POSSUM FOOD PREFERENCES UNDER PROGRESSIVE-RATIO AND CONCURRENT-SCHEDULES OF REINFORCEMENT

A thesis

submitted in partial fulfilment

of requirements for the degree of

Master of Applied Psychology in Behaviour Analysis

at the

University of Waikato

by

Ian Raymond Cronin.

University of Waikato

2012

Abstract

Three experiments compared various ways of examining food preferences in the common brushtail possum (*Trischosurus vulpecula*). The first experiment compared the preferences obtained between four foods using paired-stimulus (PS) and multiple-stimulus without-replacement (MSWO) assessments. The ranked orders identified by the two methods produced similar orders in individual possums, but were idiosyncratic across possums. Following this, Experiment 2 involved a progressive-ratio (PR) reinforcer assessment with all four foods used in the preference assessments of Experiment 1. For each possum, each of the four foods functioned as reinforcers when presented in a single-schedule arrangement, including those foods identified as less preferred. Experiment 3 used concurrent-schedules, with a PR schedule on one alternative and fixed-ratio (FR) on the other. It was found that higher break points and response rates, as well as flatter demand functions were found for the same food in both Experiment 2 and 3. It was also found that when the concurrent alternative was on an FR 50 schedule, the response rates, break points and $P_{\max}$ values of the food on the PR schedule tended to be higher than when the concurrent alternative was on an FR 20 schedule. Overall, the PS and MSWO assessments were equally effective at identifying which foods would function as reinforcers during Experiment 2 and 3.

Acknowledgements

I would like to thank my supervisors, Drs. Mary Foster and Lewis Bizo for the knowledge and support they gave me during the course of this study. Their guidance was invaluable.

I would also like to thank Jenny Chandler for her assistance in looking after the welfare of the animals, teaching me how to use MED-PC® IV and for bailing me out when the possums' mauled their equipment. Special thanks to Robb Baker and Allan Eady for their technical assistance as well, setting up the apparatus and setting up my lab computer respectively. I am also grateful to Kristie Cameron and Kathleen Doolan for their help running the experiments. If it wasn't for them, I would have had to be at the lab seven days a week. That would have sucked.

Thanks to my friends for thinking I did less work than I actually did, and to my family for thinking I did more. Big thanks in particular to Sarah for trying her best to keep me sane, even if she sometimes just made things worse. I really appreciate having you there to listen to me complain about pretty much everything.

Finally, I'd like to thank my parents for everything they've done for me. Whether it was providing me with a free dinner, letting me use their washing machine and dryer, or helping me keep my head above water as a poor student, I always knew that you were there to offer me love and support. I couldn't have done it without you!

Contents

List of Figures

List of Tables

Appendices

A list of appendices, including descriptions and file locations, can be found on the accompanying CD in the file appendiceslist.doc.

To say an organism has a “preference” for something can mean many things. It can mean that the organism will reliably select one stimulus over other alternatives, when provided with a choice. Similarly, it can mean that the organism will reliably spend more time engaging with one of the alternatives. It can also mean that the organism will work harder to obtain access to the stimulus than it will work for the other stimuli. It can also apply to any combination of the above. One thing that remains constant, however, when we talk of an organism having a preference, is that the statement tends to be based on what the organism “does”, not something that the organism “has”

When we assess “preference” then, we are assessing the organism’s behaviour in relation to multiple stimuli, some of which might be potential reinforcers. When a stimulus is said to be highly-preferred, the strength of the preference is judged relative to the other alternatives available. It is entirely possible for a stimulus to be assessed as highly-preferred among one array, while also being assessed as low-preferred among a completely different array.

Assessing the preferences of humans with developmental disabilities is an expanding area of research, as can be seen in the review conducted by Hagopian, Long and Rush (2004). However, some of the progress made in the research area has not been carried over to the assessment of preferences with animal populations. With human populations, the assessment of preferences is largely used to identify stimuli that will act as reinforcers for individuals so that their behavioural repertoires can be expanded. A great deal of operant research with animals also involves training new behaviours, but assessing the preferences of animals can be useful when assessing animals’ welfare.

Preference assessments are useful in determining what an animal ‘wants’ (Broom, 1991; Dawkins, 2004). However, it has been acknowledged that, like humans, animals may not always ‘want’ what is in their best interest (Dawkins, 2004; 2006; Nicol, Caplen, Edgar & Browne, 2009; Patterson-Kane, Pitman & Pajor, 2008), and that preference assessments tend to only assess over the short-term (Broom, 1991). Because of this, it has been suggested that it is important to assess how hard an animal will work for the stimuli identified through preference assessments (Broom, 1991; Dawkins, 2006; Patterson-Kane et al., 2008). Dawkins (2004) suggested that assessing how hard an animal will work to obtain access to a stimulus or to perform specific behaviour, provides information about how much the animal ‘values’ it. If they are willing to work very hard for it, then instead of assessing what the animal ‘wants’, this could be viewed as what the animal ‘needs’. Depriving this ‘need’ may not lead to death or physical injury, but may still cause unnecessary suffering to the animal.

Preference Assessments in Humans

The review by Hagopian et al. (2004) identified a range of preference assessment methods commonly used with individuals with developmental disabilities. They categorised the assessment methods based on the different measurement techniques they used. Preference assessments that involved questionnaires, checklists or interviews to establish preferences were said to be indirect measures, while assessments that involved measuring the individual’s observed interaction with the reinforcers were said to be direct measures.

Indirect measures. One example of an indirect method is the reinforcer survey developed by Matson, Bielecki, Mayville, Smalls, Bamburg, and Baglio (1999) for individuals with developmental disabilities. They compared primary caregivers’ judgment about whether stimuli would work as a reinforcer to the results of an undefined choice assessment procedure. It was argued that the survey was reliable in identifying the stimuli more likely to be selected in the choice assessment. Having a reliable reinforcer survey would allow for fast, cost-effective assessment of preferences (Hagopian et al., 2004). Being quick and cost-effective is an advantage shared across indirect measurement methods. Despite this advantage, Matson et al.’s (1999) survey is problematic because the results were based upon the percentage of caregivers that said each item was a suitable reinforcer for different children. This says nothing about each caregiver’s individual accuracy in relation to predicting whether a stimulus would act as a reinforcer for each child. Adding to this, Northup, George, Jones, Broussard, and Vollmer (1996) and Northup (2000) point out that reinforcer surveys actually have fairly low accuracy in predicting whether or not a stimulus can act as a reinforcer under more systematic assessment.

Northup et al. (1996) compared the results of a reinforcer survey with the results of two different direct preference assessment methods. Following the preference assessments, Northup et al. (1996) conducted a reinforcer assessment with the stimuli identified in the previous assessments to see if they would work to maintain the individuals’ behaviour. This reinforcer assessment involved individuals responding on a fixed-ratio (FR) schedule where a fixed number (different for each participant) of target responses would result in access to the stimulus. The results showed that both the direct choice assessments had higher accuracy at predicting which stimuli would serve as reinforcers, than the reinforcer survey, which had little more accuracy than pure chance. Further work by Northup (2000) investigated the accuracy of the reinforcer survey at predicting performance on a reinforcer assessment and found that the accuracy of the reinforcer survey at predicting reinforcing value was just 57%, which is little higher than chance. These two studies suggest that although indirect measures of preference assessment tend to be faster and more cost-effective to do (Hagopian et al., 2004), the results are not as reliable as direct measures at predicting which stimuli will function as reinforcers.

Direct measures. When assessing preferences using direct measures, the assessments are typically based on the time that the organism spent engaging with each stimulus (DeLeon, Iwata, Conners, & Wallace, 1999; Roane, Vollmer, Ringdahl & Marcus, 1998), or the percentage of the times the stimulus was chosen by the organism when given a choice between alternatives (DeLeon & Iwata, 1996; Fisher et al., 1992; Pace, Ivancic, Edwards, Iwata & Page, 1985; Windsor, Piché & Locke, 1994). These are labelled by Hagopian et al. (2004) as 'engagement-based' and 'approach-based' measures.

Engagement-based measures. In an example of an engagement-based method, Roane et al. (1998) presented participants with 10 or more stimuli for just 5 min, and noted which stimuli they interacted with. The results from this free-access engagement-based method were compared to the results of an approach-based method, and it was shown that the two methods produced the same most-preferred stimuli for just below 50% of the participants. A reinforcer assessment was conducted for the stimuli from the engagement-based method and it showed that the method was able to identify stimuli that would function as effective reinforcers. However, a reinforcer assessment was not conducted for the stimuli identified by the approach-based method, so a comparison between the accuracy of the two methods in selecting potential reinforcers could not be made. It was noted, however, that the engagement-based method was faster to conduct and that participants engaged in less problematic behaviours during it, making it easier to administer.

Another variation of an engagement-based measure was described by DeLeon et al. (1999). In this, the free-access component of Roane et al. (1998) was removed, presenting a single stimulus at a time to the participant for 2 min, and the time spent in contact with the stimulus was recorded. Following a reinforcer assessment, it was shown that the stimuli identified as being highly-preferred tended to function as more effective reinforcers. This was a useful outcome, because for some stimuli a choice-based method had provided unclear preference rankings. The method was also advantageous in that presenting one stimuli at a time can be easier for participants with certain disabilities to cope with.

Overall, engagement-based measures can be fast and lead to few problematic behaviours occurring, and the stimuli can be presented in a single-stimulus format. However, they can lead to a participant becoming satiated with the stimulus (Hagopian, et al., 2004). This is particularly true with edible stimuli, as the participant may consume too much in the given time when allowed free-access to the food, that the stimulus may no longer be preferred.

Approach-based measures. Rather than measuring the time spent engaging with a stimuli, approach-based preference assessments involve repeated presentations of a stimuli, and the frequency of an organism approaching or consuming the stimuli is measured. Pace, Ivancic, Edwards, Iwata, and Page (1985) developed an approach-based preference assessment that involved presenting a single stimulus to an individual for 5 s, and recording the frequency of occasions that the individual approached the stimulus. Following this, a reinforcer assessment was conducted where the results showed that items that were considered high-preference following the initial preference assessment generally functioned as more effective reinforcers than items that were considered low-preference. This method of preference assessment worked well for the population Pace et al. (1985) were working with, as they did not reliably engage in spontaneous play, rendering engagement-based measures ineffective. However, as Fisher et al. (1992) showed, there are more reliable methods than the single-stimulus (SS) method that Pace et al. (1985) developed.

Fisher et al. (1992) introduced a forced-choice between two different stimuli. This method involved presenting a pair of stimuli simultaneously, and after the participant approached one of the two stimuli, the other was made unavailable. The results of this paired-stimulus (PS) forced-choice method were compared to the results of a SS method similar to that developed by Pace et al. (1985). It was found that the while all stimuli determined to be of high preference under the PS method were also found to be of high preference under the SS method, the SS method identified many other stimuli as high preference. After conducting a reinforcer assessment, it was found that the stimuli identified by the PS method as being of high preference, functioned as more effective reinforcers compared to those stimuli identified as being of low preference. This outcome was attributed to the forced-choice nature of the assessment which prevented the participants from approaching both stimuli. When the stimuli were presented in the SS method, the participants may still approach less preferred stimuli on every presentation, so the difference in ranked preference between stimuli selected every time they were presented is lost. Choosing between two alternatives allows for this information to be collected.

Windsor et al. (1994) described a variation of Fisher et al. (1992)'s PS preference assessment, where, as with the Roane et al. (1998) study, a participant was exposed to a larger array of simultaneously-presented stimuli, in random order. They compared the results of this multiple-stimulus (MS) forced-choice method to those from a PS method and reported that although both methods identified similar stimuli as being of high-preference, over repeated sets of trials, the PS method produced more consistent preference hierarchical rankings. This difference can be attributed to the MS method allowing a participant to choose a high-preference stimulus exclusively, while no information is gathered about the relative preference for the lower-preferred stimuli. The MS method was considerably faster to administer, however, than the PS method, which makes it more practical to use in applied settings.

The preference rankings that Windsor et al. (1994) identified were also compared to those from reinforcer surveys conducted with different caregivers. It was found that there was little consistency in preferences identified between caregivers for the same participant. The results also showed that the stimuli identified as preferred by the reinforcer surveys were less likely to predict that individuals would work for the stimulus during the reinforcer assessment. This is consistent with Northup et al. (1996) and Northup (2000)'s studies on the effectiveness of indirect measures such as reinforcer surveys.

In response to the problem of exclusive-choice that was raised by Windsor et al. (1994) for the MS method, DeLeon and Iwata (1996) proposed a modified MS method. In this, after a participant selected and consumed a stimulus from an array, the item is not replaced in the array before the next presentation occurs. Thus, each successive presentation array had fewer items than the previous presentation, and the session continued in this manner until either all stimuli had been selected by the participant or no choice was made.

The results of this multiple-stimulus without replacement (MSWO) procedure were compared to those of both an MS procedure and a PS procedure similar to that described by Fisher et al. (1992). The MSWO method produced similarly consistent rankings to the PS method, while also showing that more stimuli were selected than in the MS method, as was expected by providing the forced-choice between lower-preferred stimuli. Following a reinforcer assessment, it was shown that stimuli selected in both the PS and MSWO methods were able to function as reinforcers, when they hadn’t been selected at all in the MS method. The MS procedure had therefore produced false negatives.

Additionally, it was shown that the MS method was slightly quicker than the MSWO method to administer, but both took generally half the amount of time to administer than the PS method. DeLeon and Iwata (1996) suggested that the MSWO method therefore shared the main advantages of both the MS and PS methods. It produced reliable hierarchies like the PS method, where stimuli identified as more preferred in the MSWO assessment tended to be more effective at maintaining behaviour. It was also more suitable for use in applied settings because of its faster administration time, similar to the MS method.

One issue around the use of the MSWO method, as described by DeLeon and Iwata (1996) is that determining relative preference by the percentage of times the stimulus was selected out of the total number of times it was presented, as Fisher et al. (1992) and Windsor et al. (1994) did, can distort the percentage value, as each stimuli is presented a different number of times. As Figure 1, from Ciccone, Graff, and Ahearn (2005) shows, if a perfect ranked hierarchy of preferences was to occur when using the percentage approach method, the second most-selected stimulus out of an array of seven stimuli is still only chosen 50% of the times it was presented. This remains the same regardless of how many items are in the array, and therefore while the relative ranking of the preference is

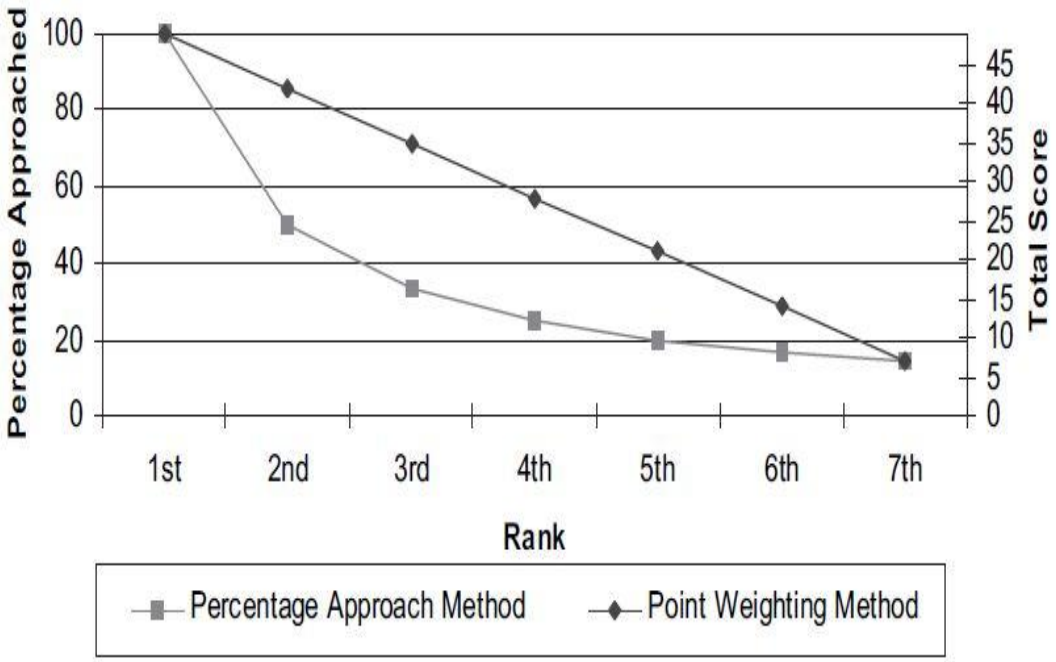


Figure 1. Comparison of perfect rankings on both the percentage-scoring method and the point-scoring method for the multiple-stimulus without-replacement (MSWO) preference assessment. Reprinted from “An alternative scoring method for the multiple stimulus without replacement preference assessment,” by F. J. Ciccone, R. B. Graff, and W. H. Ahearn, 2005, *Behavioral Interventions, 20*(2), p. 125. Reprinted with permission.

unaffected, the percentage value indicates that the stimulus is much less preferred than the assessment has shown and therefore, false negatives may arise.

Ciccone et al. (2005) described a scoring method to use with the MSWO preference assessment where each stimulus is awarded a point-based score according to the order it was selected from an array. Thus, if there are seven items in the array, then the stimulus selected on the first presentation of the array is scored with seven points. Following the DeLeon and Iwata (1996) methodology, this item is then removed and the array is presented again with only six stimuli in it. The stimulus selected on this presentation is then scored with six points, and this process continues until the final stimulus is selected, scoring one point. If no selections are made from the remaining stimuli on the array, they would all be scored as zero points from that presentation, and all the items would be replaced in the array before beginning a new set. The score, after all array orders have been presented can then be totalled. The results of this point-weighting method using a hypothetical perfect hierarchy of seven stimuli can be seen in Figure 1, where it produces a straight descending line. Compared to the percentage-approach method, the second highest-preferred item in the array is illustrated as being much higher on the scale under the point-weighting method. Though Figure 1 uses two scales on its y-axes, the total point-weighting score for a stimulus can be calculated as a percentage of the total score if the stimulus had been selected first in every array, which would place the second highest-preferred stimulus in a seven stimuli array at a percentage of 85.71%. As this is now on the same scale as the results from the percentage-approach method, it can be seen that this value is much higher than the 50% value that method produced.

Changing the scale of the preferences from how DeLeon and Iwata (1996) calculated it to the method based on Ciccone et al. (2005) can be helpful in quickly determining whether the MSWO method has identified the stimulus as being of relative high-, medium- or low-preference to an individual, and may be beneficial when a perfect hierarchy does not arise, as would commonly be the case.

Preference Assessments in Animals

In terms of using preference assessments with animals, most published assessments have occurred in laboratory settings. Compared to the use of preference assessments in applied human settings, this tends to lower the importance of shorter experimental sessions. Rigor is favoured over speed. As such, the use of indirect measures of preference is not widely practiced with animals. Though it could be theoretically possible to assess preferences in a fashion similar to the Matson et al. (1999) reinforcer survey, using pet owners in place of caregivers, no published accounts could be found. Direct measures have been favoured instead.

Engagement-based measures. Free-access procedures, like the Roane et al. (1998) study with humans, have been commonly used in preference assessment with animals. Williams, Riddell and Scott (2008) conducted two free-access procedures with rats that compared the amount of time each organism spent interacting with individual stimuli when there were two items presented together, and when there were four. The results suggested that both presentation sizes produced similar rankings of preference, though the rankings were idiosyncratic for each rat.

Blom, Baumans, Van Vorstenbosch, Van Zutphen, and Beynen (1993) and Blom, Van Tintelen, Baumans, Van Den Broek, and Beynen (1995) also used free-access procedures to assess rats' preferences for flooring material and cage height respectively. Like the Williams et al. (2008) study, reinforcer assessments were not included so the accuracy of whether or not identified preferences were able to function as reinforcers in each study was not identified. However, both Blom et al. (1993) and Blom et al. (1995) show that the use of free-access procedures is practical for use with animal populations and still share the same advantages that Roane et al. (1998) identified for human populations, where it is a quick and cost-effective procedure.

The choice of preference assessment used should be dependent on the stimuli the assessment involves, and the types of responses needed to obtain them (Hagopian et al., 2004). Assessing preference for welfare issues such as housing conditions can often involve a number of stimuli. If this is the case, then engagement-based methods may be more suitable than approach-based methods, because it may be the combination of stimuli in the environment that makes it more preferred to an organism. Sumpter, Foster and Temple (2002) also identified that free-access methods may be inappropriate to use when different stimuli require different responses to interact with. They pointed out that a hen may not spend as much time in a nesting environment as it would in a feeding environment, but that does not make it less-preferred. It just means that the organism does not need to spend as much time responding in order to receive that particular reinforcement.

Approach-based measures. An example of approach-based preference assessment methods with animal populations was the PS assessment by Hudson, Foster, and Temple (1999) with possums. Hudson et al. (1999) used a method similar to that Fisher et al. (1992) used with humans. The most frequently selected food item across all possums was then used to maintain behaviour of possums under an FR schedule, and the food was shown to generally function as a reinforcer.

The Hudson et al. (1999) study was conducted in a laboratory setting and, in contrast to this, Fernandez, Dorey, and Rosales-Ruiz (2004) conducted a PS assessment in a zoo, assessing the food preferences of tamarin monkeys. Though a reinforcer assessment was not conducted afterwards, it was shown that the PS assessment could be easily implemented in an applied setting.

As well as the free-access procedures already described Williams et al. (2008), the first choices made in the two-stimuli free-access procedure were compared, mimicking a PS assessment. This comparison produced similar ranked results to the time spent engaging with stimuli under the free-access conditions.

PS and free-access also were compared by Martin (2002) using edible items with possums. The results showed that both methods produced similar individual preferences for possums, though again, no reinforcer assessment was conducted following this.

On the basis of this, if the stimuli being assessed are deemed as being suitable for use in either preference assessment, then it may be difficult to decide which method to use. All other things equal, then the time it takes for a session to be conducted may be a strong deciding factor in choosing an assessment method. As already mentioned, a MSWO method can be administered in a shorter time than a PS method (DeLeon & Iwata, 1996). As this is an advantage that the free-access procedure has over a PS method, then achieving this while still maintaining control over the access to reinforcement an organism has, can be beneficial. Satiation can be avoided, and the assessment can be implemented practically. Unfortunately, little research has been done in assessing how well a MSWO preference assessment works when used with animals, despite the benefits that the methodology offers.

The only study found using MSWO with animals was the work that Armistead (2009) conducted with horses. The procedure used was similar to that described by DeLeon and Iwata (1996), save for that more experimental conditions were done, as every initial combination of the four foods used was presented. Armistead (2009) used a reinforcer assessment to compare the most- and least-preferred foods identified across all horses. It was found that the high-preference food from the MSWO assessment maintained behaviour at higher rates than the low-preference food, as FR schedule requirements increased.

Reinforcer Assessments

The primary purpose of a reinforcer assessment is to see whether or not the stimuli identified in prior preference assessments can effectively maintain behaviour. Reinforcer assessments have been commonly included by many of the studies into the preference of animals and humans previously discussed (Armistead, 2009; DeLeon et al. 1999; DeLeon and Iwata, 1996; Fisher et al., 1992; Northup, 2000; Northup et al., 1996; Pace et al., 1985; Roane et al., 1998). These involve providing access to the stimuli presented to the organism(s) in the preference assessments, contingent to the completion of one or more specified behavioural responses.

Fixed-ratio schedules. FR schedules have been used to determine how much ‘work’ an organism will do in order to obtain access to a potential reinforcer, across sessions. Following a MSWO preference assessment, Armistead (2009) trained horses to move a lever with their noses in order to gain access to food. They were then placed upon FR schedules where each session, the FR schedule requirements were doubled. For example, the lever needed to be moved once to receive reinforcement on Session 1, twice on Session 2, four times on Session 3, and so on. The rate at which responses were made; the pause after reinforcement; and some behavioural economic measures were used to assess how well the stimuli operated as reinforcers.

The patterns of responding expected to be seen under FR schedules of reinforcement with animals were shown in Hudson et al. (1999). The duration of the post-reinforcement pause (PRP), between when reinforcement ends and responding begins again, was shown to be shorter under smaller FR schedules. Response rates also tended to increase initially, when the schedule requirements shifted from FR 1 to a slightly higher ratio, such as FR 5.

Response rates under FR schedules increasing over sessions have shown a consistent pattern described as a bitonic function (Hursh, 1980, 1984). This bitonic function shows initially increasing response rates as the FR schedules are increased, before reaching responding reaches a maximum peak rate and then begins to decrease. When plotted, perfect bitonic functions look symmetrical. The highest FR schedule used by Hudson et al. (1999) was FR 5, however, so it was unable to be seen if the response rates would then begin to decrease, showing the bitonic function as Hursh (1980, 1984) suggested would happen.

A similar procedure was used with human participants by Northup et al. (1996). In this study, the FR schedule requirement varied between participants, and the extent to which the stimuli maintained responding over time at this ratio determined whether or not it was considered an effective reinforcer. The task Northup et al. (1996) used involved matching a letter to a number. These sorts of tasks differ from the simple pressing levers or buttons used with animals, as the human tasks are usually already in the behavioural repertoire of the participant (Roane, Lerman, & Vorndran, 2001). With animals, the behaviours used are simple but need to be trained.

The preference for specific stimuli has been found to change quite drastically as schedule requirements increase. Tustin (1994) examined how changing between different FR schedule requirements (FR 1, FR 2, FR 5, FR 10 and FR 20) each session can change the patterns of responding for individuals with developmental disabilities. Comparing the rates of reinforcer consumption showed that a stimuli that maintains behaviour well at low schedule requirements can become less effective at higher schedules, and vice versa. In the context of preference assessments, including MSWO and PS assessments, the schedule reflects FR 1. Based on the Tustin (1994) study, it is possible that the preference identified at this low schedule value will change when the schedule increases.

Another example of preference for reinforcers changing under different reinforcer schedules is shown in the study by DeLeon, Iwata, Goh, and Worsdell (1997). A similar progression in the reinforcer schedules conducted by Tustin (1994) was used with individuals with developmental disabilities. It was found that when different stimuli were compared, such as edible items versus leisure items, then there was no consistent change in the preferences observed. If similar items were used, such as two edible items, then as schedule requirements increased, clear changes in preference were observed.

Progressive-ratio schedules. Progressive-ratio (PR) schedules involve changing the required number of responses to obtain access to reinforcement, within one session, as opposed to across sessions like Tustin (1994) and DeLeon et al. (1997) did. This has the potential to assess the amount of ‘work’ an organism will do for stimuli, in fewer sessions than Tustin (1994) or DeLeon et al. (1997).

The PR schedule was introduced by Findley (1958), where to obtain access to a reinforcer, pigeons were required to make more responses for the next reinforcer than for the previous reinforcer. The first reinforcer required Findley (1958)’s pigeons to peck a key 100 times, and every reinforcer after that would require 100 more responses on the key, so the second reinforcer would require 200 responses, the third 300, and so on.

Two different types of PRs were used by Roane et al. (2001) with individuals with developmental disabilities. One of the types was an additive schedule, like that which Findley (1958) used, but where the schedule requirements for each successive reinforcer increased by one response each time. One participant in Roane et al. (2001)’s study, however, experienced a PR schedule where the responses required for each reinforcer approximately doubled the schedule requirements for the previous reinforcer. The results from both of these PR schedules that Roane et al. (2001) used, produced the same patterns of results that were obtained under FR schedules by Hudson et al. (1999) with possums. The biggest difference between the two types of schedules was that under a PR schedule, the same results could be obtained in fewer sessions. Being quicker to conduct may be an advantage when conducting reinforcer assessments outside of laboratory settings.

A direct comparison between responding under PR schedules and FR schedules that increased in subsequent sessions was made by Foster, Temple, Cameron and Poling (1997) with hens. When the hens were on PR schedules, they tended to produce higher response rates than on FR schedules. However, the patterns produced by the two different schedules of reinforcement were similar, therefore they can be used interchangeably as ways in which to assess responding under increasing schedule requirements.

Concurrent schedules of reinforcement. Another procedure used to compare the responding on higher schedules is the use of concurrent schedules of reinforcement, which presents two schedules simultaneously to an organism. The study by Findley (1958) that introduced the PR schedule of reinforcement also included a section where two keys were presented concurrently to pigeons, with schedules operating on either that were independent of each other. On these concurrent schedules, the reinforcement criteria for one schedule can be met without affecting the other schedule. For example, Findley (1958) used variable-interval (VI) schedules where reinforcement would be received after a response was made following a varying amount of time had passed, averaging in this case at 4 min. If reinforcement was received on one key, the time elapsed for that key was reset, while the other continued. Bron, Sumpter, Foster and Temple (2003) also used concurrent VI-VI schedules with possums, showing an example of how two different stimuli can be compared simultaneously using the concurrent-schedules of reinforcement method.

Using concurrent schedules of reinforcement is advantageous when comparing two or more stimuli, because when a choice is made to respond to gain access to one stimulus, the probability of responding for the other stimuli is also affected (Fisher & Mazur, 1997). When presented individually, in a single-schedule arrangement, two stimuli may produce similar overall response rates.

However, when presented concurrently, the relative response rates produced may differ

Analysis of Behaviour at Higher Reinforcement Requirements

There are several methods used to analyse behaviour under increasing FR and PR schedules. Hursh (1980, 1984) proposed one method which suggested that as well as comparing response rates, using concepts derived from economics can also be useful in assessing preference for different stimuli.

Demand and behavioural economics. Comparing the rate of reinforcer consumption to the schedule requirements, can produce a demand function that Hursh (1980, 1984) suggested is useful in analysing behaviour. These functions have been used to analyse behaviour in reinforcer assessments with both FR schedules (Armistead, 2009; DeLeon et al., 1997; Foster et al., 1997; Hudson, et al., 1999; Tustin, 1994), as Hursh (1980, 1984) first proposed them, and also with PR schedules (Foster et al., 1997; Roane et al., 2001). It has generally been shown that as price (the log of the schedule requirements) increases, the demand for the stimuli (the log of the consumption rate) decreases.

Most demand functions can be described by the equation used by Hursh, Raslear, Shurtleff, Bauman, and Simmons (1988):

$$\ln(Q) = \ln(L) + b(\ln(P)) - a(P) \qquad (1)$$

In Equation 1, Q represents the consumption and P represents the price, while three unknown parameters are also calculable: ln L for the initial demand shown on the function, b for the initial slope of the demand function, and a for rate of change in the slope of the function.

Elasticity. Demand functions, when they are plotted on log-log coordinates, are able to tell us about the elasticity of the demand for the stimulus. The elasticity of demand comments on the extent to which consumption decreases as price increases (Hursh, 1980; 1984). Elasticity can be calculated by the linear equation: Elasticity = $b - a(P)$. A steep slope of the demand function (Elasticity < -1) is described as being elastic, while a shallow slope (> -1) is described as being inelastic.

Demand is not always wholly elastic or wholly inelastic across a function. It can change as the schedule requirements increase. The value $P_{\max}$, described by Hursh and Winger (1995), shows the point at which a demand function switches from inelastic to elastic. It can be calculated by the equation:

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

The more inelastic the demand for a stimulus is, then the more an organism should respond to obtain access to that stimulus. This would suggest that it is more preferred (Dawkins, 2004). Therefore, more highly preferred stimuli should have a higher $P_{\max}$ value than less preferred stimuli, as the more-preferred stimuli are more resistant to changes in price, with demand for those stimuli remaining inelastic at higher ratios.

Elasticity of demand can be affected by whether or not an organism has access to a similar stimulus outside of the experimental conditions. This is the difference between an open- and a closed-economy. A closed-economy is when all access to that stimulus is achieved within the experimental conditions, while an open-economy is when access to that stimulus is also provided outside of experimental sessions (Hursh, 1978, 1980, 1984). For example, Armistead (2009) put horses under an open-economy where responding on a lever was reinforced with food, and supplementary food was also provided outside of the experiment.

Hursh (1978) reported that when schedule requirements increased, the response rates under a closed economy-increased, while the response rates decreased under an open-economy. Demand functions for Hursh (1978), were shown in Hursh (1980), and showed higher initial demand in the open-economy, but as schedule requirements increased, demand for reinforcers decreased.

The elasticity of demand functions has been examined in an open-economy by Armistead (2009) with horses and by Foster, Sumpter, Temple, Flevill and Poling (2009) with hens. Both of these studies found functions that had mixed-elasticity. Armistead (2009) reported the point at which demand changed from inelastic to elastic, through the same $P_{\max}$ value calculated by Equation 2, for foods that had been identified as high- and low-preference in an MSWO assessment. Generally, the food that was identified as being of higher-preference showed higher $P_{\max}$ values than the low-preference food. Higher response rates were also seen. Foster et al. (2009) also found higher response rates when the $P_{\max}$ value was higher, and that the $P_{\max}$ value reflected the point at which maximal responding occurred (the peak on a bitonic function). These results suggest that the $P_{\max}$ value may be an appropriate measure of preference at high schedule requirements.

Substitutability. Demand functions on concurrent FR-FR schedules can look very different than when presented on a single-schedule arrangement (Sørensen, Ladeweig, Ersbøll and Matthews, 2004). The study by Sørensen et al. (2004) used rats and plotted two demand functions for different foods in the face of the schedule requirements for just one of the alternatives. This shows how increasing schedule requirements for one food can result in demand changing for both the food that the requirements were increased for, as well as any other alternatives. Pedersen, Holm, Jensen and Jørgensen (2005) also used concurrent FR-FR schedules with preference for the rooting materials of pigs, and found similar results.

Hursh (1980) discussed the concept of substitution, as being when the demand for one stimuli decreases, demand for another stimuli increases. So, when two food types are presented concurrently, and the schedule requirements increase for one, decreasing the demand for it, then one would be expected that if the alternative could function as a substitute, the demand for that alternative would increase. According to Hursh (1980)’s definition, the results shown by Sørensen et al. (2004) and Pedersen et al. (2005) would have shown substitution. It can be argued that whether or not substitution can occur, can reflect the strength of preference for stimuli. For example, if the price for Stimulus A increases, but demand for Stimulus B doesn’t increase, then Stimulus B may be of lower preference than Stimulus A.

Break points. In PR schedules, the point at which an organism stops working for an extended period of time is labelled the ‘break point’. This break point has been used by Glover, Roane and Kadet (2008), in conjunction with response rates, to assess preferences at higher schedule requirements for stimuli that had been identified as high- or low-preferred following a PS preference assessment with individuals with developmental disabilities. Both FR and PR schedules of reinforcement, and single- and concurrent-schedule arrangements were compared, and it was found under all conditions that the stimulus identified as highly-preferred by the PS assessment produced higher response rates and reached a higher break point.

The break point was also used alongside response rates by Francisco, Borrero and Sy (2008) to compare preference for stimuli on a PR schedule in a similar fashion to Glover et al. (2008) with individuals with developmental disabilities. A PR schedule was implemented in a single-schedule arrangement with a stimulus identified as being low-preferred in a PS assessment, and then again in a concurrent arrangement alongside a stimulus identified as being high-preferred in the same PS assessment. The results showed that the high-preference stimulus consistently showed higher response rates and break points, but in the single-schedule presentation, the low-preferred stimulus reached comparable response rates and break points to the high-preference stimulus. This helps to demonstrate the accuracy of break points in predicting similar performance as response rates. It also lends to a question about how well low-preferred stimuli can still act as substitutes if the price for a high-preferred stimuli is increased high enough.

This Study

The aim of this study was threefold. Firstly, this study sought to provide the first comparison of the preference hierarchies produced by PS and MSWO preference assessments using possums. No comparison between these two preference assessment methods has been previously conducted with an animal population. Secondly, the foods identified in the PS and MSWO assessments were evaluated on a PR schedule of reinforcement. The purpose of this was to evaluate whether the foods could function as effective reinforcers, and if either the PS or MSWO method was more accurate at predicting which foods would function as reinforcers. Finally, each food was presented concurrently on PR-FR schedules to compare the stability of responding for, and consumption of reinforcers when there was a potential substitute available at a constant schedule requirement.

Experiment 1

There has been very little research into using the use of the MSWO preference assessment, as devised by DeLeon and Iwata (1996) with animal populations. Armistead (2009) was the only study that could be found, using horses, and this did not compare the outcomes of this assessment to more commonly used assessments such as the PS assessment originally devised by Fisher et al. (1992).

The aim of this study was to compare the outcomes of MSWO and PS, conducted with possums with four foods. The PS assessment was first conducted with eight foods. The findings of this were used to select four foods that represented a wide range of preferences, as measured by this procedure, for all possums. Four foods were then used in the MSWO assessment. Finally, the PS assessment was repeated with just those four foods. This experiment provided a direct comparison between the ranked food preferences identified by the two preference assessment procedures with possums. The use of MSWO more closely resembled the method used by Armistead (2009) than DeLeon and Iwata (1996). This was done to account for any potential preference for the position of a food that the possums may demonstrate.

Method

Subjects

6 common brushtail possums (*Trichosurus vulpecula*) served as subjects in the experiment. There were 4 females; Bonnie, Olive, Caper and Screech, and 2 males; Peppi and Norrin. All six possums had participated in at least one previous experiment, including fixed-interval timing (Olive, Caper, Peppi, Screech, and Norrin), sound discrimination (Olive, Caper, Peppi and Bonnie), and matching-to-sample experiments (Screech and Bonnie).

They were housed individually in steel cages approximately 85 cm high, 51 cm wide and 50 cm deep, that also served as the experimental housing. These cages had a shelf approximately 55 cm from the bottom of the cage, the length of which ran the entire width of the cage, and the width protruded 27 cm from the back wall. A nesting box was accessible by the possums through a hole in the top of the cage.

The possums had constant access to water, and their diet consisted of the food that they received through working in the experiment, supplemented by green leaves (broad-leaved dock, *Rumex obtusifolius*), and apple or carrot. On days when they were not exposed to the assessments, the possums received supplementary food that consisted of pellets specially-manufactured by Camtech Manufacturing Ltd. The possums were maintained at a stable body weight, and were weighed weekly. The supplementary food received was adjusted as required to limit the changes in body weight as much as possible.

The room in which the individual cages were housed in had no windows, and was kept on an artificial, reverse day/night light cycle with 12 hours light from 9 pm to 9 am, and 12 hours dark from 9 am to 9 pm. During the light cycle, the room was illuminated by two 100 W white light bulbs. Experimental sessions occurred during the dark cycle. During these sessions, and when access to the room was required during the dark cycle, the room was illuminated by three 60 W red lamps.

Apparatus

The preference apparatus consisted largely of plywood, and was attached to a possum’s home cage as in Figure 2. The apparatus opened up at the bottom to a steel grate with four 7.5 cm by 7.5 cm square openings. Food was presented in 5.5 cm high aluminium tins that could be raised manually through these openings. The grate at the bottom of the apparatus prevented the possum from choosing two different foods simultaneously. Between preference trials, food was inaccessible through these openings.

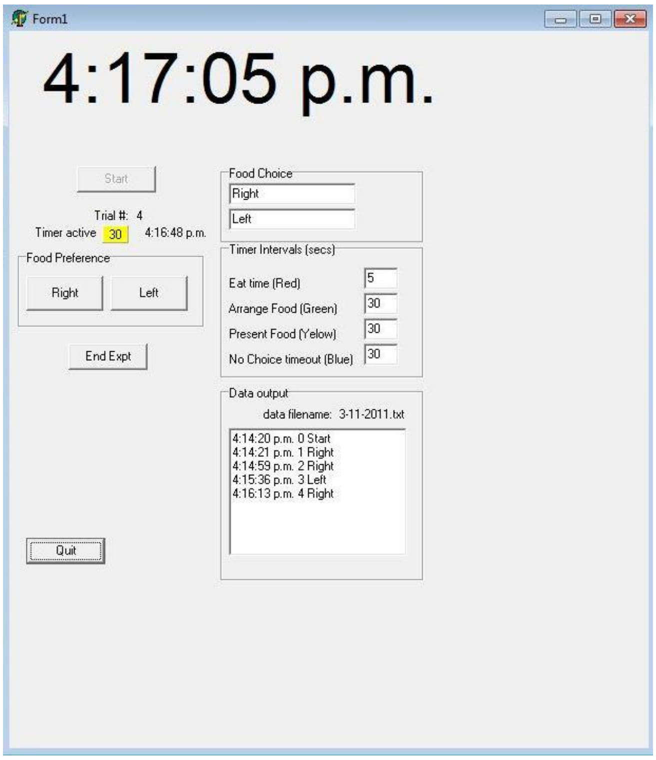
The number of tins available at one time to the possum depended on whether the PS or MSWO assessment was being conducted, and for the MSWO assessment only, the trial number and previous choices made. Figure 2 shows four tins raised up to the grate, as needed in the MSWO assessment.

A Perspex panel was positioned between the possum and the experimenter above the grate, which allowed the experimenter to identify the choice the possum made.

The foods used included soy protein (a form of textured vegetable protein), Chef® salmon and tuna flavoured cat biscuits, extruded rice, frozen corn kernels, San Bran™, rolled oats, a Cocoa Puffs™/barley mixture (a ratio of one part Cocoa Puffs™ to 15 parts hulled barley, as measured by volume); an almond slices/barley mixture (one part almond slices to four parts barley), and dried peas.

Two computer programs written in Object Pascal were used to assist in timing the intervals for the PS and MSWO assessment, respectively. The program for the PS assessment displayed two buttons on the computer screen, corresponding to the positions of the foods presented to the possum, on either the left or the right. When a food was chosen, the corresponding button could be clicked with the mouse, and the program would then move on to time the access to reinforcement, and the inter-trial interval (ITI). After the program had timed the ITI, both buttons were again clickable on the computer screen and the next trial could begin. This can be seen in Figure 3, which shows an example of what the computer screen displayed to the experimenter before a choice had

Figure 2. The preference apparatus. The top panel shows the panel attached to a possum’s home cage, and the bottom panel shows four tins raised up to the apparatus, as in the multiple-stimulus without-replacement (MSWO) assessment.



4:17:05 p.m.

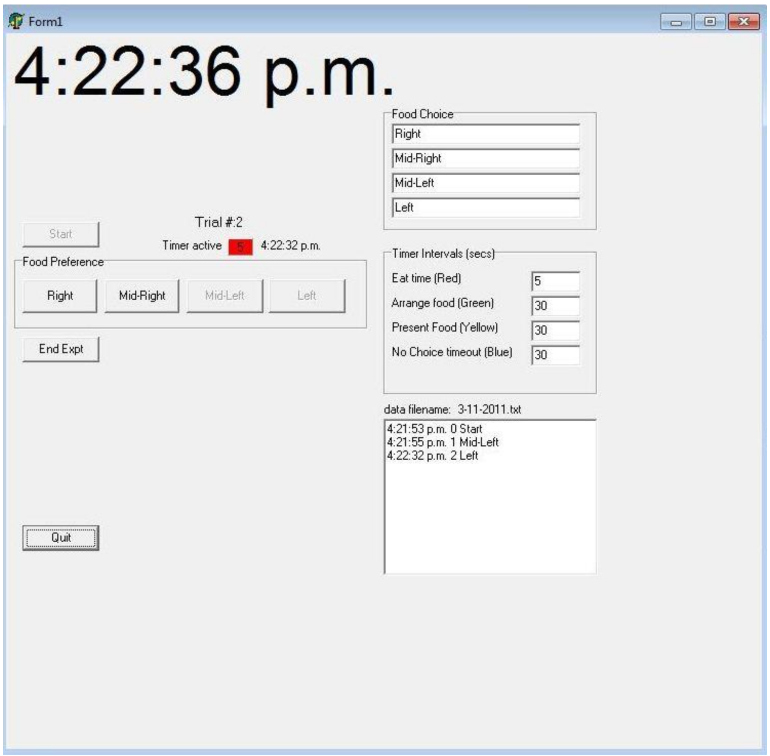
Trial #: 4
Timer active 30 4:16:48 p.m.

Food Choice: Right; Left

Eat time (Red) 5
Arrange Food (Green) 30
Present Food (Yelow) 30
No Choice timeout (Blue) 30

data filename: 3-11-2011.txt

```
4:14:20 p.m. 0 Start
4:14:21 p.m. 1 Right
4:14:59 p.m. 2 Right
4:15:36 p.m. 3 Left
4:16:13 p.m. 4 Right
```



4:22:36 p.m.

Trial #:2
Timer active 5 4:22:32 p.m.

Food Choice: Right; Mid-Right; Mid-Left; Left

Eat time (Red) 5
Arrange food (Green) 30
Present Food (Yellow) 30
No Choice timeout (Blue) 30

data filename: 3-11-2011.txt

```
4:21:53 p.m. 0 Start
4:21:55 p.m. 1 Mid-Left
4:22:32 p.m. 2 Left
```

Figure 3. The computer displays for the programs used to record choices and times. The top panel shows the program used during the paired-stimulus (PS) assessment, before a choice has been made on a hypothetical fifth trial. The bottom panel shows a hypothetical trial for the multiple-stimulus without-replacement (MSWO) assessment, where two options have already been selected, and so are unavailable to click.

been made on the fifth trial. A list of the selections made on previous trials was recorded on the screen, as well as saved by the program.

The experimenter’s timing program for the MSWO assessment was similar to the PS program, except that four buttons rather than two were available on the screen to click, and once one option was selected it was then unavailable for selection again until all four options had been selected, or a trial had timed out. Figure 3, which shows an example of what the computer screen displayed to the experimenter after two trials had passed in the first set of choices. The left and mid-left options are unavailable for clicking with the mouse, which matches the list of previous selections as both options have already been selected.

Procedure

All experimental conditions began between 9.30 and 11.30 am. They would finish according to the length of time required for the different experimental conditions.

Initial exposure to foods. Prior to the first experimental session, the foods to be used in the experiment were presented to the possums. 10 g of each food was presented, one food at a time to each possum. Each food was presented between one and six times. Up to three foods were presented successively per day, and no food presentations were repeated on one day. The amount the possum had consumed after 30 min was then measured. All foods were presented at least three times to each possum, regardless of consumption, with the exception of Cocoa Puffs™ and barley, which all six possums had previous experience of as a reinforcer. This was presented as many times as it took for each possum to consume at least 2 g on one occasion.

Initially, the intention was that in order for a food to be included in the PS assessment, the possum had to consume at least 2 g on three different presentations, or to have consumed all 10 g of the food in one time period.

Screech had not met the consumption criterion for including extruded rice, but it was decided that extruded rice would be included in the assessment as Screech had been recorded consuming 1 g and 2g on separate occasions, and had been witnessed consuming it by the experimenter. Also, all other possums had consumed the full 10 g of extruded rice on at least two occasions.

Dried peas were not included past the initial food sampling phase, as Bonnie had not consumed any dried peas at all after five days of presentation. It had also not been consumed as much as extruded rice had by the other five possums.

Two different preference assessment methods were conducted over three sessions per possum. The first session used a PS assessment with the remaining foods indicated above; the second session used four of the food types in a MSWO assessment; while the third session repeated a PS assessment using only the same four foods as in the second session. The order the foods were presented in for each assessment can be found in the Appendices.

Paired-stimulus assessment. For the first PS session, all possible pairings of the eight foods were presented to the possums for a total of 56 trials. The food tins were filled to half the volume of the tin with each food type in a different tin. The mass of the each food type was weighed before the experimental session began, and again afterwards to determine overall consumption.

The possums were presented with two tins in the middle-right and middle-left positions of the apparatus, as in Figure 4. The possum had 30 s to choose a food to consume, and the food selected was recorded. The possum then had up to 5 s access to that food tin, or until the possum raised its head from the grate. After a 30 s ITI, a new pair of the eight foods was presented. If no choice was made in 30 s, then that trial was ended and was recorded as ‘no choice’, and then after another 30 s ITI the next trial began. If two consecutive trials resulted in ‘no choice’, the experiment was paused, and was not resumed until the possum was on the bottom of the cage facing the experimental apparatus. If the next trial also resulted in ‘no choice’, then the experimental session was terminated. Otherwise, the session continued until all possible combinations of the foods were presented.

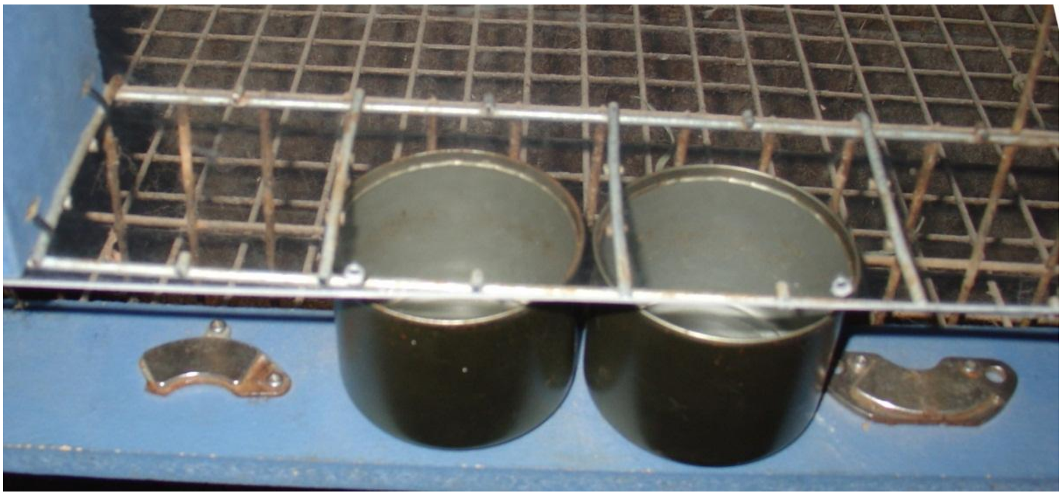


Figure 4. Tin presentation positions for the paired-stimulus (PS) assessment.

Under the second PS session (the third session overall), the same method was used as in the first session, however, only four foods were used, for a total of 12 trials. This was done so that as well as recording what choices were made, the total time taken for the assessment was also recorded, to draw a direct comparison to the MSWO assessment.

Multiple-stimulus without-replacement assessment. The MSWO preference assessment used four foods from the first PS assessment, determined by the preference hierarchy that the PS assessment produced, covering the range of preferences from most preferred to least. Only four foods were used because of limitations in the apparatus, specifically that there was not enough room to present any more than four foods to the animal at one time.

Each MSWO experimental session began with all four foods being presented simultaneously through the openings in the grate at the bottom of the preference apparatus, as seen in Figure 2. The time in which the possums were allowed to select a food, the access to the food, and the ITI were all the same as in the PS method. After the ITI, the possums were presented with the remaining three food tins, rotated by moving all tins one position to the right, with the right-most tin being rotated to the left-most position. An empty slot was left where the previously chosen food had been. The next trial would then begin, the timing for selecting a food began again. If no food had been selected in the 30 s time, or all four foods had been selected and no foods were left in the array, all four foods were presented again, in a new order. The session ended when all MSWO trials in had been conducted.

The method for calculating preference results for the MSWO assessment was adapted from Ciccone et al. (2006)’s point-scoring method, where the amount of points awarded to each food was presented as a percentage of the maximum amount of points possible if the food had been selected first each time.

Results

Figure 5 shows the average percentage of times each food was chosen, relative to the number of times it was presented over the three sessions for the PS assessment when it was conducted with 8 foods. For Bonnie, both soy protein and the almond and barley mixture were chosen 62% of times, which placed them tied for first. The Cocoa Puffs™ and barley mixture was chosen noticeably less than all other foods, at only 14% of times. For Olive, corn kernels were the most frequently selected food at 64% while the least-selected food was San Bran™ at 40%. For Caper, rolled oats were the most-selected food (67%), and soy protein was the least-selected (29%). For Peppi, the Cocoa Puffs™ and barley mixture was the most-selected (62%), and all other foods were chosen at least 40% of times with corn kernels and the almond with barley mixture tied for the lowest (40%). For Screech, soy protein was chosen considerably more than the other foods (79%) while corn kernels were chosen the least (19%). For Norrin, the most selected food was the Cocoa Puffs™ and barley mixture (69%), and soy protein was the least selected by far (2%).

Some of the information from Figure 5 is reprinted in Table 1, where only the four foods that were selected for use in further assessments are ranked according to which was chosen more frequently. A ranking of first indicates that the food was selected the most frequently out of the four foods included when compared against all eight foods shown in Figure 5. Relative to these four foods, the first-place ranked food for Bonnie was soy protein, while the lowest ranked food was Cocoa Puffs™ with barley. For Olive, the food ranked highest was Cocoa Puffs™ with barley, while the ranked last was San Bran™. For Caper, the food ranked first was rolled oats, while the food ranked lowest was soy protein. For Peppi, Cocoa Puffs™ with barley was ranked first, with San Bran™ ranked last. For Screech, soy protein was the highest ranked food, and the Cocoa Puffs™ and barley mixture was the lowest ranked. For Norrin, Cocoa Puffs™ with barley was ranked first, and soy protein was ranked in last-place.

Figure 6 shows the percentage preference scores for the four used foods under the MSWO preference assessment. These measures were calculated as outlined in the procedure. For Bonnie, rolled oats had the highest percentage at 74%, with Cocoa Puffs™ and barley the lowest at 32%. For Olive, all foods

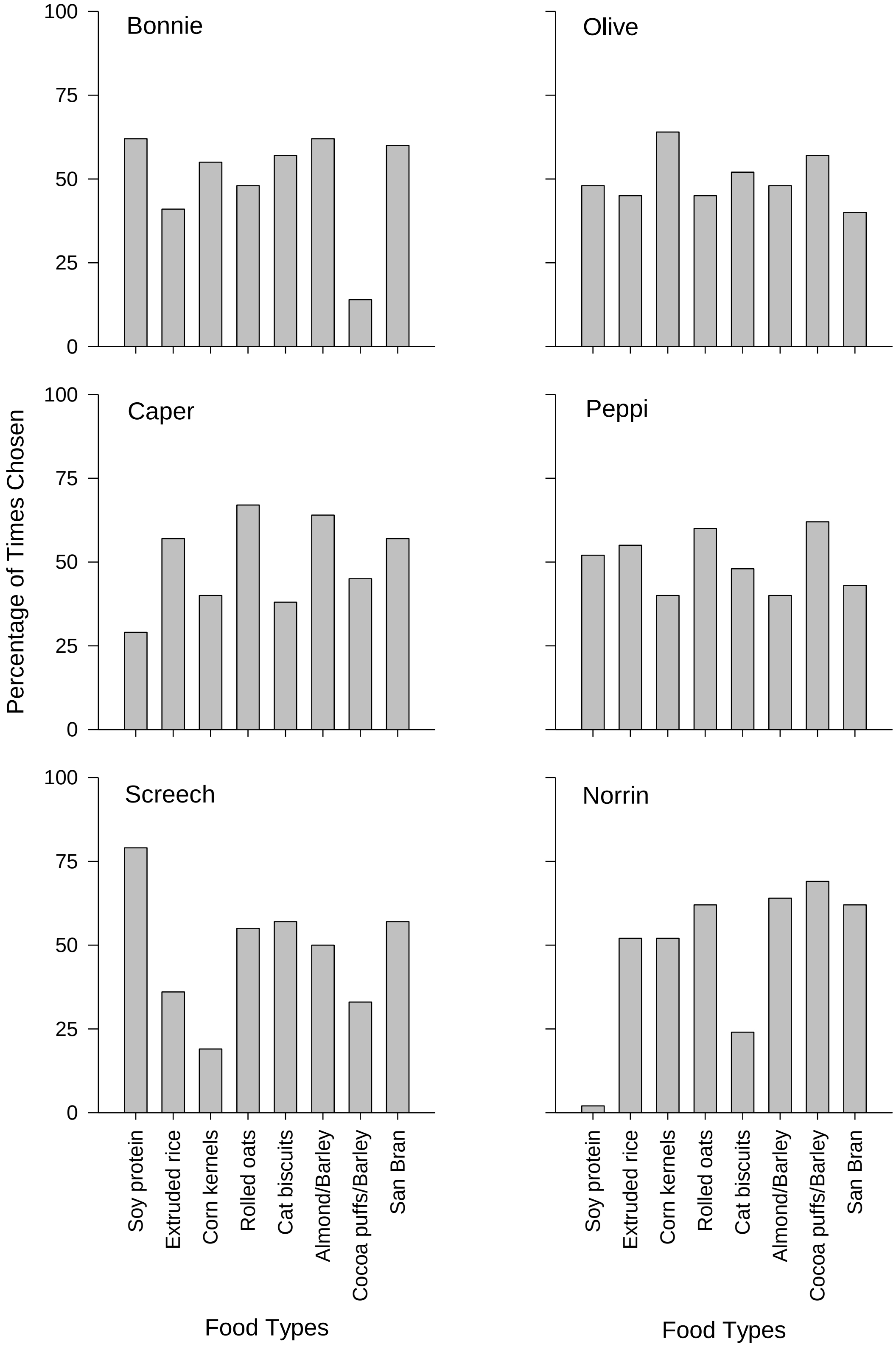


Figure 5. Percentage of times eight foods were selected by each possum, relative to the number of times they were presented under a paired-stimulus (PS) assessment.

Table 1.

Ranked Orders of Four Foods Used in the First Paired-Stimulus (PS) Assessment, Relative to Which Was Chosen the Most out of all Eight Foods.

	Ranked Selections			
Possum	1st	2nd	3rd	4th
Bonnie	Soy protein	San Bran	Rolled oats	Cocoa Puffs and Barley
Olive	Cocoa Puffs and Barley	Soy protein	Rolled oats	San Bran
Caper	Rolled oats	San Bran	Cocoa Puffs and Barley	Soy protein
Peppi	Cocoa Puffs and Barley	Rolled oats	Soy protein	San Bran
Screech	Soy protein	San Bran	Rolled oats	Cocoa Puffs and Barley
Norrin	Cocoa Puffs and Barley	Rolled oats	San Bran	Soy protein

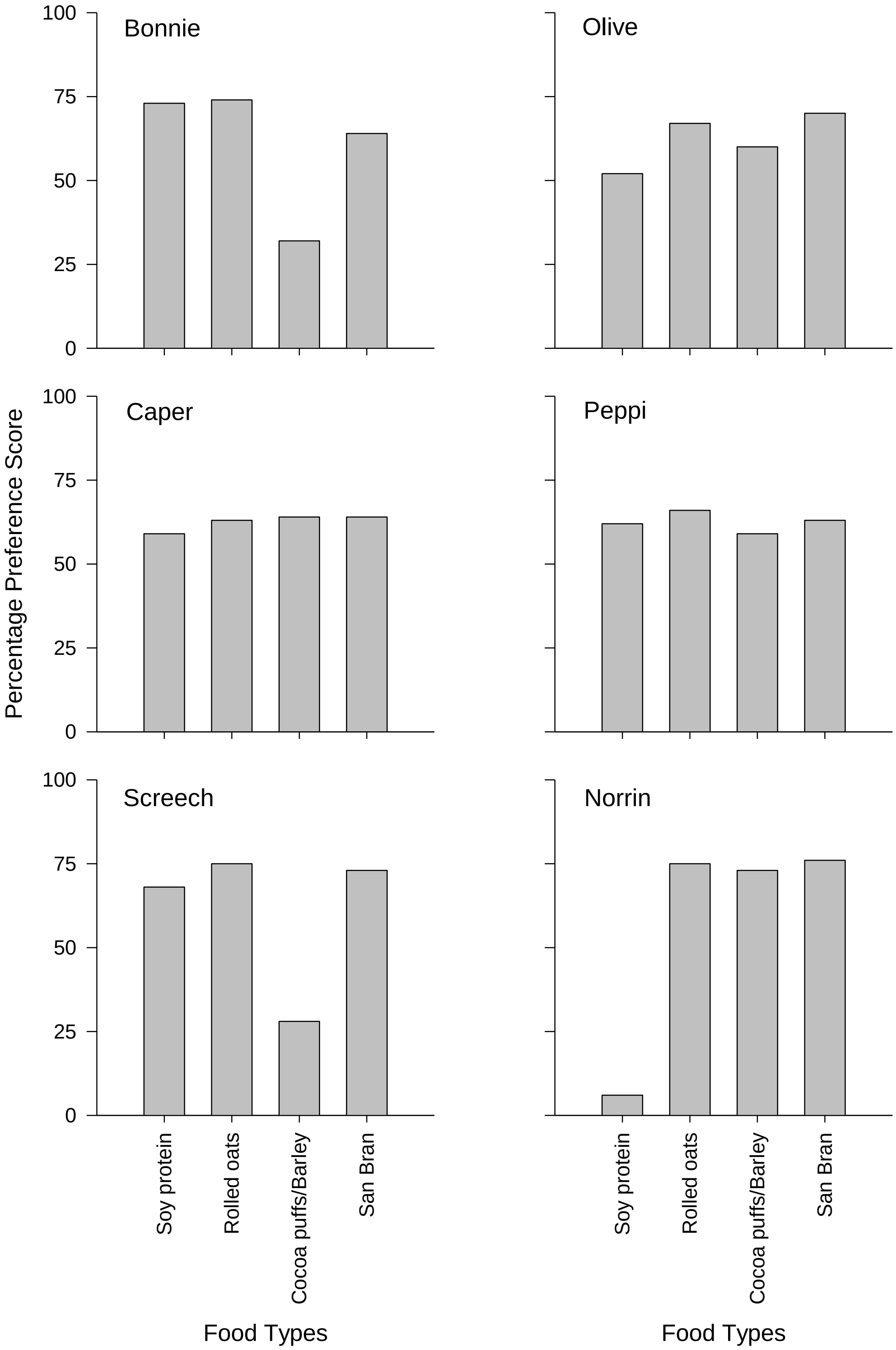


Figure 6. Percentage of maximum score under Ciccone et al.'s (2005) point-scoring method that four foods under a multiple-stimulus without-replacement (MSWO) assessment were rated based on each possum's selections.

scored between 50% and 70%, with the highest being San Bran™ (70%) and the lowest being soy protein (52%). For Caper, all foods had similar percentages. The highest rated foods were both Cocoa Puffs™ with barley and San Bran™ (64%) while the lowest rated food was soy protein (59%). For Peppi, all foods scored around 60%, with rolled oats being the highest (66%), and Cocoa Puffs™ and barley the lowest (59%). For Screech, the highest was rolled oats (75%), and the lowest was the Cocoa Puffs™ and barley mixture (28%. For Norrin, San Bran™ had the highest percentage (76%) and soy protein was considerably lower than all others (6%).

Figure 7 shows the average percentage of times each food was chosen in the repeated PS preference assessment, using just the four foods that appeared in Table 1 and Figure 6. For Bonnie, the most selected food was rolled oats, selected 83% of times it was presented. The least selected food was the Cocoa Puffs™ and barley mixture, which was not selected at all. For Olive, San Bran™ was the most selected (67%), and Cocoa Puffs™ with barley was chosen the least frequently (22%). For Caper, rolled oats was highest (61%), while both soy protein and Cocoa Puffs™ with barley were chosen the least (44%). For Peppi, soy protein was the most selected (67%), with San Bran™ the least selected (33%). For Screech, the most selected foods were both rolled oats and San Bran™ (both at 72%), and the Cocoa Puffs™ and barley mixture was not selected at all. For Norrin, the most selected food was San Bran™ (72%). Soy protein was not selected at all.

Table 2 shows the ranges between the overall highest- and the lowest- percentage of occasions in which a food was selected in Figures 1 and 3, and the overall highest- and lowest- percentage of the highest possible preference score shown in Figure 2, for each possum. All possums except Norrin showed the lowest range during the MSWO assessment, though the ranges produced by Norrin under all three assessments were all very similar. For both Caper and Peppi, the range produced by the MSWO assessment was extremely low. Bonnie, Olive, Peppi and Screech all showed an increase in range for the second PS assessment compared to the ranges produced by the other assessments.

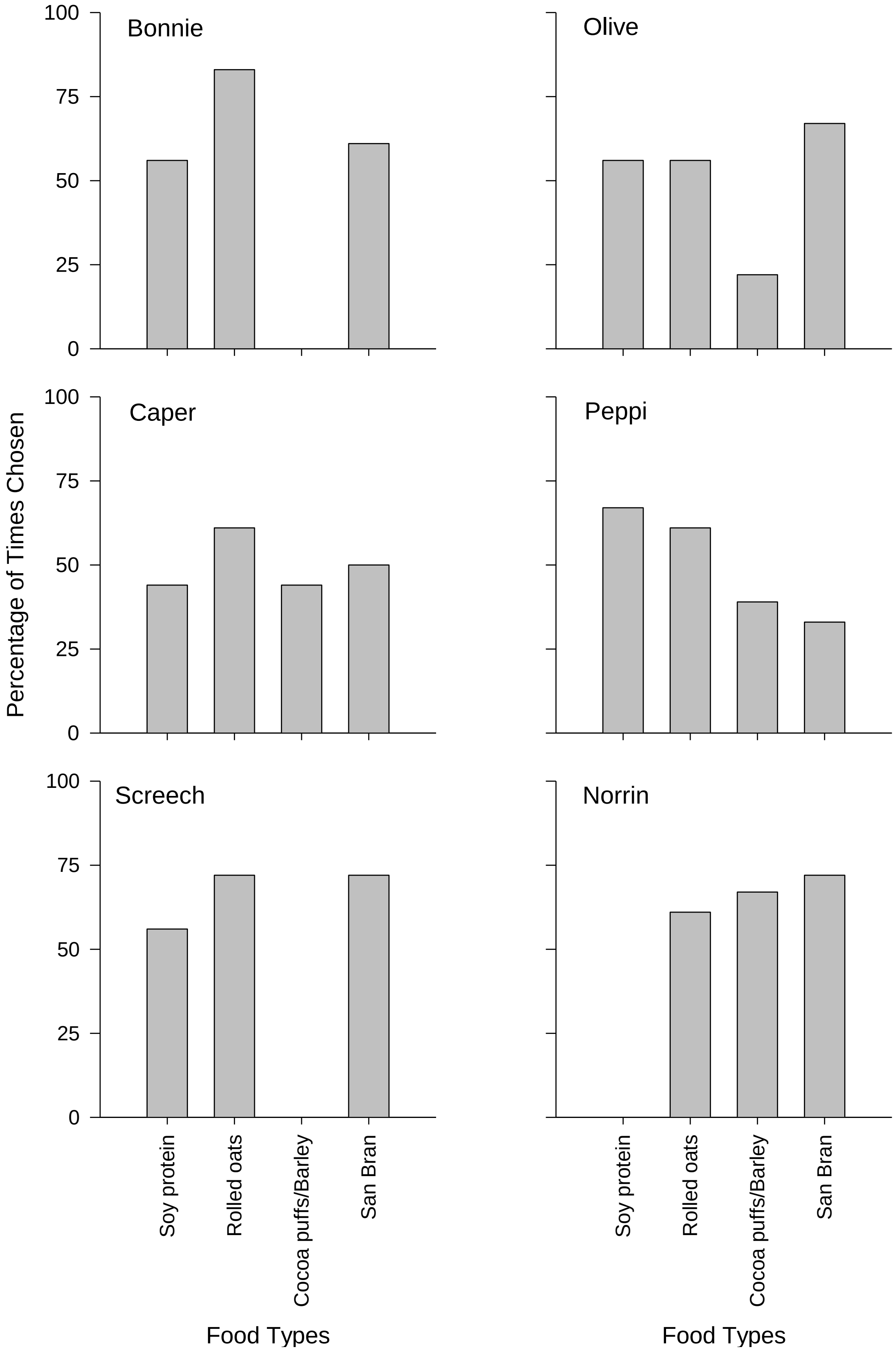


Figure 7. Percentage of times four foods were selected by each possum, relative to the number of times they were presented under a paired-stimulus (PS) assessment.

Table 2.

Total Range Between the Overall Highest- and Lowest-Percentage of Occasions a Food was Selected for Each Possum Under two Paired-Stimulus (PS) Assessments, and the Range Between the Overall Highest- and Lowest-Percentage of Maximum Preference Score Under a Multiple-Stimulus Without-Replacement (MSWO) and Preference Assessments.

	Assessment Type		
Possum	1st PS	MSWO	2nd PS
Bonnie	48%	42%	83%
Olive	24%	18%	45%
Caper	38%	5%	17%
Peppi	22%	7%	34%
Screech	60%	47%	72%
Norrin	67%	70%	72%

Spearman's rank correlation coefficient (r_s) was calculated to compare the rankings produced by the MSWO and the second PS assessment. The rankings can be seen in Figure 8 where each dot corresponds to the same food as ranked by both assessment methods. Whenever there was a tie between the preferences shown in Figure 5 or Figure 7, it was represented in Figure 8 and in the calculating of r_s by a ranking halfway between the two rankings. For example, for Caper the two least-selected foods were tied in the PS assessment, so rather than plotting them at 3 and 4 on the y-axis respectively, they are both represented as 3.5.

Overall, for Bonnie there was a fairly strong correlation between the rankings produced by the two methods, as r_s was 0.8. For Olive, the two methods produced rankings that were somewhat correlated ($r_s = 0.63$). For Caper there was little correlation between the rankings ($r_s = -0.11$). For Peppi there was no correlation between the rankings produced ($r_s = 0$). For Screech, the rankings were perfectly correlated ($r_s = 1$). For Norrin, there was a fairly strong correlation between the ranking ($r_s = 0.8$).

Table 3 shows the average times that each assessment took to complete with each possum, as well as the overall average. For all possums the MSWO assessment took significantly longer than the PS method to administer. The average session time for MSWO was over an hour long, while for the PS assessment when using the same four foods as in the MSWO assessment, all possums finished their sessions in less than 10 min. Even when the PS assessment used 8 foods, the average session time for all possums was just over half the session time for the MSWO assessment.

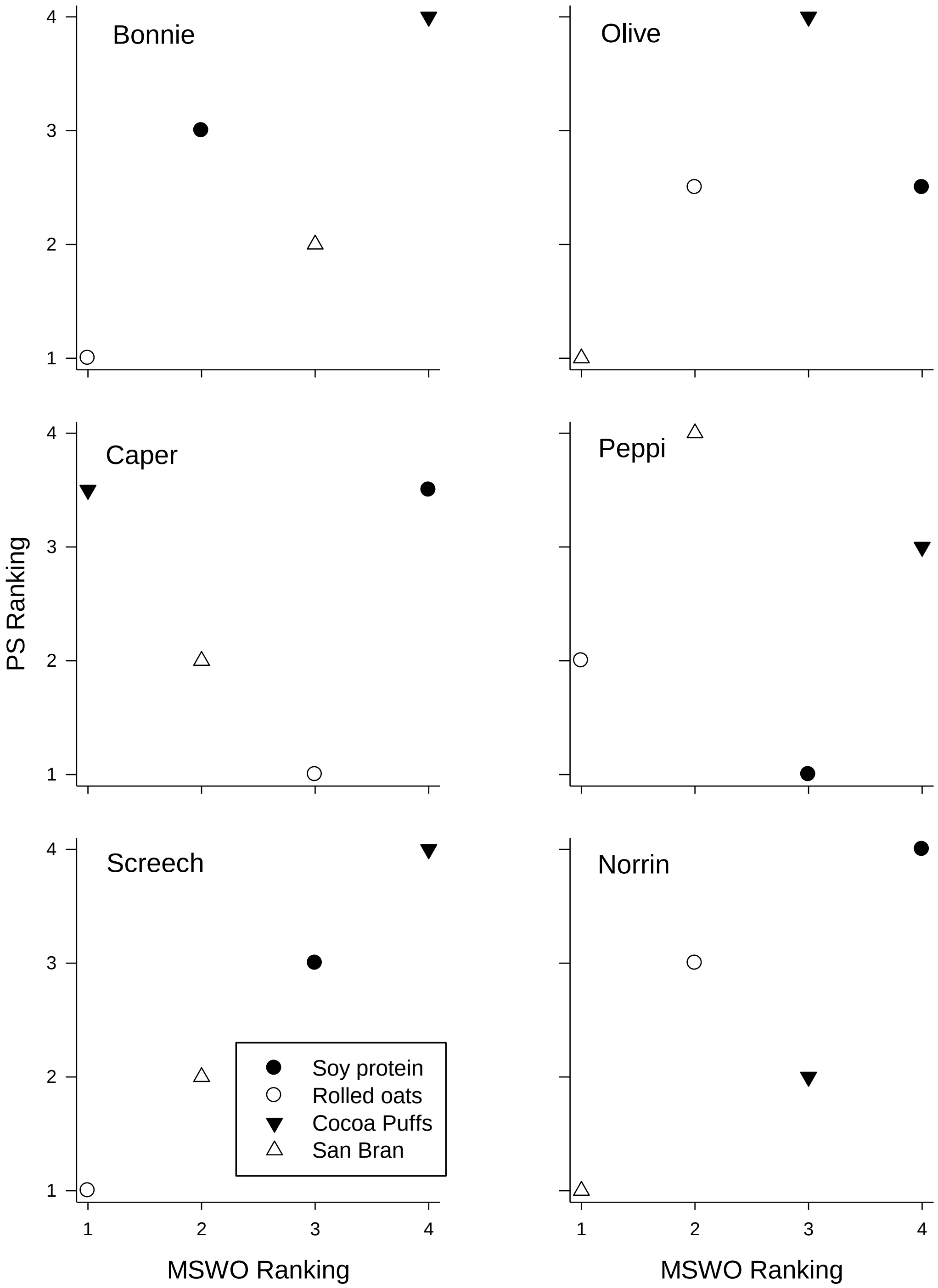


Figure 8. Comparison of rankings for four foods produced by a multiple-stimulus without-replacement (MSWO) method, and a paired-stimulus (PS) method.

Table 3.

Average Session Times in Hours by Each Possum for a Multiple-Stimulus Without-Replacement (MSWO) and two Paired-Stimulus (PS) Preference Assessments.

	Assessment type		
Possum	1st PS	MSWO	2nd PS
Bonnie	0:36:06	1:02:41	0:07:04
Olive	0:35:09	1:01:06	0:07:07
Caper	0:34:58	1:00:05	0:06:57
Peppi	0:34:47	0:59:38	0:06:59
Screech	0:39:09	1:02:32	0:07:01
Norrin	0:37:43	1:07:20	0:07:00
Overall Average	0:36:19	1:02:14	0:07:01

Discussion

This experiment aimed to compare the results of a MSWO preference assessment with those from a PS preference assessment with possums. Both the PS and MSWO produced generally similar preference hierarchies. Foods identified as more- or less-preferred relative to the other options, were generally consistent across the two methods. This reflected the findings of previous research (DeLeon & Iwata, 1996) that has shown that both PS and MSWO produce similar hierarchies when used with humans.

The difficulties of each assessment to implement, as represented by the time it takes to administer each assessment, were also compared. The PS method took considerably less time to administer than the MSWO method. This was in contrast to the findings of DeLeon and Iwata (1996), where MSWO took less time to administer.

Preferences under a Paired-Stimulus Assessment with Eight Foods

The experimental apparatus allowed for only a maximum of four foods to be presented to a possum under the MSWO assessment condition. The first PS assessment was conducted and used to identify stimuli that were possibly of high- or low-preference, so that four foods could be chosen for further study that would represent a wide range of preferences.

The percentage of times each possum selected a food when it was presented to them, relative to the other choices available, was used as a measure of the possums' preference for that food. It was found that the possums' food preferences were idiosyncratic, as no particular food was consistently chosen or avoided across possums. This is consistent with past research into preferences of individual organisms (Armistead, 2009; Fernandez, et al., 2004; Hudson, et al., 1999; Martin, 2002). As the range between the most frequently selected food and the least-selected showed, some possums also had much more variation in their degree of preference than others.

Despite the idiosyncrasies in each possums' food preferences, the PS assessment using eight foods was able to identify four foods that covered the whole range of possible preferences (highly-preferred, moderately-preferred and low-preferred) for all possums. The foods weren't necessarily in the same position for each possum, but the same foods were chosen to be used in further assessments.

Preferences under a Paired-Stimulus Assessment with Four Foods

As in the first PS assessment here, and in past research (Armistead, 2009; Fernandez, et al., 2004; Hudson, et al., 1999; Martin, 2002), the preferences obtained for each possum were idiosyncratic. Also as in the first PS assessment, the ranges between the percentage of frequency that the foods were chosen for the highest- and lowest- rated foods varied between possums.

Table 1 and Figure 7 show that for 5 out of 6 possums the least-selected food out of the four foods chosen for further use was the same under both PS assessments. The most-selected food was only consistent between both PS assessments for one possum. As there was approximately a month between assessments, this suggests that showing low-preference for the foods was more stable over time than high-preference. Ciccone, Graff, and Ahearn (2007) found that stability of preference for edible items with individuals with developmental disabilities over time was generally quite good. However, they found no noticeable difference between the stability of preference for high- and low-preferred stimuli. The results of this experiment suggest that if a stimulus tends to be avoided, the possums will choose against this stimulus more frequently than they will choose to approach a stimulus that is higher preferred.

Preferences under a Multiple-Stimulus Without-Replacement Assessment

The preferences identified for each possum through the MSWO preference assessment were idiosyncratic, zs was found for both PS assessments. The range of preference scores of the most-preferred and the least-preferred food also varied for each possum, as with the range of times chosen for the PS assessments.

Spearman's ranked correlation coefficient between the rankings for the MSWO assessment and the PS assessment for each possum showed that for 4 out of 6 possums, there were moderate to very high correlations. This suggests that both assessments identified similar stimuli as being potential reinforcers. DeLeon and Iwata (1996) also found moderate to very high correlations between their

MSWO and PS rankings, however, they found these for every participant in their study.

The 2 possums that did not show high correlation between the hierarchies produced by the PS and MSWO methods generally had the lowest range from the most- and least-frequently chosen stimuli (Table 2). This means that all four foods were chosen on a similar number of occasions, suggesting that all may be of similar preference for these possums.

The correlation between preference hierarchies produced by both the PS and MSWO method for four of the six possums used suggests the two methods would have similar effectiveness at predicting stimuli that would function as reinforcers, a similar finding to DeLeon and Iwata (1996).

Administration Time

The MSWO method took significantly longer to administer than the PS method even when both methods used the same number of different stimuli. This is the opposite to the findings of DeLeon and Iwata (1996). They suggested the quicker administration time was an advantage of the MSWO method. Based upon the time taken to administer in this experiment, the PS method is likely to be more appropriate than the MSWO method for use in applied settings. There were differences in the procedure used for the MSWO preference assessment here, compared to that used by DeLeon and Iwata (1996) with humans, however, which will be discussed later in the General Discussion.

Experiment 2

This experiment conducted a reinforcer assessment for each of the four foods that were used in both preference assessments in Experiment 1. The aim of this reinforce assessment was to examine whether the preference hierarchies identified through MSWO or PS assessments would predicted the performance of possums on a PR schedule for each of the four foods. The response rates, break points, PRPs and obtained reinforcement rates on each ratio of the PR schedules were examined, as with many other studies using either PR or FR schedules. Demand functions were fitted to the consumption rates using Equation 1 (Hursh et al., 1988), and the point at which the slope of the functions grew steeper than -1 was examined using the $P_{\max}$ values (Hursh & Winger, 1995).

Method

Subjects

Experiment 2 involved 5 of the possums (Caper, Peppi, Screech, Norrin & Bonnie) that had participated in Experiment 1.

Apparatus

The door panel of the home cage served as the experimental apparatus. The dimensions of the panel can be seen in Figure 9. For four of the possums (Caper, Peppi, Screech, & Norrin), two amber LED lights were displayed on the apparatus, and below these were two small holes in which micro-switch levers could be inserted. A feedback beep sounded following a successful lever press. Below the lever holes there were two openings in which the food magazines were placed, which could be filled with the food types that were being worked for.

Bonnie’s experimental panel differed in that there was only one light, lever and food magazine. These were identical to those used by the other four possums, except they were situated directly in the middle of the panel.

Procedure

Prior to participating in this experiment, all 5 possums had experience pressing levers to receive access to food.

For Caper, Peppi, Screech and Norrin, only one of the two magazines in the apparatus was made available in each session. As such, the corresponding lever and light on that side of the panel were also the only ones used in that session. The side that was in use alternated for each session, so if in one session the lever, light and magazine on the right-hand side were in use, then during the following session the lever, light and magazine on the left-hand side were used.

All four food types used in the MSWO assessment of Experiment 1 were used as reinforcers. The order they were used in can be found in the appendices. A possum would progress onto the next food in the table after at least six sessions were conducted (three sessions on each of the right and left levers for Caper, Peppi, Screech and Norrin) where at least three reinforcers were obtained.

Figure 9. Photo of the response panel for Caper, Peppi, Screech and Norrin showing the positions of the lights, response levers and magazine openings.

Before each session started, the equipment was tested, and the lever to be used in that session was inserted into the hole in the response panel. The possums were then required to be on the bottom of the cage before the session would be started. When the amber light above the lever turned on, it signalled the beginning of the session.

The schedules used for all five possums were the same, and were controlled by a computer program in MED-PC® IV. The first 1.5 s access to food was available after each possum made one response on the lever (fixed-ratio 1 (FR 1)), and after that access to reinforcement was available on an arithmetic progressive-ratio of 10 (PR 10) schedule, so that after every reinforcement received, the next access to reinforcement would be provided after the possum made 10 more responses than were required for the previous reinforcer. This was not dependent on the initial FR 1, therefore the number of responses required for each access to reinforcement went 1, 10, 20, 30, and continued in this fashion until the termination of the experiment.

The point at which no responses were made after 300 s had passed was deemed the ‘break point’ of the PR schedule. Each session terminated either when this break point was reached, or after the session had been running for 120 min without reaching break point.

At the end of each session, the reinforcer used, the total responses made, the highest PR ratio reached, the total reinforcers obtained, the total session time, and the total time each possum spent eating from the magazine were recorded. As well as this, the computer program recorded the times that every event occurred in the experiment.

Results

Table 4 shows the break points averaged over six sessions for each possum when each food was made available on a PR schedule of reinforcement. The highest overall break point was reached by Screech when responding for rolled oats (185), and the lowest break point was reached by Bonnie for San Bran™ (30). Responding for San Bran™ generally resulted in all possums reaching their lowest break points, and responding for rolled oats tended to produce higher break points for most possums.

Figure 10 shows the response rates averaged over six sessions for each possum on each PR, plotted against the log to the base 10 of the PR schedule requirements. Averages were calculated when there were at least three sessions for which that ratio was reached. If each of the break points of four sessions were at 100, for example, no data would be included for ratios 110 and onwards, even if the schedules requirements were met for the other two sessions. Generally, all response rates showed bitonic functions, and responding for San Bran™ tended to produce the highest initial response rates across possums, before dropping off.

For Bonnie, San Bran™ produced the highest overall response rates, while the Cocoa Puffs™ and barley mixture showed lower response rates. For Caper, responding for soy protein showed higher response rates at higher schedule requirements and response rates for San Bran™ For Peppi, responding for rolled oats produced higher response rates at higher schedule requirements, and responding for Cocoa Puffs™ and barley was generally at slower rates. For Screech, responding for Cocoa Puffs™ and barley showed the highest peak in responding, and San Bran™ dropped off the earliest. For Norrin, responding for the Cocoa Puffs™ and barley mixture produced higher rates at higher schedules, and no food consistently produced the lowest response rates.

Figure 11 shows each possums' PRP durations for the four foods from six sessions averaged in the same manner as the response rates, plotted against the log of the PR schedule requirements. PRPs for all possums, responding for all foods, tended to increase as the schedule requirements increased. For Bonnie, the Cocoa Puffs™ with barley mixture showed steeper increases in PRP duration, and responding for San Bran™ showed the lowest PRPs. For Caper, soy protein

Table 4.

Average Break Point Achieved by Each Possum for Four Foods Under a Progressive-Ratio (PR) Schedule.

	Break Point for Each Food			
Possum	Cocoa Puffs with Barley	San Bran	Soy Protein	Rolled Oats
Bonnie	40	30	78.33	115
Caper	105	65	125	75*
Peppi	141.67	135	153.33	181.67
Screech	165	123.33	170	185
Norrin	176.67	71.67	108.33	138.33

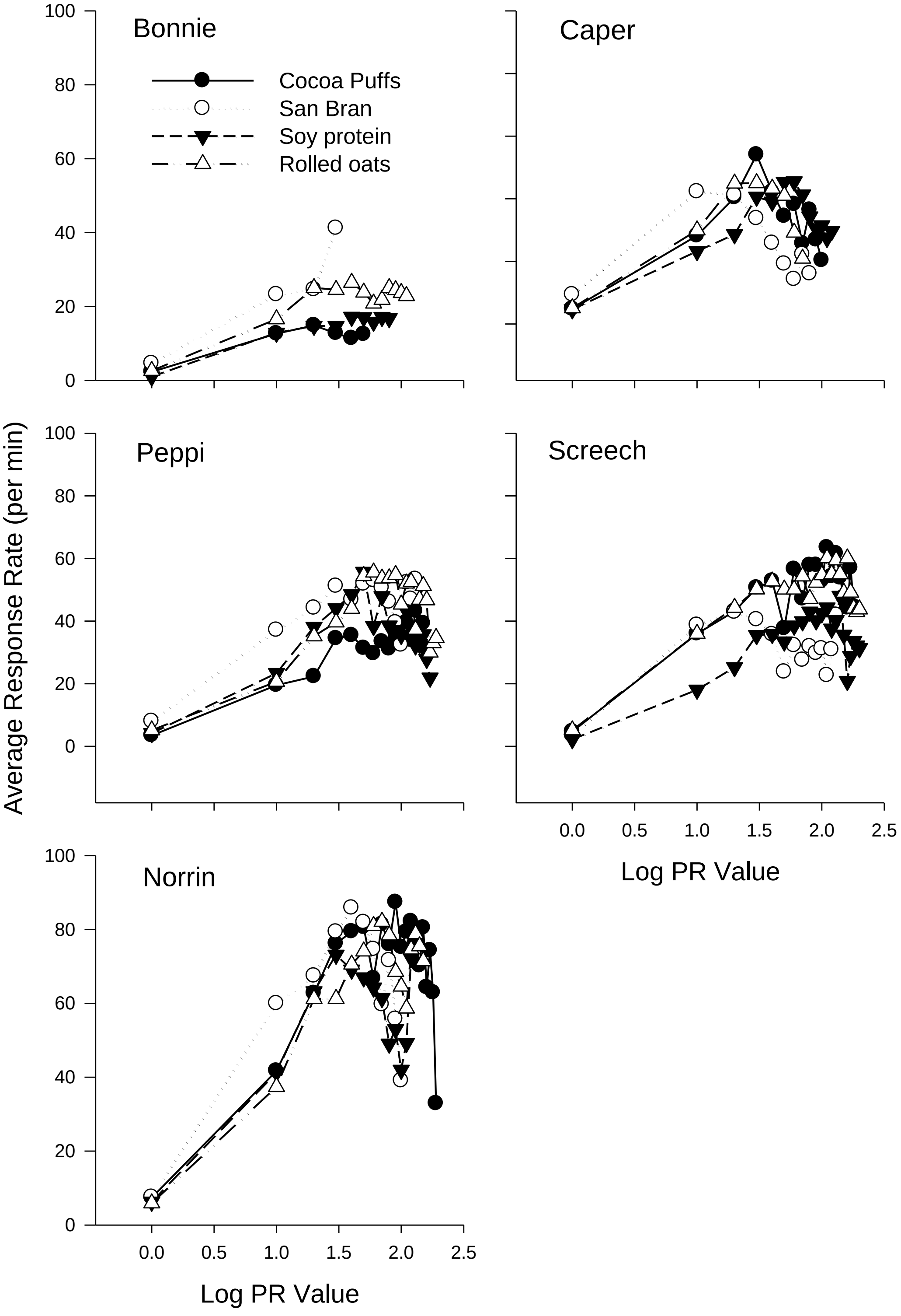


Figure 10. Average response rates per minute for four foods on progressive-ratio (PR) schedules of reinforcement.

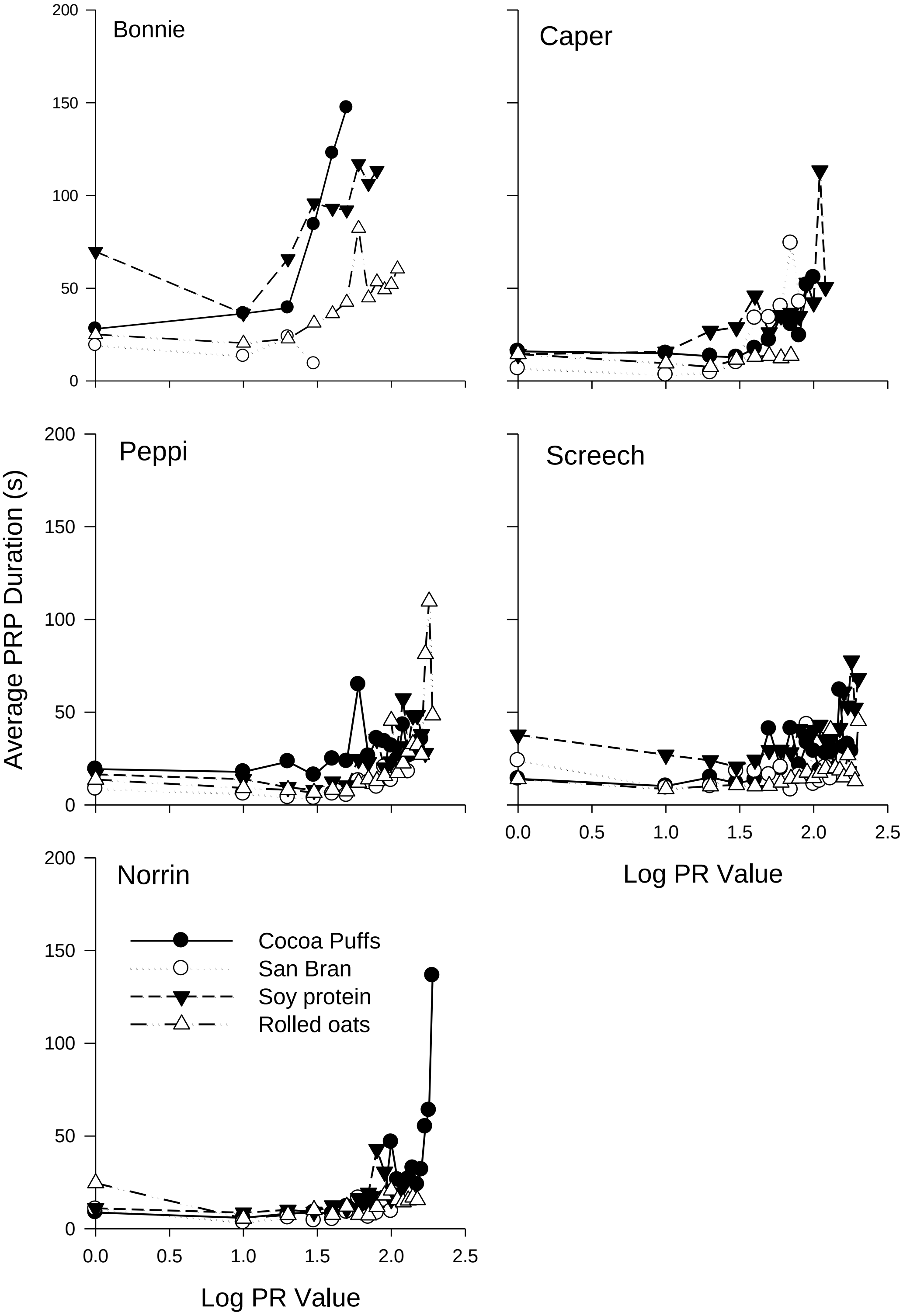


Figure 11. Average post-reinforcement pause (PRP) in seconds for four foods on progressive-ratio (PR) schedules of reinforcement.

increased slightly quicker than the others, eventually achieving the longest PRP duration. Responding for rolled oats generally showed the smallest PRPs. For Peppi, longer PRP durations were shown when responding for rolled oats as schedule requirements increased, and the PRPs for responding for San Bran™ were slightly lower. For Screech, responding for soy protein showed the highest PRP durations, and the PRPs observed when responding for both San Bran™ and rolled oats were fairly low in comparison, with little difference between them. For Norrin, PRPs generated when responding for the Cocoa Puffs™ and barley mixture rose to higher levels, while the PRPs generated when responding for San Bran™ were lower.

Figure 12 shows the log of the reinforcer consumption rate per min, averaged in the same manner as the response rates and PRPs, for each food plotted against the log of the schedule requirements. The fitted lines were calculated using Equation 1 (Hursh, et al. 1988). *Table* 5 presents the parameters a, b, and ln L, for this equation, derived from the method of least squares, as well as the percentage of the variance covered by the lines, the standard errors of the estimates, and the $P_{\max}$ value described by Equation 2. The percentage of variance that the fitted lines accounted for was above 90% for all possums under all foods, except on two occasions. The fitted lines for Bonnie and Screech on San Bran™ accounted for between 80 and 90% of the variance in the data. This poorer fit was also reflected in higher standard error of estimates for these two conditions.

The parameters a, b, and ln L in Table 5 describe the demand functions shown in Figure 12. Initial slopes of the demand curves (b) tended to be negative, and the rates of change (a) were generally quite low (ranging between 0.002 and 0.040). For Bonnie, San Bran™ showed the highest initial demand (ln $L = 1.368$), and the function did not decrease as steeply as the other foods did. At higher log PR values, the function for the Cocoa Puffs™ and barley mixture was lower. For Caper, San Bran™ showed the highest initial demand (ln $L = 2.348$), but then the function dropped off quite steeply. The functions for the three other foods were all quite similar at higher log PR values. For Peppi, San Bran™ gave the highest initial demand (ln $L = 2.108$) and Cocoa Puffs™ and barley gave the lowest (ln $L = 1.334$). These patterns stayed similar as log PR increased.. For Screech, soy protein had the lowest initial demand (ln $L = 0.730$), and the function was

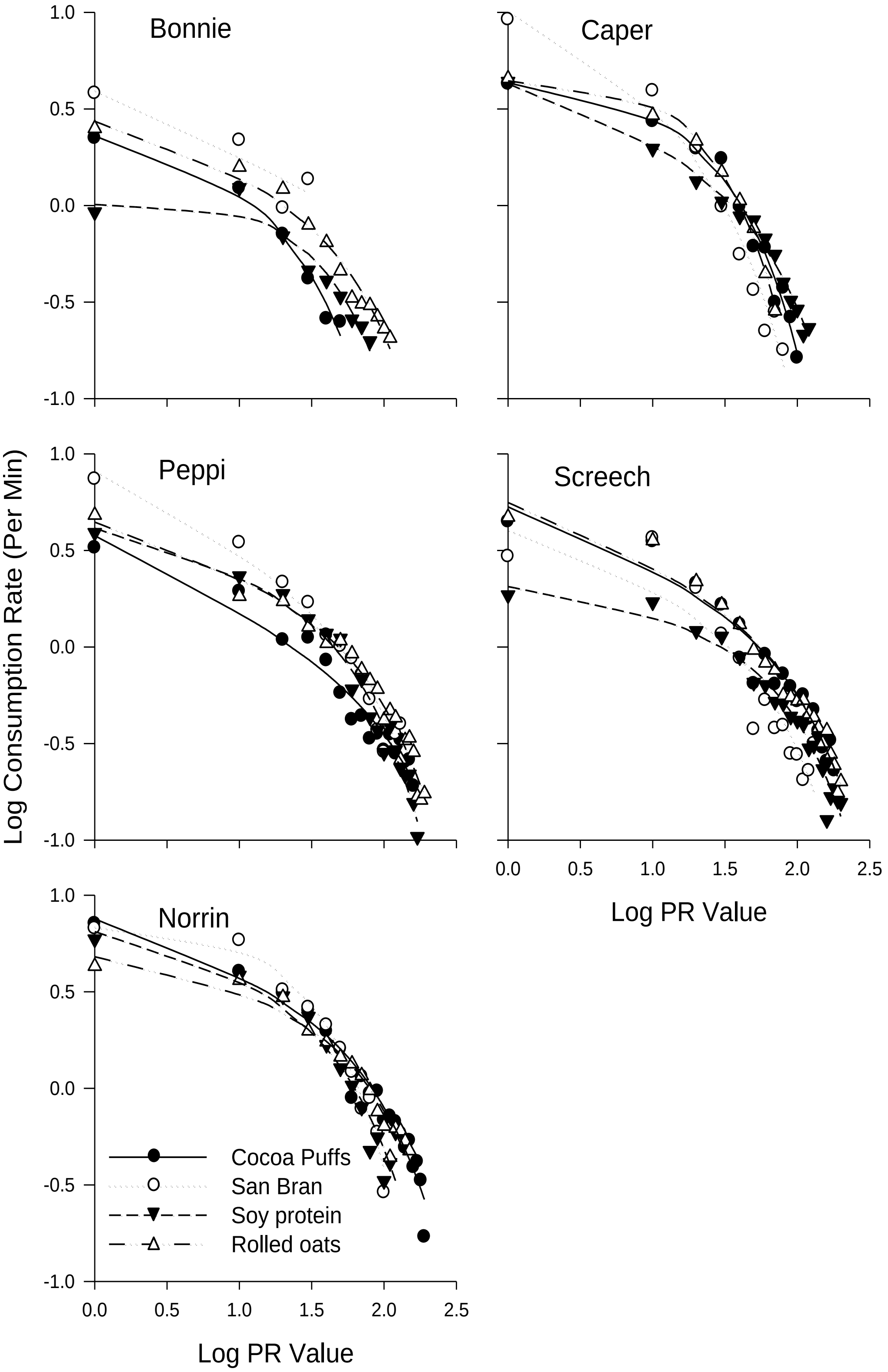


Figure 12. Average log 10 consumption for foods under progressive-ratio (PR) schedules of reinforcement. Also plotted are the lines of fit shown by Equation 1 (Hursh et al., 1988).

Table 5.

The Parameters a, b, and ln L for the Fitted Lines in Figure 12 Using Equation 1 (Hursh et al., 1988). The Percentage of Variance Covered by the Fitted Lines (%Var), the Standard Errors of the Estimates (SE), and the P_{max} Value Calculated by Equation 2 (Hursh & Winger, 1995) are also Shown.

Possum	Food	*a*	*b*	ln *L*	%Var	SE	$P_{\max}$
Bonnie	Cocoa Puffs with barley	0.034	-0.184	0.863	98	0.163	24
	San Bran	0.002	-0.337	1.368	82	0.432	285
	Soy protein	0.024	0.0298	0.035	94	0.183	43
	Rolled oats	0.014	-0.244	1.018	97	0.148	52
Caper	Cocoa Puffs with barley	0.029	-0.086	1.493	98	0.171	31
	San Bran	0.031	-0.404	2.348	97	0.266	19
	Soy protein	0.015	-0.268	1.465	99	0.098	50
	Rolled oats	0.040	0.015	1.525	99	0.082	25
Peppi	Cocoa Puffs with barley	0.006	-0.380	1.334	95	0.185	98
	San Bran	0.011	-0.399	2.108	96	0.213	54
	Soy protein	0.014	-0.206	1.430	98	0.198	55
	Rolled oats	0.010	-0.261	1.497	98	0.148	73
Screech	Cocoa Puffs with barley	0.009	-0.305	1.678	95	0.199	81
	San Bran	0.014	-0.267	1.405	87	0.378	51
	Soy protein	0.010	-0.125	0.730	96	0.166	83
	Rolled oats	0.009	-0.311	1.731	97	0.152	79
Norrin	Cocoa Puffs with barley	0.010	-0.268	2.029	96	0.185	71
	San Bran	0.028	-0.019	1.947	97	0.175	34
	Soy protein	0.017	-0.199	1.884	93	0.266	47
	Rolled oats	0.011	-0.153	1.580	95	0.173	73

generally the lowest of all the demand functions. There was no food that showed considerably higher demand than the others for this possum. For Norrin, the demand function for rolled oats showed the lowest initial demand (ln $L = 1.580$), and function for San Bran™ did not decrease as quickly as the other foods, but as log PR values increased, the functions for all foods became similar.

Table 5 shows the $P_{\max}$ values for the demand functions for each possum responding for each food. These are the ratios at which the slope of the demand function grew steeper than -1. The highest $P_{\max}$ value was produced by Bonnie for San Bran™ at 285. No other $P_{\max}$ value was above 100. The lowest $P_{\max}$ value was produced by Caper for San Bran™ (19). For Peppi, the highest was for Cocoa Puffs™ mixed with barley (98) and the lowest was for San Bran™ (54). For Screech, the highest was soy protein (83) and the lowest was San Bran™ (51). For Norrin, the highest was rolled oats (73) and the lowest was San Bran™ (34).

Discussion

This experiment aimed to compare the performance of 5 possums under a PR 10 schedule of reinforcement for four different foods, to determine which food functioned more effectively as a reinforcer for each possum, characterised as supporting higher rates of responding, larger break points, and more inelastic demand.

Break Points

If a possum stopped responding on a lever for 5 min, the current schedule requirements of the PR schedule was deemed the break point, and the session would terminate. Comparing the break points between different foods can suggest which food functioned as a stronger reinforcer. When a break point for one food is higher than for another, it means that the organism performed more total responses in order to continue gaining access to the higher food, than it did for the other.

Though there was great variation in the break points achieved by each possum, the foods that produced the highest and the lowest break points were fairly consistent between possums. For 3 out of 5 possums, rolled oats gave the highest break point, while for all possums the lowest break point was achieved while being reinforced with San Bran™. This consistency was surprising, given the idiosyncratic nature of preferences identified during the PS and MSWO assessments in Experiment 1. Francisco et al. (2008) had shown that high- and low-preference stimuli identified from a PS assessment were strong predictors of which stimuli would give higher or lower break points respectively on a PR assessment. In this experiment, rolled oats were generally highly-preferred for all possums in Experiment 1, but San Bran™ was not generally low-preferred. The results of Francisco et al. (2008) were only shown, then, for stimuli identified as being of high-preference.

Response Rates

Unlike the consistency found in the break points, there was no consistency in the food that gave the highest or the lowest response rates across all possums. San Bran™, despite reaching the lowest break point, tended to give higher initial response rates than other foods for all possums. This was not found with humans (seen in the graphs for Roane et al., 2001) or on low FR schedules with horses (Armistead, 2009). Foods that produced higher break points tended to be associated with higher response rates than other foods as break point neared. This is consistent with past research finding that stimuli function differentially as reinforcers at high- and low-schedule requirements (DeLeon, et al., 1997; Tustin, 1994). So, this suggests that looking at break point could be a suitable measure of quickly identifying which stimuli may function as effective reinforcers for more difficult tasks.

Regardless of the food used, response rates generally gave bitonic functions, as Hursh (1978, 1980, 1984) found. The exception to this was the response rate function for Bonnie when responding for San Bran™. An initial increase in slope at low ratios was present, as would happen in a bitonic function, the tail-end of the function was not present. When Bonnie was reinforced with the other three foods, a flatter response rate function was produced. These may be a reflection of the food that Bonnie generally reached the lowest break-points on, and so experienced fewer ratios. It may also be a product of the way the response rates were averaged, where the bitonic functions shown in individual session data were lost, due to there being fewer than three sessions that reached that ratio.

Hursh (1978, 1980, 1984) stated that bitonic functions were more likely to occur when the experiment was conducted under closed-economy conditions. Because this experiment maintained animals at a stable body weight it was necessary to provide supplementary feed to the possums, creating an open-economy. The response rate functions were similar to those Armistead (2009) found with horses on FR schedules, which also used open-economy conditions and found bitonic functions. If presented under closed-economy conditions, however, the response rates produced by all foods for all possums might have continued to increase (Hursh, 1980, 1984), and the break point reached would then be higher.

Post-Reinforcement Pauses

The delay between receiving reinforcement and beginning to respond again generally increased as the schedule requirements were increased across all possums and foods. This finding is similar to those seen with FR schedules hens (Foster et al., 1997) and possums (Hudson et al., 1999).

For 4 out of 5 possums, the food that was identified as having the lowest break point also generated shorter PRP durations. This result was also shown by Foster et al. (2009) with hens, and is consistent with foods with the lowest break points having the highest initial response rates, as the possums pause less and respond more.

There was no relation between the foods that possums recorded higher PRPs for, and the break points reached for those foods. There was also no relationship between the PRPs and the response rates for those foods. Armistead (2009)'s findings contradicted this statement, as it was found that responding for a stimuli that produced higher response rates generally produced lower PRPs.

Demand

For all possums with all foods, as the schedule requirements increased the demand for the reinforcer tended to decrease. Equation 1 described the trend of observed demand well, with the lowest percentage of variance accounted for by the fitted lines being 82%. Most were above 90%, which matches Hursh et al. (1988)'s findings. It also matches the fits found in other research that identified the variance accounted for by their fits (Armistead, 2009; Foster et al., 1997).

All functions, save for those for Bonnie when the reinforcer was San Bran™ showed mixed elasticity. The $P_{\max}$ values calculated by Equation 2 showed the ratio where, as the schedule requirements increased, the slope of the demand function grew steeper than -1, changing from inelastic to elastic demand. When Bonnie was responding for San Bran™, the $P_{\max}$ value was much higher than the ratio requirement that Bonnie achieved, which means that the demand for San Bran™ remained inelastic throughout the period where Bonnie was responding. This is surprising, as under an open-economy it was expected that demand for reinforcement would give mixed-elasticity as did results shown by Armistead (2009). Instead, the results of Bonnie for San Bran™ resemble the results Hursh (1978, 1980, 1984) predicted for closed-economic conditions. The most likely explanation for this deviation from what was predicted is that there were not enough actual data points to accurately reflect a complete demand function. As previously discussed, because the break point that Bonnie reached for San Bran™ was low, the tail end of a bitonic function for response rates was not present, and patterns of response rates from individual sessions were lost.

The rate of change in elasticity (*a*), the initial slope of demand (*b*), and the initial demand (ln *L*) did not show a consistent pattern when compared to the break points that each possum achieved on each food. There was a slight trend for the food that produced the highest *a* value, and the steepest *b* value to result in the lowest response rates at higher schedule requirements, and that foods that resulted in the higher initial response rates generally had higher ln *L* results. There was no general trend shown by *a* and *b* as PRPs changed, though the higher the ln *L* value, then generally the initial PRPs were shorter. Armistead (2009) had found on FR schedules that the *a* and *b* values showed no distinct trends compared to the other measures, so these results are not surprising.

Overall, the break points, response rates, and measures of demand all showed similar results as each other, suggesting that they are each suitable measures of assessing preference on increasing schedules of reinforcement.

Experiment 3

Experiment 2 examined responding on single PR schedules for each of the four foods used in Experiment 1. This next experiment examined the effects of making each of the four foods concurrently available. The aim was to compare performance on the PR schedules for the four foods when each of the others was available on an FR 20, and on an FR 50.

One aim of this experiment was to compare how performance on a PR schedule for the foods used in Experiments 1 and 2 would change when one of the other foods was made concurrently available on a constant FR schedule. The same measures (response rates, break points, PRPs and reinforcer consumption rates), as well as lines of fit plotted from Equation 1 (Hursh et al., 1988) and the $P_{\max}$ values from Equation 2 (Hursh & Winger, 1995) were used as in Experiment 2. Only the data from the PR schedule was examined, so as to draw direct comparisons between patterns produced in Experiment 2 to those in Experiment 3.

It was predicted that the foods would be substitutes to some degree. As discussed in the main intro (Hursh, 1980)**,** response rates would be higher, and PRPs lower when the alternative foods were on an FR 50 schedule, than on an FR 20. The preference rankings from Experiment 1 were expected to match the degree to which these changes occurred. Foods ranked higher for a possum were predicted to reach greater response rates, break points, consumption rates and $P_{\max}$ values on the PR schedule than low ranked foods. When the highly ranked foods were on the FR alternative, it was expected that the same measures on the PR food would be less than if low ranked foods were on the FR schedule.

Method

Subjects

Experiment 3 involved the same 5 possums as Experiment 2.

Apparatus

The experimental apparatus for all 5 possums was the same as that used by Caper, Peppi, Screech, and Norrin in Experiment 2, and shown in Figure 9.

Caper began ‘stealing’ food from an inactive magazine after a session. This was prevented by removing the magazines from Caper’s apparatus following the end of every session, and reattaching them before the next session began.

Procedure

The beginning of the session was identical to that of Experiment 2, save that both magazines, lights and levers on the apparatus were used. Pressing the lever on the right-hand side would result in reinforcement being provided by the right-hand magazine on a PR 10 schedule identical to that used in Experiment 2. Reinforcement for responding on the left lever was provided by the left magazine under one of two different FR schedules. The first time the possums experienced the each food presentation, the left magazine operated on an FR 20 schedule, where 1.5 s access to food was made available after the possum had made 20 responses on the left lever. Once all combinations had been experienced, the FR schedule was changed to an FR 50, and the series of food combinations was repeated in the same order.

Each session terminated after 90 min had passed. Following the session, the food used in each magazine; the FR schedule in place; the current PR schedule requirements in place at the end of the experiment; the total number of responses made on each lever; the total number of times each magazine provided access to reinforcement; the total session time; the total run time for each lever; and the total time spent eating from each magazine were recorded. As well as this, the times that every event occurred at during the session were recorded by the MED-PC® IV program that controlled the schedules of reinforcement in effect on both levers.

Results

Table 6 shows the break points of the food on the PR schedule averaged for each possum over three sessions for every PR-FR combination, for each food. Bonnie gave the highest overall average break point (303) for rolled oats when San Bran™ was presented concurrently on an FR 50 schedule. Caper gave the lowest overall average break point (4) for San Bran™ when presented concurrently with rolled oats on an FR 20 schedule. Generally, when the alternative food was on an FR 50 schedule, higher break points were reached than when the alternative food was on an FR 20 schedule, for all possums except Norrin. For all possums, higher break points were generally reached when responding for rolled oats, across all alternative food types and FR schedules (*M* ranging between 99.5 and 175.5). For all possums except Screech, the lowest break points were generally reached when responding for San Bran™ (*M* ranging between 33.2 and 78.2). The lowest break points reached by Screech across all concurrent combinations occurred when responding for the Cocoa Puffs™ and barley mixture (*M* = 101.5).

Figure 13 shows the overall response rate for each ratio on the PR schedule for each possum with each of the four foods on the PR schedules. Each plot shows the response rates generated in light of the three other foods being concurrently available on an FR 20 schedule of reinforcement. Figure 14 shows the same data, but from conditions when the concurrent alternative was on an FR 50 schedule. The rates are plotted against the log 10 of the PR schedule requirements, and were calculated when at least two out of three sessions contained data for that ratio requirement. The data from the different possums are plotted across rows, while the different foods on the PR schedule are shown in each column. Generally higher response rates for the food on the PR schedule were shown when the alternative food was available on an FR 50 schedule, than on an FR 20 schedule. Aside from the initially very high response rate that some possums demonstrated when the PR requirement was 1, due to the speed at which they stared the session, the functions were generally bitonic.

For all possums, responding for rolled oats on the PR schedule tended to occur at higher rates than responding for the other foods. As well as this, responding by Bonnie for soy protein on an FR 20 schedule, against a rolled oats

Table 6.

Average Break Point per Session for Each Possum of Four Foods on Progressive-Ratio (PR) Schedules of Reinforcement, When a Different Food is Made Concurrently Available on a Fixed-Ratio (FR) 20 or FR 50 Schedule.

		PR = Cocoa Puffs with Barley		PR = San Bran		PR =Soy Protein		PR = Rolled Oats	
Possum	Concurrent Food	FR 20	FR 50	FR 20	FR 50	FR 20	FR 50	FR 20	FR 50
Bonnie	Cocoa Puffs with Barley	-	-	53	113	80	177	70	230
	San Bran	70	113	-	-	93	203	93	303
	Soy Protein	57	93	37	30	-	-	70	143
	Rolled Oats	23	37	30	40	177	100	-	-
Caper	Cocoa Puffs with Barley	-	-	20	27	47	14	47	117
	San Bran	53	47	-	-	53	43	83	147
	Soy Protein	107	100	57	67	-	-	90	113
	Rolled Oats	13		4	24	14	23	-	-
Peppi	Cocoa Puffs with Barley	-	-	70	20	50	53	213	63
	San Bran	110	177	-	-	103	90	180	150
	Soy Protein	187	97	93	83	-	-	133	120
	Rolled Oats	113	163	70	133	80	110	-	-
Screech	Cocoa Puffs with Barley	-	-	127	110	190	133	130	173
	San Bran	87	176	-	-	97	187	190	220
	Soy Protein	147	150	147	150	-	-	140	200
	Rolled Oats	37	147	30	53	150	67	-	-
Norrin	Cocoa Puffs with Barley	-	-	93	63	127	90	150	110
	San Bran	133	163	-	-	97	230	180	50
	Soy Protein	150	127	107	103	-	-	187	183
	Rolled Oats	17	10	7	17	47	10	-	-

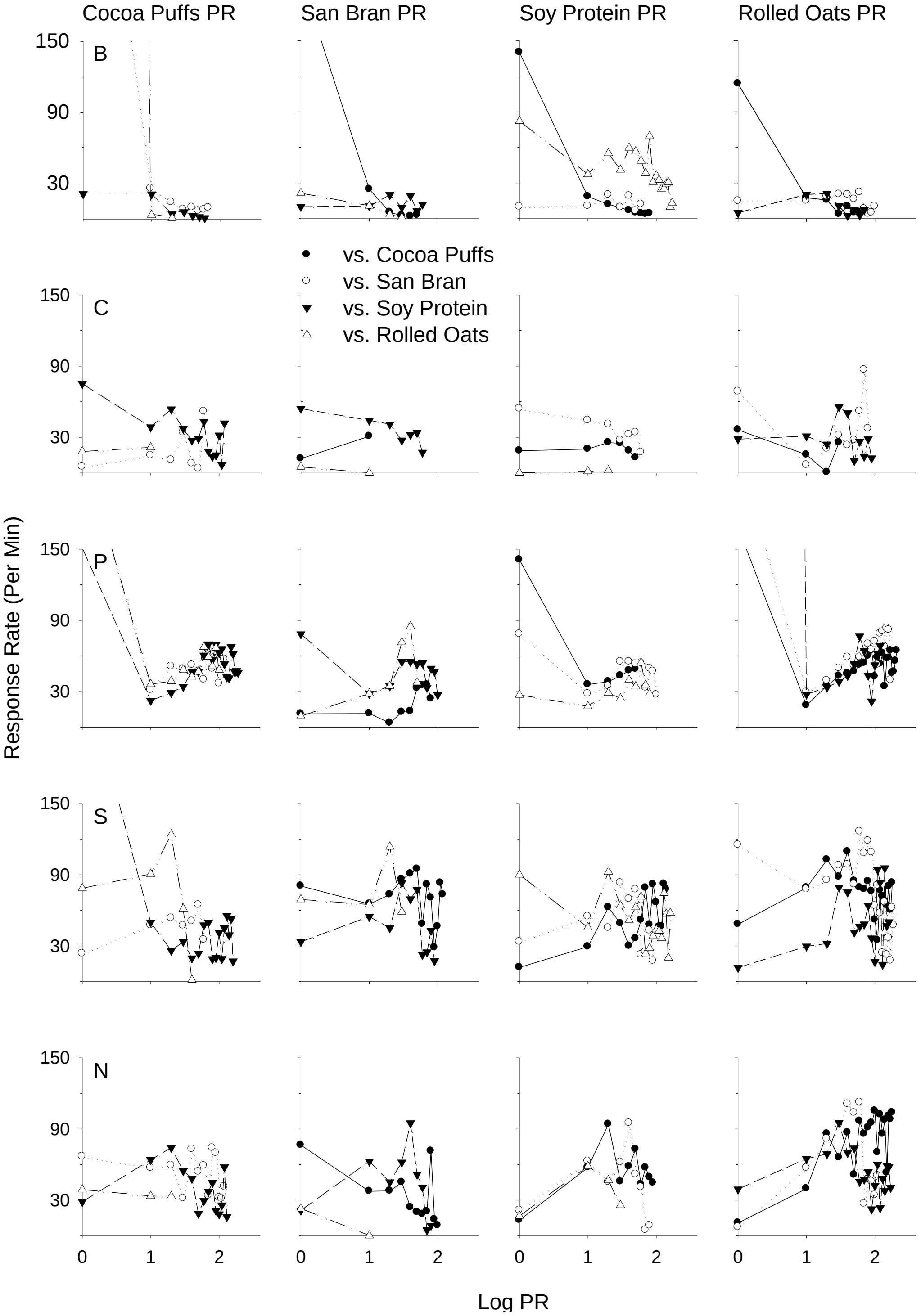


Figure 13. The response rates that possums displayed when working four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 20 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule.

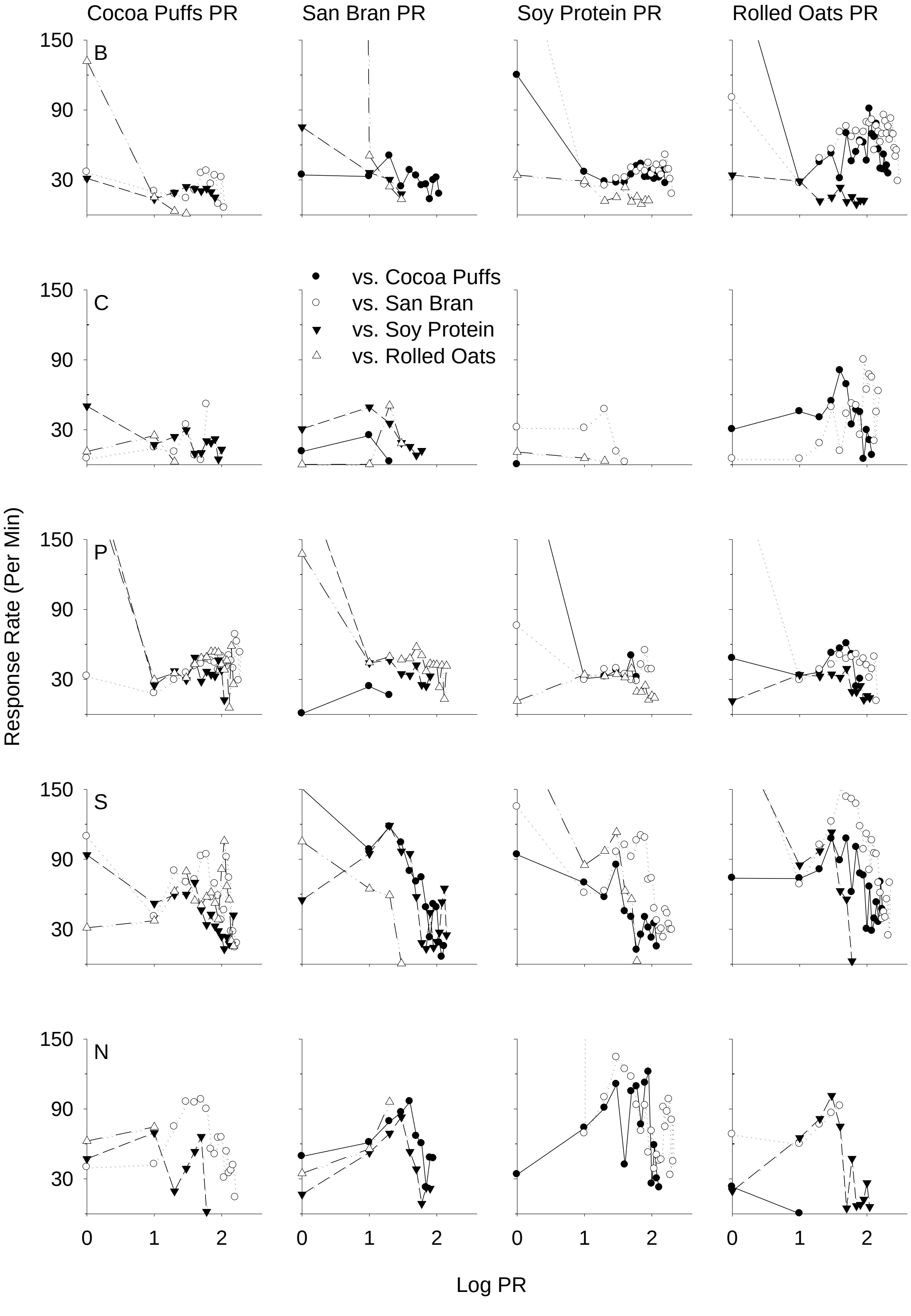


Figure 14. The response rates that possums displayed when working four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 50 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule.

alternative reached the highest individual rate. When the alternative schedule was FR 50, Norrin showed the highest responding for soy protein.

Figure 15 shows the averaged PRP durations for each possum when responding on a PR schedule with the concurrently available food on an FR 20 schedule, plotted as in Figure 13. The PRP data was converted to a log 10 scale, as some possums showed a large variance in PRP, and so the patterns where smaller PRPs were recorded were lost on the scale. A log 10 scale allows this to be seen more easily. Figure 16 is similar to Figure 15, but for the FR 50 schedule conditions. Across allalternatives, PRPs tended to increase as PR ratio requirements increased. Generally, when the alternative was presented on an FR 50 schedule, longer PRPs were observed across all possums.

For Bonnie, longer PRPs were recorded for all foods on the PR schedule, across all FR conditions, when the alternative food was rolled oats. For Peppi, no food on the PR was observed as resulting in the highest PRPs across FR alternatives, however, responding for the Cocoa Puffs™ and barley mixture, generally resulted in lower PRPs. For Caper, Screech and Norrin, responding for all foods produced similar PRPs

Figures 17 and 18 show the demand functions, plotted as a log 10 scale of the reinforcer consumption rate against the log 10 of the schedule requirements, and averaged over sessions, as in Figures 13-16. Figure 17 shows the consumption data when the alternative was on an FR 20 schedule, while Figure 18 shows the consumption when the alternative was on FR 50. Also shown are the lines of best fit generated where applicable by Equation 1 (Hursh & Winger, 1995). When there was only one data point the lines of fit could not be calculated

The parameters and fits of these functions can be seen in the appendices. The percentage of variance accounted for by the fits was generally above 70%, though for the consumption rates shown by Caper, the percent variance averaged and at some times was even a negative value because the functions predicted greater variance than was seen in the data. Generally, both the rate of change (*a*) and the initial slope of the demand (*b*) shown by all possums were similar. The

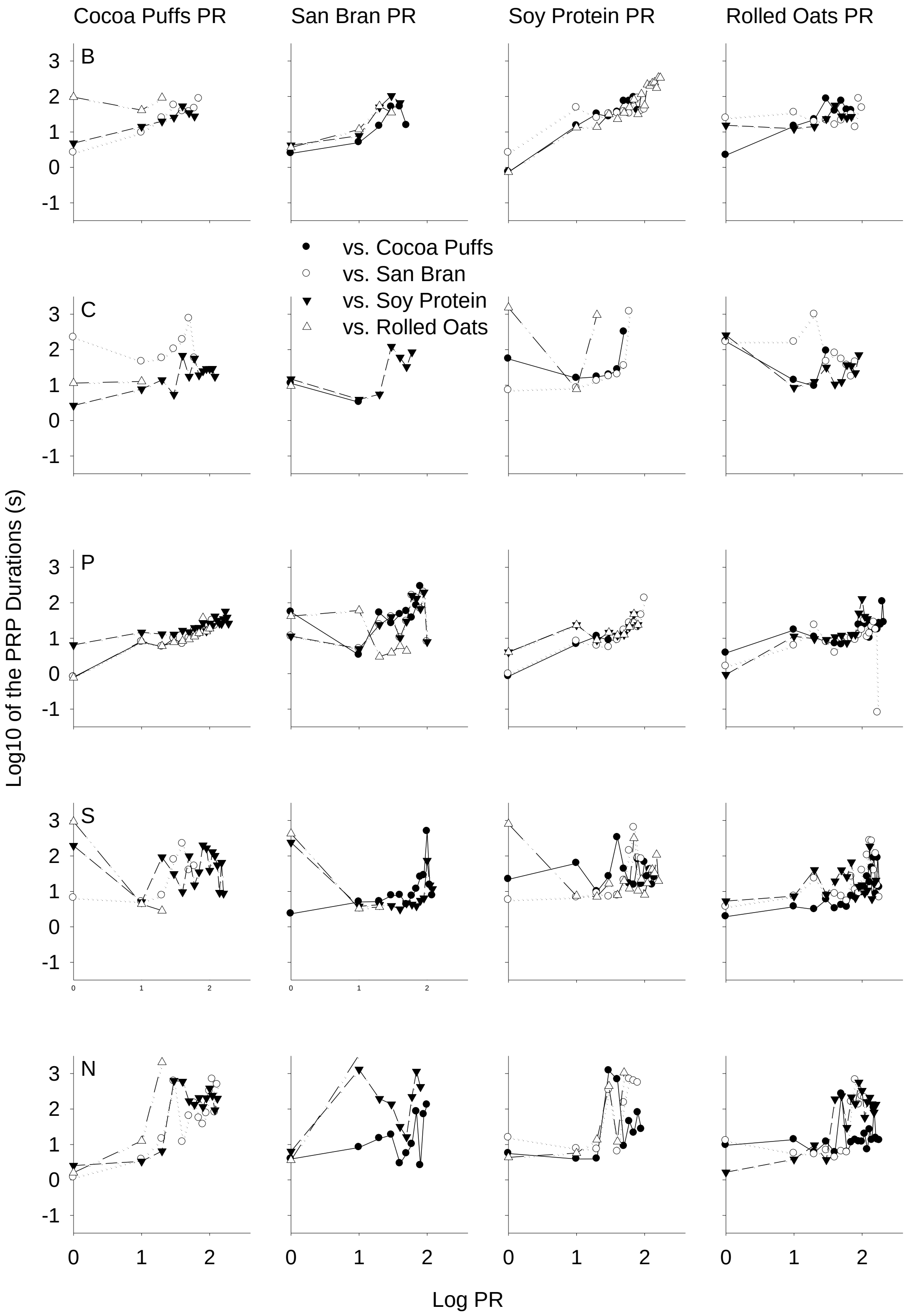


Figure 15. The log 10 of average post-reinforcement pauses that possums displayed working for four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 20 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule.

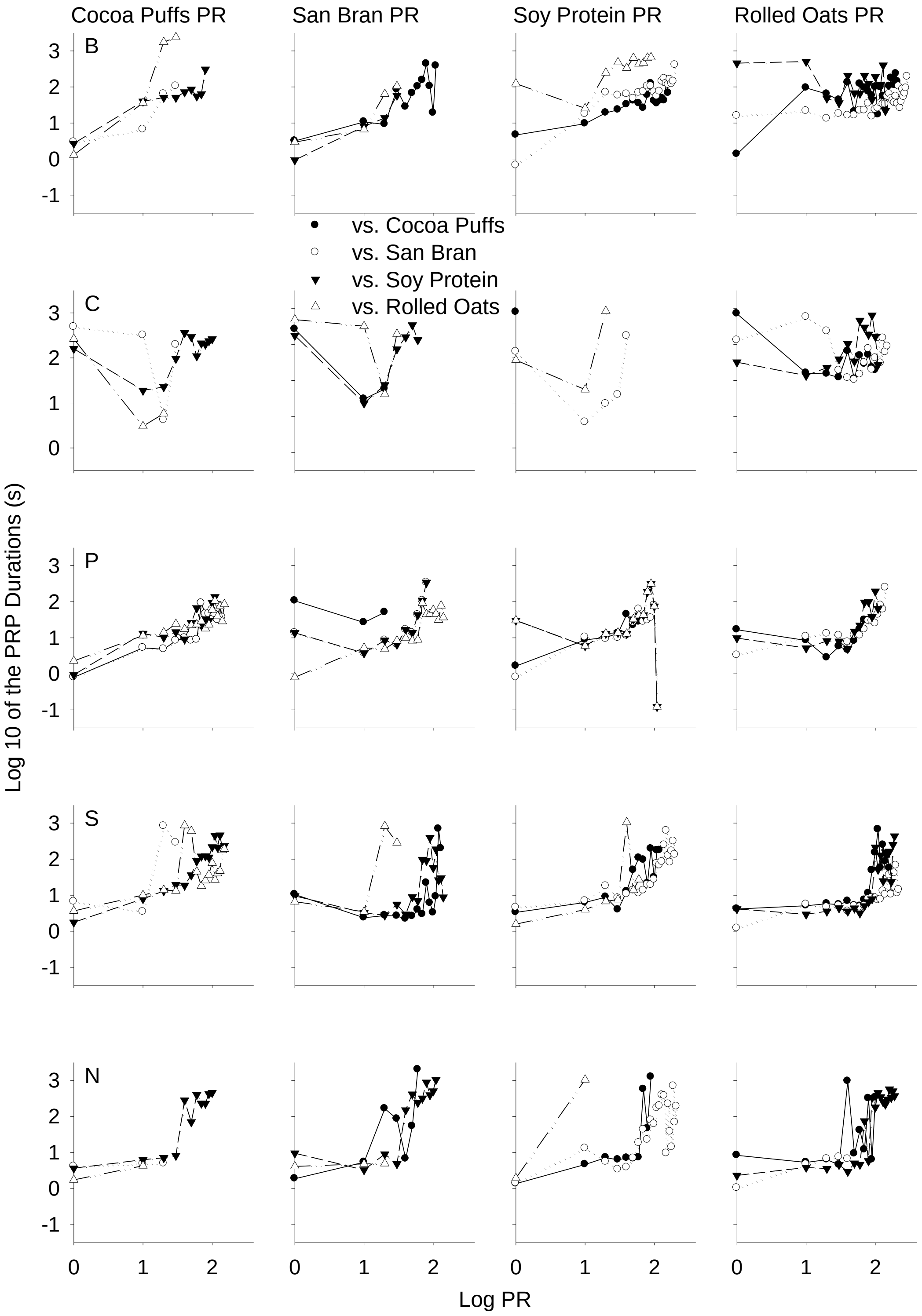


Figure 16. The log 10 of post-reinforcement pauses that possums displayed working for four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 50 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule.

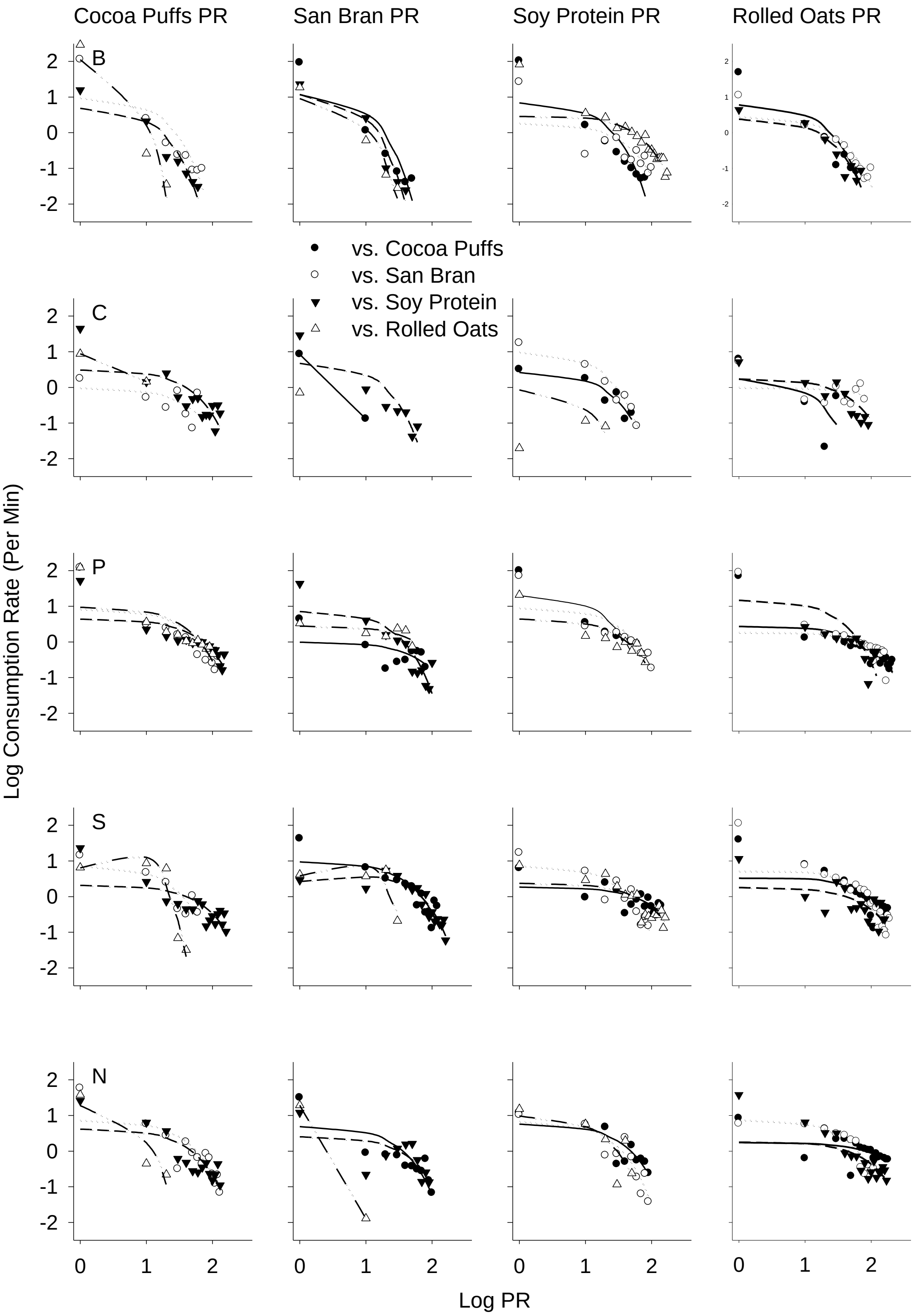


Figure 17. The log 10 of the reinforcer consumption rate that possums displayed working for four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 20 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule. Also plotted are the lines of fit shown by Equation 1 (Hursh et al., 1988).

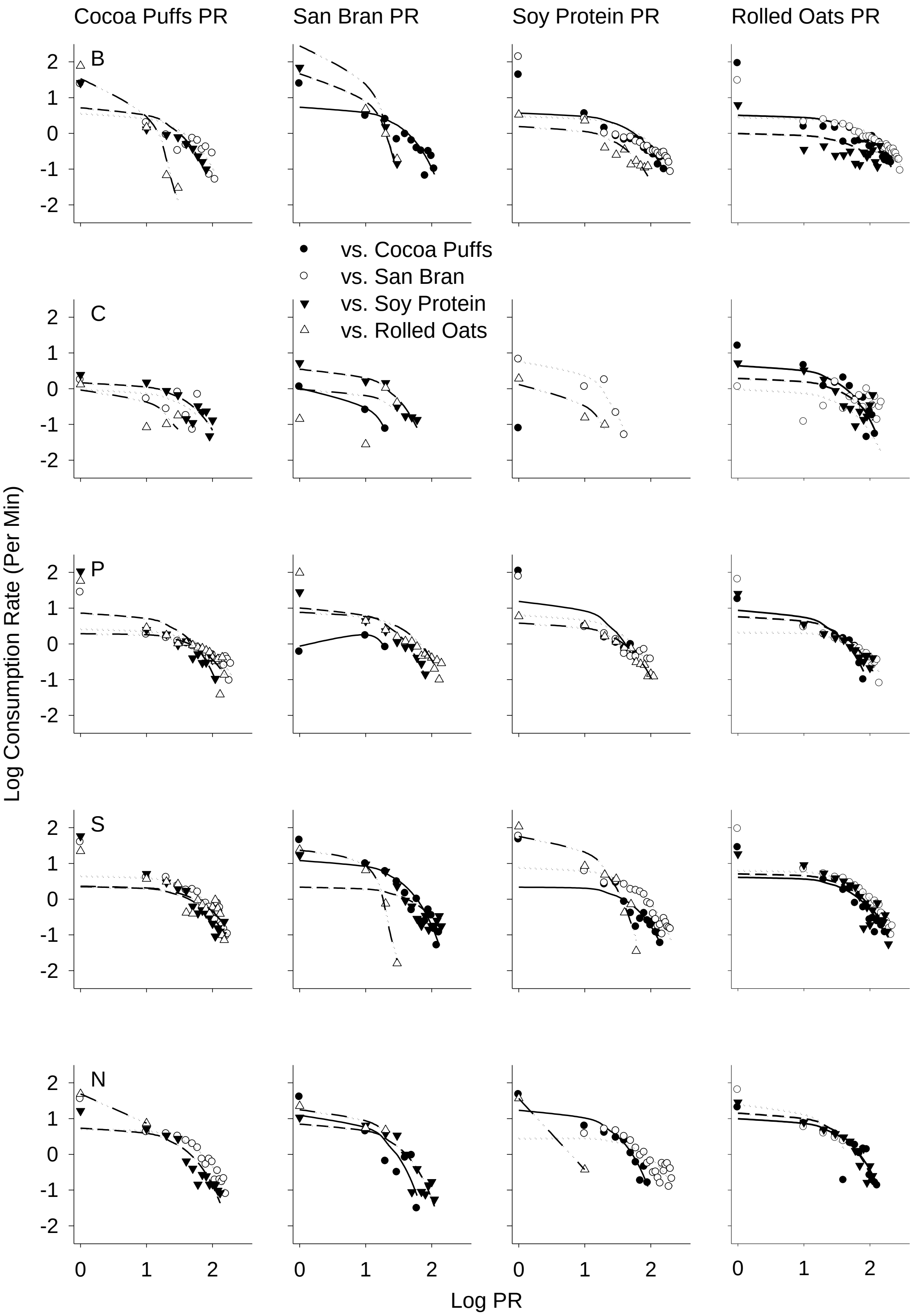


Figure 18. The log 10 of the reinforcer consumption rate that possums displayed working for four foods on progressive-ratio (PR) schedules, presented concurrently wih an alternative food on a fixed-ratio (FR) 20 schedule. Each row represents a different possum, while each column represents a different food on the PR schedule. Also plotted are the lines of fit shown by Equation 1 (Hursh et al., 1988).

$P_{\max}$ values, generated by Equation 2 (Hursh & Winger, 1995) are shown in Table 7 for all possums under all conditions, and the initial demand (ln L) is shown in Table 8. For all possums across all conditions, the higher the ln L value, the smaller the $P_{\max}$ value tended to be.

For all possums except Bonnie, the $P_{\max}$ values tended to be lower when the alternative food was on an FR 50 schedule, compared to an FR 20. The $P_{\max}$ values obtained were generally higher when responding for rolled oats on the PR schedule, for all possums across all conditions. For Bonnie and Norrin, the lowest $P_{\max}$ values were obtained when responding for San Bran™, and for Caper, Peppi and Screech the lowest $P_{\max}$ values were obtained when responding for soy protein. These $P_{\max}$ values reflect the point on Figures 17 and 18 when the fitted lines began to decrease more steeply. The functions shown in Figure 18, where the alternative food was available on an FR 50, began to decline more steeply at an earlier point than those in Figure 17 did, when the alternative was on FR 20.

Table 7.

P_{max} Values for Each Possum, Calculated by the Equation Used by Hursh and Winger (1995) for Each Combination of Foods on Progressive-Ratio (PR) and a Concurrently Available Fixed-Ratio (FR) 20 or FR 50 Schedule. Values of N/A Represent Occasions When P_{max} Could not be Calculated.

Possum	Concurrent Food	PR = Cocoa Puffs with Barley		PR = San Bran		PR = Soy Protein		PR = Rolled Oats	
		FR 20	FR 50	FR 20	FR 50	FR 20	FR 50	FR 20	FR 50
Bonnie	Cocoa Puffs with Barley	-	-	7	25	13	42	13	63
	San Bran	12	28	-	-	27	55	22	92
	Soy Protein	10	19	6	5	-	-	16	69
	Rolled Oats	2	4	5	4	44	28	-	-
Caper	Cocoa Puffs with Barley	-	-	2	7	16	N/A	10	28
	San Bran	34	34	-	-	12	9	159	36
	Soy Protein	34	32	12	16	-	-	37	40
	Rolled Oats	49	11	N/A	22	7	6	-	-
Peppi	Cocoa Puffs with Barley	-	-	54	13	13	15	70	20
	San Bran	64	29	-	-	25	28	83	50
	Soy Protein	26	48	17	18	-	-	24	31
	Rolled Oats	55	28	54	32	28	28	-	-
Screech	Cocoa Puffs with Barley	-	-	30	24	82	37	63	45
	San Bran	44	17	-	-	21	42	46	52
	Soy Protein	48	54	42	49	-	-	70	56
	Rolled Oats	59	86	10	5	63	9	-	-
Norrin	Cocoa Puffs with Barley	-	-	22	11	27	18	146	30
	San Bran	28	39	-	-	18	65	30	14
	Soy Protein	33	27	33	21	-	-	67	25
	Rolled Oats	4	5	1	13	13	2	-	-

Table 8.

The Initial Demand (as Shown by the Natural Log of the Consumption Rate) For Food Presented on a Progressive-Ratio (PR) Schedule, Derived From the Equation Used by Hursh et al. (1988) When an Alternative Food was Presented on Either a Fixed-Ratio (FR) 20 or FR 50 Schedule. Values of N/A Represent Occasions When Initial Demand Could not be Calculated.

		PR = Cocoa Puffs with Barley		PR = San Bran		PR = Soy Protein		PR = Rolled Oats	
Possum	Concurrent Food	FR 20	FR 50	FR 20	FR 50	FR 20	FR 50	FR 20	FR 50
Bonnie	Cocoa Puffs with Barley	-	-	2.61	1.73	2.00	1.33	1.87	1.18
	San Bran	2.34	1.33	-	-	0.65	1.14	1.09	1.07
	Soy Protein	1.68	1.70	2.64	4.03	-	-	0.94	0
	Rolled Oats	5.18	3.80	2.43	5.91	1.07	0.47	-	-
Caper	Cocoa Puffs with Barley	-	-	2.60	0.17	1.02	N/A	0.65	1.51
	San Bran	0	0	-	-	2.37	1.90	0	0
	Soy Protein	1.14	0.40	1.63	1.32	-	-	0.56	0.68
	Rolled Oats	2.39	0	N/A	0	0	0.42	-	-
Peppi	Cocoa Puffs with Barley	-	-	0	0	3.08	2.80	1.01	2.21
	San Bran	2.16	0.98	-	-	2.24	1.90	0.62	0.77
	Soy Protein	1.49	2.02	2.01	2.37	-	-	2.73	1.77
	Rolled Oats	2.27	0.67	1.04	2.06	1.51	1.37	-	-
Screech	Cocoa Puffs with Barley	-	-	2.27	2.53	0.62	0.80	1.20	1.43
	San Bran	2.05	1.52	-	-	2.04	2.06	1.67	1.87
	Soy Protein	0.74	0.82	1.00	0.79	-	-	0.59	1.65
	Rolled Oats	2.13	0.85	1.55	3.51	0.87	4.15	-	-
Norrin	Cocoa Puffs with Barley	-	-	1.63	2.60	1.78	2.89	0.56	2.33
	San Bran	2.02	1.67	-	-	1.98	1.05	2.05	3.31
	Soy Protein	1.45	1.72	0.95	1.99	-	-	0.59	2.69
	Rolled Oats	3.21	4.10	3.77	2.95	2.34	4.12	-	-

Discussion

This experiment aimed to compare the break points, response rates, PRPs and demand of possums on a PR10 schedule of reinforcement, when four foods were presented in a concurrent PR-FR schedules arrangement. The alternative food was on either an FR 20 or FR 50 schedule, and all PR-FR combinations were used with the four foods, excluding comparing performance for the same food on different schedules.

Break Points

The higher the break point the more an organism is willing to 'work' to get access to that stimulus. This suggests that a high break point indicates that the stimulus is of higher preference. The break points in this experiment were defined as no response being made for a period of 5 min. Across all possums, the highest and lowest break points were generally recorded for the same foods. This would mean that degree of preference for those foods at higher schedules were similar across possums. This is inconsistent with the results of the PS and MSWO assessments in Experiment 1. Other PS (Fernandez et al., 2004; Hudson et al., 1999; Martin, 2002) and MSWO assessments that were conducted, also found idiosyncratic preferences. The similarity in the foods that each possum reached the highest break points for in this experiment were consistent with the similarity in which foods each possum reached the highest break point for in Experiment 2.

Higher break points were achieved when the alternative food was available on an FR 50 schedule of reinforcement, than on an FR 20 schedule. This shows that when the schedule requirements for the FR alternative were increased, more responses were emitted on the PR schedule. As the schedule requirements for the FR alternative increased from FR 20 to FR 50, responding for that alternative would be expected to decrease. This would coincide with responding increasing for the food on the PR schedule, which was seen. Hursh (1978, 1980, 1984) found similar results, as when schedule requirements were increased for one alternative, responding decreased for that alternative and increased for another. This was labelled as substitution in Hursh (1978, 1980, 1984)'s studies. In this experiment, the trend generally occurred across all four foods, suggests that may each be substitutes for one another. as one food can be a reinforcer take over as a reinforcer that all four foods used might work as effective substitutes for one another.

Response Rates

The bitonic response rate functions that Hursh (1980, 1984) showed were generally present in these data. When the functions were not very bitonic, there are two reasons could that account for this. When there were very few data points, the possums had not responded to a high enough ratio enough times to generate a bitonic function. Another explanation was that it may be a product of the way the data were averaged. The averaged data for a ratio on the PR schedule were plotted only when two out of three sessions for each possum under each condition reached that ratio requirement. If the individual session data showed a bitonic function, but there was variation in the break points achieved over sessions, then the maximal responding for one session may occur at the same ratio requirement as minimal responding for another, flattening the function. It remains to be seen whether conducting the experiment in closed-economy conditions would also result in bitonic functions when response rates should be higher across all PR-FR combinations (Hursh, 1978, 1980, 1984).

Higher response rates were found when the FR alternative was 50 than when it was 20, which matches the higher break points were found. This reflects the findings of other research that compared break points and responding on PR schedules with humans (Francisco et al., 2008; Glover et al., 2008; Roane et al. 2001), and suggests that both measures are equally effective at identifying preference at higher schedule requirements. This difference between the response rates of the food on the PR schedule when the alternative food was on an FR 20 or 50 schedule, lends support to the suggestion that all four foods used in this experiment can act as substitutes for one another, as already discussed with relation to break points (Hursh, 1978; 1980; 1984).

Post-Reinforcement Pauses

There was no pattern shown in the PRPs that each possum generated for each food. Across all possums and conditions, however, the PRPs tended to increase as schedule requirements increased. This matches what has been found on increasing FR schedules with hens (Foster et al., 1997) and possums (Hudson et al., 1999).

Longer PRPs were also found when the alternative food was presented on an FR 50 schedule than on an FR 20, which was not expected based on the response rate data. Higher response rates were shown on the PR schedule when the alternative food was on FR 50. Armistead (2009) had found that higher response rates on FR schedules tended to be associated with shorter PRPs, which suggests that the PRPs when alternative food was on FR 50 should have been shorter than those on FR 20. The opposite of what was expected was found.

Demand

The fitted lines (from Equation 1) did not account for as much of the variance in consumption rates that Hursh et al. (1988) found. Other research that has presented the percentage variance accounted for by the fits (Armistead, 2009; Foster, et al., 1997; Foster et al., 2009), as Experiment 2 in this study, also showed higher percentages than the present data set. As with the response rates, this difference could also be a result of the way the data were averaged, losing some of the trends that the individual session data may have shown. In the cases where the negative values were calculated for Caper, the averaging of the data could have pulled the plotted data points into an oscillating pattern, for which the Hursh et al. (1988) equation was not suitable.

The higher the initial demand (ln L) and the flatter the curve of the demand function, the higher-preference the stimulus is thought to be to the organism. However, higher ln L values were seen when $P_{\max}$ values were lower than when $P_{\max}$ values were high, which means that the curve steepened faster when initial demand was high. Both ln L and $P_{\max}$ can still be considered measures of preference however, with ln L indicating preference at low schedule requirements, while $P_{\max}$ can indicate preference as the requirements increase. In light of this experiment, this view would be consistent with the findings of Roane et al. (2001) and Tustin (1994), where preference for reinforcers changed between low- and high-ratio requirements.

The $P_{\max}$ values calculated by Equation 2, that Hursh and Winger (1995) used, showed the point at which the slope of the demand curve grew steeper than -1, turning from inelastic to elastic demand. This $P_{\max}$ value was lower when the alternative food was presented on an FR 50 schedule. This was not expected for the same reasons as higher PRPs being found when the alternative food was on FR 50, as well as what has been mentioned previously in relation to substitutability (Hursh, 1978, 1980, 1984).

The highest $P_{\max}$ values were obtained when the food on the PR schedule was rolled oats. As well as showing the point at which demand shifts from inelastic to elastic, the $P_{\max}$ value also shows the point of maximal responding (Foster et al, 2009; Hursh & Winger, 1995), so this result was expected, as response rates for rolled oats tended to be greater at higher schedule requirements. In all cases save for one, the $P_{\max}$ value obtained was within the average break point of the sessions, which shows the mixed elasticity that Hursh (1978, 1980, 1984) found in open economies on increasing FR schedules, and Armistead (2009) found for horses on FR schedules. For Caper, when rolled oats was presented on the PR schedule and San Bran™ was concurrently available on an FR 20 schedule, the demand function showed inelasticity throughout, which resembled the Hursh (1978, 1980, 1984)'s predictions for closed-economy conditions. As has been mentioned, this may be a result of few data points being plotted, or the manner in which the sessions were averaged.

General Discussion

One aim of this study was to compare how preferences identified in both a PS and a MSWO preference assessment related to how well those same foods functioned as reinforcers for possums when placed on PR schedules of reinforcement. Direct comparisons were made between the preference hierarchies that the different methodologies established for the possums when using the two preference methodologies. It was found that the two methods produced similar preference hierarchies, a finding that reflected those by DeLeon and Iwata (1996) with individuals with developmental disabilities.

When a reinforcer assessment was conducted using a PR schedule, it was shown that all four foods maintained behaviour as schedules requirements increased. The food that was generally more preferred in the PS and MSWO assessments was also shown to result in higher response rates, break points and less steep demand functions. Response rates patterns for all four foods by each possum tended to change bitonically with increases in ratio requirements, similar to response rates found from FR schedules (Armistead, 2009; Hursh, 1978, 1980, 1984; Tustin, 1994) and those from PR schedules (Roane et al., 2001). The patterns shown by the PRP durations that each possum generated for each food were generally consistent with those found both FR and PR schedules (Foster et al., 1997). Behavioural economic measures were also consistent with those found by Hursh (1978, 1980, 1984), Hursh et al. (1988) and Hursh and Winger (1995).

Concurrent PR-FR schedules of reinforcement resulted in that break points that were generally higher on the PR schedule the higher the FR alternative was. The response rate functions produced on the PR were generally bitonic for every PR-FR combination for each possum, and changed similarly to the rates found in past FR research (Armistead, 2009; Hursh, 1978, 1980, 1984; Tustin, 1994) and on PRs in Experiment 2. The lines of fit generated by Equation 1 (Hursh et al., 1988) generally described the data well, but not as well as they did in Experiment 2, or as well as past research that presented the percentage of variance accounted for (Armistead, 2009; Foster et al., 1997; Foster et al., 2009). The $P_{\max}$ values from Equation 2 (Hursh & Winger, 1995), generally matched well to the point of maximal responding and the point where the demand function became steeper than -1. $P_{\max}$ values for rolled oats on the PR were generally higher than the other foods, regardless of the FR schedule in effect.,

PS and MSWO Preferences as Reinforcers

Generally, the same foods were identified as potential reinforcers by the PS and MSWO assessment methods for each possum, and to the same degree. DeLeon and Iwata (1996) found similar results when using the two methods with human populations, and found that the stimuli identified as being highly-preferred in both preference assessments were more likely than the other stimuli to maintain behaviour at higher schedules of reinforcement.

Comparing the preference hierarchies identified in Experiment 1 with the results of the reinforcer assessment in Experiment 2, it was found that the PS assessment gave a slightly more reliable prediction of which food would give the highest break point, and the MSWO assessment was slightly more reliable at predicting which food would give the highest response rates. Longer PRPs were produced by possums for foods were generally less preferred on both assessments. The foods that resulted in the higher $P_{\max}$ values were generally predicted as highly preferred in both the PS and MSWO assessments.

With both the MSWO (Armistead, 2009; DeLeon &Iwata, 1996) and the PS (Fisher et al., 1992; Hudson et al., 1999; Martin, 2002) assessments, past research has showed that the stimuli identified as high-preference consistently functioned as more effective reinforcers based on the measures of preference used at higher schedules, than those identified as low-preference. While this was generally seen in this study, it did not occur for every possum. The findings of Francisco et al. (2008) account for this. High- and low-preference stimuli on single-schedule and concurrent PR-PR schedules were compared. It was found that stimuli identified as being of low-preference on a PS assessment did not maintain high levels of behaviour when presented with a more highly-preferred stimulus, but when presented in a single-schedule arrangement the low-preference stimuli maintained behaviour at levels comparable to that of the high-preference stimuli. In relation to this study, this could state that even if the foods were of low-preference to the possums, they may still function as a reinforcer when no other alternative was provided.

Roane et al. (2001) and Tustin (1994) showed that when schedule requirements increase, the preference for stimuli can change. As mentioned previously, the degree to which preference was consistent between Experiment 1 and Experiment 2 was not as great as with other studies (Fisher et al., 1992; Hudson et al., 1999; Martin, 2002), and the findings of Roane et al. (2001) and Tustin (1994) may explain this. The preference assessments in Experiment 1 can be considered to be operating on an FR1 schedule. After the first reinforcer is obtained on the PR schedule, all subsequent reinforcers require higher ratios to be completed. Thus, if the stimuli in Experiment 2 were identified as high-preference at low-schedule requirements through Experiment 1, then a change in preference at higher ratios on the PR schedule follows what Roane et al. (2001) and Tustin (1994) showed.

Single-Schedule and Concurrent-Schedules of Reinforcement

Presenting the foods under a single-schedule arrangement, as in Experiment 2, should lead to higher response rates, break points and $P_{\max}$ values than either of the two concurrent presentations. This was supported by research already discussed, suggesting that even stimuli that are of low preference can function as reinforcers when there is no other alternative (Francisco et al., 2008). The response rates, break points and $P_{\max}$ should be lower when the concurrently-presented alternative was on an FR 20 schedule, compared to an FR 50. This is suggested by Hursh (1978, 1980, 1984), as discussed previously. Here, as schedule requirements for one alternative increased (from FR 20 to FR 50), the responding and demand for another option increased.

Break points for the food on the PR schedule were fairly similar between Experiment 2 with the FR 50 alternative in Experiment 3. Thus, the concurrently-presented FR 50 schedule did not affect the responding on the PR schedule as much as the FR 20 schedule did.

Response rates appeared to be higher for both concurrent presentations in Experiment 3 than in Experiment 2. This does not show substitutability, as was predicted based on Hursh (1978; 1980; 1984), as already discussed.

Past research with FR schedules (Armistead, 2009; Foster et al., 1997; Foster et al., 2009) and both Experiment 2 and 3 in this study showed that as schedule requirements increased, PRP durations tended to increase. The PRPs began to increase at lower schedule requirements in both of the concurrent presentation types, which may have been a result of the presence of the alternative.

Responding for the same food across Experiment 2 and the two PR-FR concurrent presentations in Experiment 3 tended to produce the same pattern of results, though to different degrees. For example, response rates tended to be the highest for Experiment 2, and the lowest for the concurrent PR-FR 20 presentation, though all three presentations gave bitonic functions. Even if foods were identified as being low-preference to the organism, the same patterns being observed supports the idea that low-preference stimuli can still function as reinforcers (Francisco et al., 2008). The extent they function as reinforcers, however, may not be to the same degree as highly-preferred stimuli.

The demand functions derived from Equation 1 (Hursh et al., 1988) accounted for more variance in the consumption data in Experiment 2, similar to other research (Armistead, 2009; Foster et al., 1997; Foster et al., 2009) than they did for either of the presentation types in Experiment 3. This suggests that Equation 1 may not be as suitable for use in concurrent schedule arrangements, particularly when one alternative is held constant and the price, or ratio requirement, for the other alternative is increased.

The $P_{\max}$ values showed the point at which demand functions became steeper than -1, shifting from inelastic to elastic demand. It was generally shown that higher $P_{\max}$ values were found for Experiment 2 than those found for either of the PR-FR presentations in Experiment 3, and the lowest $P_{\max}$ values were from the sessions when the alternative was on an FR 20 schedule, regardless of food type. This has been suggested by Hursh (1980) as showing that the foods are substitutes, since as the price increases for one stimulus, the animals work less for that stimulus decreases, and increase the amount they work for the alternative.

It was observed for all possums that usually when rolled oats was the alternative on either the FR 20 or FR 50 schedule, the break point, response rates and the $P_{\max}$ values was lower. This suggests that rolled oats was of higher preference at higher schedules, as predicted for most possums by both the PS and MSWO preference methods in Experiment 1.

Overall, Experiment 2 and Experiment 3 generally showed that the lower the schedule requirements on a concurrently presented alternative, then the lower the response rates, break points and $P_{\max}$ values for a PR schedule will be. It can also be suggested that all three of these measures are appropriate for comparing preference when an increasing schedule requirement is in effect.

Choice of Preference Assessments

A PS assessment was conducted by Fernandez et al. (2004) to assess the preferences for food of tamarin monkeys in a zoo. A number of other assessments (Hudson, et al., 1997; Martin, 2002; Sumpter et al., 2002; Williams et al., 2008) have used PS assessments with animals in laboratory settings. The results of this study, as well as the only other study identified as using MSWO with animals (Armistead, 2009), suggest that the MSWO is just as appropriate to use.

As has been identified, it is important to choose the right preference assessment according to the type of stimuli you are assessing preferences for (Hagopian et al., 2004; Sumpter et al., 2002). Therefore, the ease of administrating the assessments was examined here. Both PS and MSWO are examples of direct, approach-based measures of preference, and the time taken to administer each session can be compared. The MSWO method in this study used every possible starting combination of the four foods, in a similar way to Armistead (2009) with horses. So, for four foods, 24 different starting combinations were used. This meant the MSWO assessment took longer to administer than it would have had only four starting combinations been used, as was done by DeLeon and Iwata (1996). If Experiment 1 used the same method as DeLeon and Iwata (1996), this would have drastically cut the length of the session down because fewer trials would have been conducted. It is unclear, however, whether or not conducting the MSWO assessment in the same way as DeLeon and Iwata (1996) would have made the MSWO assessment quicker to administer than the PS assessment. The average time taken in this study was approximately an hour, and so if a sixth of the trials were conducted, then a sixth of the time may have been taken. This would put the session time at 10 min, still longer than DeLeon and Iwata (1996).

The reason for conducting the MSWO assessment in the manner of Armistead (2009) instead of DeLeon and Iwata (1996) was that it was thought that rigor was more important than speed. The reliability of the method was more important than how quick the method was to administer. This ties back to the purpose of why a preference assessment is being used, dictating how the assessment is used (Hagopian et al., 2004).

An advantage observed for the MSWO assessment was that it allows for ‘no choice’ to be recorded as a choice. An advantage observed for the PS assessment is that it may be easier to control animal behaviour. It was found that some possums would reach through the grate at the bottom of the apparatus when the food was unavailable. With fewer foods being presented to the animals, the easier this may be to avoid.

Limitations

As mentioned in the method section for Experiment 3, Caper began to ‘steal’ food from inactive magazines after a session. Fortunately, this study used an open-economy, so access to food outside of the experimental conditions did not compromise the experiment. The food magazines were removed from the apparatus at the end of every session to keep Caper’s weight stable.

One issue when looking at how well the preference assessments used in Experiment 1 predicted performance on the schedules was the type of foods used. Cocoa Puffs™ contain milk powder, and nuts such as almonds are high in oils, which can cause health issues for the possums (Martin, 2002). Combining Cocoa Puffs™ and almond slices with barley dilutes the health risks, but the preference for these food mixtures would likely be different than if each food was presented on its own. Rolled oats, San Bran™ and the barley component of the Cocoa Puffs™ and barley mixture are all grain-based. Using a variety of different foods as well as grain, such as seeds, nuts, foliage and fungi could provide larger differences between foods. This was shown by Martin (2002), where mango pieces and banana chips were generally of high preference to possums. Brown, Innes and Shorten (1993) also showed that possums occasionally eat eggs and small animals, but suggested that they may be less frequently consumed than leaves or fruit.

The reason that similar foods were used in this study was related to the equipment used. Martin (2002) used similar magazines as those used in this study, and found that when sweet foods like mango and banana chips were combined with the possums' saliva, it made the magazines too sticky for the food to easily be delivered. This was acceptable, as the comparison between the methods were more important to the aims of this study than the specific foods that the possums preferred.

Future Research

This research provides the first comparison of PS and MSWO preference assessments with animal populations. Conducting more assessments with a variety of other species, particularly those commonly used in operant research such as pigeons, rats and hens, could provide more information as to the suitability of using MSWO as an assessment with animals. So far, only this study and Armistead (2009) have contributed to this knowledge base.

More comparisons between the structure of the MSWO trials should also be made. Conducting every starting possible combination (Armistead, 2009) results in much longer administration times relative to the PS assessment than DeLeon and Iwata (1996) found with humans, when each food was only positioned in each starting position once. Comparing the outcomes of each different method of presenting trials should be done, to see if it is really necessary to conduct as many trials as this study conducted.

This research, where a food alternative was placed on an FR schedule, could also benefit from the alternative being placed upon the same PR schedule that the other food was placed on. Though this experiment sought to look at performance in comparison to a food held constant, comparing the performance on the same schedule working in a concurrent-arrangement may tell us more about the preference at higher schedules for one food over the other, as measures that could not be compared in this experiment, such as the break point, could be looked at.

Overall conclusion

The MSWO preference assessment was equally as effective as a PS assessment at predicting the effect that foods would function as reinforcers.

Depending on further methodological testing, it may be seen that one of these methods is more appropriate to use when direct, approach-based measures are sought, as one could be more time- and resource-efficient.

All foods, including those identified as low-preference in the PS and MSWO assessments were shown to function as reinforcers when presented in single-schedule PR schedules of reinforcement. This shows that preference is relative to the other alternatives available, and stimuli identified as low-preference when assessed through PS or MSWO methods may still be appropriate to use as reinforcers to maintain operant responding in other contexts.

When the foods were presented in concurrent-schedule arrangements, measures of preference such as the response rates, break points and the lines of fit for the demand functions were lower for the FR 20 schedule than the FR 50. This suggests that when less ‘work’ is needed to obtain reinforcement on an alternative, then responding for the food being assessed will decrease. Providing a choice between alternatives can change the demand for a stimulus.

This experiment contributed to knowledge by providing the first comparison between MSWO and PS preference assessments with animal possums, and used behavioural economic measures to examine the predictions of these two methods in identifying potential reinforcers. When examined on single-schedule and concurrent PR-FR schedules, rolled oats was found to generally produce more consistent patterns of responding, compared to the other foods. The findings of the PR assessments were generally more consistent than the PS or MSWO assessment at identifying which foods were ‘highly preferred’ by the measures used in each respective assessment. It was also found that possums would continue responding past the ratio that was equal to the FR alternative, suggesting that the schedule requirement was not the only contributing factor to possums’ preferences. Some aspect of quality-discrimination was present.

References

Armistead, M. (2009). *A comparison of demand for two different feeds with horses* (*Equus callabus*) (Unpublished master's thesis). University of Waikato, Hamilton, New Zealand.

Blom, H. J. M., Baumans, V., Van Vorstenbosch, C. J. A. H. V., Van Zutphen, L. F. M., & Beynen, A, C. (1993). Preference tests with rodents to assess housing conditions. *Animal Welfare, 2*, 81-87.

Blom, H. J. M., Van Tintelen, G., Baumans, V., Van Den Broek, J., & Beynen, A. C. (1995). Development and application of a preference test system to evaluate housing conditions for laboratory rats. *Applied Animal Behaviour Science, 43*(4), 279-290.

Broom, D. M. (1991). Animal welfare: Concepts and measurement. *Journal of Animal Science, 69*(10), 4167-4175.

Bron, A., Sumpter, C. E., Foster, T. M., & Temple, W. (2003). Contingency discriminability, matching, and bias in the concurrent-schedule responding of possums (*Trichosurus vulpecula*). *Journal of the Experimental Analysis of Behavior, 79*(3), 289-306.

Brown, K., Innes, J., & Shorten, R. (1993). Evidence that possums prey on and scavenge birds' eggs, birds and mammals. *Journal of the Ornithological Society of New Zealand (Inc.), 40*(3), 169-177.

Ciccone, F. J., Graff, R. B., & Ahearn, W. H. (2005). An alternative scoring method for the multiple stimulus without replacement preference assessment. *Behavioral Interventions, 20*(2), 121-127.

Ciccone, F. J., Graff, R. B., & Ahearn, W. H. (2007). Long-term stability of edible preferences in individuals with developmental disabilities. *Behavioral Interventions, 22*(3) 223-228.

Dawkins, M. S. (2004). Using behaviour to assess animal welfare. *Animal Welfare, 13,* S3-7.

Dawkins, M. S. (2006). Through animal eyes: What behaviour tells us. *Applied Animal Behaviour Science, 100,* 4-6.

DeLeon, I. G. & Iwata, B. A. (1996). Evaluation of a multiple-stimulus presentation format for assessing reinforcer preferences. *Journal of Applied Behavior Analysis, 29*(4), 519-533.

DeLeon, I. G., Iwata, B. A., Conners, J. & Wallace, M. D. (1999). Examination of ambiguous stimulus preferences with duration-based measures. *Journal of Applied Behavior Analysis, 32*(1), 111-114.

DeLeon, I. G., Iwata, B. A., Goh, H., & Worsdell, A. S. (1997). Emergence of reinforcer preference as a function of schedule requirements and stimulus similarity. *Journal of Applied Behavior Analysis, 30*(3), 439-449.

Fernandez, E. J., Dorey, N. R., & Rosales-Ruiz, J. (2004). A two-choice preference assessment with five cotton-top tamarins (*Saguinus oedipus*). *Journal of Applied Animal Welfare Science, 7*(3), 163-169.

Findley, J. D. (1958). Preference and switching under concurrent scheduling. *Journal of the Experimental Analysis of Behavior, 1*, 123-144.

Fisher, W. W. & Mazur, J. E. (1997). Basic and applied research on choice responding. *Journal of Applied Behavior Analysis, 30*(3), 387-410.

Fisher, W., Piazza, C. C., Bowman, L. G., Hagopian, L. P., Owens, J. C., & Slevin, I. (1992). A comparison of two approaches for identifying reinforcers for persons with severe and profound disabilities. *Journal of Applied Behavior Analysis, 25*(2), 491-498.

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.

Foster, T. M., Temple, W., Cameron, B., & Poling, A. (1997). Demand curves for food in hens: Similarity under fixed-ratio and progressive-ratio schedules. *Behavioural Processes, 39*, 177-185.

Francisco, M. T., Borrero, J. C., & Sy, J. R. (2008). Evaluation of absolute and relative reinforcer value using progressive-ratio schedules. *Journal of Applied Behavior Analysis, 41*(2), 189-202.

Glover, A. C., Roane, H. S., & Kadey, H. J. (2008). Preference for reinforcers under progressive- and fixed-ratio schedules: A comparison of single and concurrent arrangements. *Journal of Applied Behavior Analysis, 41*(2), 163-176.

Hagopian, L. P., Long, E. S., & Rush, K. S. (2004). Preference assessment procedures for individuals with developmental disabilities. *Behavior Modification, 28*(5), 668-677.

Hudson, D., Foster, T. M., & Temple, W. (1999). Fixed-ratio performance of possum (*Trichosurus vulpecula*). *New Zealand Journal of Psychology, 28*(2), 79-85.

Hursh, S. R. (1978). The economic concepts of daily consumption controlling food- and water-reinforced responding. *Journal of the Experimental Analysis of Behavior, 29*(5), 475-491.

Hursh, S. R. (1980). Economic concepts of the analysis of behavior. *Journal of the Experimental Analysis of Behavior, 34*(2), 219-238.

Hursh, S. R. (1984). Behavioral economics. *Journal of the Experimental Analysis of Behavior, 42*(3), 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*(3), 419-440.

Hursh, S. R. & Winger, G. (1995). Normalized demand for drugs and other reinforcers. *Journal of the Experimental Analysis of Behavior, 64*(3), 373-384.

Martin, J. L. (2002). *Food preference assessment with brushtail possums* (*Trichosurus vulpecula*) (Unpublished master’s thesis). University of Waikato, Hamilton, New Zealand.

Matson, J. L., Bielecki, J., Mayville, E. A., Smalls, Y., Bamburg, J. W., & Baglio, C. S. (1999). The development of a reinforcer choice assessment scale for persons with severe and profound mental retardation. *Research in Developmental Disabilities, 20*(5), 379-394.

Nicol, C. J., Caplen, G., Edgar, J., & Browne, W. J. (2009). Associations between welfare indicators and environmental choice in laying hens. *Animal Behaviour, 78*(2), 413-424.

Northup, J. (2000). Further evaluation of the accuracy of reinforcer surveys: A systematic replication. *Journal of Applied Behavior Analysis, 33*(3), 335-338.

Northup, J., George, T., Jones, K., Broussard, C., & Vollmer, T. R. (1996). A comparison of reinforcer assessment methods: The utility of verbal and pictorial choice procedures. *Journal of Applied Behavior Analysis, 29*(2), 201-212.

Pace, G. M., Ivancic, M. T., Edwards, G. L., Iwata, B. A., & Page, T. J. (1985). Assessment of stimulus preference and reinforcer value with profoundly retarded individuals. *Journal of Applied Behavior Analysis, 18*(3), 249-255.

Patterson-Kane, E. G., Pittman, M., & Pajor, E. A. (2008). Operant animal welfare: Productive approaches and persistent difficulties. *Animal Welfare, 17*(2), 139-148.

Pederson, L. J., Holm, L., Jensen, M. B. (2005). The strength of pigs' preferences for different rooting materials using concurrent schedules of reinforcement. *Applied Animal Science, 94*, 31-48.

Roane, H. S., Lerman, D. C., & Vorndran, C. M. (2001). Assessing reinforcers under progressive schedule requirements. *Journal of Applied Behavior Analysis, 34*(2), 145-167.

Roane, H. S., Vollmer, T. R., Ringdahl, J. E., & Marcus, B. A. (1998). Evaluation of a brief stimulus assessment. *Journal of Applied Behavior Analysis, 31*(4), 605-620.

Sørensen, D. B., Ladewig, J., Ersbøll, A. K., & Matthews, L. (2004). Using the cross point of demand functions to assess animal priorities. *Animal Behaviour, 68*(4), 949-955.

Sumpter, C. E., Foster, T. M., & Temple, W. (2002). Assessing animals' preferences: Concurrent schedules of reinforcement. *International Journal of Comparative Psychology, 15*(2), 107-126.

Tustin, R. D. (1994). Preference for reinforcers under varying schedule arrangements: A behavioural economic analysis. *Journal of Applied Behavior Analysis, 27*(4), 597-606.

Williams, C. M., Riddell, P. M., & Scott, L. A. (2008). Comparison of preferences for object properties in the rat using paired- and free-choice paradigms. *Applied Animal Behaviour Science, 112*, 146-157.

Windsor, J., Piché, L. M., & Locke, P. A. (1994). Preference testing: A comparison of two presentation methods. *Research in Developmental Disabilities, 15*(6), 439-455.