as the requirement increases, the initial demand value (ln *L*) shows the preference at low schedule requirements. The higher the initial demand (ln *L*) and the flatter the curve of the demand function, the more highly valued the reinforcer is thought to be to the subject. However, higher ln *L* values were seen when the P_{max} values were lower which meant the curve steepened fast when the initial demand was high. This finding is consistent with Cronin (2012) who looked at demand with possums on arithmetic progressive-ratio of 10 (PR 10) schedule and found higher values of ln L when the P_{max} values were lower than when they were higher. There were no other consistent patterns among the rate of change in elasticity (*a*) and the initial slope of demand (b) similar to previous studies (e.g., Cronin, 2012; Harris, 2010).

As previously mentioned, Hursh and Silberberg (2008) argued that their Equation 3 was the best way to assess the value of a commodity using the one single parameter α. However, in order to compare the value of a commodity across conditions, the k value must remain constant. In the present study, the *k* value was found using the maximum range of consumption across all four conditions for each hen. Hursh and Silberberg (2008) argued that one of the main characteristics of their parameter α is that it is unaffected by the scalar properties of a reinforcer such as magnitude or quantity. Based on this assumption, if adding either a delay or ITI to an experimental session has similar effects to changing the quantity of the rreinforcer, then the value of α should not change. This was not found in the present study. Consistent across all hens' was that the α was larger in the delay conditions than the corresponding ITI conditions and therefore the largest in the 16-s delay condition. This finding suggests then that by adding either a delay or the ITI, the essential value of the reinforcer is directly affected and thus the effects of delay and ITI are not similar to changes in quantity of the reinforcer. The change in the parameter α is consistent with the change in parameter of initial demand, indicating that the reinforcer is more valued in the ITI conditions.

The P_{max} values for Hursh and Silberberg's parameters were found using the Hursh excel spread sheet provided through the link in their article, which fitted the equation using solver (Hursh & Silberberg, 2008, p.192). Consistent with the P_{max} found using Equation 2, the P_{max} values obtained from the Hursh and Silberberg's (2008) equation data, the P_{max} value was generally higher in the delay conditions than the equivalent ITI conditions *a* and for three cases from five (excluding Hen 36 who didn't complete final condition), the 16-s ITI condition had the highest P_{max} value. The FR value associated with the highest point of responding in Figure 5 is expected to relate to the P_{max} value. When overall response rates from Figure 5 are examined for each hen and each condition, the P_{max} values appear relatively the same, or closer to the Hursh et al. (1988) P_{max} values than they are to those of the Hursh and Silberberg’s (2008) P_{max} values. Harris (2010) also found that when comparing the P_{max} values from the two demand equations, the Hursh et al. (1988) equation P_{max} values derived from Equation 2 were closer to the FR values corresponding to maximum response rate.

Another consistent finding across demand equations was that the 16-s delay condition often produced levels of initial demand that was the smallest across all conditions. The higher initial demand in the ITI conditions suggests that the reinforcer in the ITI conditions is valued over the reinforcer in the delay condition. However, the P_{max} value suggests that during the 4-s conditions, the delay conditions maintained more behaviour, but generally as the duration increased to 16 s, the ITI maintained more behaviour so may be argued to be more valuable.

Foster et al. (2009) found that the higher the price at which peck response rate occurred, the more preferred the food (i.e., P_{max} values increased with the degree of preference). With this in mind, it would suggest that the delay maintained a stronger degree of preference for responding at the higher FR values during the 4-s conditions. In accordance with Foster et al. (2009), the present experiment also found that the delay conditions had smaller initial consumption for the demand function (i.e., smaller In L values) than the ITI conditions. Of interest to note here, is that these findings suggest that the more valued reinforcer which occurred during the delay condition, the less the demand at the lower price. This is similar again to Foster et al. (2009) who found the most-preferred food (wheat) gave smaller initial intensities for the demand function but gave high prices associated with peck response.

The same data was also applied to the MPR equation (Equation 4) to predict response patterns. It was also found that hens' increased responding up to the mid FR values before decreasing at the higher values as predicted by the model (Figure 4). This finding is consistent with previous MPR studies (e.g., with hens'; Bjarnesen 2012) which have also found a bitonic function of responding. Equation 4, which was used to fit the model to the obtained data, consists of parameters a_s, λ , δ and ε. These reflect the amount of responding elicited by a single incentive (parameter a_s), the minimum time required to complete a response (parameter δ), the rate of decay of response traces (parameter λ) and the degree of erasure of memory for the target response (ε) (Killeen & Sitmomer, 2003). It was expected that the faster response rates would be seen in the ITI conditions than in the equivalent delay conditions with the slowest response rate seen in the 16-s delay condition. Likewise, it was expected that if the delay devalues the reinforcer more than the ITI, longer delays should produce smaller estimates of a_s. This was not found in the present study. While a_s was smallest in the 4-s ITI conditions for all hens' (with exception of Hen 31 & 32), there was no other general trend.

Because the present experiment was only looking at devaluing the reinforcer, the other parameters should have remained relatively constant. In the present experiment, changes to the other parameters δ and λ were seen. For seven of 11 cases, parameter estimates for δ were greater during the delay conditions than the equivalent ITI, and was the largest during in the 16-s delay condition for three out of five cases. The parameter λ was generally smaller in the delay conditions than in the ITI conditions. This suggests that there was interaction between the parameters which should be independent of one another. The other parameters were influenced by changes in delay to reinforcement and ITI duration. Future research could investigate other possible ways of devaluing the reinforcer and the effects it has on the MPR parameters, in particular changes to λ as a result of changes to a_s.

The variances accounted for by the MPR Equation 4 in this experiment are lower than the fits reported in other papers. Studies with humans have generated mean R^2 value between 0.79 to 0.98 (Bizo, Remington, D'Souza, Heighway, & Baston, 2002) and fits to data using rats have generally ranged between 0.84 to 0.99 (Reilly, 2003). The poorer fits found in this experiment are similar to fits generated by hens' ranging from 0.25 to 1 (Bjarnesen, 2012).

The reason for the unusual findings from MPR and PRP rates is not clear. One reason might be that intermittently eggs were laid in the chamber during experimental session, resulting in variable data. Egg laying during an experimental session can occupy a significant proportion of time, resulting in less responding and therefore unusual data. The computer programme was designed to progress to the next FR value the following session if the hen obtained at least one reinforcer for the current FR value. For example, a typical FR 2 session would result in above 50 reinforcers gained. If the hen was responding to a FR 2, laid an egg and only got 10 reinforcers, they would still progress to a FR 4 the following session. For future experiments, the FR value should be re-run the following session and data from session in which eggs were laid should be removed. Due to time constraints and a collective lab running approach, this was not possible.

For the full duration of the present experiment an open economy was used meaning hens only took part in an experimental session if they were within 85% ± 5% of their free feeding weight. While this meant for many hens running only every second or third day when at low FR values, for Hen 36 her weight was more unstable. Due to the unstable weight, Hen 36 was unable to complete the full experiment. While the experiment ran for just under 12months, time restrictions meant Hen 36 only completed up until the third condition. Hen 36 data is presented up until the third condition along with the other hens.

There is a possible confound in the present experiment when comparing data from the ITI conditions to the delay conditions. The magazine was raised immediately following the final FR response during the ITI conditions. Time taken for the hen to get down to the mag was approximately 1 s, restricting the actual eating time in the ITI conditions to 1 s. During the delay conditions, the magazine was raised at the end of the delay. This meant that the hens could move their heads close to or inside the magazine during the delay, allowing them to access the full 2 s of reinforcement. Therefore, it could be said that during the ITI conditions, the subjects received a smaller magnitude of reinforcement. One way to ensure that the hens received the same access to wheat during both the ITI and delay condition would be to use an infrared beam in the magazine. The 2-s access to reinforcer would start from the moment the subjects head entered the magazine, thus ensuring consistency in reinforcer magnitude across all conditions.

The present study aimed to include a fifth condition which looked at the effect of 0-s delay and ITI on responding as the FR value increased. However due to time constraints, only three hens' completed this condition. Hens' 31, 32 and 33 were exposed to a condition where there was no delay or ITI present. The methodology was otherwise identical to that of the main experiment. Data for Hen 31 is presented in Figure 9 below. Consistent with the other two hens', the overall response rates for the 0-s delay and ITI condition were not higher than in the other four conditions used in this experiment. Harris (2010) included a 0-s delay in their study and found that although initial demand was largest in the 0-s delay condition, the α was smallest in the 8-s delay condition. However, because they found that the number of reinforcers obtained decreased with increases in the delay, it seemed plausible to suggest that if actual eating time had been the same in the 0-s delay, the value of α may have been larger.

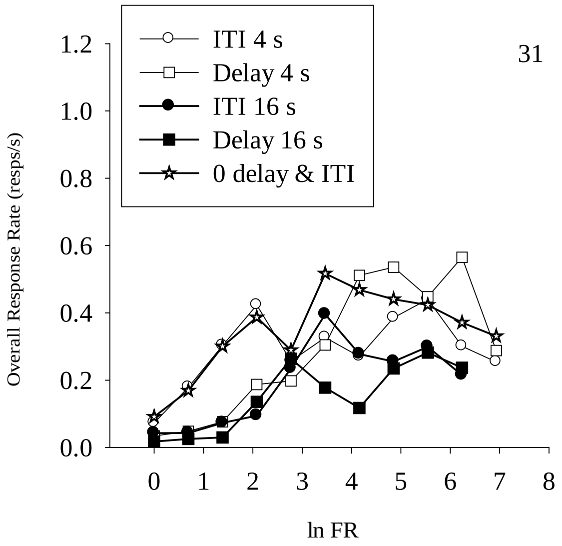


Figure 9: The overall response plotted for Hen 31 for each ITI and delay condition including the 0-s delay and ITI condition. The data are means of the series of each condition.

As previously mentioned, with any ITI duration or 0-s delay, the time taken to get the head into the mag would mean less time to eat and therefore less magnitude of the reinforcer. Previous studies have shown that changing the magnitude of a reinforcer changes response rates (e.g., Bizo & Killeen, 1997; Grant, 2005). It seems possible then to suggest that had the hens' had full access to the 2 s of reinforcement as they did in the delay condition, responding during the ITI condition and 0-s delay and ITI condition may have been different. Future research could not only look at including an infrared beam in the magazine but also extend the duration of both the ITI and delay to examine whether there is a clearer effect than the one in the present study.

Overall the assessment of demand in the present experiment resulted in similar findings with both equations. The MPR equation appeared to have some problems with changes to the parameters with some low fits. However, what is interesting to note is the correlation between a_s and α values in the 16-s ITI and delay conditions. This illustrates that both the demand and MPR model's parameters which access the value of the reinforcer for the same data from the same hen and same condition, were consistent. The assessment of the demand in the present study resulted in similar findings with both equations tested. The Hursh and Silberberg's (2008) exponential equation did not seem to clarify or add any new information to the findings found with the Hursh et al. (1988) nonlinear equation. This is similar to findings from Harris (2010) who stated the Hursh and Silberberg's (2008) equation did not add any new information and that it is was not fitting to say that this model was superior to the Hursh et al. (1988) nonlinear equation and needed further investigation. This seems plausible based on the findings in the present experiment and the change in the α values. This also seems relevant to the MPR equation. While there was a correlation between the demand and MPR values in the 16 s condition, overall the MPR parameters values were not consistent with the theory regarding the models predictions of changes to the parameters. Further study needs to look at other ways of devaluing the reinforcer and the changes in parameter values.

Increasing the ITI appears similar to increasing the delay or increasing the FR response requirement. However, it appears that overall; it is the delay which devalues the reinforcer to a greater degree. Future study could increase the durations of the ITI and delay to determine if there is a clearer effect as both the delay and ITI duration is increased.

In sum, the present experiment found that a delayed reinforcement had more of an effect on hens' performance on FR schedules than the ITI with the 16-s ITI condition maintaining behaviour at the higher FR values. Generally, the value of the reinforcer was generally found to be greater during the ITI condition than in the delay conditions suggesting it is the time between the effective response and the delivery of reinforcement rather than the increase of intervals between reinforcers which devalues the reinforcer. The data was described well by both demand equations and the MPR equation and there was a moderately strong positive relationships between the parameter values of a_s and α in the 16-s ITI (r = .51, p = 0.29) and delay (r = .44, p = .44) conditions

REFERENCES

Alling, K., & Poling, A. (1995). The effects of differing response force requirements on fixed ratio responding of rats. *Journal of the Experimental Analysis of Behavior, 63*, 331-346.

Azzi, R., Fix., D. S., Keller, F. S., & Rocha E Silva, M. I. (1964). Exteroceptive control of response under delayed reinforcement. *Journal of the Experimental Analysis* of Behavior, 7, 159-162.

Baron, A., & Herpolsheimer, L. R. (1999). Averaging effects in the pattern of fixed ratio response patterns. *Journal of the Experimental Analysis of Behavior, 71,* 145-153.

Bizo, L. A., & Killeen, P. R. (1997). Models of ratio schedule performance. *Journal of Experimental Psychology: Animal Behavior Processess, 23*, 351-367.

Bizo, L. A., Remington, B., D'Souza, L. S., Heighway, S. K., & Baston, C. (2002). Human variable ratio performance. *Learning and Motivation, 33,* 411-432.

Bjarnesen, R. C. (2011). *The effect of effort: An analysis of Killeen's (1994) mathematical principles of reinforcement.* Unpublished master's thesis, The University of Waikato, Hamilton, New Zealand.

Bouton, M. E., & Garcia-Gutiérrez, A. (2005). Intertrial interval as a contextual stimulus. *Behavioural Processes, 71,* 307-317.

Bouton, M. E., Westbrook, R. F., Corcoran, K. A., & Maren, S. (2006). Contextual and temporal modulation of extinction: behavioral and biological mechanisms. *Biological psychiatry, 60*, 352-360.

Chung, S. H., & Herrnstein, R. J. (1967). Choice and delay of reinforcement. *Journal of the Experimental Analysis of Behavior, 10*, 67-74.

Church, R. M. (1997). Quantitative models of animal learning and cognition. *Journal of Experimental Psychology: Animal Behavior Processes, 23,* 379-389.

Collier, G, Johnson, D. F., Morgan, C. (1992). The magnitude-of-reinforcement function in closed and open economies. *Journal of the Experimental Analysis of Behaviour, 57,* 81-89.

Cronin, I. R. (2012). *Possum food preferences under progressive-ratio and concurrent schedules of reinforcement.* Unpublished master's thesis, The University of Waikato, Hamilton, New Zealand.

Crossman, E. K., Bonem, E. J., & Phelps, B. J. (1987). A comparison of response patterns on Fixed-Variable, and Random-Ratio schedule. *Journal of the Experimental Analysis of Behavior, 48*, 395-406.

Dews, P. B. (1960). Free-operant behaviour under conditions of delayed reinforcement. I. CRF-type schedules. *Journal of the Experimental Analysis of Behavior, 3*, 221-234.

Felton, M., & Lyon, D. O. (1966). The post reinforcement pause. *Journal of the Experimental Analysis of Behavior, 9,* 131-134.

Ferster, C. B., & Hammer, C. (1965). Variables determining the effects of delay in reinforcement. *Journal of the Experimental Analysis of Behavior, 8*, 243-254.

Fester, C. B., & Skinner, B. F. (1957). *Schedules of Reinforcement*. USA: Prentice-Hall, Inc. Acton, Massachusetts: Copley Publishing Group.

Foster, T. M., Blackman, K. A., & Temple, W. (1997). Open versus closed economies. Performance of domestic hens under fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior, 67*, 67-89.

Foster, T. M., Sumpter, C. E., Temple, W., Flevill, A., & Poling, A. (2009). Demand equations for qualitatively different foods under fixed-ratio schedules: A comparison of three data conversions. *Journal of the Experimental Analysis of Behavior, 92*(3), 305-326.

Harris, A. (2010). *The effects of delay-to-reinforcement, response requirement and schedule duration on performance under fixed-ratio schedules.* Unpublished doctoral dissertation, The University of Waikato, Hamilton, New Zealand.

Harris, A., Foster, T. M., Levine, J., & Temple, W. (2012). Effects of a signalled delay to reinforcement in the previous and upcoming ratios on between ratio pausing in fixed-ratio schedules. *Journal of Experimental Analysis of Behavior, 98,* 295-309.

Hastjarjo, T., Silberberg, A., & Hursh, S. R. (1990). Risky choice as a function of amount and variance in food supply. *Journal of Experimental Analysis of Behavior,53*, 155-161

Holt, G. L., & Shafer, J. N. (1973). Function of intertrial interval inmatching-to sample. *Journal of the Experimental Analysis of Behavior, 19,* 181-186.

Hursh, S. R. (1980). Economic concepts for the analysis of behavior. *Journal of the Experimental Analysis of Behavior, 34*, 219-238.

Hursh, S. R. (1984). Behaviour economics. *Journal of the Experimental Analysis of Behavior, 42,* 435-452.

Hursh, S. R., Raslear, T. G., Shurtleff, D., Bauman, R., & Simmons, L. (1988). A cost-benefit analysis of demand for food. *Journal of the Experimental Analysis of Behavior, 50,* 419-440.

Hursh, S. R., & Silberberg, A. (2008). Economic demand and essential value. *Psychological Review, 155*, 186-198.

Hursh, S. R., & Winger, G. (1995). Normalised demand for drugs and other reinforcers. *Journal of the Experimental Analysis of Behavior, 64*, 373 384.

Kaplan, P. S. (1984). Importance of relative temporal parameters in trace autoshaping: From excitation to inhibition. *Journal of Experimental Psychology: Animal Behavior Processes, 10*, 113-126.

Killeen, P. R. (1968). On the measurement of reinforcement frequency in the study of preference. *Journal of the Experimental Analysis of Behavior, 11*(3), 263-269.

Killeen, P. R. (1994). Mathematical principles of reinforcement. *Behavioral and Brain Sciences, 17,* 105-172.

Killeen, P. R. (1995). Economics, ecologics, and mechanics: The dynamics of responding under conditions of varying motivation. *Journal of the Experimental Analysis of Behavior, 64,* 405-431.

Killeen, P. R., & Bizo, L. A. (1998). The mechanics of reinforcement. *Psychonomic Bulletin & Review, 5*, 221-238.

Killeen, P. R., Hanson, S. J., & Osborne, S. R. (1978). Arousal: Its genesis and manifestation as a response rate. *Psychological Review, 85*, 571-581.

Killeen, P. R., & Sitomer, M. T. (2003). MPR. *Behavioural Processes, 62*, 49-64.

Kirshenbaum, A. P., Szalda-Petree, A. D., & Haddad, N. F. (2003). Increased effort requirements and risk sensitivity: A comparison of delay and magnitude manipulations. *Behavioural Processes, 61*, 109-121.

Lattal, K. A. (1984). Signal functions in delayed reinforcement. *Journal of the Experimental Analysis of Behavior, 42*, 239-253.

Lattal, K. A. (2010). Delayed reinforcement of operant behavior. *Journal of the Experimental Analysis of Behavior, 93,* 129-139.

Lea, S. E. G. (1978). The psychology of economics and demand. *Psychological Bulletin, 85*(3), 441-466.

Lydersen, T., & Crossman, E. K. (1974).Fixed-ratio discrimination: Effects of response-produced blackouts. *Journal of the Experimental Analysis of Behavior, 22*, 547-551.

Mazur, J. (1997). Choice, delay, probability, and conditioned reinforcement. *Animal Learning & Behavior, 25*, 131-147.

Mazur, J. E. (1983).Steady-state performance on fixed-, mixed-, and random-ratio schedules. *Journal of the Experimental Analysis of Behavior, 39,* 293-307.

Meunier, G. F., & Ryman, F. (1974). Delay of reinforcement in fixed-ratio behavior. *Psychological Reports, 34*, 350-350.

Morgan, M. J. (1972). Fixed-ratio performance under conditions of delayed reinforcement. *Journal of the Experimental Analysis of Behavior, 17*, 95 98.

Perkins, C. C., Beavers, W. O., Hancock, R. A., Hemmendinger, P. C., Hemmendinger, D., & Ricci, J. A. (1975). Some variables affecting rate of key pecking during response-independent procedures (autoshaping). *Journal of the Experimental Analysis of Behavior, 24,* 59-72.

Pierce, C. H., Hanford, P. V., & Zimmerman, J. (1972).Effects of different delay of reinforcement procedures on variable-interval responding. *Journal of the Experimental Analysis of Behavior, 18,* 141-146.

Ploog, B. O., & Williams, B. A. (2010). Serial discrimination reversal learning in pigeons as a function of intertrial interval and delay to reinforcement. *Learning & Behavior, 38*, 96-102.

Powell, R. W. (1968).The effect of small sequential changes in fixed-ratio size upon the post-reinforcement pause. *Journal of the Experimental Analysis of Behavior, 11*, 589-593.

Powell, R. W. (1969). The effect of reinforcement magnitude upon responding under fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior, 12,* 605-608.

Reilly, M. P. (2003). Extending mathematical principles of reinforcement into the domain of behavioural pharmacology. *Behavioral Processes, 62,* 75-88

Reilly, M. P., & Lattal, K. A. (2004). Within-session delay-of-reinforcement gradient. *Journal of the Experimental Analysis of Behavior, 82*, 21-35.

Richards, R. W. (1981). A comparison of signalled and unsignalled delay of reinforcement. *Journal of the Experimental Analysis of Behavior, 35,* 145 152.

Richards, R. W., & Hittesdorf, W. M. (1978). Inhibitory stimulus control under conditions of signalled and unsignalled delay of reinforcement. *The Psychological Record, 28,* 615-625.

Roberts, W. A., & Kraemer, P. J. (1982). Some observations of the effects of intertrial interval and delay on delayed matching to sample in pigeons. *Journal of Experimental Psychology. Animal Behavior Processes, 8,* 342.

Roitblat, H. L., & Scopatz, R. A. (1983). Sequential effects in pigeon delayed matching-to-sample performance. *Journal of Experimental Psychology. Animal Behavior Processes, 9*(2), 202-221.

Schaal, D. W., Schuh, K. J., & Branch, M. N. (1992). Key pecking of pigeons under variable-interval schedules of briefly signalled delayed reinforcement: Effects of variable-interval value. *Journal of the Experimental Analysis of Behavior, 58*, 277-286.

Shull, R. L., Guilkey, M., & Witty, W. (1972). Changing the response unit from a single peck to a fixed number of pecks in fixed-interval schedules. *Journal of the Experimental Analysis of Behavior, 17*, 193-200.

Silberberg, A., Warren-Boulton, F. R., & Asano, T. (1987). Inferior-good and giffen-good effects in monkey choice behavior. *Journal of Experiment Psychology, 13*, 292-301.

Sizemore, O. J., & Lattal, K. A. (1978). Unsignalled delay of reinforcement in variable-interval schedules. *Journal of the Experimental Analysis of Behavior, 30*, 169-175.

Spetch, M. L., & Rusak, B. (1989). Pigeon's memory for event duration: Intertrial interval and delay effects. *Animal Learning & Behavior, 17*, 147-156

Thomas, J. R. (1979). Matching-to-sample accuracy on fixed-ratio schedules. *Journal of the Experimental Analysis of Behavior, 32*, 183-189.

Topping, J. S., Johnson, D. L., & Mc Glynn, F. D. (1973). Effects of delayed reinforcement and FR size on pre-ratio pausing. *Psychological Reports, 32*, 1295-1298.

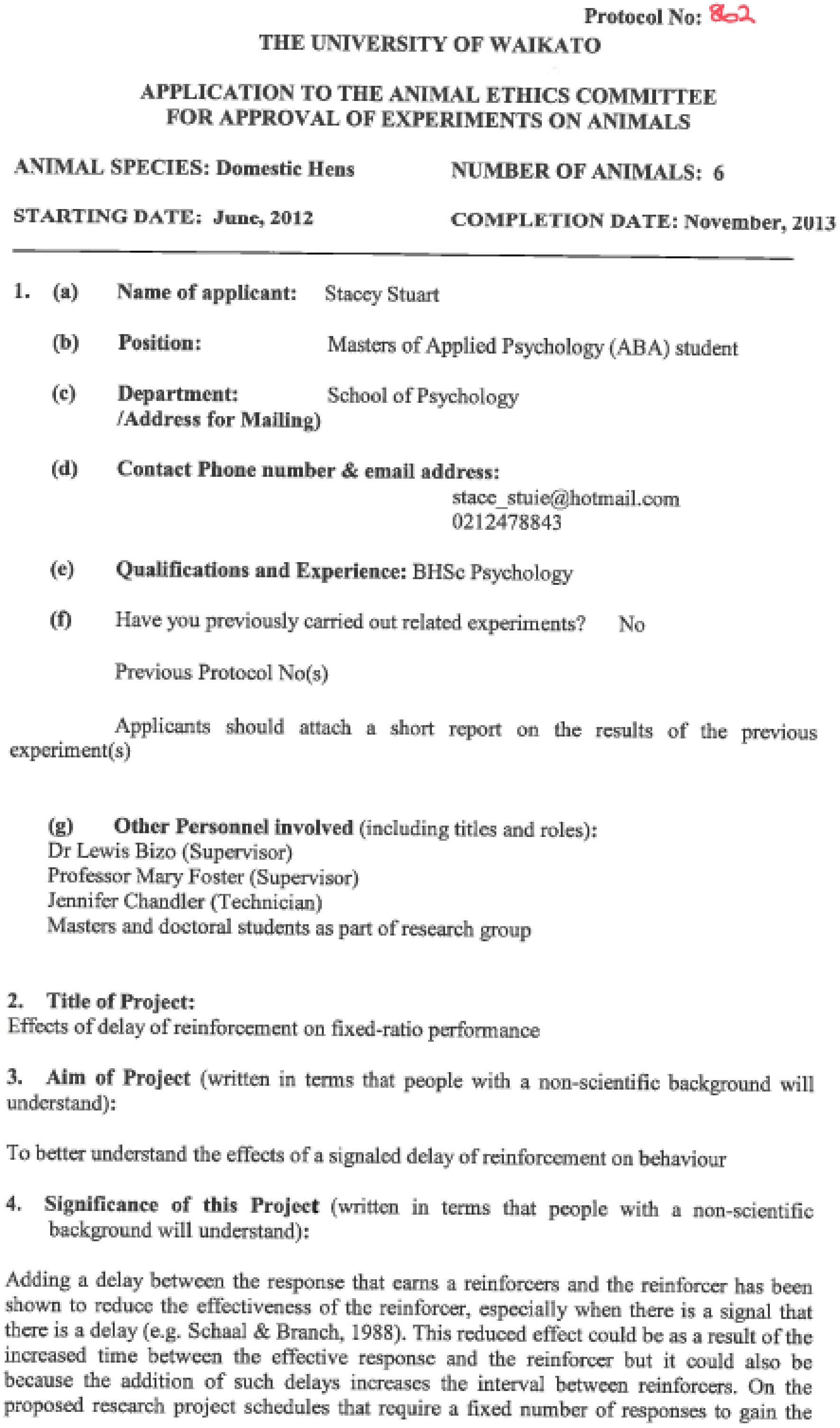
Williams, B. A. (1971). The effects of intertrial interval on discrimination reversal learning in the pigeon. *Psychonomic Science, 23*, 241- 243.

Williams, B. A. (1976). The effects of unsignalled delayed reinforcement. *Journal of the Experimental Analysis of Behavior, 26*, 441-449.

Williams, B. A. (1998). Relative time and delay of reinforcement. *Learning & Motivation, 29*, 236-248.

Zeiler, M. D. (1999). Reversed schedule effects in closed and open economies. *Journal of the Experimental Analysis of Behavior, 71* (2), 171-186.

Appendix A



Protocol No: 802

THE UNIVERSITY OF WAIKATO

APPLICATION TO THE ANIMAL ETHICS COMMITTEE
FOR APPROVAL OF EXPERIMENTS ON ANIMALS

ANIMAL SPECIES: Domestic Hens **NUMBER OF ANIMALS:** 6

STARTING DATE: June, 2012 **COMPLETION DATE:** November, 2013

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1. (a) **Name of applicant:** Stacey Stuart

(b) **Position:** Masters of Applied Psychology (ABA) student

(c) **Department: /Address for Mailing)** School of Psychology

(d) **Contact Phone number & email address:**
stacc_stuie@hotmail.com
0212478843

(e) **Qualifications and Experience:** BHSc Psychology

(f) Have you previously carried out related experiments? No

Previous Protocol No(s)

Applicants should attach a short report on the results of the previous experiment(s)

(g) **Other Personnel involved** (including titles and roles):
Dr Lewis Bizo (Supervisor)
Professor Mary Foster (Supervisor)
Jennifer Chandler (Technician)
Masters and doctoral students as part of research group

2. **Title of Project:**
Effects of delay of reinforcement on fixed-ratio performance

3. **Aim of Project** (written in terms that people with a non-scientific background will understand):

To better understand the effects of a signaled delay of reinforcement on behaviour

4. **Significance of this Project** (written in terms that people with a non-scientific background will understand):

Adding a delay between the response that earns a reinforcers and the reinforcer has been shown to reduce the effectiveness of the reinforcer, especially when there is a signal that there is a delay (e.g. Schaal & Branch, 1988). This reduced effect could be as a result of the increased time between the effective response and the reinforcer but it could also be because the addition of such delays increases the interval between reinforcers. On the proposed research project schedules that require a fixed number of responses to gain the reinforcer will be used and in one series of conditions the delay from the last response to the reinforce will be varied and in another series those same delays will be used but these will be inserted prior to the first response on the schedule, thus increasing the inter-reinforcer interval over the same range as used with delay to reinforcer and the outcomes will be compared. This will help clarify which of these delays contributes most to the reduced effectiveness of the reinforcer. The outcome has significance for understanding the effects of reinforces on behaviour in the laboratory and its results will also help clarify the effects of delays to reinforcers which often happen in applied setting where delays to reinforcers frequently occur when reinforcement is used in attempting to change the behaviour of both humans and other animals.

5. Is/Has this work already being/been carried out (provide details)

(a) In New Zealand? Related research has been conducted by Aimee Harris for her PhD. Dr Harris varied the delay to the reinforcer and showed that this functioned to reduce the effectiveness of the reinforcer (Harris, 2011). The present research follows on from that research and will clarify the effects of the inter-reinforcement interval over and above the effects of delays.

(b) Overseas? No

6. Have alternative methods to achieving the aims that do not involve the use of animals been explored? Yes

Please provide details.
Since such schedules are used in procedures that assess animal needs such as in behavioral economic studies of preference it is important that animals be involved to help clarity how delays to outcomes effect the animal's behaviour.

7. How will the results of this work be disseminated?

Firstly the study will be conducted as part of a Master's thesis and so will be submitted to the university library. Secondly the results will be presented at the New Zealand Association of Behaviour Analysis. And thirdly, if the data is suitable, it will be put forward for publication in a peer reviewed journal

8. Description of Experiments
All experiments should take into account the statutory responsibility to adhere to the three important principles governing the use of animals in research, testing and teaching:

a) Refinement (refinement of procedures applied to decrease to the minimum practicable extent the negative impacts they have on the animals):
b) Reduction (reduction in the numbers of those sentient animals to the minimum necessary to achieve the scientific objective):
c) Replacement (replacement of animals with non-sentient animals or non-animal alternatives):

(a) Full details of procedures

Subjects

This project will use six hens all experiencing all of the conditions. The hens will be housed individually for the duration of the research project in order to facilitate the management of the hen's weight. In the hen's cages, the hens will have access to their feeding basket and free access to water, and access to an enrichment device. The hen's will be given supplementaly feedings of vitamins and health grit on a regular basis. Hens will have access to normal sunlight hours and will be housed on a 12 hour light, 12 hour dark cycle.

Their ad-libitum body weight will be established after period of free food access (typically 2-3 weeks) immediately prior the first experimental condition. Then their body weight will be maintained at 85% +/- 5% of their ad-libitum body weight. The hens will earn the majority of their food during an experimental session and will be given supplementary food as required to maintain their body weights within the desired range. The hens will only be included in an experimental session if their weight falls within the prescribed weight range.

Experimental sessions will be planned for 7 days a week, and will be run at about same time each day. At the end of an experimental session the hens will be returned to their home cages. At the conclusion of the experiments the hens will be removed from their home cages and moved to group aviaries, where they will be housed with other hens that are not currently involved in experiments.

Apparatus:
The apparatus for this experiment is one operant chamber. The dimensions of this operant chamber will be 800mm wide, 500mm high and 500mm deep. Inside the chamber on one of the internal walls will be at least one response key which can be lit. The hen will be trained to respond to the key when it is illuminated. The hen will be provided access to reinforcers in the chamber through an opening positioned underneath the response key (food magazine).

Procedure:
The hens will be in the experiment chamber for no more than one-hour each day. The experimental chamber has one response key, which will be lit with a coloured light and a food hopper.

The hens will be responding under Fixed Ratio (FR) schedules, where the reinforcer will be available after a fixed number of responses. The number of responses required will be varied over sessions – depending on the condition. Over conditions a delay to reinforcement will be varied. This delay will follow the completions of the ratio and will be signaled by the key light going out and the chamber being in blackout. Once reinforcement has been delivered (access to wheat), the key light will again be lit. In each condition the FR will start at FR 1 and requirement will be doubled each session until no reinforcers are received when the key is available for 40-min. The FR series will then be repeated. In other conditions the same delays will be used as inter-trial intervals. That is the FR will be increased each session and once a reinforcer is received there will be a blackout that will be varied over the same lengths as the delays to reinforcement. After the selected inter-trial interval has passed, the key light will again go on and the hen can respond under the schedule in effect until reinforcement is gained. The delays and inter-trial intervals will be matched and will be within the range of 0 to 32 s.

(b) The statistical design of the experiments

This is a repeated measures experiment where all the hens experience all the ratios and delays. The data used will be the between-ratio or post-reinforcement pauses and the response rates. These will be graphed as a function of the FR and associated delays. The project will use non-linear least squares regression to describe the obtained functions and will fit mathematical models to the data gained. The data will determine the parameters of the models and comparisons of the parameters obtained in the different conditions will be conducted.

9. List the relevant SOP's (number and full title) to be used:
N/A

10. (a) **Where experiments will be conducted:** Psychology Animal Behavioural Laboratory, No. 3 Dairy, Ruakura

(b) **Where the animals will be housed:** Hens will be individually caged at Psychology Animal Behavioural Laboratory, No. 3 Dairy, Ruakura,

(c) **Person in immediate charge of laboratory and housing:** Jennifer Chandler

(d) **Veterinary advisor to the laboratory:** Ali Cullum

11. **Is there an operational procedure required for the use of a product (drug/chemical) in these experiments?** Yes/[✓ No]

If 'Yes' this will require an Institutional Drug Administration Order, this should be arranged with the Institutional Operating Plan Validator.

See Appendix 1: ***Is an Institutional Drug Administration Order Required?*** Yes/No

Name the product:

12. (a) **Anaesthetic:**

Local: N/A

General: N/A

(b) **Method of Restraint:** N/A

(c) **Will the animal have to recover from anaesthetic?** N/A

(d) **How will you deal with post-operative pain and/or discomfort?** N/A

13. **What is the fate of the animals at termination of experiment?** They will be retained in the experiment colony, released to backyard flocks.

14. **Has this application in whole or in part previously been declined approval by another Animal Ethics Committee?** Yes/[✓ No]

15. **For experiments to be undertaken at Ruakura or at other facilities under the control of another Animal Ethics Committee, has an application also been made to that Committee:** **Yes/[✓ No]**
If 'YES' state which Committee

16. **Is any of this work being used in a thesis to be submitted for a degree at The University of Waikato?** **[✓ Yes]/No**

17. **Are any permits (e.g. DOC) or approvals (e.g. Iwi) required?** **Yes/[✓ No]**

If 'YES':
Have the permits or approvals been obtained? **Yes/No**

List details of permits/approvals required ______________________

18. **I have read and understand the conditions outlined in the Code of Ethical Conduct for the Use of Animals for Teaching and Research.** **[✓ Yes]/No**
http://www.waikato.ac.nz/research/unilink/uow_only/Approved%20Code%202010%20-%202014.pdf

19. **I have read the Good Practice Guide for the Use of Animals in Research, Testing and Teaching**
http://www.biosecurity.govt.nz/files/regs/animal-welfare/pubs/naeac/guide-for-animals-use.pdf
[✓ Yes]/No

20. **Further conditions:**
If this application is approved, I will inform the Committee of any changes in the project or unexpected outcomes affecting animal welfare, and any event (beyond any approved manipulation) impacting adversely on animal welfare.

Signed by the applicant: ______________________ **Date:** 11/5/12

I accept responsibility for this project's compliance with the University's Code of Ethical Conduct for the Use of Animals for Teaching and Research.

Signed by the Supervisor: ______________________ **Date:** 15/5/12.

I accept responsibility for this project's compliance with the University's Code of Ethical Conduct for the Use of Animals for Teaching and Research.

[✓ Approved]/~~NOT approved~~

Signed on behalf of the Committee: ....
(Chairperson)

Date: 18/5/12