CATANIA’S CONCEPT OF THE OPERANT REVISITED: EMPIRICAL ANALYSIS OF RESPONSE VARIATION AND CONTROLLING CONTINGENCIES.

A thesis

submitted in partial fulfilment

of the requirements for the Degree

of

Master of Applied Psychology

At the

University of Waikato

By

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University of Waikato

2009

Abstract

Six Shaver-Starcross hens with no prior experimental experience served as participants in two experiments which were designed to empirically test Catania's concept of the operant. The stimulus consisted of a cream coloured rectangle against a black background shown on a standard LCD computer monitor. An infrared touch screen mounted to the front of the LCD monitor recorded the location of all responses made by the participants. Experiment one consisted of autoshaping the rectangle pecking response. This was done using an automated computer program designed to eliminate latencies between responses and reinforcement, as well as positional biases which may have been introduced via manual autoshaping. The program successfully eliminated latencies and positional biases introduced by the experimenter, but took longer than anticipated to autoshape the desired response in the participants. It is suggested that procedural differences account for the unusual length of time taken to autoshape the participants in this experiment. Preliminary inquiry investigating procedural differences shows that it may be possible to model speed of acquisition more accurately than done so at present, without retrospective analysis of the acquisition data itself. In experiment two the active, reinforced zone of the rectangle was reduced. The participants had no visible cue demarcating active and inactive zones of the rectangle, yet in accordance with Catania's operant, responding across all participants came to fall within the active, reinforced zone of the rectangle. The results; shifts in response distributions in relation to the changes in contingencies, offer empirical support for Catania's operant in terms of positive reinforcement across a single parameter of responding. The implications of these findings imply that when variability in responding is important; for example in learning, exploring, creating, and problem solving, Catania's operant may be favourable over Skinner's operant as a vehicle for identifying and controlling variables associated with behavioural outcomes due to its greater topographical inclusivity. Contemporary behavioural analysis favours a behavioural systems approach

where the respondent and operant class distinction merges; the environment affects the organism as much as the organism affects the environment. Catania's operant is complementary to behavioural analysis in this vein.

Acknowledgements

Many thanks to Dr James McEwen for his constructive criticism and support throughout the process. Likewise the technical team: Jennifer Chandler, Rob Backker, Andrew, Allan Eddey for turning ideas into practice. Recognition also goes to all the members of the dairy #3 lab.

Finally, to friends and family who have had to endure many months of chicken-related ramblings; and my sudden conversion to quasi vegetarianism.

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"To have a science of psychology at all, we must adopt the fundamental postulate that human behavior is a lawful datum, that it is undisturbed by the capricious acts of any free agent – in other words, that it is completely determined."

-(Skinner, 1947, p.73)

Occasionally control over behaviour is easily achieved; it is more common however for behaviour to appear variable, unpredictable or even random (Neuringer, 2002). Skinner always held the opinion that initiating causes of behaviour lie in the environment, and remain there (Skinner, 1988). Our inability to identify true causes of behaviour result in the use of 'mental way stations' (Skinner, 1963) that is, we incorrectly attribute the cause of behaviour to moods, cognitions, expectances, or other internalised states. There are two processes through which new behaviour emerges in novel situations. The processes are (i) respondent conditioning, where responses prepared in advance by natural selection come under control of new stimuli, and (ii) operant conditioning where new responses can be reinforced, or strengthened by positive consequences which follow them (Skinner, 1988). Generally studies only record target responses, while the overall distribution of target, off target, and other behaviour related to the contingencies are ignored. It is reasonable to suggest that fixation on target responses may often lead to the underlying causes of behaviour being overlooked, and way stations resorted to as a convenient means of explanation.

Respondent refers to a "class of responses defined in terms of stimuli that reliably produce them" (Catania, 1992). The most influential example of respondent condition is Pavlov's (1927/1960) discussion of unconditional and conditional reflexes in dogs. Pavlov found that the introduction of a stimulus (meat, powered biscuits, or mild acid) reliably produced salivary and gastric responses in his dogs. The relationship between any stimulus and its naturally occurring, or unconditional response is an example of an unconditioned reflex. Pavlov also found that repeated pairings of a previously ineffective stimulus (initially the laboratory assistant) with the food came to produce similar, yet more varied salivary and gastric responses in the dogs. The responses share properties with the unconditional response, but are conditioned to occur in the presence of a substituted stimulus. Over time the laboratory assistant alone came to produce salivary and gastric responses in the dogs, without the presence of food. The relationship between a previously neutral stimulus and its conditioned response is known as a conditional reflex. Neither a stimulus alone nor a response alone can be classified as a reflex. It is the relationship between the two events that defines a reflexive relationship (Skinner, 1930; Skinner, 1935; Catania, 1973).

Operant refers to a "class modifiable by the consequences of the responses in it" (Catania, 1992). In 1930, Skinner was studying the frequency at which rats depressed a lever that produced pellets of food. He found that the rate of the rats responding decreased when pellets were withheld over consecutive trials, and increased when pellets were reintroduced. The terms ‘reinforcement’ and ‘extinction’ were expanded upon in his paper to describe these observations. Skinner called the procedure of pairing the reinforcer with a stimulus ‘Type S conditioning’ or respondent conditioning. In both conditional and unconditional cases, the participants behaviour arouse in response to a stimulus deliberately presented by the experimenter. The procedure of pairing the reinforcer with a response was called ‘Type R conditioning’, or operant conditioning. The arrangement determined that the participant must operate on the environment to produce its reinforcer. The difference between respondents and operants is that the presentation of a stimulus is necessary for the elicitation of a response, but not for the emission of a response (Rehfeldt & Hayes, 1998).

Skinner’s primary objective has always been to “discover the functional relations which prevail between measurable aspects of behavior and various conditions and events in the life of the organism. The success of such a venture is gauged by the extent to which behavior can, as a result of the relationships discovered, actually be predicted and controlled” (Skinner, 1972, pp. 257-258). Measurable behaviour requires reproduction before it can become the subject of experimental investigation. What counts as a reproduction of a behavioural instance is a significant question. For Skinner, both stimulus and response could vary in the values of their relevant properties. Rather than separating each variation into a stimulus or response in its own right, Skinner found it more convenient to apply the opposite logic, and group stimuli (meat, powdered biscuits, mild acid) and responses (gastric or salivary reactions) which were functionally equivalent into classes. Behaviour was conceptualised as an observable correlation between a class of stimulus properties and a class of response properties, rather than relationships between individual stimuli and individual responses (Skinner, 1935).

For the interaction between an organism and its environment to be accurately portrayed however, the correlations have to be described in terms of (i) the occasion in which a response occurs, (ii) the response itself and (iii) the reinforcing consequences of the response. The interrelationship between these three elements is known as “contingencies of reinforcement” (Skinner, 1969, p.7).

The dashed line in Figure 1 represents the probability of a stimulus being presented contingent on a response. If a rat’s bar press is taken to be the parameter of responding, then a response is reinforced if the bar press falls between ‘X’ and ‘Y’ Newtons. The initial probability of a response occurring in relation to reinforcement is represented by ‘A’. Over time, the correlation between responses emitted in the range of ‘X’ and ‘Y’ Newtons and reinforcement strengthens, resulting in response distributions represented by ‘B’ and finally ‘C’.

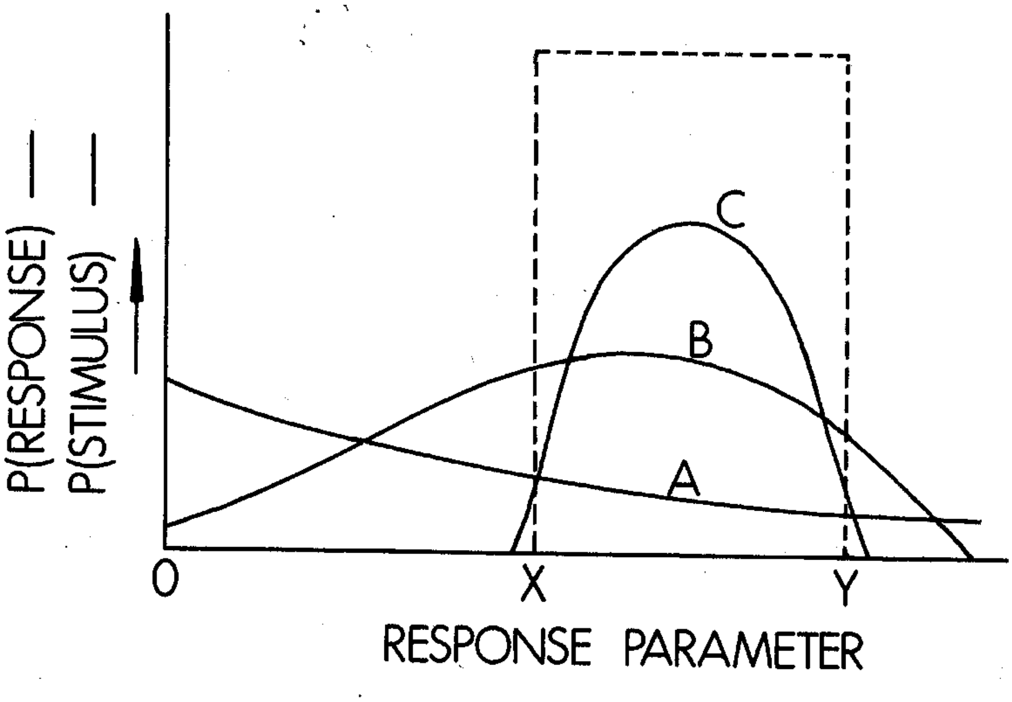

Figure 1: Hypothetical representation response and stimuli probabilities shown as a function of an arbitrary response parameter (Catania, 1973, p. 107)

Skinner’s concept of the operant is illustrated, as there is an observable change in the correlation between the response class (‘A’ to ‘B’ to ‘C’), and the stimulus class (Newtons between ‘X’ and ‘Y). Both classes contain members which are functionally equivalent, but vary topographically in the case of the response class, and vary across force in the case of the stimulus class. The contingences of reinforcement dictate that responses falling in the range of ‘X’ and ‘Y’ Newtons are reinforced, while those outside this range are not. The target responses under Skinner’s operant are those that fall within the dashed rectangular line shown in Figure 2. Skinner’s operant then, is defined as an observable change in correlation between classes of stimuli and responses, bound by contingecies of reinforcement (Skinner, 1969; Catania, 1973).

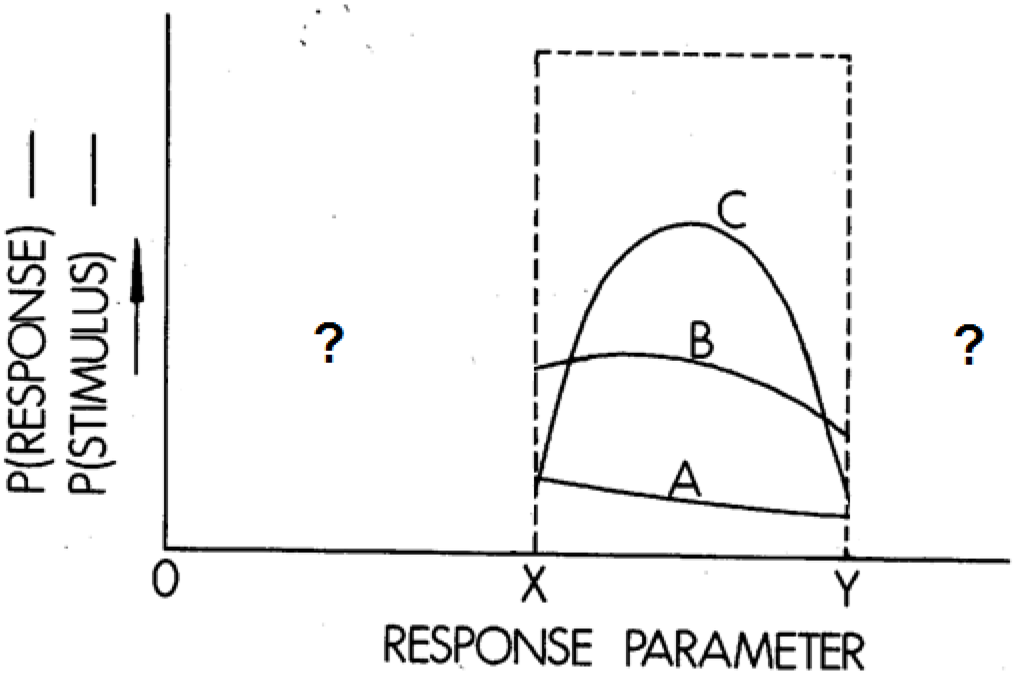

Figure 2: Hypothetical presentation of Skinner's operant. Distributions of response probabilities 'A', 'B', and 'C' are known to continue outside the range of 'X' and 'Y', but are nonetheless discarded. Figure adapted from Catania (1973), p. 107.

One implication of Skinner's operant is that parts of the relevant response distributions are truncated. A comparison of figures 1 and 2 confirms that it is much easier to visualise the changes in response distributions when the entire response distributions are actually presented. More importantly, sometimes responses outside the targeted range tell us a great deal about functional relationships between the organism and its environment. Variability in responding has significant applications. For example processes of learning, exploring, creating, and problem solving may partly depend on it (Neuringer, 2002). Skinner's operant was developed to limit the range of responses subject to analysis: A result of excessively truncating the range of behavioural variability analysed is a reduction in ability to predict, control, and ultimately understand that behaviour. In terms of operant correlations, a weak correlation suggests that other behavioural factors may be operating, or that the operant relation may involve other dimensions of responding beyond those on which the operant correlation was determined (Catania, 1973). These subtleties are overlooked in Skinner's conceptualisation.

Paradoxically, Catania extended the application of Skinner's operant by relaxing the requirement that target responses had to fall within the contingencies of reinforcement. He argued that responses falling outside the contingencies of reinforcement are still important and subject to analysis. In his 1973 paper, Catania discussed two usages of the term 'operant'. "…the first class is the class of responses for which consequences are arranged; the second class is the class of responses generated when consequences are arranged for responses in the first class" (Catania, 1973, p.105). Catania termed the first class a 'descriptive operant', and the second class a 'functional operant'. Catania's concept of the operant grows out of the correlation between these two classes. Catania's concept of the operant is best illustrated by response distributions 'A' through 'C' shown in figure 1. While Skinner's operant runs the risk of being too exclusive, Catania's operant runs the risk of being too inclusive. Exactly how much of a response distribution should be included in analyses?

Catania's paper is quiet on this issue, but he does suggest one dimension on which the correlation between descriptive and functional classes can easily be measured; the response rate. "If responses produce stimuli, or in other words, if stimuli occur within time periods that include a response but not within those that do not (*cf* Schoenfeld and Cole, 1972), an increase in the proportion of time periods that includes responses will necessarily be accompanied by an increase in correlation" (Catania, 1973, p. 108).

Once an operant correlation has been established, the response distribution is likely to narrow and shift until the distribution reaches a point where the majority of responses fall outside the 'X – Y' range (Figure 3). This is observed in studies of response force, duration, and other temporal parameters of responding when the law of least effort is applicable (Catania, 1973). The narrowing of the response distribution is also accompanied by a decrease in correlation between descriptive and functional operant classes. Changes in the strength and direction of obtained correlations must therefore be interpreted with care, as the statistical logic behind the correlation says one thing (responses are moving away from the production of stimuli), but the behaviour it is meant to represent actually says another (the participant is attempting to optimise return on effort).

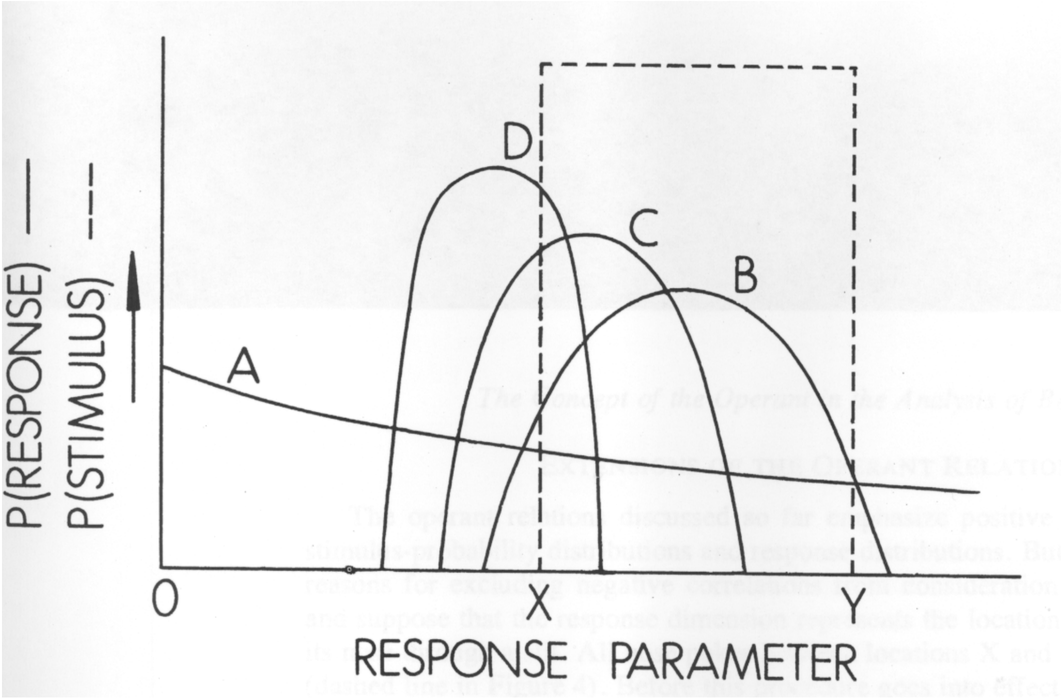

Figure 3: Hypothetical response distributions where B, C, and D, shows a narrowing and shift of the response distribution toward X, the lower requirement of contingent reinforcement indicative of the law of least effort (Catania, 1973, p. 110).

Further complications arise when behaviour is autoshaped, or when the method of sucessive approximations is applied to a particular dimension of responding (Catania, 1973). Here, the probabilities of reinforcement for different responses can vary from moment to moment (Figure 4). Skinner's operant is also hard pressed to account for behaviour adequately in these situations (Pear & Eldridge, 1984). The shaping process is also affected by a host of other variables. Some of which include the partipant's history with pretraining reinforcers (Downing & Neuringer, 1976), the order in which stimulus and food are presented (Brown & Jenkins, 1968; Bilbrey & Winokur, 1973), the durations of stimulus presentation, intertrial intervals, as well as interactions between the background context and the true rate of reward associated with the stimulus (Gallistel & Gibbon, 2000; Kakade & Dayan, 2002). The underlying processes of autoshaping are not well understood, party because they do not appear to fit neatly into either operant or respondent frameworks. Autoshaping is therefore a sutiable acid test for any concept which claims to have any explanatory power over either of the more traditional conceptualisations.

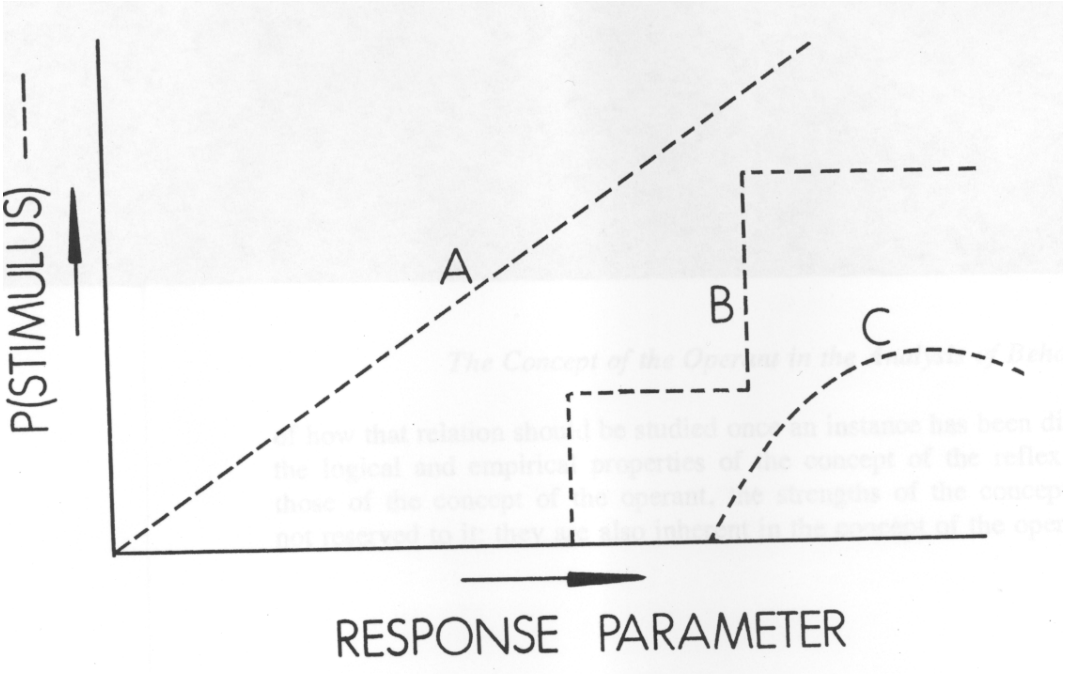

Figure 4: Catania's depiction of three stimulus distributions with varying weights of probability (Catania, 1973, p. 114).

In 1968, Brown and Jenkins pioneered the foward pairing autoshaping proceedure which produced the key pecking response in pigeons with "suprising regularity" (p. 8). In this procedure, a key light was presented for 8-sec followed immediately at the offset of the light by a 4-sec tray operation. If the key was pecked before the 8-sec had elapsed, then the key light was immediately blackened, and the tray operated for 4-sec. Between trials, the key light was off and the intertrial intervals varied between 30 and 90-secs in duration around a mean of 60-sec. Key pecking resulted from the unconditional presenation of food. One conclusion was that key pecking was the result of a conditioning process of some nature. Operant conditioning is evident, but respondent conditioning may also be involved through stimulus substiution. The conditioned stimulus (key light) may prime the response (key peck) elicited by the unconditioned stimulus (food). Also, classical pairings of a stimulus with food make the stimulus capable of affecting operant responses that were not, and could not have been shaped or reinforced during the pairings (Brown & Jenkins, 1968).

The respondent operant distinction has been debatable since its introduction. (Konorski & Miller, 1937) for example, suggested that any response must occur after some kind of stimulus presentation, and that Skinner's operant with no antecedent stimulus, simply does not exist. The debate is similar to asking if the chicken came before the egg or vice versa: Does all behaviour need to be driven by external stimuli, or can behaviour driven by consequences occur in the absence of antecedent stimuli?

Skinner recognized that stimuli occasion responses; approximately 18 years later he also stated that "operant conditioning may be described without mentioning any stimulus which acts before the response is made" (Skinner, 1953, p. 107). Depending on frame of reference, the same behaviour can be seen as respondent (discriminative stimulus ‘x’ occasions behaviour ‘y’), or operant (behaviour ‘y’ is done to gain consequence ‘z’). Some scholars have proposed that respondent and operant class interactions are constantly present in the environment of any organism (Donahoe, 1991) in which case discriminative stimulus ‘x’ occasions behaviour ‘y’, which is done to gain consequence ‘z’ that is, the same behaviour can also be seen as a combination of respondent and operant processes (Novak & Pelaze, 2003).

In his review of the operant, Timberlake (2004) suggested that “the efficacy of the operant contingency can be improved further by continued analysis of its implementation, mechanisms, and assumptions and by increasing its links to other approaces and concepts” (p. 197). As outlined earlier in the introduction, Catania (1973) extended Skinner’s concept operant arguing that the entire response topography (which likely includes both respondent and operant processes) is important in understanding behaviour, not just reinforced responses. Since then however, and in spite of many articles citing Catania’s 1973 paper (PsycINFO n = 29; Google Scholar n = 94) no empirical data has been reported to support Catania’s operant.

The present thesis is justifiable as an exercise in gathering data to support or refute Catania’s operant. This is to be done via two experiments. In the first, the pecking response in experimentally naive hens will be autoshaped. In the second, the stimulus distribution along a single parameter of responding (in this case peck location) will be changed. If Catania’s concept proves to be true, the response distribution should change in accordance with the stimulus distribution. The results from both experiments will discuss the validity of Catania's concept of the operant in terms of Skinner's operant and more contemporary approaches to the analysis of behaviour.

EXPERIMENT 1

Method

Participants

Six shaver starcross hens approximately seven years of age were used as participants for the experiment. The hens had no prior experimental experience, were previously free range, and had been debeaked. The hens were maintained at 80% (± 5%) of their free feeding weights. Hens were weighed on a daily basis, and additional food (commercial laying pellets) was given where insufficient reinforcements were gained within sessions. The calculation for post feed in these cases was based on the number of reinforcements received during a session, and the hens current weight. The Animal Ethics Committee for the Approval of Experiments on Animals at the University of Waikato approved the use of the participants in the current experiments (Protocol No.: 723).

Apparatus

A computer (specifications in Appendix B) was used to control experimental events and record data. The operant chamber was a 62 x 58 x 41cm ply wood box, with the interior walls painted white. An iron tray was placed on the floor of the chamber and was covered with a wire mesh grid. A 15 inch infrared touch panel (specificaitons in Appendix C) was attached to the front of a 15 inch LCD computer monitor. The touch panel, used to record response location, and the LCD panel used to display the stimulus were both located at one end of the experimental chamber.

Below the mounted panels, was a rectangular hole measuring 7 x 10.5cm in the chamber wall that allowed hens' access to a magazine. The food hopper itself was lowered and raised by a solenoid, giving the hens' access to wheat for 4-secs. A photocell was also placed near the opening of the food hopper. This was used to determine that the hens were eating during the predetermined access time to the wheat reinforcer. When the food hopper was raised, the magazine was illuminated by a 1 watt white bulb. No light was present in the experimental chamber beyond that provided by this bulb, and the LCD screen used to display the stimulus.

Procedure

Experimental sessions took place six days per week. The hen was placed alone in the chamber. The duration of each session was 30 minutes. For the first session, the magazine was inoperative, and the LCD monitor was blacked out. This first session provided the hens with a period of adaption to the experimental chamber.

For the following session, the response rectangle was visible in the middle of the LCD monitor against a black background. The magazine was disabled. This session was used to gauge the operant level of responding for the hens.

A session of magazine training followed, where the response rectangle was again not visible, and the magazine and 1 watt bulb were simultaneously operated on a variable interval schedule around a mean duration of one minute (VI 1min). The food hopper was made available for 4-secs. This meant that over the course of the 30 minute session, a hen was presented with access to wheat via the magazine approximately 30 times.

Following magazine training, an adapted version of the Brown and Jenkins (1968) autoshaping procedure was used to shape the hen's key pecking response. The response rectangle was made visible for 8-secs durations on a VI 1min schedule. When the 8-secs had elapsed, the response rectangle was immediately blacked out, and the food hopper was simultaneously operated for 4-secs. If the response rectangle was pecked before the 8-secs had elapsed, then the response rectangle was immediately blacked out, and the magazine operated for 4-secs. All responses made in the autoshaping sessions were recorded.

Results

The white section of each bar in Figure 5 shows the number of trials required for each participant to peck the rectangle for the first time in the autoshaping procedure. The black section of each bar represents the additional number of trials required before the fifth rectangle peck was observed. Bird 501 was the first to peck the rectangle, requiring 5 trials to do so. Bird 505 was the last to peck the rectangle requiring 192 trials to do so. Birds 502, 503, 504, and 506 required 168, 163, 174, and 155 trials before emitting the first response. Bird 501 required a further 227 trials before the fifth peck was observed. Bird 504 required 27 additional trials and bird 503 required 9 additional trials before accumulating five rectangle pecks. Birds 502, 505 and 506 all required 4 additional trials before five rectangle pecks had occurred.

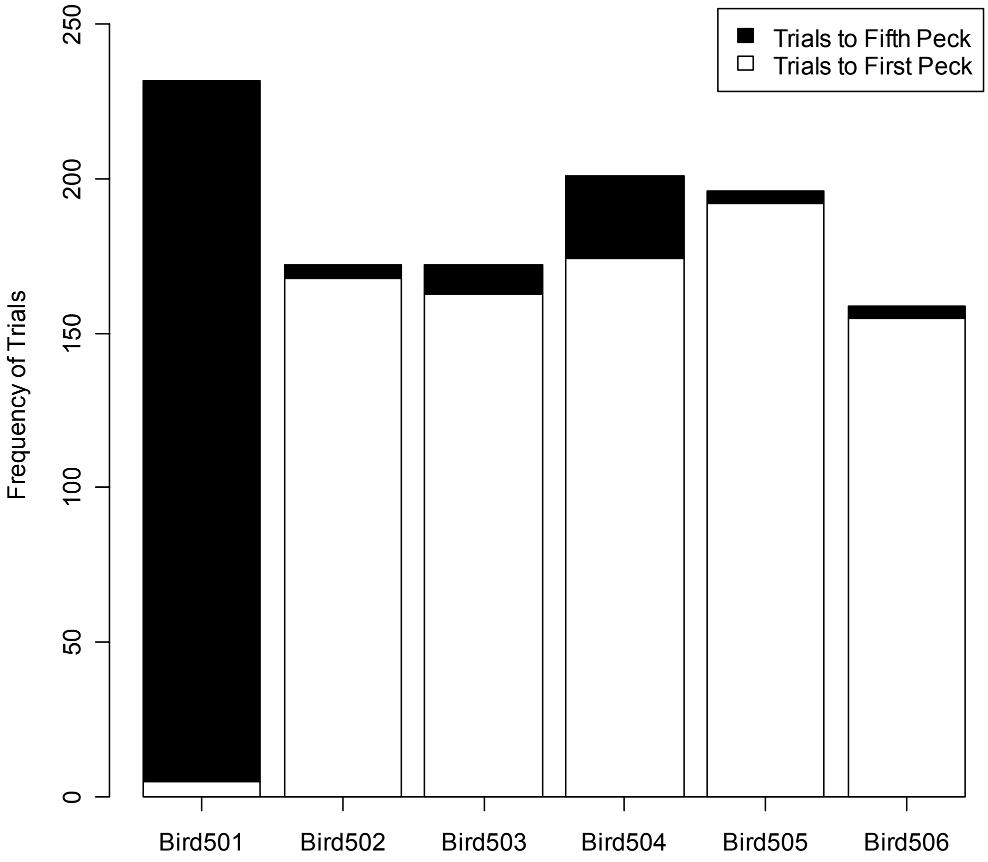

Figure 5: Number of Trials to First and Fifth Peck for each Participant.

Figure 6 shows the rate of responding per reinforcer for each participant during the autoshaping procedure. The dashed horizontal line represents the optimum response rate of one peck per trial. The response rates of birds 502 ($\mu = 6.43$), 503 ($\mu = 1.65$), 505 ($\mu = 12.68$) and 506 ($\mu = 3.06$) are stable in that they became higher than the optimum rate early on in the autoshaping procedure, and remained consistently higher than the optimum rate during the extended phases of autoshaping. The standard deviation and range in response rates for birds 502 ($\sigma = 8.64$, range = 43.81), 505 ($\sigma = 15.29$, range = 70), and 506 ($\sigma = 2.16$, range = 9.24) otherwise fluctuated considerably. In comparison, bird 503 ($\sigma = 0.96$, range = 5.73) best represented ‘optimum’ responding for the autoshaping procedure with little deviation and changes in response rate across sessions. Bird 501 ($\mu = 1.37$, $\sigma = 2.41$, range = 22.4) had peaks in response rates during early (2, 13) and late (43, 44) sessions, but overall 501 responded below the optimum rate across sessions. Bird 504 ($\mu = 2.15$, $\sigma = 3.96$, range = 25) also responded infrequently, the data stabilising below the optimum response rate. The conditional break in Figure 6 for bird 504 represents a change in the stimulus (T) and intertrial interval (I) durations for bird 504; the initial values ($T = 8$sec, $I = 60$sec) were halved becoming ($T = 4$sec, $I = 30$sec). Within five sessions bird 504 was responding above the optimum rate. The response rates across the participants were significantly different ($F[1,522] = 21.806$, $p < 0.001$) as illustrated in Figure 7.

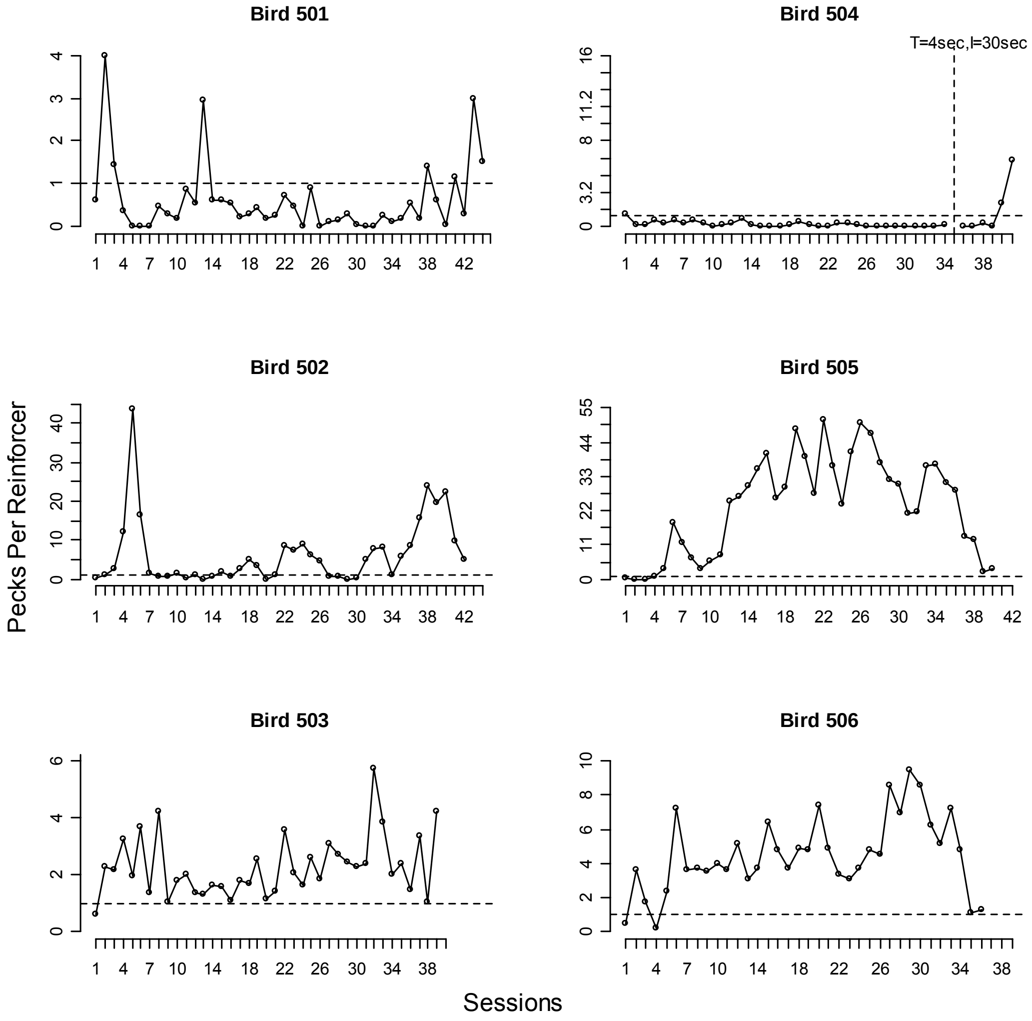

Figure 6: Rates of Responding (Pecks Per Reinforcer) by Autoshaping Session for the Respective Participants.

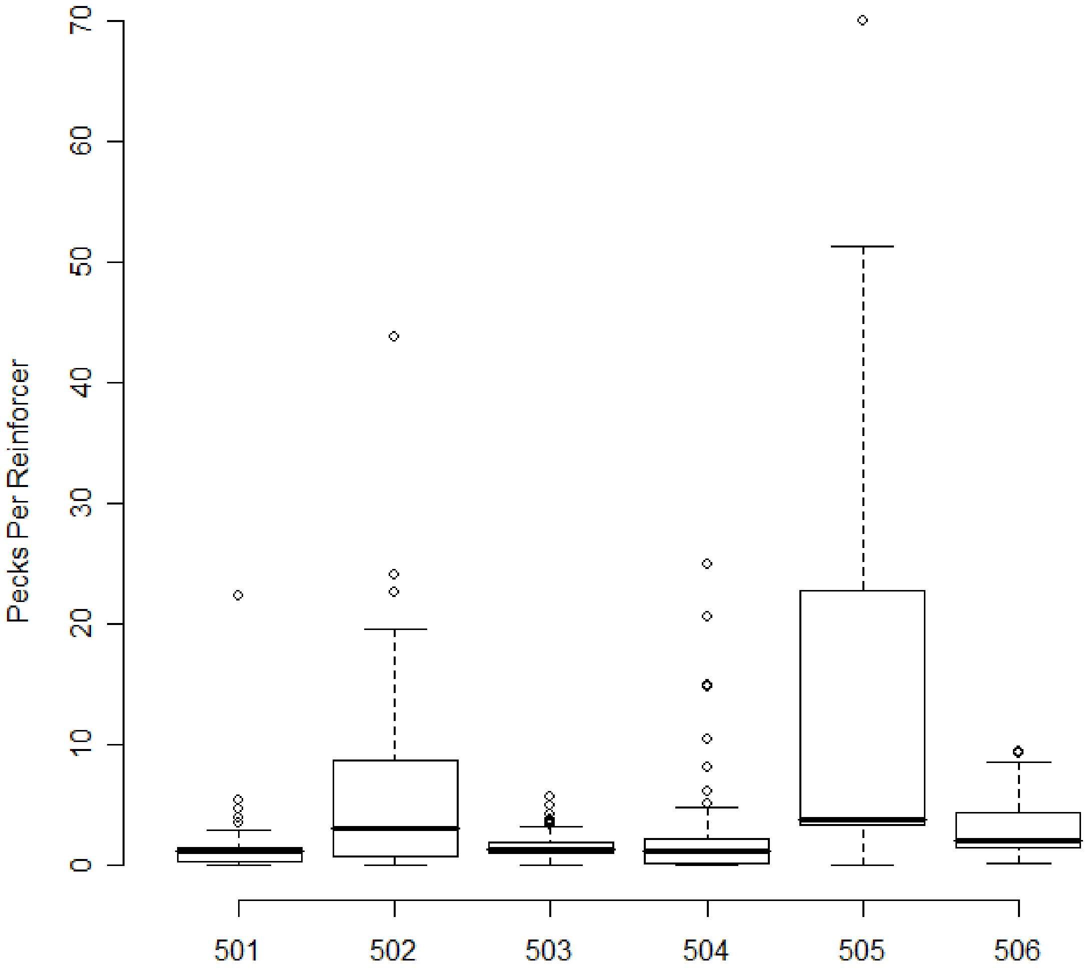

Figure 7: Rates of Responding Compared Across Participants.

Figure 8-13 show the first 16 autoshaping sessions for each of the participants. Responses made while the rectangle was not visible are represented as ‘.’, while responses made while the rectangle was visible are represented as ‘X’.

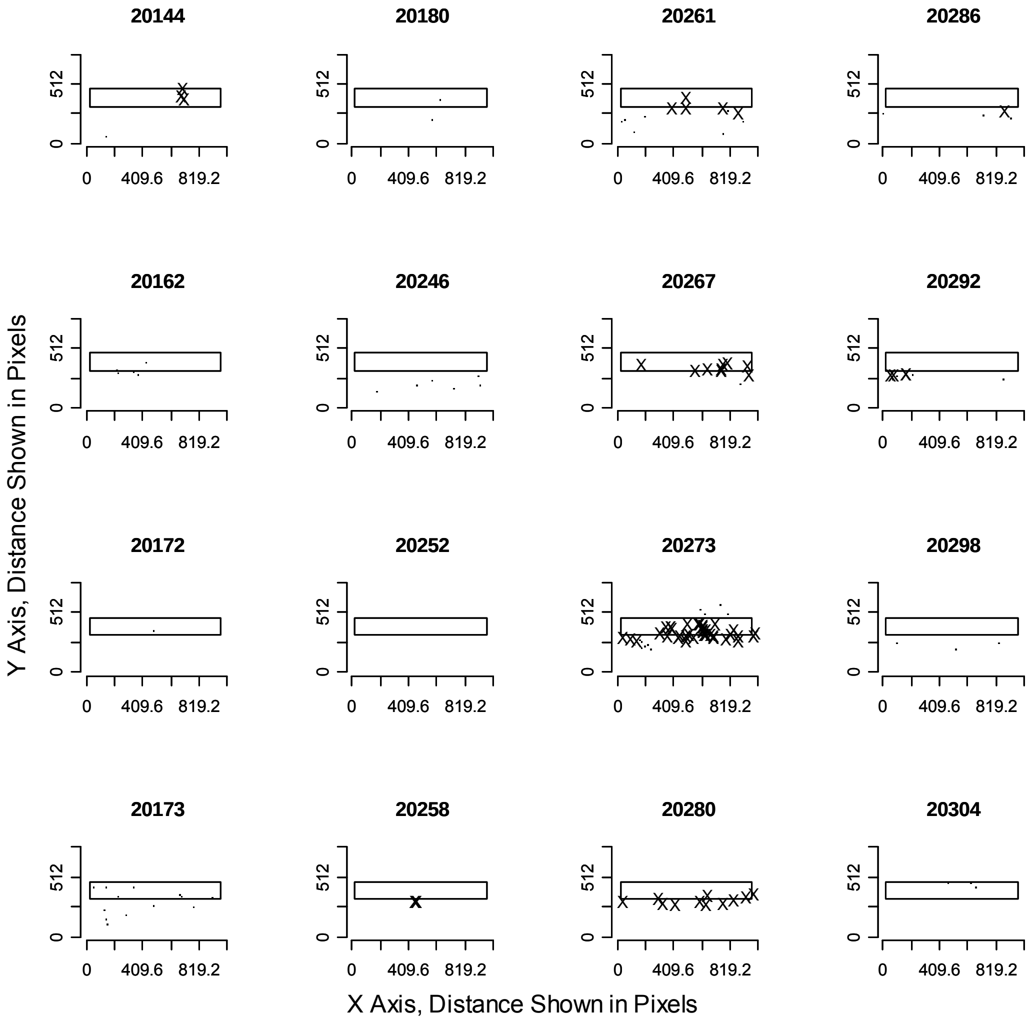

Figure 8: First 16 autoshaping sessions for Bird 501

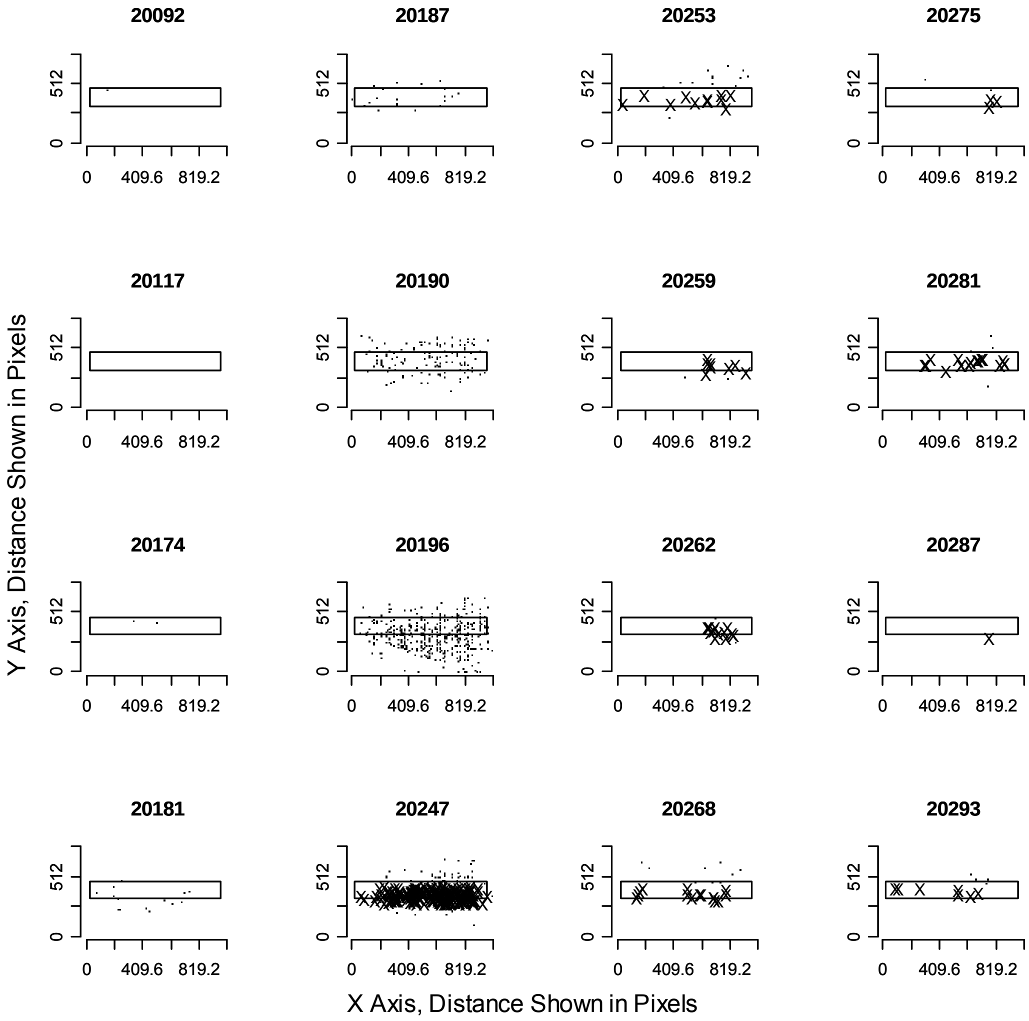

Figure 9: First 16 autoshaping sessions for Bird 502

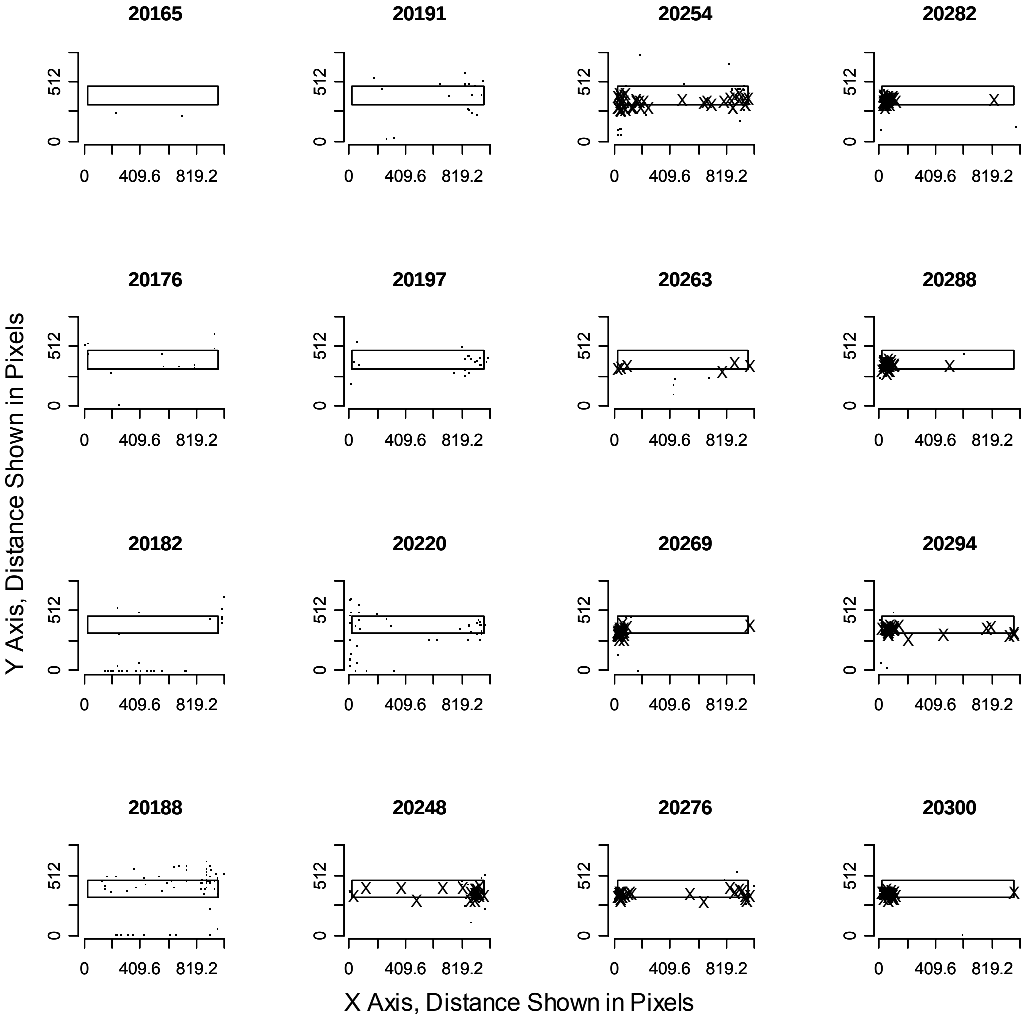

Figure 10: First 16 autoshaping sessions for Bird 503

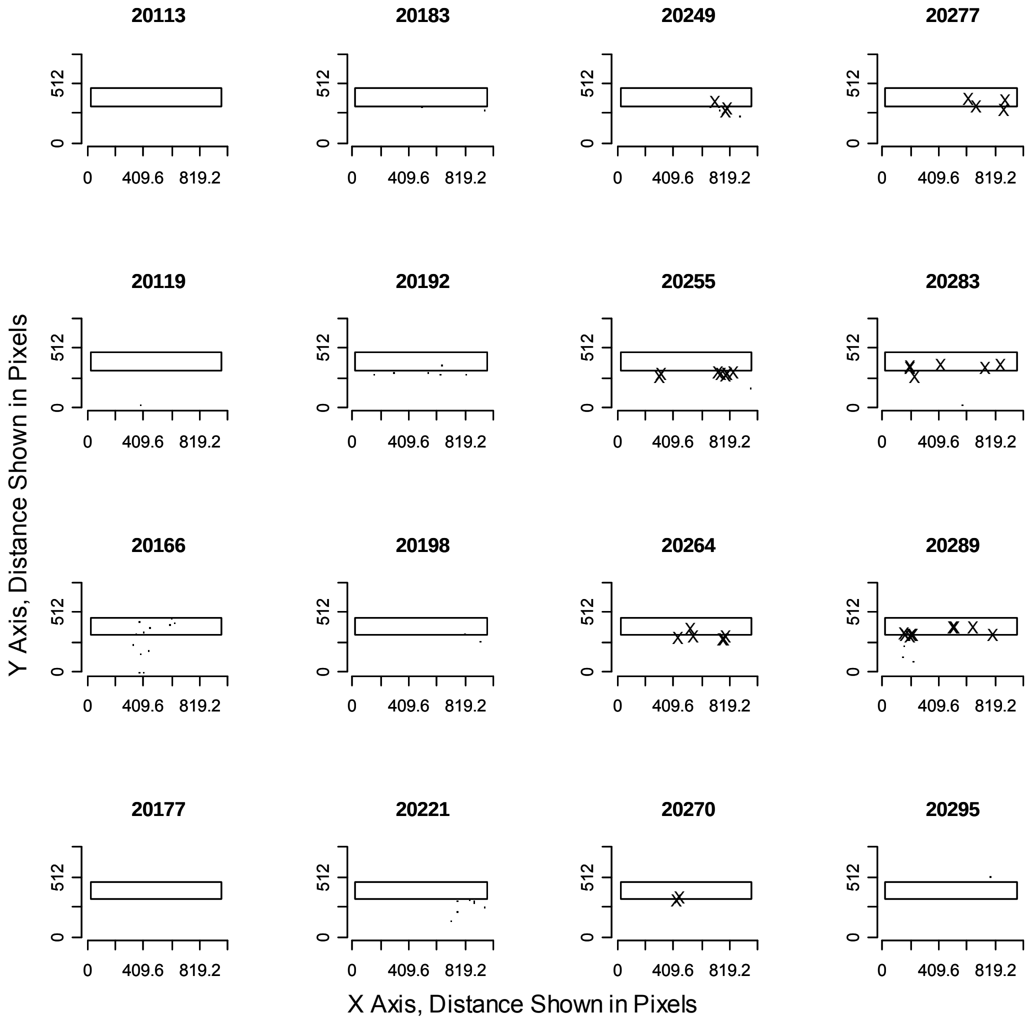

Figure 11: First 16 autoshaping sessions for Bird 504

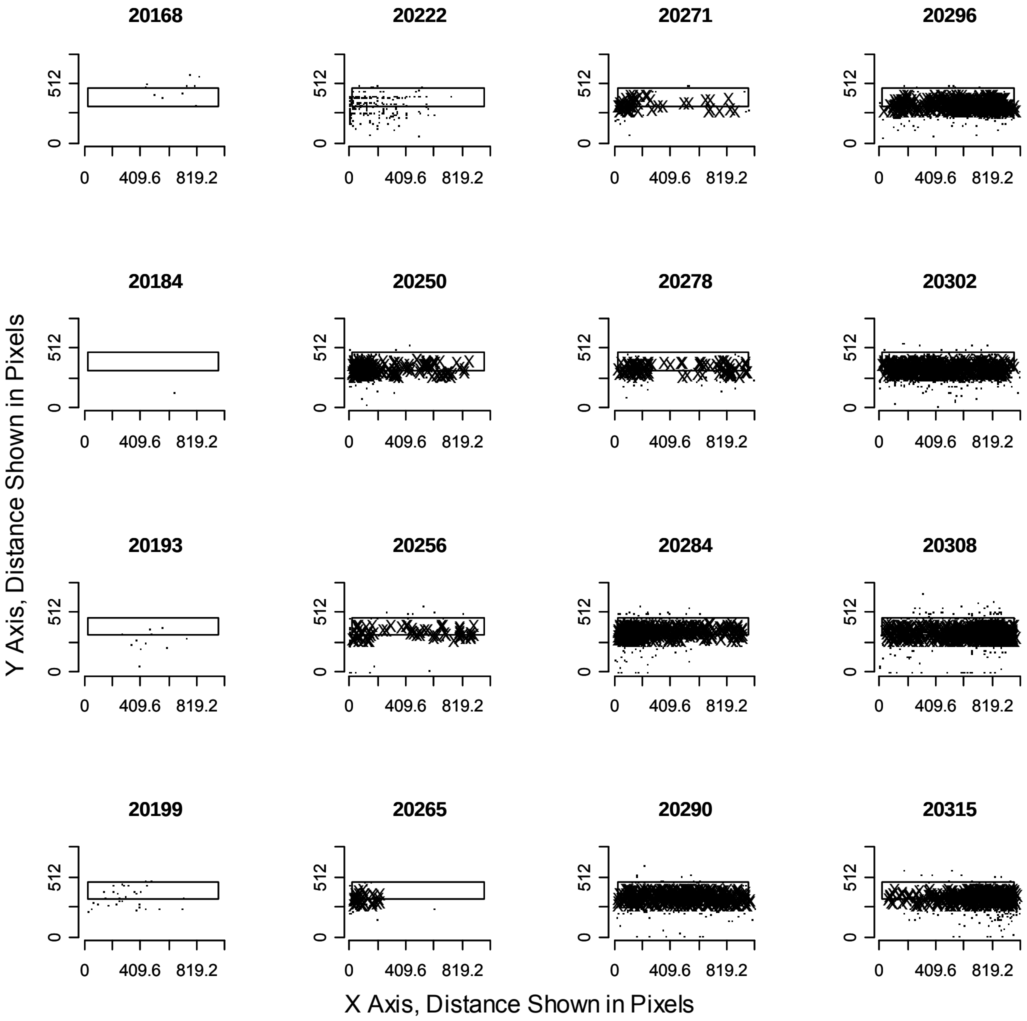

Figure 12: First 16 autoshaping sessions for Bird 505

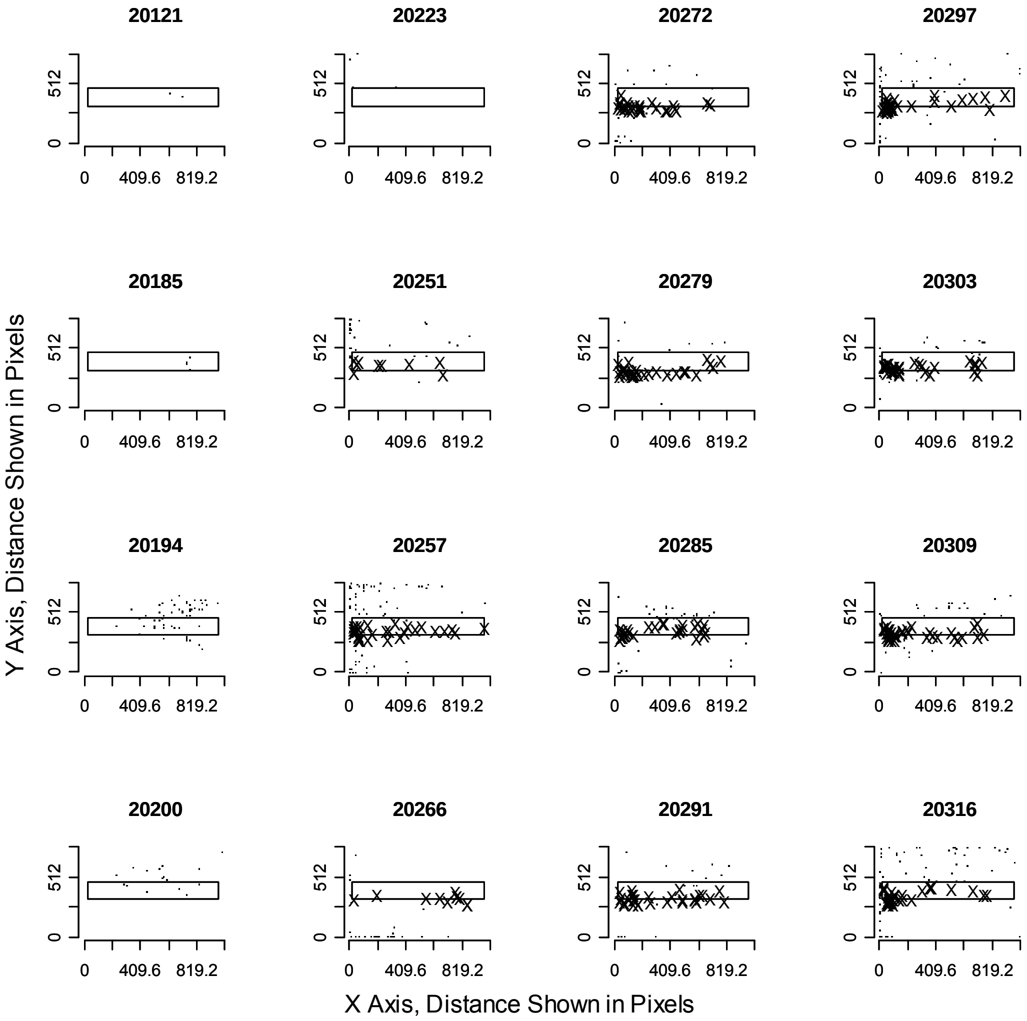

Figure 13: First 16 autoshaping sessions for Bird 506

The standard criterion for autoshaping (3 out of 4 successful trials Kakade & Dayan, 2002) was reached by all birds 501 (in session 20267), 502 (in session 20247), 503 (in session 20248), 504 (in session 20255), 505 (in session 20250), and 506 (in session 20251) refer to Figure 8-13.

Figure 14-19 show the response rate of participants in the absence of the rectangle (these are the same as those plotted by '.' in figures 8-13) for the specified session. Reinforcers were delivered unconditionally on a VI 1min schedule. A characteristic of variable interval schedules is steady rates of responding over time. This is true for birds 502 and 505. The response rates for birds 501, 503, 504 and 506 however, resemble a stepwise pattern, which is more commonly representative of fixed ratio schedules. Interestingly, the increases in response rate occur just before or just after expected reinforcement.

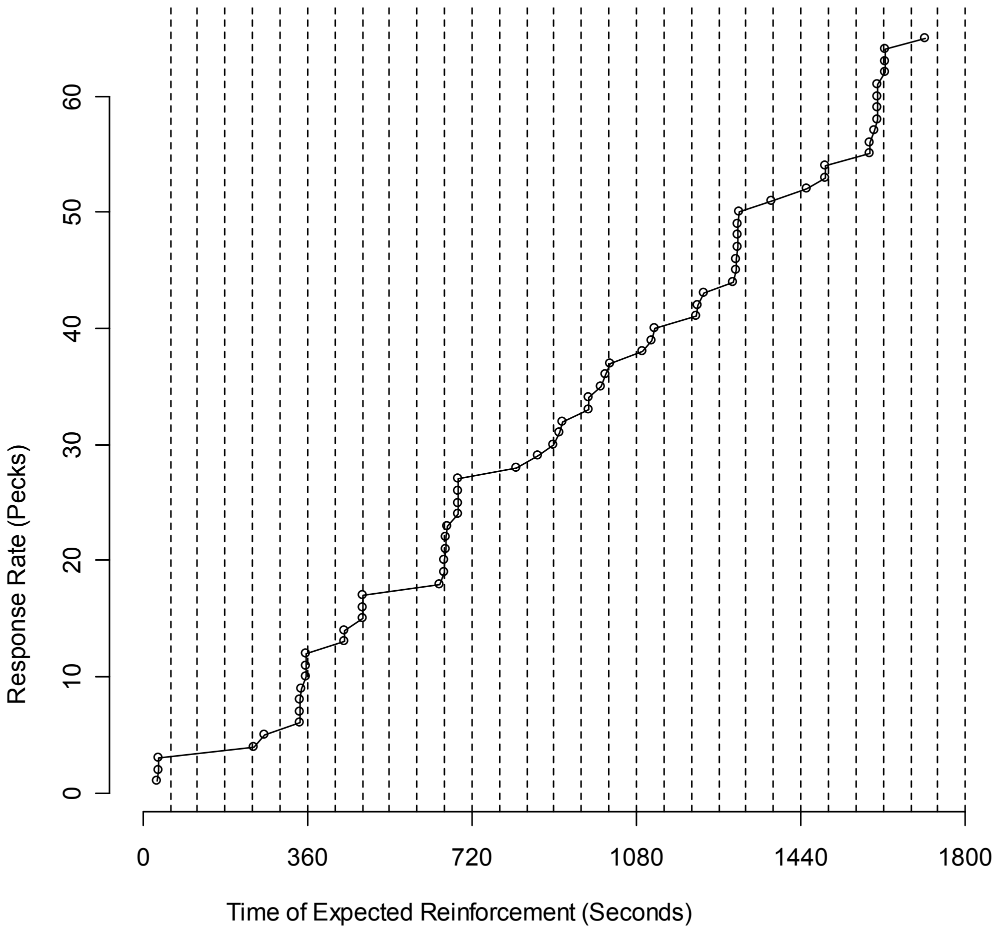

Figure 14: Bird 501 Session: 20173. Response rate in the absence of the rectangle as a function of expected reinforcement time.

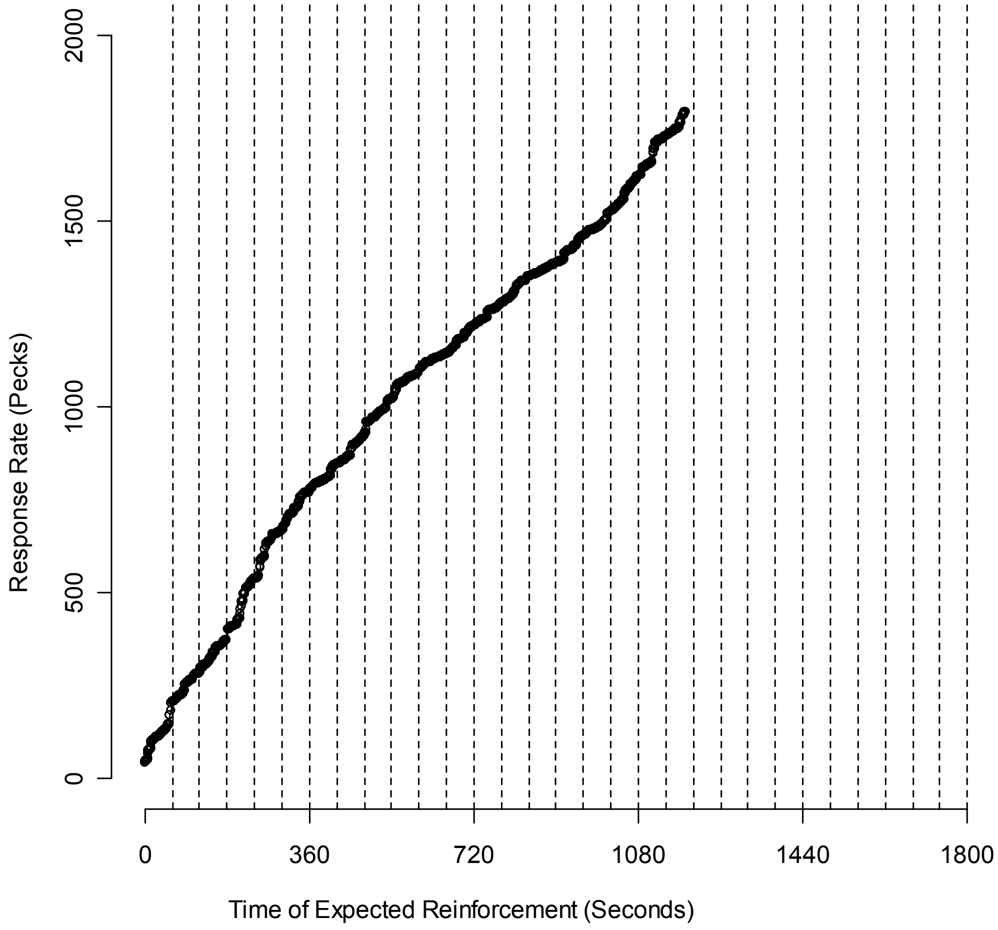

Figure 15: Bird 502 Session: 20196. Response rate in the absence of the rectangle as a function of expected reinforcement time.

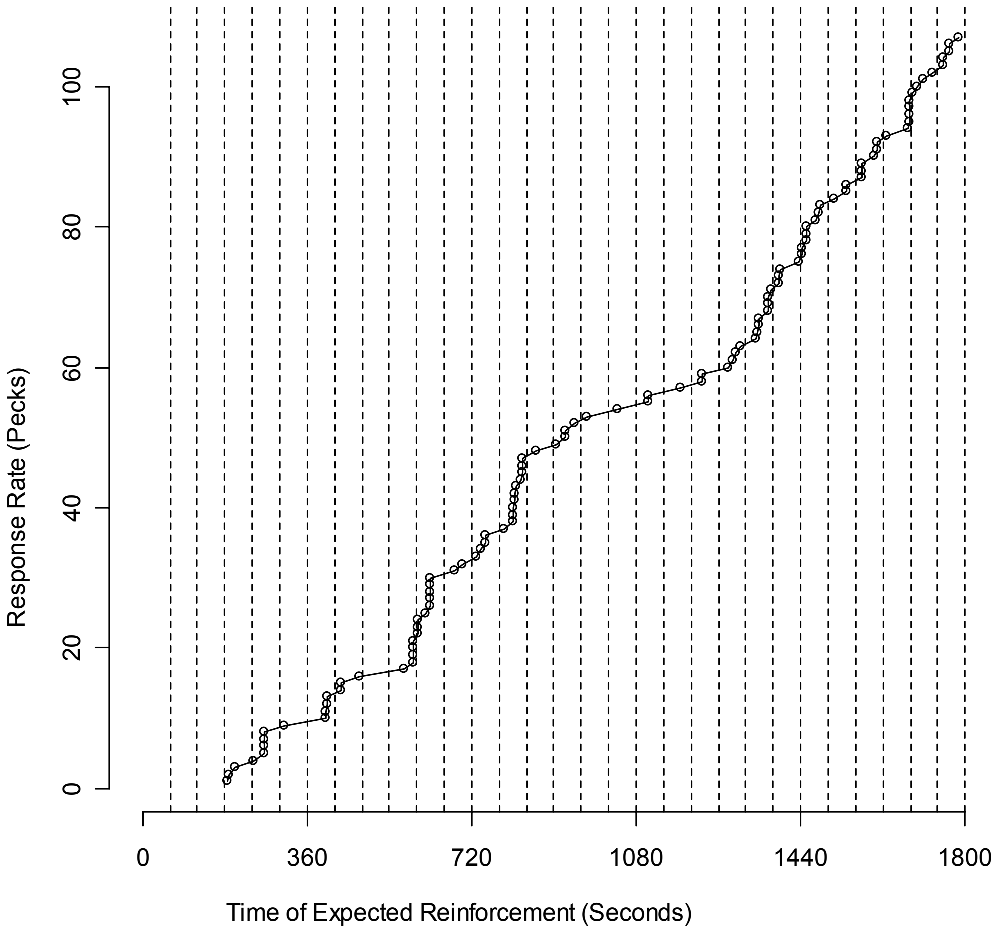

Figure 16: Bird503, Session: 20220. Response rate in the absence of the rectangle as a function of expected reinforcement time.

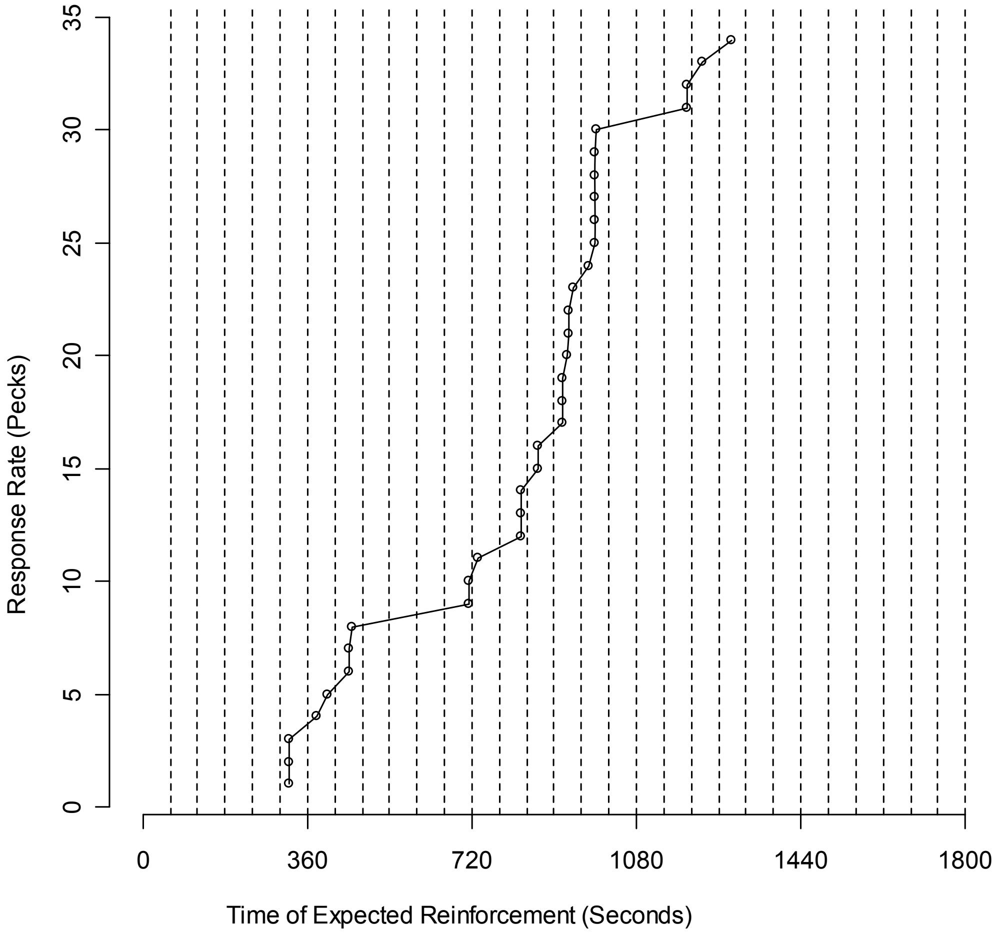

Figure 17: Bird 504 Session: 20166. Response rate in the absence of the rectangle as a function of expected reinforcement time.

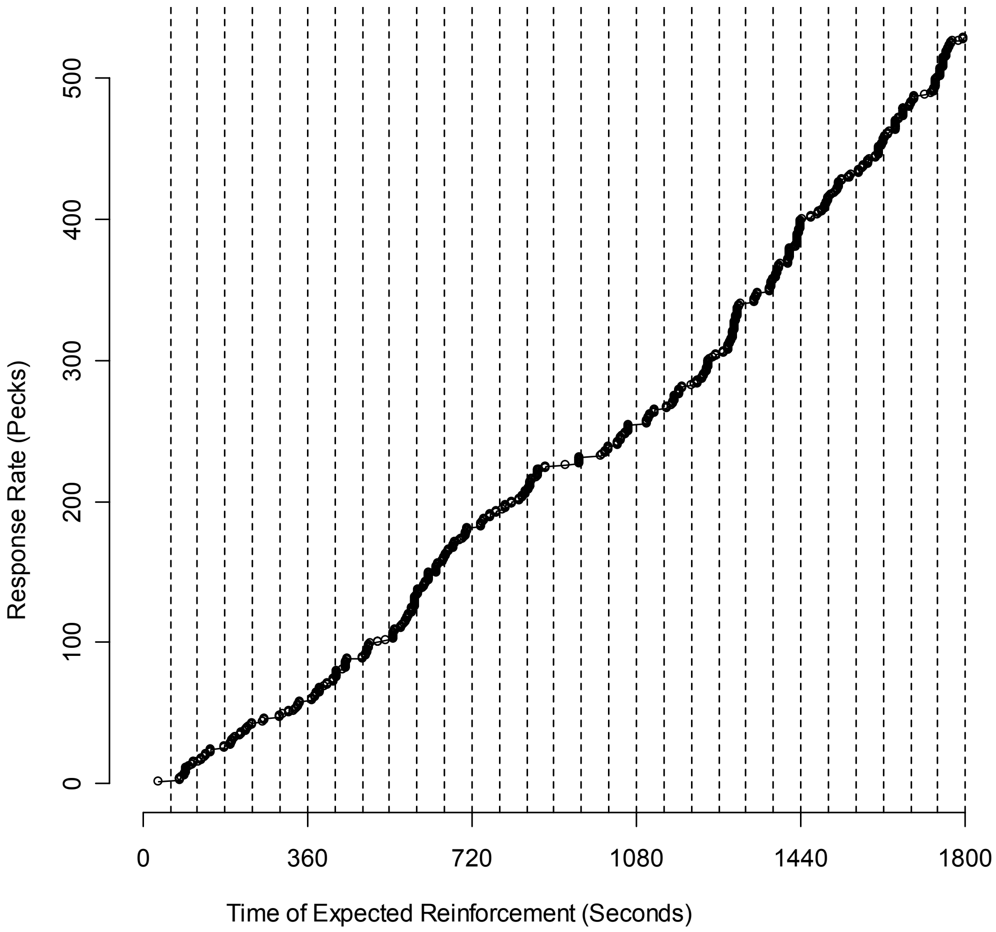

Figure 18: Bird 505, Session: 20166. Response rate in the absence of the rectangle as a function of expected reinforcement time.

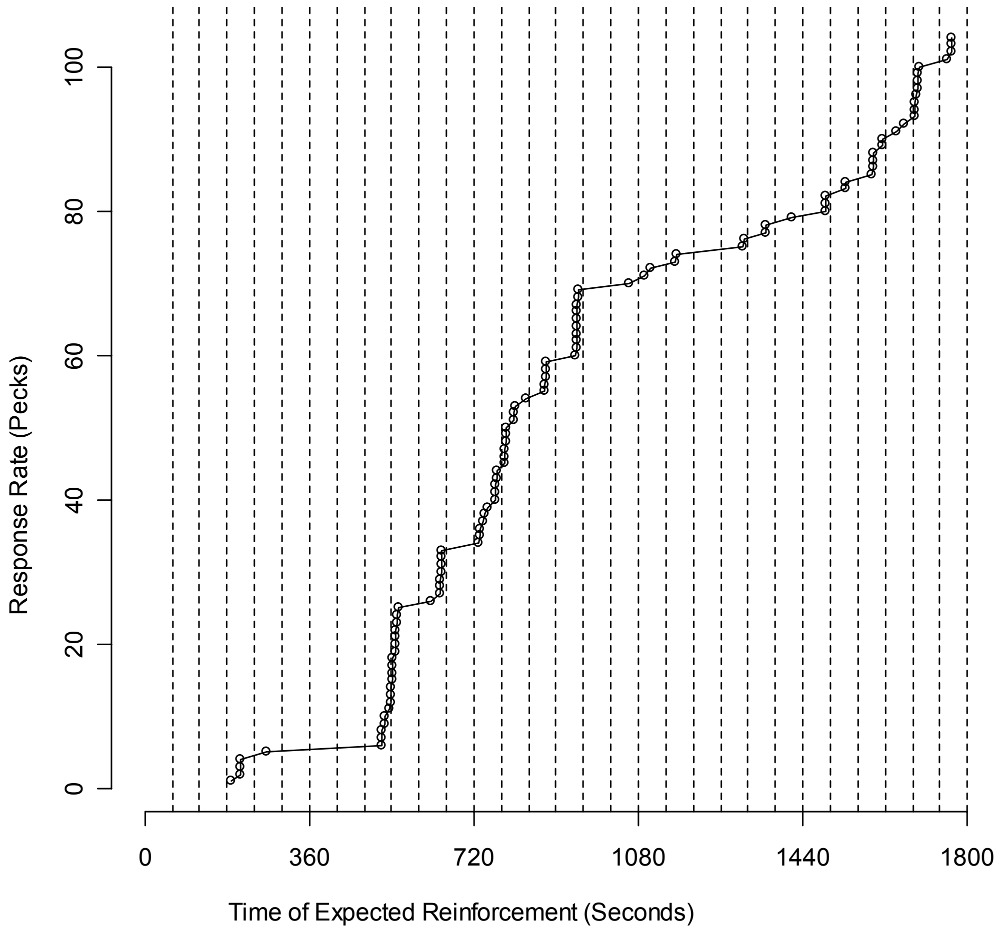

Figure 19: Bird 506 Session:20149. Response rate in the absence of the rectangle as a function of expected reinforcement time.

Discussion

The automated method developed to autoshape participants in this experiment overcame some difficulties in earlier studies. Antonitis for example, reported "from time to time during the hour, the S was frequently observed to run back and forth from one extreme of the slot to the other with its nose sliding along in the slot; this behavior sometimes resulted in several interruptions of the light beam at random positions along the slot" (Antonitis, 1951, p. 276). Similarly, response bursts were common in the Antonitis study, especially at the beginning of sessions. This too resulted in many photographs of multiple nose pokes in very similar positions. As the photos had to be analysed individually, it was difficult to ascertain the exact location of individual responses which made up any given response burst. Responses were automatically recorded in the present experiment, and consequences delivered without undue latencies between response and reinforcer. The scope for human error in terms of recording data and controlling experimental events was reduced to zero.

The present methodology however, was not without its own limitations. The infra red grid used to record data for example, recorded any break in the infra red grid regardless of which part of the hen made contact with it. Pecks were predominantly recorded by the apparatus; but so too were instances of hen's wings, claws, and so on making contact with gird. The labels 'pecks' and 'responses' were used to describe behaviour of the participants in the results section as a matter of convenience. It would be more accurate to describe all behaviour as 'bird-grid events'. Bird 506 for example, clawed the lower edges of the screen frequently during autoshaping. Video footage shows a few instances of alternative responses being registered outside of pecking. This provides partial explanation for recorded peaks well below the visible rectangle (y coordinates in the range of 1 to 60 pixels). It was clawing; not the desired response of pecking. Breaks in the grid were registered on initial contact with the screen. Hardware latency was 12ms, while software latency was slightly longer. It is possible, but unlikely that some responses were masked by latencies in software recording and others by simultaneous contact in two or more separate locations of the screen being recorded as one response instance. Another important detail of the procedure is the effort required by the hens to interact with the apparatus. The screen provided no tactile resistance compared to a traditional operant key, or button. In terms of behavioural economics, the cost of individual responses was therefore very low. These drawbacks are greatly outweighed by the fact that the majority of the response distributions of the participants were able to be recorded accurately.

Kakade and Dayan (2002) point out that most experiments do not show data during the slow phase (pre aquisition) of autoshaping, and cite this as a major reason for our current lack of understanding on the topic. The results from this experiment indicate that responses in the slow phase of autoshaping initially occurred in the absence of the conditioned stimulus (Figure 8-13). Moreover, the rate of these responses increases just before, and after the presentation of a reinforcer (Figure 14-19). This supports suggestions that (i) pre acquisition data is of importance in our attempts to understand autoshaping and (ii) responded conditioning appears to be present in the early stages of autoshaping (Brown & Jenkins, 1968).

It would seem that the unconditional presentations of food initially increase elicitations of pecking responses at, or around the time of expected reinforcement, thereby increasing the salience of the conditioned stimulus in relation to food. A peck on the conditioned stimulus results in early access to reinforcement. This presumably happens accidentally at first. It is theorized that the temporal discrepancy between early and full length termination of the conditioned stimulus brought about by the ‘accidental’ response is accountable for the development of operant control. Other papers dealing with autoshaping (Kakade & Dayan, 2002; Gallistel & Gibbon, 2000) have found that the process of autoshaping happens quickly once the first response has been made. The present thesis generally supports this conclusion.

The experiment also provides further evidence in favour of effective behavioural analysis occurring on an individual basis (Skinner, 1938). The response rates and location of responses for the participants in the present experiment varied significantly; these differences (especially in autoshaping procedures) are often overlooked through averaging processes (Kakade & Dayan, 2002). This has the effect of obscuring factors which may have a critical bearing on acquisition, and in a more generalised sense obscuring factors maintaining other behaviours.

The participants in the present study took a considerably longer time to autoshape than other animals in using similar procedures. Pigeons in Brown and Jenkins (1968) averaged 45 trials to first peck; pigeon's in Steinhauer, Davol and Lee (1976) averaged 2.3 trials to first peck; pigeons in Bilbrey and Winokur (1973) averaged 76 trials to first peck. Young chickens in Downing and Neuringer (1976) required approximately 25 trials to first peck, and 48 trials to the fifth peck. A number of procedural differences were found that might reconcile these differences.[1]

Firstly, in the original Brown and Jenkins (1968) experiment, pecks that were made during the intertrial interval reset the time before the subsequent trial was presented. In the present experiment, responses made during the intertrial interval had no consequences. The punishing effects of resetting the intertrial interval may reduce the time to acquisition in autoshaping procedures.

Secondly, the amount of magazine training can reduce or increase time to acquisition. Downing and Neuringer (1976) gave groups of hens 1, 10, 100, or 1000 magazine trials before commencing autoshaping. They found that the group who had received 100 trials acquired pecking the fastest, while those who experienced fewer trials (1, 10) and more trials (1000) took more autoshaping trials to shape. The hens in the current procedure had 30 magazine trials, and according to Downing and Neuringer (1976), should have been shaped in approximately 25 autoshaping trials.

Thirdly, the ratio between the stimulus (*T*) and intertrial interval (*I*) durations has an impact on the speed of acquisition. "...the greater effectiveness of short intervals is that the longer the interval, the greater the number of

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[1] The studies listed each contained a number of experiments. The respective findings discussed here, are those that most closely matched the procedure used in the current experiment

intervening responses emitted without reinforcement. The resulting extinction cancels the effect of an occasional reinforcement." (Skinner, 1948, p.169). It was found that halving the intertrial and stimulus durations for bird 504 resulted in an increased response rate. It is probable that the use of shorter *T* and *I* durations at the beginning of this experiment would have shortened acquisition time.

Fourthly, the background pre training context (λb) is known to have an impact in time to acquisition (Kakade & Dayan, 2002). In their treatment of "Expert Systems", Kakade and Dayan argue that each stimulus (the light context, or rectangle context in this case (λl) and background context (λb) are treated as individual experts. That is participants predict the rate of reward under each context independently from the other, rather than viewing the two contexts as part of a single procedure. Under this conception, if many rewards are apportioned to λb, then it is unlikely that responding will come under stimulus control of λl. Kakade and Dayan (2002) suggest that this is one of the reasons why autoshaping occurs rapidly when λb is driven to extinction before autoshaping; participants come to discount λb as a reliable reinforcing context, while λl becomes more reliable. Generally magazine training is also done in a separate chamber from that used in the autoshaping process. In this experiment no attempt was made to extinguish λb, and magazine training occurred in the experimental chamber.

Fifthly, the time elapsed between magazine training as well as context manipulations before the commencement of the autoshaping procedure has an effect. Experimental evidence for this comment comes from Lee et al. (1976) where participants were shaped within a mean of 2.3 trials, given the same *I* and *T* durations as the present experiment, Brown and Jenkins (1968), and Bilbrey and Winokur (1973). In Lee et al. (1976) the autoshaping procedure took place immediately after the magazine only trials (that is, within the same sessions).

Appendix A shows initial attempts to integrate procedural differences into a single model which may be helpful in understanding the autoshaping process.

EXPERIMENT 2

Participants

Same as for experiment 1.

Apparatus

Same as experiment 1.

Procedure

Experimental sessions took place six days per week. The hen was placed alone in the chamber. The duration of each session was 30 minutes. The rectangle was visible at all times during all sessions and conditions of experiment 2. The schedule of reinforcement in both conditions was continuous, or based on a fixed ratio of 1 (FR1). In the first condition, a peck in any part of the rectangle was reinforced. In the second condition, only pecks in the active zone of the visible rectangle were reinforced. The mode of each participant's response distribution generated in the first condition was used to divide the visible rectangle into active and inactive zones.

Results

The overall pattern of results shows that all birds reacted to the change of contingency introduced in the second condition. All birds pecked with greater frequency within the reduced active region of the visible rectangle. The distributions of responses obtained in the first condition changed to fall within the reduced active zone of the visual stimulus.

Figure 20 is made up of six panels. Each panel shows two density distributions for the given participant. The black distribution represents the first condition, in which hens were reinforced for pecking anywhere within the visible rectangle. The red distribution represents the second condition, in which hens were reinforced for only those pecks which fell within the active, more restricted part of the visible rectangle. The x axis represents the location of pecks along the length of the screen in pixels, and the y axis represents the frequency of these pecks. The black dotted vertical line represents the mode of responses from the first condition (the black distribution). The left and right edges of the visible rectangle are indicated by the solid blue vertical lines at both 20 pixels and 980 pixels respectively.

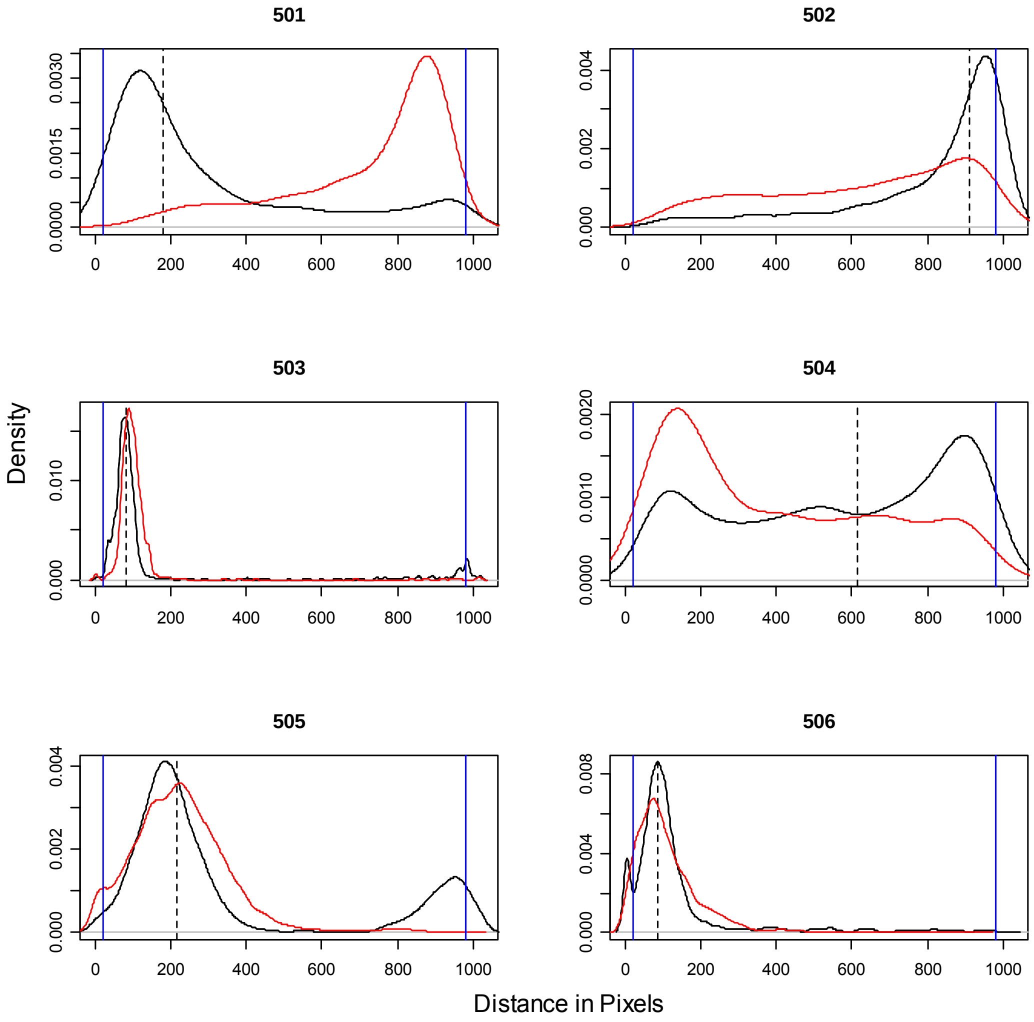


Figure 20: Density distributions as a function of the x coordinate of pecks across experimental conditions.

The distribution of pecks from the first condition for bird 501 (top left panel, black distribution) is positively skewed (skew=1.26); meaning 501 responded with greatest probability on left hand side of the visible rectangle. Across all sessions in condition one, 501 pecked most frequently (n=58) where x = 159 pixels, approximately 3.6cm in from the left edge of the rectangle. A second peak occurs (n = 14) in 501’s peck distribution where x = 159 pixels, approximately 0.9cm in from the right hand edge of the rectangle. The distribution for 501’s second condition (top left panel, red distribution) shows a mirrored pattern. The distribution is negatively skewed (skew = -1.15). Here, 501 responded most frequently 3.3cm in from the right hand edge of the rectangle where x = 875 pixels (n = 77). 501 responded with greater consistency in the second condition (σ = 219.9 pixels) compared to the first (σ = 275.8 pixels) in spite of the range being slightly greater in the second condition (1010 pixels verses 1002 pixels in the first condition).

The distribution of pecks from the first condition for bird 502 (top right panel, black distribution) is negatively skewed (skew= -1.57); meaning 502 responded with greatest probability on the right hand side of the visible rectangle. Across all sessions in condition one, 502 pecked most frequently (n = 162) where x = 966 pixels, approximately 0.9cm in from the right hand edge of the rectangle. 502's responding decreased at a consistent rate moving away from the mode to the left. Responses ranged from 26 to 1021 pixels across all sessions in the first condition. The distribution for 502's second condition remained negatively skewed (skew = -0.43, top right panel, red distribution) Here, 502 responded most frequently (n = 82) 2.3cm in from the right hand edge of the rectangle where x = 912 pixels compared to a distance of 0.9cm in from the right as in the first experimental condition. 502's responses were less consistent in the second condition (σ = 267.3 pixels) compared to the first condition (σ = 226 pixels). The range of 502's responding was 995 pixels in the first condition compared to 1009 pixels in the second condition.

The distribution of pecks from the first condition for bird 503 (mid left panel, black distribution) is positively skewed (skew = 2.4); meaning 503 responded with greatest probability on the right hand side of the visible rectangle. Across all sessions in condition one, 503 pecked most frequently (n = 112) where x = 67 pixels, approximately 1.2cm in from the left hand edge of the rectangle. In the first condition 503 also pecked on and around the right hand edge of the rectangle. The most responses (n = 24) in this peak occurring just outside the right hand edge of the rectangle where x = 985 pixels. 503 also responded in a number of locations along the length of the entire rectangle, seen as faint density peaks in the given plot. Responses ranged between 1 and 1021 pixels with a deviation of 269.57 pixels. Bird 503's pattern of responding in the second condition (mid left panel, red distribution) was similar to that observed in the first. The most frequent (n = 89) response occurred 1.7cm in from the left hand edge of the rectangle where x = 86 pixels. The range was the same as in the first condition however, the variability in pecking responses seen in the first condition (269.57 pixels) had less presence in the second (σ = 110.65 pixels).

Unlike the previous three participants, bird 504 responded frequently across the entire length of the rectangle (mid right hand panel, black distribution). Despite most pecks (n = 87) occurring 2.3cm in from the right hand side of the rectangle where x = 912 pixels, the response rate was high (n = 42) near the middle of the rectangle (13cm from the right hand edge of the rectangle at x = 508 pixels), as well as 5.6cm in from the left hand edge of the rectangle (n = 38,). The greater variability in 504's responding compared to the other birds is evident in terms of standard deviation (σ = 302.15 pixels) and range (1023 pixels). Bird 504 pecked more on the left hand side of the rectangle in the second condition (mid left panel, red distribution). Here, pecks occurred most frequently (n = 63) 3.6cm in from the left hand edge of the rectangle where x = 159 pixels. Across sessions in the second condition, 504 responded less right of the active zone (marked at x = 613 pixels) in comparison to the first condition. There is however, an increase in pecks around x = 912 pixels. This peak of unreinforced responding roughly corresponds to the area of the mode from the first condition.

During the first condition (lower left panel, black distribution), bird 505 pecked most frequently (n = 207) 4.7cm in from the left hand edge of the rectangle. 505 also pecked frequently (n = 46) 0.9cm in from the right hand edge of the rectangle where x = 966 pixels. Responding on both ends of the rectangle is illustrated by the resulting bi-modal distribution depicted. In the second condition (red distribution) 505 responded most frequently (n = 156) 5.1cm in from the left hand edge of the rectangle where x = 214 pixels; the same location as the cut off for the active zone of the visible rectangle. 505 did not peck near the right hand side of the visible rectangle with any notable regularity in the second condition.

Bird 506 pecked most frequently (n = 167) 1.7cm in from the left hand side of the rectangle, where x = 86 pixels within the first condition (bottom right panel, black distribution). 506 responded along the length of the rectangle infrequently. There is a small spike of responses (n = 124) one pixel in from the left hand side of the screen. The number of responses quickly decreases to reach a trough of two responses where x = 20 pixels (the left hand edge of the visible rectangle). Further right, the number of responses increases quickly until the mode (n = 167, where x = 86 pixels). During the second condition (bottom right panel, red distribution) 506 pecked most frequently (n = 162) where x = 67 pixels, or 1.2cm in from the left hand edge of the rectangle. There was less variability in 506's responses across sessions in the second condition (σ = 104.98, range = 929 pixels) compared across sessions in the first condition (σ = 168.8, range = 1020 pixels).Figure 21 shows density distributions as a function of y coordinates along the height of the rectangle, rather than as a function of x coordinates along the length of the rectangle. The black distributions represent responding within the first condition, while the red distributions represent responding across the second condition. The two solid blue lines indicate the minimum height (320 pixels) and maximum height (470 pixels) of the visible rectangle. The distributions for the respective birds show a large degree of similarity across the two experimental conditions.

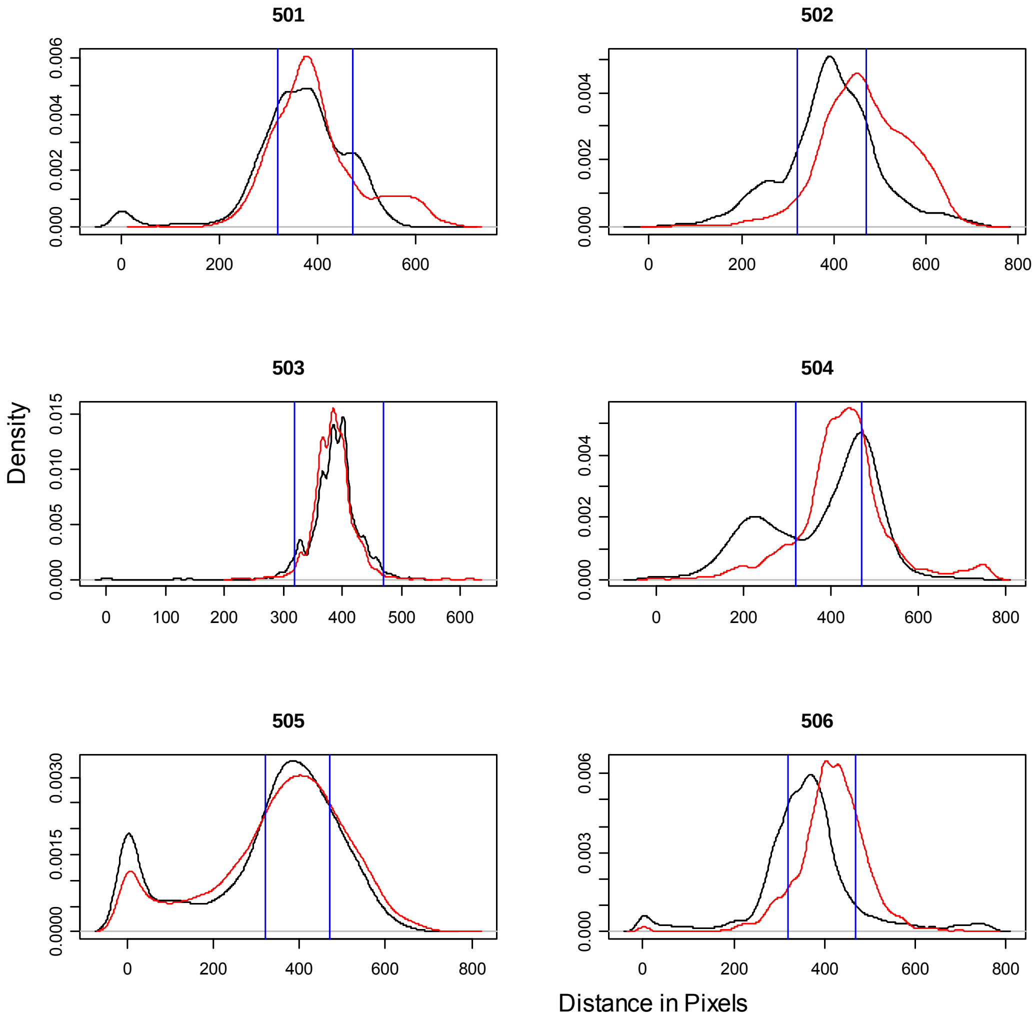


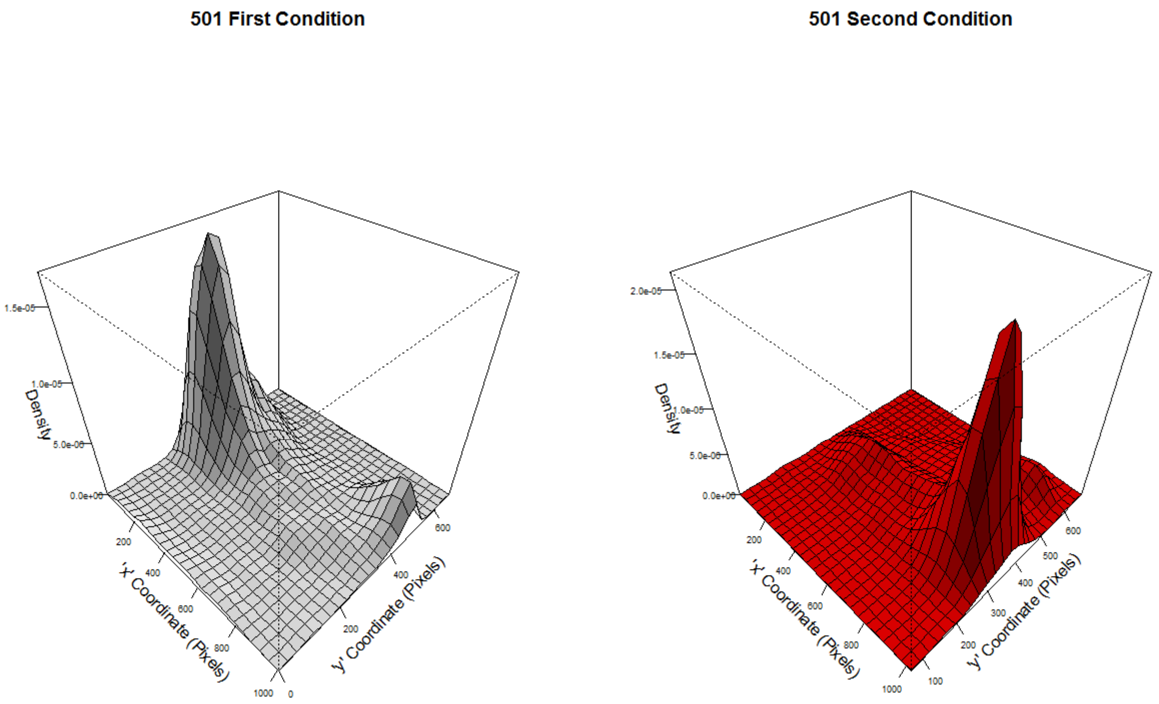
Figure 21: Density distributions across experimental conditions as a function of y coordinates of pecks recorded.

In most cases, the peaks of both density distributions fall within the minimum and maximum heights of the visible rectangle. One noticeable peculiarity is that bird 505 (bottom left panel, black distribution) shows an initial peak in responding (n = 387) at a height of 1 pixel.

Bird 501 (top left panel, black distribution) and 506 (bottom right panel, black distribution) also have similar anomalies, but they occurred with less frequency (n = 26, and n = 30 respectively) than 505. In these cases, responses well below the minimum height of the rectangle reduced in overall frequency within the second condition (see red distributions for birds 501, 505 and 506).

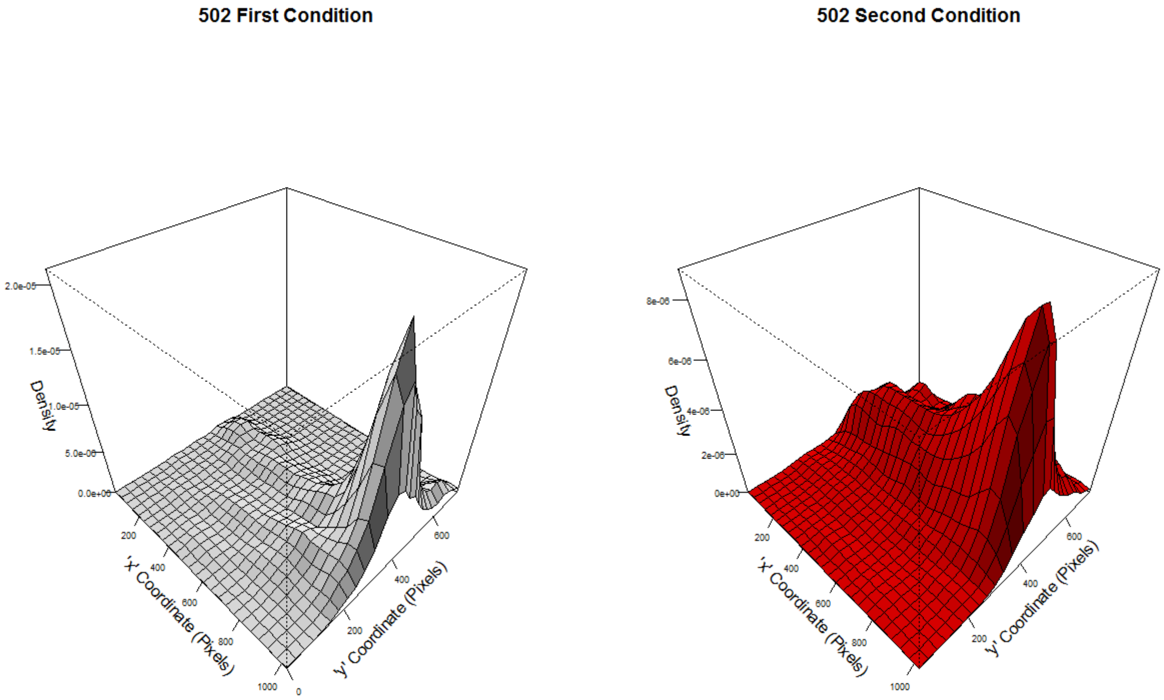
Medians for each session within the two experimental conditions were calculated for all birds. Welch two sample t-tests were then conducted to measure the overall degree of difference between the two conditions for each bird. The differences in all cases were found to be significant. 501 ($p < 0.05$, $t = -12.1582$), 502 ($p < 0.05$, $t = 2.9572$), 503 ($p < 0.05$, $t = -3.2139$), 504 ($p < 0.05$, t = $t = 6.0839$), 505 ($p < 0.05$, $t = -10.3679$) and 506 ($p < 0.05$, $t = -5.3206$).

The contours in Figure 22-27 represent the density of responding for each participant in terms of both x and y coordinates. The figures support general claims that (i) response distributions moved considerably from condition one to condition two and (ii) responding became less variable within condition two.


501 First Condition

501 Second Condition

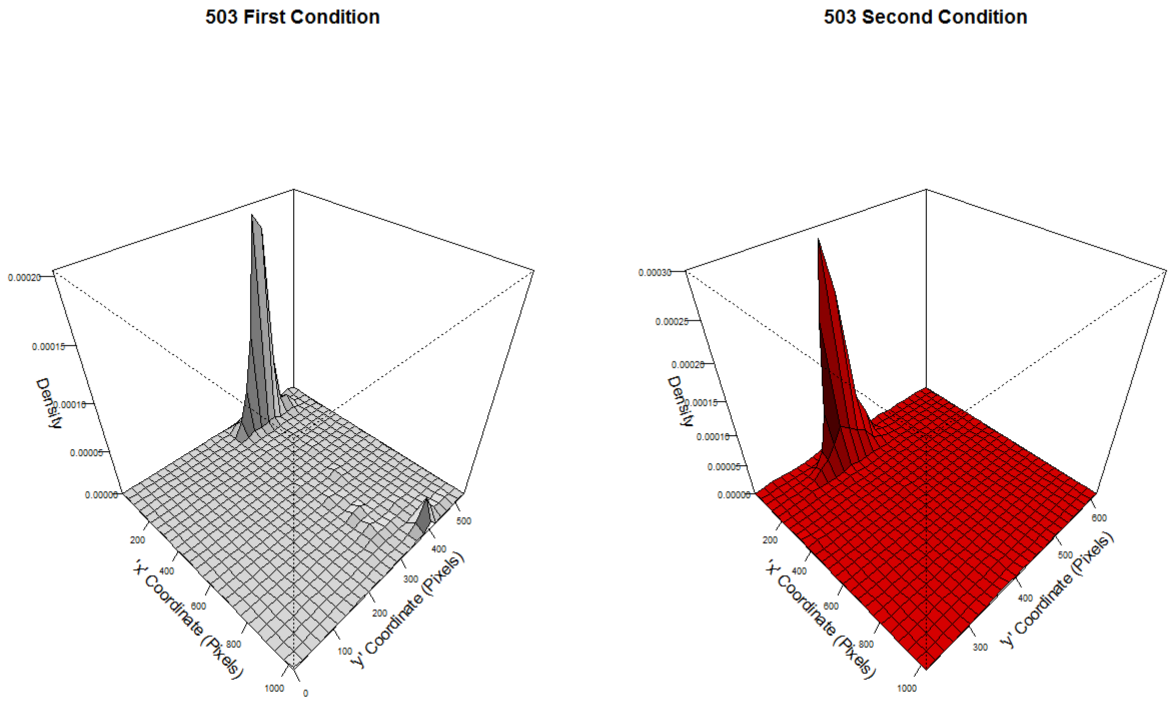
Figure 22: Density plots of bird 501's responses across first and second experimental sessions.



502 First Condition

502 Second Condition

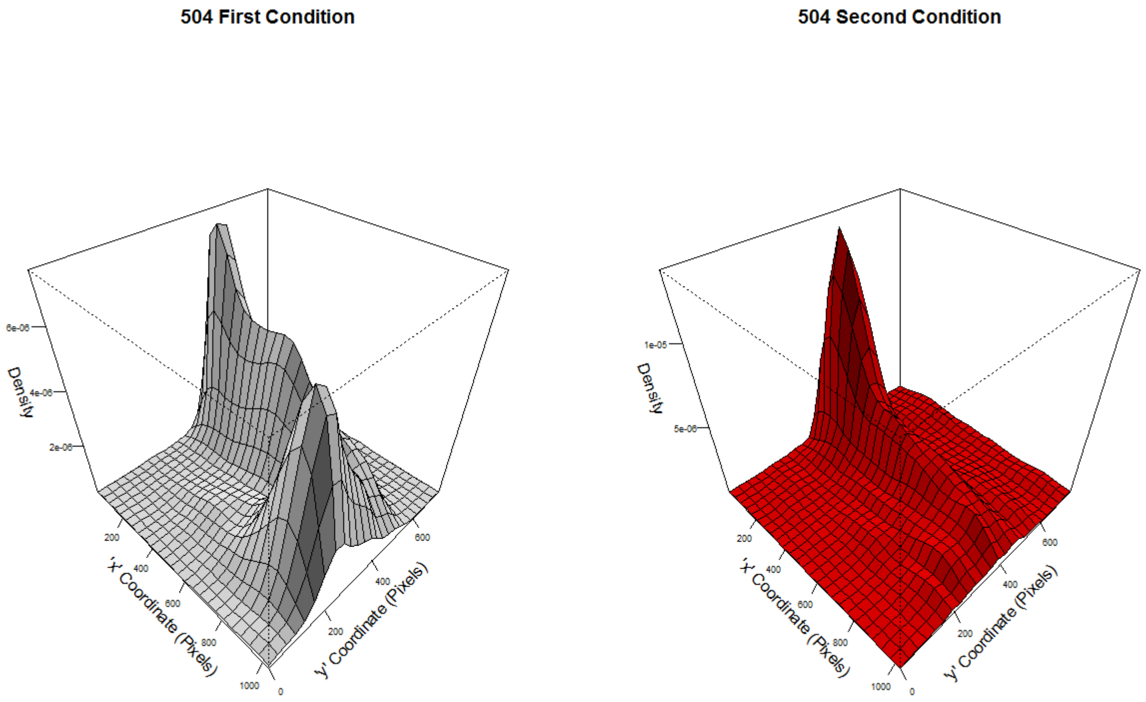
Figure 23: Density plots of bird 502's responses across first and second experimental sessions.



503 First Condition

503 Second Condition

Figure 24: Density plots of bird 503's responses across first and second experimental sessions.



504 First Condition

504 Second Condition

Figure 25: Density plots of bird 504's responses across first and second experimental sessions.

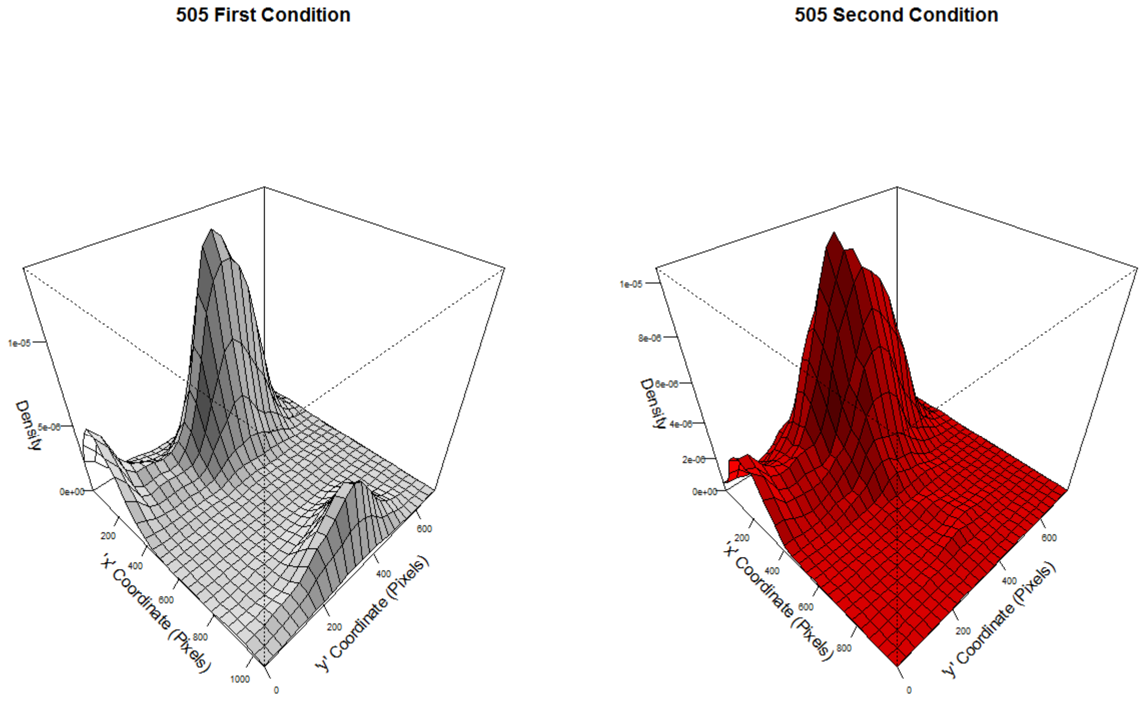
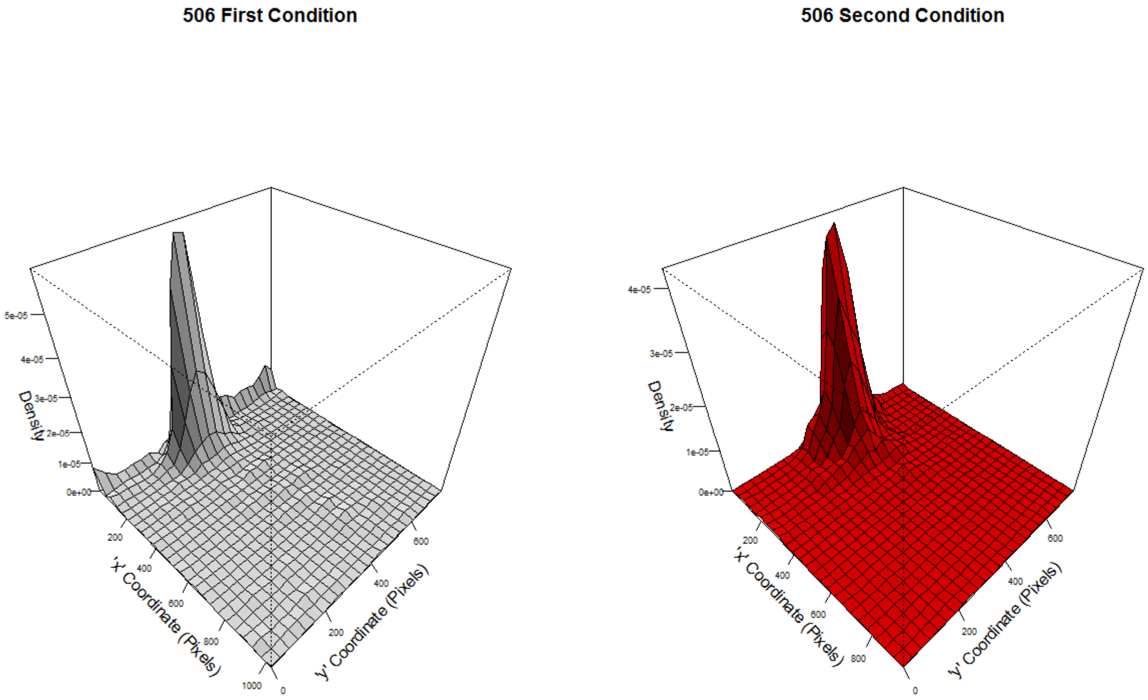


Figure 26: Density plots of bird 505's responses across first and second experimental sessions.



506 First Condition

506 Second Condition

Figure 27: Density plots of bird 506's responses across first and second experimental sessions.

Discussion

Catania suggested that response and stimulus distributions come to be highly correlated with one another. Subsequently, there is a narrowing of response distribution, and a decrease in correlation. Eventually, the majority of responses come to fall just outside the lower range of the stimulus distribution (Figure 3). The results from this experiment empirically confirm the first three stages where response and stimuli distributions initially have a low correlation (‘A’), then a high correlation (‘B’), followed by a narrowing of the response distribution, and a weakening of the correlation (‘C’). The transition from ‘A’ to ‘B’ is seen in the data from experiment 1, while the transition from ‘B’ to ‘C’ is seen in the data from experiment 2. The last stage (‘D’) where responding falls largely outside the lower range of the stimulus distribution is not evident in the data presented. Distribution ‘D’ represents the law of least effort and presumably does not apply to the present experiment, as the effort required to register a response on a touch screen is minimal.

One concern raised by the use of touch screens is whether the lack of tactile feedback (as present with a traditional response key) has any impact on the responses emitted by the participants. The present data suggests that the underlying psychology does not differ, but the rate of responding is likely to increase via touch screen than under a mechanical equivalent which is physically more demanding to operate. It seems logical to assume that using a touch screen equates to a reduction in task demand. It would be interesting to see if this comment proves correct. A simple experiment could compare the effects of two parallel experiments where the same high fixed ratio requirements are in effect using (i) touch screens and (ii) traditional keys.

The distribution of response location in terms of y coordinate variation across the two conditions was very little (figure 21). This was to be expected, as the contingences which limited the active zone of the rectangle were based on x coordinates (the length of the rectangle), rather than y coordinates (the height of the rectangle). It is suggested that basing the active zone on reduced height of the rectangle would have resulted in the response distributions varying little across x coordinates, while the distributions would have changed to fit within the reduced height of the rectangle. There are a number of other changes to the stimulus probability distribution mentioned in Catania's (1976) paper that have yet to be experimentally validated (Figure 4).

An interesting observation is that the shapes of density distributions based upon the y coordinates are comparable to those based on the x coordinates for the respective birds. For example, a defining feature of bird 503's responding in regards to both x and y coordinates would be very narrow distributions. Bird 505 had bi-modal tendencies; responding on the left and right ends of the rectangle, while also responding below and within the rectangle. Bird 504 responded across length and width of the rectangle with greater frequency than the other participants arguably resulting in rectangular like distributions for both x and y coordinates within the first condition.

The distributions of response locations across the rectangle are generally characterised by a peak of responding near the left or right hand edge of the rectangle, with occasional 'sampling' pecks being made in other locations. Bird 504 responded frequently across all available locations in terms of the x coordinate, as evident by the distribution of responses in the first condition (Figure 20 mid right panel, black distribution). While this pattern of responding is unusual, it also makes sense in the first condition, as all pecks made in the visible rectangle were reinforced with the same probability. The account which best describes the resulting response distributions is optimum foraging theory.

Pyke, 1984 outlined some basic assumptions around optimal foraging theory. Firstly, if the survival of a particular species of individuals is dependent on foraging, it follows that an individual's contribution to the subsequent generation depends on that individual's behaviour while it is foraging. Those who are able to forage survive and breed, while those unable to do so die out. Foraging theory applies regardless of whether the foraging behaviour is learned or innate. The offspring of successful foragers may either adopt appropriate behaviours through observational learning (watching their parents), or there could be some heritable genetic component. Either way, offspring of successful foragers typically come to forage in similar ways to their parents. Optimal foraging occurs when the forager acts in ways that maximize their expected ‘fitness’ (survival or longevity) subject to any functional constraints.

One kind of constraint foragers are confronted with is known as a patch choice situation, where foraging in one patch may offer greater rewards over the other alternatives. The most simplistic patch choice situation is based on the following assumptions: (a) the locations and "qualities" of all patches are known to the foraging animal; (b) these locations and qualities are constant; (c) there is no resource depletion during the time the animal spends in a patch; and (d) fitness is increasing linear function of the animal’s net rate of food gain. Under these assumptions, the animal’s optimal strategy is to spend all its time in the most conveniently located patch with the greatest net rate of food gain.

The divided rectangle is analogous to three separate patches, each with a related probability of reward (1 in the active zone of the rectangle, 0 in the inactive zone of the rectangle, and 0 on the black background). The participants in the present experiment were therefore subjected to a patch choice situation. The results obtained (peaks of responding in a particular location) fit the patch choice assumptions outlined, where the optimal strategy was to spend the available session time responding in the most conveniently located patch.

The ‘sampling’ responses, most noticeable in birds 503 (Figure 20, mid left panel) and 506 (Figure 20, bottom right panel) may be evidence of optimum foraging where the birds are testing (i) that the qualities of the less frequented patches have not changed and (ii) that the rate of return in less frequented patches has not changed. Under optimum foraging theory, the changes in all response distributions between conditions one and two are illustrations of the birds coming to maximise their fitness by responding in the richest available patch (the active zone).

General Discussion and Conclusion

In experiment 1, it was found that the off target responses (measurable under Catania's operant, but not Skinner's) provided the most interesting data, which advocates that autoshaping may develop through classical conditioning initially, followed by operant conditioning once the participants have 'learnt' the contingencies interrelating the conditioned stimulus, response and reinforcer. In focusing only on target pecks, this finding would have been overlooked, or at the very least, no data would be available to support the comment.

The most important general conclusion drawn from the current experiments is that off target responses are just as crucial to understanding behaviour as are target responses. In applied settings, it would therefore be wise to note variables maintaining the behaviours of interest, but also variables in effect when the behaviours are not present. Attempts to generate very precise scientific accounts of behaviour merely provide a cross section of related responses and stimuli. To have an effective analysis of behaviour, this cross section needs to be viewed within the greater context of when, where and why any given behaviour is likely to occur (Novak & Pelaez, 2003).

Questions remain as to how much, or how little of a response distribution should be recorded. In choosing a narrow range of stimulus probabilities, the risk is that critical responses made outside this range may be missed, while a broad range of stimulus probabilities can result in critical information being masked by a flood of irrelevant data. It is suggested that Skinner's concept of the operant is suited to situations where the analyst is able to control the independent variables, and has a very specific idea of how these interact with the dependent variables of interest. Catania's concept of the operant is suited to situations where variability within the dependant variables is expected. In these circumstances, recording as much of the response distribution as is pragmatically possible is recommended.

It has been shown that response distributions change when the stimulus distributions change. Unfortunately, the direction and magnitude of these changes are not uniform across participants. Appendices D – I show summaries of the participants responding during all experimental conditions. The only procedural difference between autoshaping and condition one, was that the rectangle was visible at all times during condition one. Changes in response location were unexpected, but did occur for birds 501, 502, 504, and 505. When the active zone of the rectangle was reduced, 501 appeared to revert back to a similar response location that was favoured during the autoshaping procedure. Birds 504 and 505 did the reverse, and responded on the opposite end of the rectangle to the one favoured during autoshaping. The implications in behavioural analysis are that well intentioned changes can result in unpredicted behavioural patterns, which may not always be for the best. Moreover, seemingly insignificant changes can have significant implications.

Catania's operant allows greater scope to 'see' unpredictable response patterns in a generalized context. In the present thesis, changes in distributions reflect optimal foraging heuristics. It is likely that applying Catania's operant to behavioural analysis in other situations will likewise unearth a greater understanding of the controlling contingencies in those situations.

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Appendix A

Factors affecting autoshaping procedures.

Gallistel and Gibbon (2000) suggested a simple quantitative relationship between the speed of acquisition in autoshaping and the three critical variables shown in Equation 1. The first is *I,* the length of intertrial interval; the second is *T,* the time during the trial for which the conditioned stimulus (CS; a light in this case) is presented; and the third is the training schedule, 1/*S,* which is the fractional number of deliveries per light (for those birds that were only partially reinforced).

$$n = 300 * (\frac{I}{T})^{-1}$$

Equation 1: Speed of acquisition **(Gallistel & Gibbon, 2000)**

As the duration of (*T*) is increased, and no responses are made in the presence of the stimulus, the stimulus' function as a reliable indicator of reinforcement diminishes. In these circumstances, when (*T* = *I*) the stimulus has no predictive effect in terms of reinforcement beyond those associated with (*I*). The animal is reinforced every (*I*) seconds independent of both its actions, and the stimulus.

Another effect of increasing values of (*I*), is that the time for one trial (*C = I + T)* becomes lengthier, which detracts from the autoshaping procedure (Skinner, 1948). Studies of self-control demonstrate that animals who display impulsivity prefer short temporal gaps between reinforcers in spite of greater, delayed alternatives. Moreover, most animals display impulsivity in the initial phases of such experiments before they 'learn' about the said larger, delayed alternatives (Gibbon, Farrell, Locurto, Duncan, & Terrace, 1980).

It follows that short temporal gaps between not only trials, but also short stimulus durations in autoshaping processes are more effective than lengthy alternatives.

The ratio $(\frac{I}{T})$ represents a rate of change, $(\frac{I}{T}\ dT)$ in the effectiveness of the stimulus duration (*T*) as a reliable indicator of reinforcement. The rate is in relation to the intertrial interval (*I*) and implicitly the total duration of a given trial (*C*). A rate of change in the reliability of (*T*) as a predictor of reinforcement is suggestive of a higher order function that may be useful in determining the speed of acquisition in terms if the given variables, that is:

$$\int \frac{I}{T} dT = I \log(T) \pm C$$

In the above equation, (*C*) represents the constant of integration rather than the duration of an autoshaping trial. The constant of integration allows accommodation for other variables affecting autoshaping, namely the background context (λb), and the stimulus context (λl).

The relationship between these contexts is expressible as:

$$\frac{\lambda \mathrm{b}}{\lambda \mathrm{l}}$$

When rewards given in the presence of the stimulus (λl) exceed those of the background context (λb), the stimulus context becomes associated with a higher rate of reinforcement than the background context (Kakade & Dayan, 2002; Downing & Neuringer, 1976). This increases the rate of acquisition in the presence of the stimulus, or put another way, decreases the number of trials to acquisition. The reverse is true if reinforcers obtained in the background context outnumber those associated with the stimulus.

The speed of acquisition in trials (*n*) is likely to be a product of the reliability of the stimulus signalling reinforcement, and the effects of the ratio of rewards presented in the background and stimulus contexts:

$$n = I \log(T) * \left(1 - \frac{\lambda \mathrm{b}}{\lambda \mathrm{l}}\right)$$

One special case occur when ($\lambda \mathrm{l} = 0$), here there is division by zero: This means however, there are no stimulus – reinforcer pairings, no autoshaping procedure, and nothing to estimate in the first instance[2]. Another case arises when the ratio of background and stimulus rewards are the same:

---

[2] (λb) must always be 1 or greater for similar reasons (see equation 4 below).

$$\lim_{\lambda l \to \lambda b}\left(1-\frac{\lambda b}{\lambda l}\right) \quad = 0$$

This would suggest a speed of acquisition comprising of zero trials when ($\lambda b = \lambda l$), which is nonsensical. When the ratio of background rewards and context rewards is equal to 1, neither context is more reliable than the other with respect to signalled reliability of reinforcement. In such cases, the only variables which provide information regarding reinforcement are the durations of (I) and (T).

$$\left\{\begin{array}{ll} \boldsymbol{n = I\log(T) * \left(1-\frac{\lambda b}{\lambda l}\right)}, & \boldsymbol{for\ all\ \frac{\lambda b}{\lambda l}} < 1 \\ \\ \boldsymbol{n = I\log(T) * \frac{\lambda b}{\lambda l}}, & \boldsymbol{for\ all\ \frac{\lambda b}{\lambda l} \geq 1} \end{array}\right\}$$

Equation 2: Estimated trials to acquisition with provision for background and stimulus contexts.

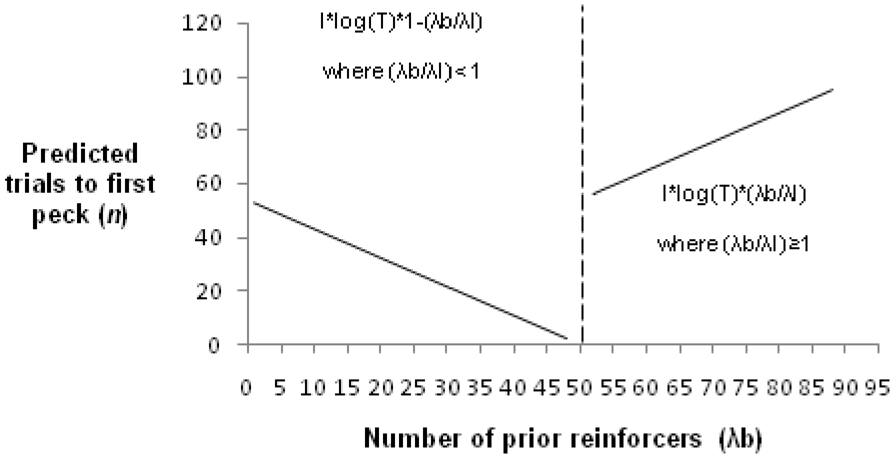


Figure 28: Hypothetical predictions using equation 2 where (I=60; T=8, & λl held at 50). The effect of prior reinforcers can serve to either decrease (when $\lambda b < \lambda l$) or increase (when $\lambda b \geq \lambda l$) the number of trials to the first response. This models the "U-shaped

Table 1: Comparison between acquisition data and two predictive models, '*' represents figures calculated with = $\mathbf{n = I\log(T) * \frac{\lambda b}{\lambda l}}$

	I	T	λb	λl	Trial of first peck	$n = 300 * (\frac{I}{T})^{-1}$	$n = I\log(T) * (1 - \frac{\lambda b}{\lambda l})$
Brown & Jenkins (1968)	60 sec	8 sec	11	160	μ=45	40	50.46
Downing & Neuringer (1976)	15 sec	4 sec	1	250	25	80	9
			10	250	35	80	9
			100	250	μ=4.4	80	5.4
			1000	250	100	80	36 *
Bilbrey & Winokur (1973)	60 sec	8 sec	450	270	71, 81, μ=76	40	90*

The background context is always partially present in autoshaping procedures, even when the context has been driven to 'extinction'. The magazine and lack of stimuli are common to the extinguished context and the intertrial intervals of the stimulus context regardless of the presence or absence of reinforcement. The temporal delay experienced between the two contexts may increase the number of trials to acquisition.

In some procedures (Lee et al., 1976) magazine training is followed immediately with the introduction of the stimulus. That is to say, the stimulus – reinforcer pairings begin after an arbitrary number of food only trials (background context) within the same session. The result is that animals become very sensitive to the introduction of the stimulus to the present context:

$$n = I\log(T) * \frac{1}{\lambda\mathrm{b}}$$

Equation 3: Speed of acquisition when stimulus is introduced immediately after (within the same sessions) food only presentations.

In such circumstances, it should be expected that autoshaping will occur within a maximum of ($I\log(T)$) trials:

$$\lim_{\lambda\mathrm{b}\to 1} I\log(T) * \frac{1}{\lambda\mathrm{b}} = I\log(T), \qquad 1 \le n \le I\log(T)$$

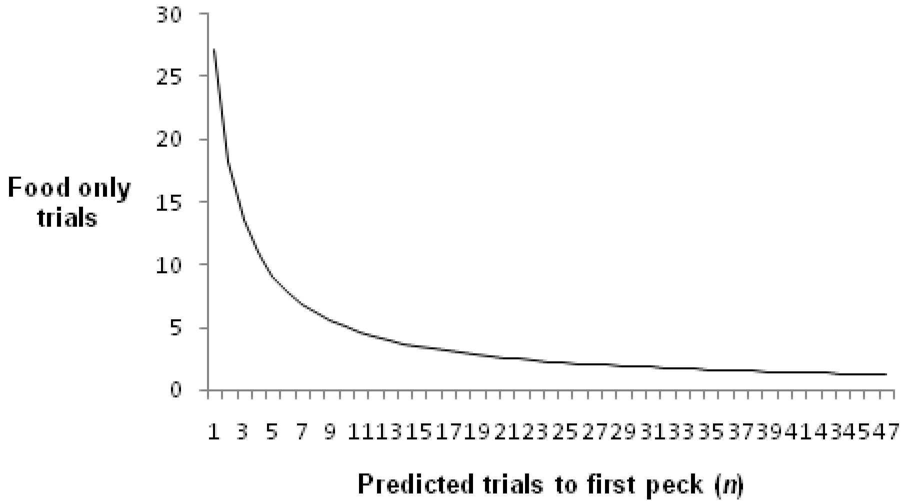


Figure 29: Introduction of the stimulus into the background context within the same session heightens sensitivity to the reliability of the stimulus as a predictor of reinforcement. In such cases, autoshaping occurs very rapidly as illustrated.

Table 2: Further comparison between predictive models and acquisition data from experiments employing different procedures.

	I	T	0 trials (food only)	3 trials (food only)	10 trials (food only)	25 trials (food only)
Lee et al., (1976)	60 sec	8 sec	μ=100 *no pigeons emitted response	μ=16.75	μ=24	μ=2.3
$n = 300 * (\frac{I}{T})^{-1}$			40	40	40	40
$\mathrm{n} = \mathrm{I}\log(\mathrm{T}) * \frac{1}{\lambda\mathrm{b}}$			54.19	18.06	5.42	2.17

Equations 2 and 3 provide a better fit for the empirical data than does Equation 1 (Gallistel & Gibbon, 2000). They also do not rely on retrospective fitting to acquisition data in order to determine critical parameters as does the model suggested by Kakade and Dayan (2002). The effect of delaying magazine training prior to autoshaping has not been addressed at this stage. Nonetheless, initial inquiry suggests that like many other natural occurring phenomenon, a logarithmic function of some sort could provided the best basis for a model which accounts for the speed of acquisition in autoshaping.

Appendix B

Computer Specifications

OS Name	Microsoft Windows XP Professional
Version	5.1.2600 Service Pack 2 Build 2600
OS Manufacturer	Microsoft Corporation
System Name	BPSQL
System Manufacturer	Dell Inc.
System Model	OptiPlex GX280
System Type	X86-based PC
Processor	x86 Family 15 Model 4 Stepping 1 GenuineIntel ~2992 Mhz
BIOS Version/Date	Dell Inc. A03, 17/09/2004
SMBIOS Version	2.3
Windows Directory	C:\WINDOWS
System Directory	C:\WINDOWS\system32
Boot Device	\Device\HarddiskVolume2
Locale	New Zealand
Hardware Abstraction Layer	Version = "5.1.2600.2180 (xpsp_sp2_rtm.040803-2158)"
User Name	BPSQL\Administrator
Time Zone	New Zealand Standard Time
Total Physical Memory	1,024.00 MB
Available Physical Memory	565.20 MB
Total Virtual Memory	2.00 GB
Available Virtual Memory	1.96 GB
Page File Space	2.38 GB
Page File	C:\pagefile.sys

Appendix C

Touch screen specifications

ETwoTouch Infrared Touch Screen

Table 3: Sizes of IR screens available

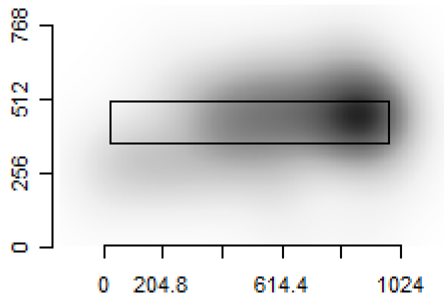
Model No.	Classification	Touchscreen Thickness(mm)	Glass Thickness(mm)	Shape Size(mm)		Effective touch size(mm)	
				X	Y	X	Y
EIR3L15	**15"LCD**	**9.4**	**3**	**380.8**	**290.8**	**304**	**228**
EIR3L17	17.1"LCD	9.4	3	412.8	332.8	341	273
EIR3L19	19.1"LCD	9.4	3	446.3	361.8	377	303
EIR3L30	30"LCD	7.4	0	720	297	610	229
EIR3L23	23"LCD	9.4	3	622	387	508	286
EIR3L26	26"LCD	9.4	3	686	423	576	324
EIR3L27	27"LCD	9.4	3	712	439	602	339
EIR3L32	32"LCD	9.4	0	776.8	457.3	692	391
EIR3L42	42"LCD	9.4	0	1013.8	609.8	930	530

Table 4: Specifications of IR screens

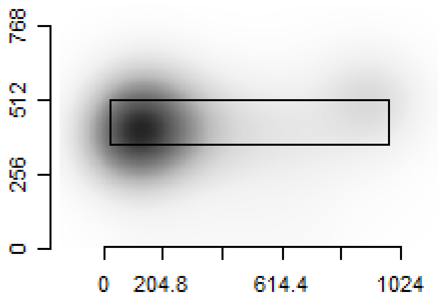
!	!
Touch Resolution	4096 x 4096
Transparency	> 92%, Up to 100%
Scanning Speed	>50Scans/S
Response Speed	<12ms
Minimum Touch object	>=5mm
Touch Intensity	Over 60,000,000 Single Point Touch
Operation System	Win9x\Win2000\WinXP\WinNT\Win2003\Linux
Operating Voltage	DC 5V ±5%
Power Supply	Keyboard Serial Interface
Power	<1W (Current<200mA)
Communication	RS-232,USB
Sunlight Operable	Operable in various light conditions, indoor and outdoor
Vandal-Proof	Steel Ball (Diameter 63.5mm 1040g Weight) drop from 1040mm, No break
Temperature Operating	–41°C ~ 70°C
Temperature Storage	–50°C ~ 85°C
Humidity Operating	0 to 85%
Humidity Storage	0 to 95%
Altitude	3,000 m
No Drift	Maintenance free
Life Time	7-year

Appendix D

Experiment 1 (Autoshaping)



Experiment 2 (First Condition)



Experiment 2 (Second Condition)

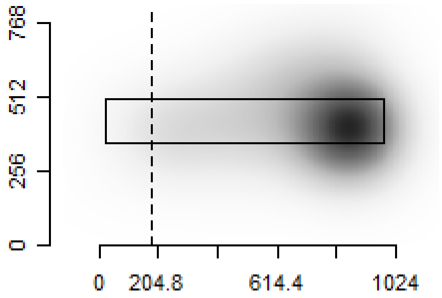


Figure 30: Bird 501 summary of experimental conditions

Appendix E

Figure 31: Bird 502 Summary of experimental conditions

Appendix F

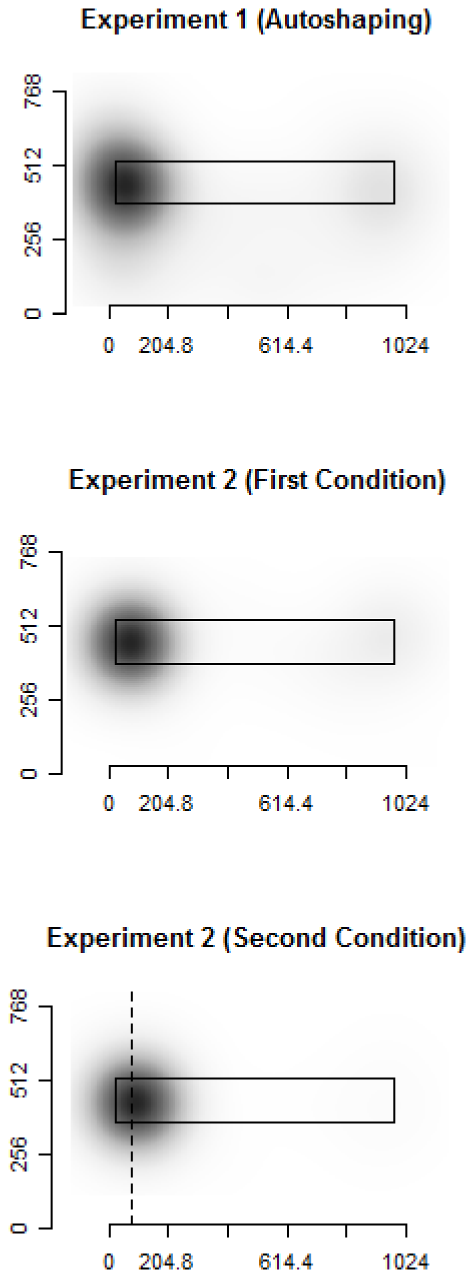


Figure 32: Bird 503 Summary of Experimental Conditions.

Appendix G

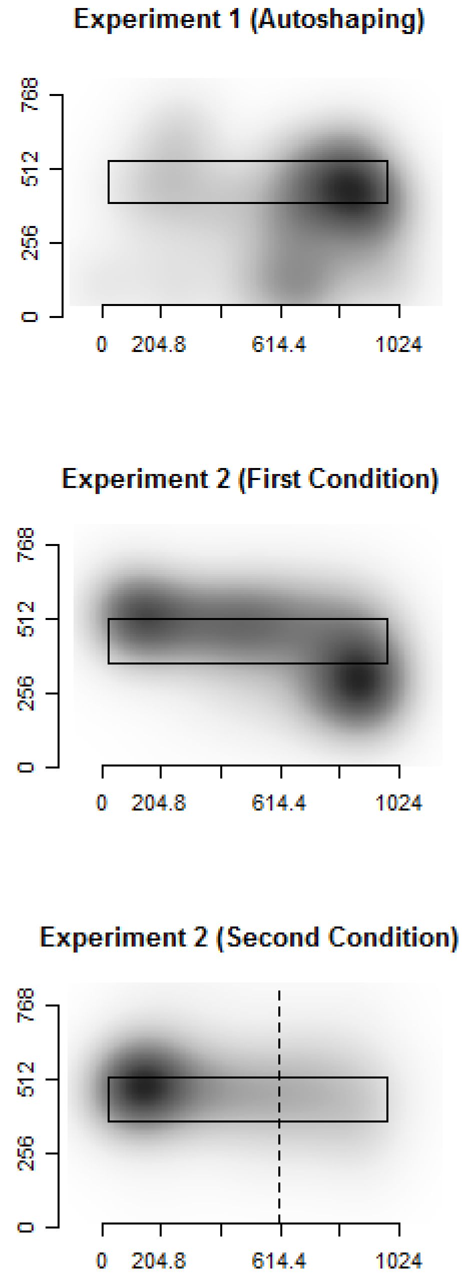
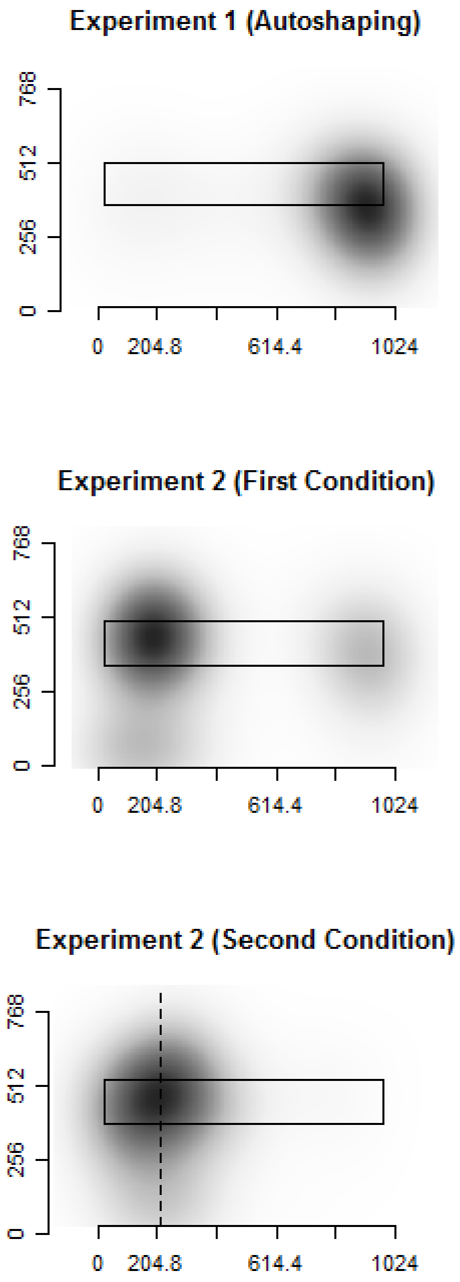


Figure 33: Bird 504 Summary of Experimental Sessions.

Appendix H



Experiment 1 (Autoshaping)

Experiment 2 (First Condition)

Experiment 2 (Second Condition)

Figure 34: Bird 505 Summary of Experimental Conditions.

Appendix I

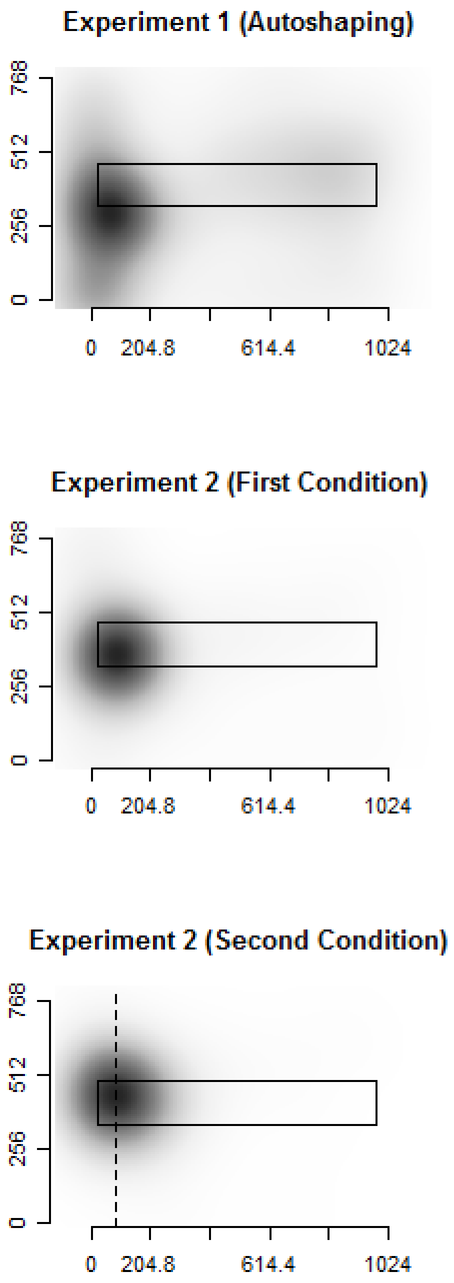


Figure 35: Bird 506 Summary of Experimental Conditions.

Appendix J

Autoshaping descriptive statistics

Table 5: Descriptive statistics for all participants across autoshaping sessions.

	mean	sd	median	trimmed	mad	min	max	range	skew	kurtosis	se
Bird 501											
NumPecks	30.73	30.57	32.5	26.89	28.17	0	224	224	2.92	15.08	3.15
NumReinforcements	25.5	6.54	27	27.01	4.45	1	32	31	-1.98	3.67	0.68
PPR	1.37	2.41	1.17	1.02	0.86	0	22.4	22.4	7.18	59.27	0.25
Bird 502											
NumPecks	165.52	226.93	75.5	120.18	102.3	0	1183	1183	2.47	7.45	35.02
NumReinforcements	25.57	2.06	25	25.35	1.48	23	30	7	0.81	-0.2	0.32
PPR	6.43	8.64	3.06	4.7	4.17	0	43.81	43.81	2.31	6.34	1.33
Bird 503											
NumPecks	43.98	22.22	37	40.73	10.38	0	126	126	1.45	2.38	2.26
NumReinforcements	27.93	4.31	30	28.67	0	1	30	29	-4.52	24.25	0.44
PPR	1.65	0.96	1.3	1.46	0.4	0	5.73	5.73	1.94	4.01	0.1
Bird 504											
NumPecks	45.92	70.05	35	33.21	44.48	0	537	537	4.34	24.68	7.08
NumReinforcements	26.51	5.4	30	27.61	0	1	30	29	-2.47	7.26	0.55
PPR	2.15	3.96	1.17	1.26	1.48	0	25	25	3.77	15.62	0.4
Bird 505											
NumPecks	341.61	401.18	116	273.74	47.44	0	1960	1960	1.55	1.81	40.32
NumReinforcements	28.51	2.04	30	28.78	0	23	30	7	-0.9	-0.72	0.21
PPR	12.68	15.29	3.87	10.1	1.63	0	70	70	1.46	1.23	1.54
bird 506											
NumPecks	83.46	51.87	62	76.75	39.29	7	228	221	0.94	-0.12	5.35
NumReinforcements	28.5	2.42	30	28.95	0	16	30	14	-2.1	6.14	0.25
PRP	3.06	2.16	2.07	2.73	1.36	0.26	9.5	9.24	1.18	0.59	0.22

Appendix K

Table 6: Descriptive statistics for experiment 2

501 descriptive														
First Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1178	296.72	275.77	178	58	251.32	145.3	1	1003	1002	1.26	0.34	8.03
Y	5	1178	363.38	98.72	366		370.65	80.06	0	673	673	-1.24	3.31	2.88
Second Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1168	722.25	219.86	814	77	755.09	145.3	12	1022	1010	-1.15	0.32	6.43
Y	5	1168	396.61	91.39	384		388.81	80.06	67	678	611	0.71	0.46	2.67
502 descriptives														
First Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1746	807.07	226.02	912	162	850.74	108.2	26	1021	995	-1.57	1.65	5.41
Y	5	1746	393.92	105.56	397		394.61	87.47	0	727	727	-0.08	0.84	2.53
Second Condition														
X	4	2104	627.32	267.29	673	83	644.06	326.2	12	1021	1009	-0.43	-1.1	5.83
Y	5	2104	468.11	95.25	462		470.11	89.7	39	723	684	-0.39	0.87	2.08
503 descriptives														
First Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1088	175.93	269.57	80	112	98.31	23.72	1	1021	1020	2.4	4	8.17
Y	5	1088	387.44	41.11	384		388.68	28.17	0	534	534	-1.92	16.6	1.25
Second Condition														
X	4	859	109.42	110.65	93	89	94.53	23.72	1	1021	1020	6.87	49.2	3.78
Y	5	859	385.25	33.88	384		384.67	26.69	220	616	396	0.49	5.57	1.16
504 descriptives														
First Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	2547	573.14	302.15	613	87	585.83	388.4	12	1023	1011	-0.29	-1.3	5.99
Y	5	2547	379.29	126.42	421		387.54	114.2	0	739	739	-0.55	-0.5	2.5
Second Condition														
	var	n	mean	sd	median	mode	trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1581	397.7	286.68	317	63	376.1	309.9	1	1021	1020	0.51	-1.1	7.21

Y	5	1581	429.65	104.34	432		428.51	71.16	0	767	767	0.2	2.17	2.62
505 descriptives														
First Condition														
	var	n	mean	sd	median		trimmed	mad	min	max	range	skew	kurtosis	se
X	4	4289	346.53	308.68	214		303.28	108.2	1	1049	1048	1.25	-0.1	4.71
Y	5	4289	329.75	166.98	366		342.54	137.9	0	696	696	-0.71	-0.4	2.55
Second Condition														
	var	n	mean	sd	median		trimmed	mad	min	max	range	skew	kurtosis	se
X	4	4892	227.89	134.45	214		218.14	109.7	1	979	978	1.36	4.24	1.92
Y	5	4892	351.17	159.12	381		363.51	139.4	0	751	751	-0.63	-0.2	2.28
506 descriptives														
First Condition														
	var	n	mean	sd	median		trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1715	136.18	168.8	86		97.34	54.86	1	1021	1020	3.05	9.62	4.08
Y	5	1715	359.95	119.1	360		358.53	63.75	0	767	767	0.11	3.15	2.88
Second Condition														
	var	n	mean	sd	median		trimmed	mad	min	max	range	skew	kurtosis	se
X	4	1899	114.53	104.98	86		98.39	54.86	1	930	929	3.09	15.1	2.41
	5	1899	415.42	80.1	421		418.06	56.34	0	751	751	-0.76	4.59	1.84

Appendix L

Raw data and video footage on attached CD.