THE EFFECT OF ALTERING MAINTENANCE DIET ON DEMAND FOR REINFORCERS.

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Abstract

Six hens' preferences between whole grain wheat, commercial laying pellets and puffed wheat were assessed using a free-access procedure. Wheat was found to be the preferred food of three hens, pellets were preferred by one, puffed wheat was found to be not preferred by four, and two hens had no preference for any food. The hens were then maintained at 80% ± 10% of their free-feeding body weights by one of the three foods while responding under a progressive ratio schedule in which the response requirement doubled after each reinforcer. A session terminated after a hen had ceased responding for 300 s. All three foods were used as reinforcers and then the maintenance food was changed. Thus all three foods served as reinforcers with each of the three maintenance diets. Response rates, post-reinforcement pauses and demand functions (i.e., the relation between estimated consumption rate and response requirement) under each response requirement were examined. Performance was not affected systematically across hens by diet or reinforcer type. There were no systematic relations between the individual hen's food preferences and any of the performance measures. The same hens were then maintained at 80% ± 10% of their free-feeding body weight by pellets and responded under fixed ratio schedules with the response requirement doubling each session until a hen received no reinforcers in a session. Sessions terminated after 40 reinforcers or 40 min. Each of the three foods served as the reinforcer for two series of the increasing fixed ratio schedules. The resulting demand functions did not differ over reinforcer type and no relation found between the type of reinforcer and the individual hen's preferences. Performance (including the shape of the demand functions) was found to be similar under both the progressive and fixed ratio schedules. It is suggested that the provision of post-feed outside of the

experimental sessions and the hen's low body weights could explain why there was no difference in demand between conditions with different maintenance diets and reinforcer types.

Acknowledgments

I would like to thank Drs' Mary Foster and James McEwan for all their guidance and support throughout undertaking this thesis. I am especially grateful for the time invested in ensuring that the standard of work was the best I could produce

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Progressive ratio (PR) schedules (first described by Hodos, 1961) have been established as a method for assessing the strength of the motivation an animal has to obtain a reinforcer. Under a PR schedule the response requirement is increased systematically (typically after a fixed number of reinforcers). The largest completed response requirement (or "breakpoint") is taken as the measure of the animal's motivation (Robinson, Foster, Temple and Poling, 1994). Response requirements are usually increased arithmetically but are sometimes increased geometrically (Killeen, Posadas-Sanchez, Johansen & Thraikill, 2009). PR schedules have been used to assess dose related effects of various drugs on motivation to work for reinforcers (usually food or water). For example, Foltin and Evans (2000) investigated the effect of D-amphetamine on monkeys responding for candy and fruit drink.

Fixed Ratio (FR) schedules have also been used to assess the motivation of animals to obtain reinforcers. A FR schedule has a fixed number of responses that an animal is required to do to gain a reinforcer. For example under a FR1 schedule, one response would be required by the animal to earn reinforcement. The FR value does not change over the session, though several studies have increased FR values over subsequent sessions (e.g., Johnson & Bickel, 2006; Hursh, Raslear, Shurtleff, Bauman & Simmons, 1988). Rates of responding under FR schedules are typically high with the post-reinforcement pauses (PRP) increasing with the FR value (Felton & Lyon, 1966). The response rates tend to decrease with increases in FR values (Felton & Lyon, 1966).

Dawkins (1983) posited that the study of human economic theory, such as demand, could aid development of a framework on which animal welfare decisions could be based. She suggested that demand functions could be used as a methodology for identification of what are essential and what are non essential commodities to animals. Demand functions, are a mathematical representation of the relationship between price and consumption of a commodity (Hursh, 1980). Demand functions often have a negative slope, indicating that for most commodities, as price increases, consumption falls (Hursh, 1980). Creating a demand function is done by manipulating the price that must be paid by an organism to access a commodity (such as a food reinforcer) and measuring the consumption rate of the reinforcer at the various prices. Both PR and FR schedules have been used with animals to derive demand functions (Foster, Temple, Cameron & Poling, 1997). PR and FR schedules allow construction of demand curves as the number of responses an animal must do before a reinforcer is gained can be directly manipulated

Hursh et al. (1988) proposed an equation that can be used to describe the relation between price (e.g., response requirement) and consumption (e.g., number of reinforcers obtained). The equation is:

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

Q represents total consumption, *P* is the unit price (or the FR/PR ratio) and *L* is the point at which the demand function intersects the y axis. *L* is also the estimate of the level of consumption at the lowest price e.g. PR1. Parameter *b* represents the initial slope (initial elasticity) of the demand curve. Parameter *a* reflects the rate of change of elasticity, which is the sensitivity of consumption to increases in price. Systematic changes in the value of *a* show that an independent variable has altered the slope or shape of the demand function.

The parameters, defined in Equation 1, can be used to calculate the point at which demand changes from elastic to inelastic, This point is known as P_{max} (Hursh, et al. 1988). P_{max} may be determined by the equation:

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

Calculting P_{max} provides an additional mechanism for comparing demand for different commodities.

Hursh (1980) suggested that elasticity coefficients (the slope of the demand curve) may be useful for describing the changes in an animal's rate of responding as the response requirement is varied. Figure 0.1, taken from Figure 10 in Hursh (1980), shows the examples of possible demand curves, response rate curves and elasticity coefficients of log-log demand curves. An elasticity coefficient of 1.0 represents unit (equal) demand. If an animal was showing unit demand the response rate would remain the same across price changes. An elasticity coefficient less than 1.0 represents inelastic demand, and more than 1.0 represents elastic demand (Hursh, 1980). If an animal shows inelastic demand for a commodity it is said to be essential, as its value is such that the animal is willing to work harder to maintain consumption. If elastic demand for a commodity is found then the commodity is said to be not essential (Hursh, 1980).

There are several factors that can affect demand. Hursh (1980) suggested that the type of economy which an experiment is conducted in can affect the animal's behaviour and thus the shape of the demand function produced. Hursh (1980) mentions two types of economy: open and closed. An open economy is one in which the access to the commodity (such as a food reinforcer) the animal is working for, is not solely within the experiment, but rather is arbitrarily controlled by the experimenter (Hursh, 1980). A closed economy is one where the commodity is not available outside of the experimental chamber, e.g. if an animal, is working to earn food reinforcers, the only time they receive food is by earning it in the experimental chamber (Hursh, 1980).

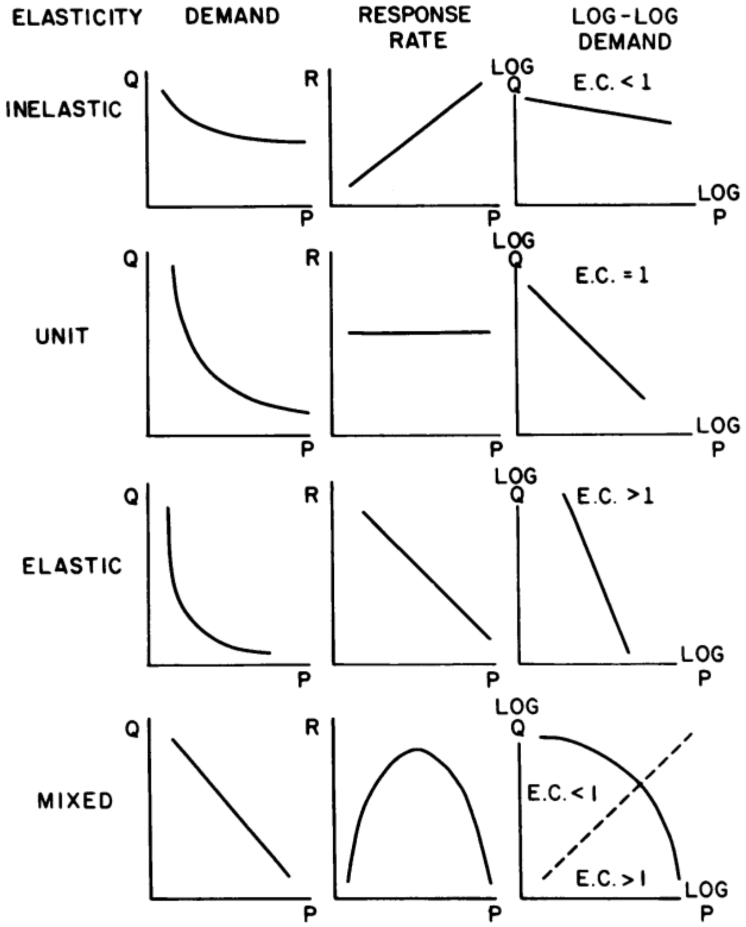

Fig. 10. Definitions of inelastic, unit elastic, elastic and mixed demand in terms of the demand curves, the response rate curves and the elasticity coefficients of the log-log demand curves (see text for explanation).

Figure 0. 1. Figure 10 from Hursh (1980).

Ladewig, Sørensen, Nielsen and Matthews. (2002) conducted research using FR schedules in closed and open economies. They found that varying availability of water both before, and after, exposing rats to a FR schedule with water as the reinforcer, significantly affected the slope of demand curves produced. They found that water given one hour ten minutes before the test produced the steepest slope (-1.09) and half an hour after the test the second steepest slope (-0.81). They also found that the access period to water (10-min access or 30-min access) had an effect on the slopes generated. They suggest their findings showed that the availability of the commodity outside the test situation should be taken into consideration when using demand functions to assess the strength of an animal's motivation.

Variables that affect demand in this way could also be termed establishing operations. An establishing operation is said to be something that has an effect on the efficacy of a reinforcer and therefore an animal's motivation to obtain a reinforcer (Michaels, 2000). An example of a known establishing operation is food deprivation. Food deprivation is an establishing operation because it makes food a more effective reinforcer (Michaels, 2000). Examples of studies that have manipulated establishing operations are Ferguson and Paule (1997) who manipulated body weight, and Ladewig et al. (2002) who manipulated the availability of the reinforcer before the test situation. To this author's knowledge, no studies with animals have investigated whether the type of food provided prior to the experimental situation would function as an establishing operation.

Manipulations of establishing operations that have been carried out with PR schedules include Hodos (1961). Hodos (1961) found that the breakpoints reached, and number of responses made by rats working under PR schedules varied reliably with changes in body weight and the magnitude of the reward offered. Body weight can be considered to be an establishing operation as it changes the reinforcing value of food. In an extension of Hodos (1961); Hodos and Kalman (1963) reported on behaviour that can be seen in rats working under PR schedules. They state that as the PR ratio value increases over the experiment so does the number of responses made by the rats. They also state that there are frequent pauses in responding at the higher ratios. Baron, Mikorski and Schlun (1992) found with rats, working under PR schedules, that PRP duration increased when the reinforcer concentration was reduced (i.e., the flavour was lessened). They also reported that as the PR ratios increased the response rates decreased, however, the response rates were not influenced by the reinforcer magnitude or the post reinforcement timeouts.

Though manipulations of establishing operations, as well as, manipulations of the reinforcer have been carried out, (e.g. Hodos, 1961; Hodos & Kalman, 1963) few studies utilising PR schedules have systematically altered access to the reinforcer outside of the test environment. Ferguson and Paule (1995) investigated the effect of various partial-satiation intervals on PR performance of rats. Partially satiated animals are maintained at a weight below their free-feeding body weight but are allowed access to the reinforcer (e.g., food) prior to the experiment (pp.153-154). Ferguson and Paule (1995) pre-fed rats at periods between 0.25 and 6 h prior to operant assessment as opposed to the usual 23 hours. The rats were pre-fed with standard rat chow which differed from the sucrose reinforcer that was available in the experiment. The results showed that there were no significant effects of short term food deprivation or pre-feeding intervals on PR performance or breakpoint. Ferguson and Paule (1997) then investigated whether body weight would have an effect on rats PR schedule performance. The results showed that for rats maintained between 75%-100% of free feeding body weight, the PR breakpoints were significantly affected and the number of reinforcers earned over the schedule was inversely related to the percentage of free-feeding body weight the rats were maintained at. The reinforcer used in this study was standard rat chow which differed from the sucrose reinforcer used in the 1995 study. If the reinforcer had been something more palatable to the rats, such as the previously used sucrose, it is possible different results could have been obtained.

Several studies have been undertaken using PR schedules with hens. Bokkers, Koene, Rodenburg, Zimmerman and Spruijt (2003) investigated the breakpoint a broiler hen would reach under two conditions of food restriction (50% and 75% of ad libitum food). Food restriction could also be termed an establishing operation as it changes the reinforcing value of food. The results showed that 50% feed restricted birds would pay a higher price for access to a food reinforcer during the first week of testing; however, no significant differences were found during the second week. The latency for head in feeder was also lower for the 50% birds than for the 75%. When the hens were not food deprived all birds were shown to make a much smaller number of key pecks. No short term effect of feed restriction was found as when the groups were swapped and the 50% group received 75% feed and vice versa the results were no different. As broiler hens have been specifically bred for their appetitive behaviour the results may be affected by this.

A study that does not involve manipulating establishing operations, but demonstrates PR schedules can be used with domestic hens, was done by Robinson et al. (1994). Robinson et al. (1994) investigated the effect that PR schedules (with initially different response requirements) had on break point values of domestic hens working for W. This was the first published study using domestic hens and PR schedules. Breakpoints were higher when the hens worked under a PR schedule that increased by increments of 10 (PR10) as opposed to a PR2 schedule and findings suggested that the satiation of an animal (due to a larger number of reinforcers obtained under the lower PR schedule) and the number of response requirements needed to gain reinforcement affected the breakpoints. Robinson et al. (1994) determined that demand for W was elastic for these hens; however, it is important to note food was provided outside of the test situation.

Foster, Temple, Cameron and Poling (1997) demonstrated use of FR and PR schedules with domestic hens to create demand curves. Foster, Temple et al. (1997) found that consumption decreased as the number of response required increased and that the demand equation developed by Hursh et al. (1988) They also found (Equation 1) could be applied to findings from both PR and FR schedules. They also found a higher rate of responding under PR schedules than under the same ratios under a PR schedule, however; hens worked to a higher ratio under the FR schedules. Similar demand curves were generated under both PR and FR schedules, nevertheless Foster, Temple et al. (1997) caution that demand curves should only be interrupted in the light of those generated in a comparable ratio schedule.

At this time, no published research can be found that has investigated the effect that altering the type of food available outside of the experimental environment as well as the type of reinforcement available has on demand. As PR schedules have been established as a capable assessment of demand and shown to be sensitive to other establishing operations (e.g. body weight). It is possible that the food used in the maintenance diet might affect hens' responding under a PR schedule for that food or for other foods used as reinforcers. One aim of this study was to investigate this possibility with hens. However, to study this required the use of foods that are of different 'values' to the hens. Although PR schedules are used to establish 'value' their use for this purpose here would serve as a confound and another method of establishing hens' food preferences was required.

A free-access preference assessment was conducted with whole grain wheat (W), feed pellets (P) and puffed wheat (PW) available as the options. PR schedules were then used to assess the animal's demand for all three food types as reinforcers when fed solely W, P or PW outside of the experimental chamber in place of the hen's usual diet of P.

Experiment 1: Preference Assessment

Introduction

There are a range of methods that have been used to assess preference in animals. Examples are T-Maze tests, free-access procedures and concurrent schedules. It is important to note that any preference assessment only offers an indication of preference relative to the choices offered within the tests. This is significant if the intended use of a preference test if to assess whether the choice the animal makes is best for its welfare, as an animal will indicate a preference for one choice over the others offered regardless of whether the choice is actually necessary to the animal's wellbeing or not (Dawkins, 1983).

T-Maze tests involve offering an animal the choice between two environments connected to a runway or start box (e.g. Guillemet, Comyn, Dourmad & Meunier- Salau¨n (2007). Sumpter, Foster and Temple (2002) report that the latency to leaving the start box, the option selected, and the number of times each option is selected, are taken as the measures of preference. For example, Dawkins (1978) used latency in assessing preference between two environments. One issue for T-Maze tests is that the amount of time spent in an area by an animal may not be the most accurate measure of preference, as an area where an animal spends a small portion of time, e.g. an area containing material for a hen to dust bathe may still be highly valued by the animal even though proportionally the animal does not spend much time there. Another issue with T-Maze tests is that no degree of preference between how much an animal prefers one environment over the other can be obtained.

One method that can provide information as to the degree of an animal's preference for one alternative over another which can be used to rank preferences is concurrent schedules (Sumpter, et al. 2002). Concurrent schedules have been used to measure food preferences with animals (Matthews & Temple, 1979) and specifically hens, (Foster, Sumpter, Temple, Flevill & Poling, 2009). Concurrent schedules are an operant procedure where an animal has a choice to respond on one of two schedules of reinforcement via two incompatible methods. For example Variable Interval (VI) schedules are commonly used. When an animal is working under a VI schedule the animal will not be reinforced for a specified period of time after they have received reinforcement (the times are pre selected but can vary). Schedules can be either independent or dependent. Under independent schedules an available reinforcer on one schedule does not affect the availability of one under another. Under dependent schedules the animal has no choice but to sample both alternatives as the other schedule will stop timing until the reinforcer is collected (Sumpter et al. 2002). One issue with using dependent schedules is that as an animal has to respond on both schedules, dependent schedules may result in smaller preferences being observed than would otherwise be observed if the animal was not required to respond on both schedules (Sumpter et al. 2002).

The measures of preference for concurrent schedules are the amount of time responding on each alternative and the number of responses made (Sumpter, et al. 2002). However despite the merits of concurrent schedules Sumpter, et al. (2002) caution of the length of time involved in conducting concurrent schedule preference assessments, as well as, the expense involved in equipment needed.

Foster et al. (2009) used concurrent schedules with hens to obtain log *q* values (where log *q* is “the bias resulting from the different food qualities”, p.207) which they interpreted as measures of preference. Both honey puffed wheat and PW were compared to W. They then ranked the three foods using these comparisons and found that W was the highest ranked food and PW the least. This indicates that hens may have a preference for W over PW.

Another less time consuming way of assessing food preferences is free-access procedures, free-access procedures involve offering an animal access to two or more alternatives that cannot both be experienced at the same time, such as floor types (Hughes & Black, 1973), different sized cages (Patterson-Kane, 2002) or types of food (Bruce, Prescott & Wathes, 2003; Bouvarel et al, 2009). In the case of Hughes and Black (1973) the amount of time spent on each floor type was taken as the measure of preference. Bruce, Prescott and Wathes (2003) and Bouvarel et al. (2009) used relative amount consumed of each food as the measure of preference. Issues with free-access procedures involving food include the possibility that animals may consume all of a preferred food first, and then all of another food, resulting in no discernable preferences (Sumpter et al. 2002). Therefore; it is necessary to give significant quantities of food that cannot be entirely consumed over the testing period.

Bouvarel et al. (2009) used a free-access procedure to assess food preferences in hens for low energy and high energy, hard and soft pellets. The free-access procedure involved exposing the hens to eight micro feeders, half of which had one type of food and half of which had another, for a 1 hour period. The position of the micro feeders was changed randomly between experimental sessions. The relative amount of each food consumed was taken as the measure of preference. Results were also compared to the relative amounts of each food consumed when given free access over a longer period. Bouvarel et al. (2009) found that hens showed a preference for high energy diets in the 1 hour choice test however this was not reflected by higher consumption of the preferred food in a 24 hour period.

Bruce, Prescott, and Wathes (2003) also used a free-access procedure with hens. Their hens were exposed for 15 minute periods, to a randomly assigned selection of six different foods. The relative amount consumed of each food was taken as the measure of preference. It was found that consumption of maggots was much higher than of the other foods (which included whole grain wheat and feed pellets). The results of a demand assessment (using a PR1 schedule), with pellets and maggots used as the reinforcers, found that hens consistently worked to higher ratios for maggots. This finding supported the result of the preference assessment, despite the access periods for the foods being only 15 min. Bruce,et al. (2003) also found that food depriving the hens for up to 6 hours before conducting the demand assessment had no effect on preference for maggots. These results may possibly have been influenced by the novelty of maggots as a food, as pellets were fed daily to the hens. In addition it may be that a longer free-choice period may have led to different results.

One concern with free-access procedures is that Bouvarel et al. (2009) found that preferences shown by hens in a one hour choice test did not reflect higher consumption of the preferred food over a 24 hour period. However, as also pointed out earlier, Bruce, Prescott and Wathes (2003) found that a free-access procedure, that was only 15 minutes long, resulted in the preferred food (maggots) also being the food the hens would work to higher ratios consistently.

Issues which are pertinent to all preference tests include the affects of post-ingestive consequences and the affects of social learning. Forbes and Kyriazaki (1995) state that it is essential to offer animals types of foods for some number of days, not hours, to allow time for conditioned associations between the food and the post-ingestive consequences of eating that food to develop (p.432). Guillemet et al. (2007) also agree that short term tests only allow assessment of animal's feed preferences relative to the taste and ease of eating as opposed to post-ingestive factors that may ultimately affect preference. Subsequently any choice test conducted should involve lengthy presentation of the foods in order to better assess innate preferences and not short term preferences.

The result found in a preference test where an animal has witnessed the choices another animal has made may be affected by social learning. Sherwin, Heyes and Nicol (2002) investigated whether hens are influenced by social learning while eating and found that they are sensitive to the preferences showed by a demonstrator hen when eating palatable foods. Therefore to avoid any possible confounds of social learning hens should be unable to see other hens while they are eating.

The method selected for the current experiment was a free-access procedure. Within the assessment the hens were given access to commercial P, W and PW simultaneously for a period of 24 hours over two weeks. The reason for selecting this time period was to ensure long term preferences are assessed. The relative consumption of the foods will be used as the measure of preference as has also been used by Bruce, Prescott, and Wathes (2003) and Bouvarel et al. (2009).

Another reason for selecting this method was that it allowed identification of food preferences in a relatively short amount of time, as all foods could be presented together, and no complicated equipment needed to be developed such as for concurrent schedules. Speed of method was important to allow enough time for the planned demand assessment to be undertaken within the time frame of this project. The foods were selected as they were readily available at the laboratory where the hens were housed; they differed significantly from each other in appearance and texture and had been proven to be foods that were readily consumed by hens. W and PW were also used as the data presented by Foster et al. (2009) suggested that hens have a preference for W over PW.

In addition, the foods selected were appropriate for use in a feed hopper so could all be used in the further demand experiments. The amount of each food made available to the hens was chosen to be more than they could consume in a 24 hour period. To avoid any confounds of social learning hens were unable to see the other hens while they were eating.

Method

Hens

Six Brown Shaver hens numbered 71, 72, 73, 74, 75 and 76 served as subjects. Hens 71-75 were approximately 4 years old; Hen 76 was approximately 1 year old. Prior to the experiment commencing the hens were maintained at 80%, ± 10%, of their free-feeding body weights (this was determined by calculating 80 % of the hens average daily weight over a three week period, during which time they had unlimited access to their normal food (commercial laying P)) and were weighed daily. Hens were housed individually in 300 mm (w) by 440 mm (d) by 460 mm (h) home cages. The hens were given supplementary feedings of vitamin enriched food and health grit on a weekly basis. All hens had prior experimental experience receiving food reinforcers for pecking touch screens.

Apparatus

Two food troughs were used in this experiment. The troughs were 1520 mm long and had a straight back, 170 mm high, which sat against the home cages. The bottom of the trough measured 90 mm, the front 130 mm and across the top 200mm. Each trough was divided into nine equal sized sections of 100 mm width each. Each hen had access to three sections, with a 200 mm partition in place every 300 mm (see Figure 1.1) so that hens could not reach over into the sections of other hens. The three sections available to each hen extended across the entire front of each hen’s cage (see Figure 1.2).

Figure 1. 1. Food trough.

Figure 1. 2. Food trough in use.

Procedure

The experiment started when concurrent access to three different types of food was given. The foods were W, PW and P. The required amounts of the three foods were measured and the food was poured into the appropriate section in the food trough. The amounts given were 400 gm W, 60 gm PW and 350 gm P (these weights gave approximately 500 cc in volume of each food). The section of the trough in which each food was presented was changed daily according to a randomised pattern.. The front bars on the cage were spaced at equal distances (see Figure 1.2) so that the hens could reach through into all three sections of the trough easily. All foods were made available for 24 hours, no supplementary feed was given. Water was freely available at all times. At approximately the same time each day the food troughs were taken down and the remaining food of each type was removed from the section using a measuring cup. The remaining food was weighed and the weight (gm) and volume (cc) of consumed food was calculated and recorded. No food was spilled by the hens throughout this experiment.

Results

Figure 1.3 shows the volume (cc) of three types of food consumed by each hen over 14 separate 24 hour periods, plotted as proportions of the total volume of the three foods consumed over the same period. This shows that, during the 14 days, Hens 72, 73 and 75 consistently consumed more cc of W than either PW or P. Hens 73, 74 and 75 consumed much lower volumes of PW than any other food. Hen 76 consumed more PW, when measured by volume, than any other food and Hen 71 consumed variable volumes of all foods.

Figure 1.4 shows the weight (gm) of the three foods consumed over the same period as Figure 1.3. Figure 1.4 shows Hens 72, 73 and 75 consistently consumed more W, when measured by weight, than either PW or P. Hens 71,72,73, 74 and 75 consumed less PW by weight than any other food. Hen 76 consumed variable weights of all foods.

Table 1.1 shows the total amount of each food consumed by each hen (in cc and gm) over the experiment as well as the total amount of each food consumed as a proportion of the total amount of food consumed. Table 1.1 shows that Hens 71 and 76 consumed more PW than the other two foods, when measured by volume, over the 14 day period. Hens 72 and 73 consumed more cc of W and Hens 74 and 75 consumed more cc of P over the 14 day period. Table 1.1 also shows that Hens 72, 73,75 and 76 consumed the more gm of W than the other two foods over the 14 day period. Hen 71 consumed the more gm of P and 74 consumed an equal weight of P and W.

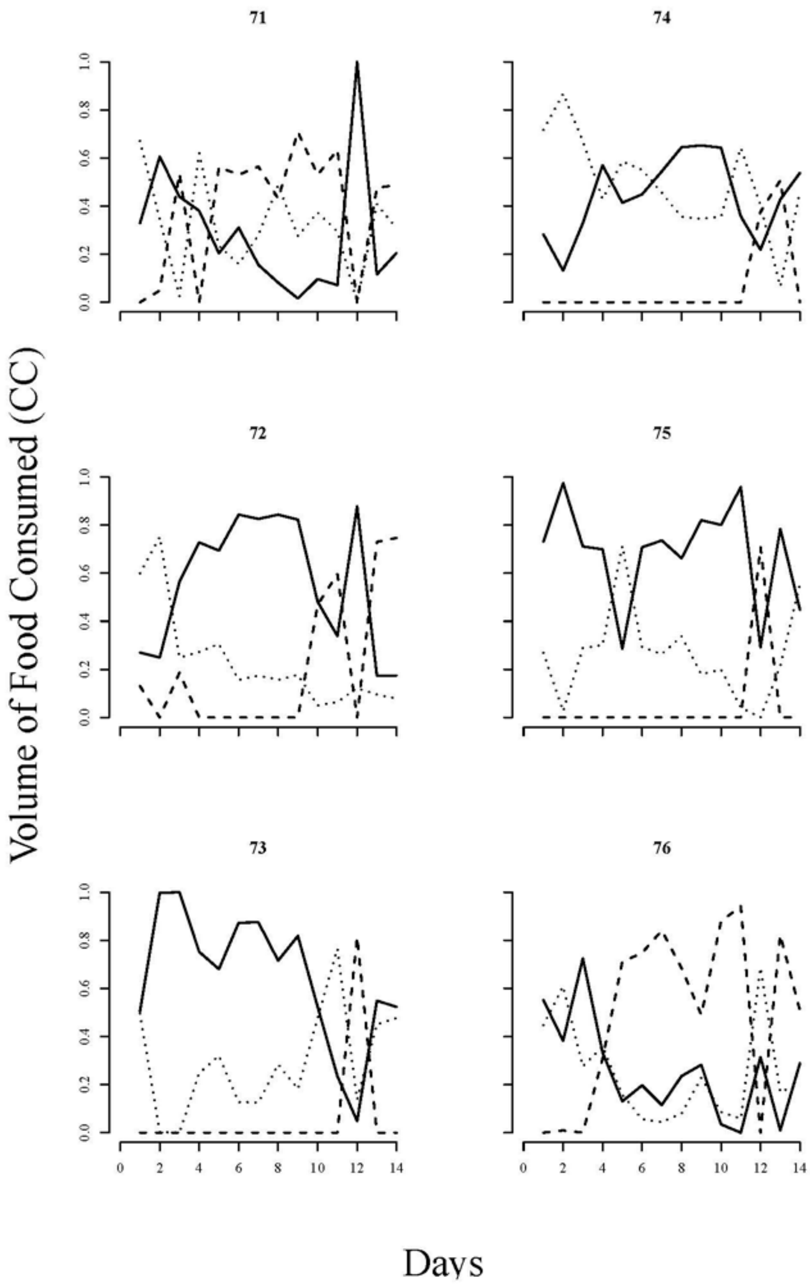

Figure 1. 3. The volume (cc) of W, PW and P consumed across the experimental period. The black line represents W, the dotted line represents P and the dashed line represents PW.

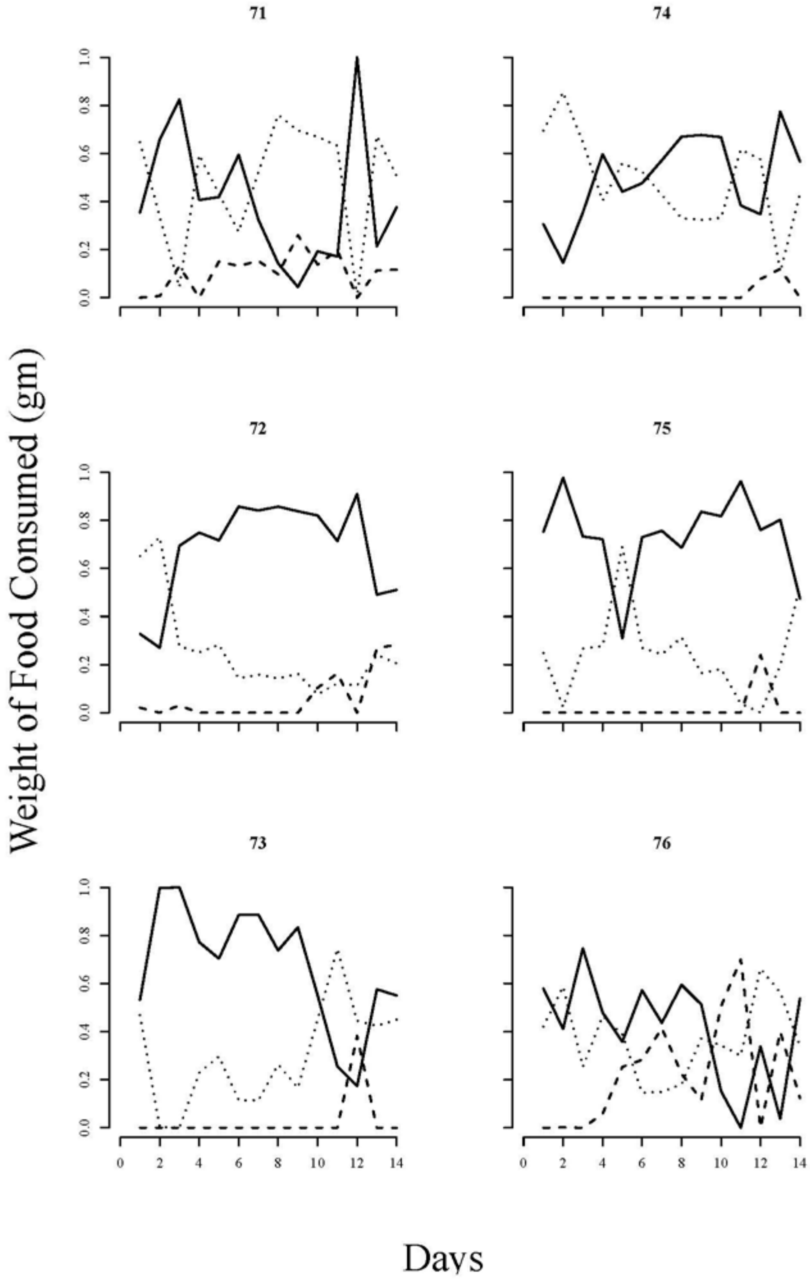

Figure 1. 4. The weight (gm) of W, PW and P consumed across the experimental period. The black line represents W, the dotted line represents P and the dashed line represents PW.

Table 1. 1. *Total weight (gm), volume (cc) and proportion (prop) of W, PW and P consumed over fourteen days by each hen.*

Hen	W				PW				P			
	gm	cc	prop gm	prop cc	gm	cc	prop gm	prop cc	gm	cc	prop gm	prop cc
71	595	772.7	0.36	0.20	178.8	1788.0	0.11	0.47	864.9	1253.5	0.53	0.33
72	1052.3	1366.6	0.71	0.52	72	720.0	0.05	0.27	367.6	532.8	0.25	0.20
73	1073.8	1394.5	0.66	0.54	44.2	442.0	0.03	0.17	499.9	724.5	0.31	0.28
74	809.7	1051.6	0.49	0.42	26.5	265.0	0.02	0.11	818.9	1186.8	0.49	0.47
75	1273.3	165.4	0.73	0.15	25.8	258.0	0.01	0.24	454.1	658.1	0.26	0.61
76	866.4	1151.2	0.44	0.20	367.5	3675.0	0.19	0.63	714.8	1035.9	0.37	0.18

Table 1.2 shows the number of days out of 14 that each food was consumed the most (in gm and cc) by each hen. Table 1.2 shows that Hens 73, 74 and 75 consumed more cc of W than any other food on the majority of days (nine, 11 and 12 respectively). Hen 72 consumed more P by volume (cc) than any other food on eight of the 12 days. Hens 71 and 76 consumed more cc of PW than any other food on nine days. Hens 72, 73, 74 and 75 had three, two, one and one days respectively where they consumed more cc of PW than any other food. Table 1.2 also shows that Hens 72, 73,75 and 76 consumed more weight (gm) of W than any other food on the majority of days (12,12,12 and 8 respectively) Hens 71 and 74 consumed more weight of P than any other food on 10 days out of 14 days. Hens 71,72,73,74 and 75 never consumed more weight of PW than any other food. Hen 76 consumed more weight of PW than any other food on one day only.

Table 1. 2. *Number of days each food was consumed the most when the amount was measured by weight (gm) and by volume (cc) for each hen.*

Hen	W		PW		P	
	gm	cc	gm	cc	gm	cc
71	4	2	0	9	10	3
72	12	9	0	3	2	2
73	12	9	0	2	2	3
74	6	5	0	1	8	8
75	12	11	0	1	2	1
76	8	3	1	9	5	2

Discussion

The purpose of this experiment was to investigate the preferences between the three foods, W, PW, and P, using a free-access method.

The results show that Hens 72, 73, and 75 consumed more W, in both volume and weight, than either PW or P. This suggested that this was their preferred food. Hen 74 consumed P the most across volume and weight, suggesting that she preferred P. Hens 71 and 76 showed no clear preferences for any food over the 14 days. In addition Hens 72, 73, 74 and 75 consumed PW the least (by volume and weight) over the 14 days – suggesting that this was their least preferred food.

Hens 72 to 75 showed no preference for PW by volume or weight of the foods. However, for Hens 71 and 76 an issue arose in interpreting their results as the same volume of PW as of W or P has a significantly smaller weight when compared to the weight of the W or P. Thus, when looking at the results by volume the PW consumption for Hens 71 and 76 appeared to be different than when looking at the results by weight. It is true that an amount of PW (when assessed through weight) would contribute to filling a hen's crop more than the same weight of P or W. Therefore density of foods should be taken into account for future reinforcer choices.

Comparing the results from the first five days of the experimental period with the last five days does show that there are differences in consumption of the foods by all hens. It is possible that the different experiences the hens had had with each food as well as the length of the assessment period affected the results. All hens had experience eating P as this was the normal diet provided at the laboratory where they were housed. As stated in the introduction, Forbes and Kyriazakis (1995) warned that preference assessments needed to be of reasonable length in order to assess stable preferences. All the hens had been exposed to W as they had all participated in experiments in which W was used as the reinforcer. No hens had been exposed to PW. At the beginning of the assessment period three hens consumed more P than W and a very small amount of PW was consumed by Hens 71, 72 and 76. However during the last few days of the assessment period all hens consumed some PW, including the three hens 73, 74 and 75 whom up until that point had consumed no PW at all. It may be that the reason little PW was consumed near the beginning of the experimental period was due to the fact the hens had had no exposure to PW before the experiment began.

A possible factor that may influence preference for foods is the nutritional content of the food (Forbes & Kyriazakis, 1995). Forbes and Kyriazakis (1995) suggested if an animal is eating for protein, they may eat less of a food that has a higher protein content per gram than of a food that has a lower protein content per gram. The protein content of the three foods used in this experiment were 14.1 gm per 100 gm for P, 11.6 gm per 100 gm for PW and 12 gm per 100 gm for W respectively. As all foods have a similar protein content it is unlikely this would have affected their preferences largely. However, it is important to note that a large volume of PW would need to be consumed in order for a hen to obtain the same amount of protein that could be obtained from eating a smaller volume of P or PW. So even though the hens ate less PW (which is different to what Forbes and Kyriazakis, 1995 suggested – that animals would eat more of low protein foods), the sheer volume of PW that would need to be eaten to gain protein could be a possible reason it was found to be the least preferred food by the majority of the hens. One way to assess if hens adjust the volume of food they consume according to the protein content, would be to measure amount eaten of the foods when provided one at a time to the hens.

As stated earlier, Bouvarel et al. (2009) found that preferences over a short time period did not reflect preferences over a long time period. It may have been worth examining which foods were eaten at certain points in time through a 24 hour period (possibly by use of a sensor to record which section of the trough had been entered) in order to establish whether the initial consumption of the foods had any relation to the overall consumption in each 24 hour period.

Foster et al. (2009) found using concurrent schedules, that out of three foods (W, honey puffed W and PW) W was the more preferred food and PW the least preferred food. The results of the free-access experiment are reflective of the results found by Foster et al. (2009), suggesting that free-access can be a comparable measure to concurrent schedules.

In summary, across this experiment, preferences between foods were established for four out of six hens. Three hens preferred W and one hen preferred P. The free-access procedure was successful with accurate amounts and volumes of foods recorded due to no spillage occurring. Also, at no point was the entire amount of any food consumed thus the amount of food consumed being taken as the measure of preference was deemed to be acceptable.

Experiment 2: PR Demand Assessment

Introduction

In this next experiment hens responded under PR schedules in which the response requirement doubled after each reinforcer. Three different reinforcers (W, PW and P) were used. The hens were maintained at 80 % ± 10% of their free feeding body weight by one of three different foods (W, PW and P). The hens responded for each of the three different reinforcers while their body weights were maintained by one of the foods. Once all hens had been exposed to PR schedules with all three reinforcers the maintenance food was changed. The hens were fed the new diet for 4 days and the PR schedules were then repeated, until all three foods had been used to maintain their weight. Equation 1 was fitted to the data, the parameter estimates and the values of P_{max} were used to assess whether demand differed across the different feeds. The overall response rates, running response rates, post-reinforcement pauses for each response requirement were also examined. It was found that there was no effect of maintenance diet on demand for reinforcer type.

Method

Hens

Hens were the same six Brown Shaver hens that took part in Experiment 1.

Apparatus

The experimental chamber measured 410 mm (w) by 595 mm (h) by 555 mm (d). The interior of this chamber was white. The floor of the chamber was covered by a plastic sheet. One of the sides measuring 410 mm by 555 mm contained a response key, and a hole to allow access to a food magazine attached to a hopper. The response key was centred 50 mm above the food magazine hole which was 100 mm above the floor of the chamber and measured 100 mm by 155 mm. The response key was a 25 mm semi translucent Perspex circle backlit with a 28 v green multichip LED. Each peck to the key (minimum of 0.1 n required) resulted in an audible beep of 65db being generated. The response key was surrounded by an aluminium plate measuring 110 mm high by 400 mm wide. When the key was pecked, responses were recorded by MedPC on a computer. A response was defined as the key being pushed in and then released only while they key was lit, responses to the darkened key were not recorded. A food hopper containing a food magazine was set to be level to the bottom of the food access hole. The magazine could be refilled manually with the appropriate food when needed. Entries of the hens head into the magazine were recorded by a sensor located in the magazine and the time of such entries recorded in MedPC.

Procedure

Hens were placed in the experimental chamber and the magazine was raised manually to allow the hens to eat from it; all hens ate from the magazine without prompting. The magazine was filled with W. The hens were trained to peck the lit key using a method where successive approximations (shaping) towards the key resulted in the magazine being raised. It took three sessions of shaping before all hens were pecking the key reliably. Hens were then exposed to a FR5 schedule where five key pecks were required for the hens to receive two s access to the magazine. A maximum of 20 reinforcers could be obtained per session, ten sessions were conducted at which point responding was deemed stable (all hens were earning the twenty available reinforcers within 270 s over several sessions). A PR schedule with a doubling response requirement was then introduced. The response requirement doubled e.g. the initial response requirement was one; the next response requirement was two, then four etc, after a reinforcer was earned. Sessions ended when the hen had obtained either seven reinforcers or 2400 s had elapsed, whichever occured first. Hens were exposed to training for 16 daily sessions at which point responding was deemed stable (when all the hens were earning seven reinforcers within 270 s over several sessions).

There were ten conditions, during each condition hens were fed a base diet (whole grain W, commercial laying P or PW) via food containers in their home cages for four days, the hens did not work in the experiment during this time. The amount of food given during this period was adjusted to maintain the hens around 80% of their free-feeding body weight but was always a minimum of 50cc P (or the equivalent weight in W or PW). Hens remained in their cages throughout this time except for once a day when they were removed to be weighed. On the fifth day Hens 71, 72 and 73 were exposed to a PR schedule with the doubling response requirement. Hens were responding for 2 - s access to one of the three feeds. When the session started the response key would light up white and it remained on until a peck was made. At this point it went off until the reinforcer had been delivered (the magazine raised and then lowered again). Once the magazine had been raised the light would come on again. The next response requirement was two pecks, the response requirement continued to double until the breakpoint was reached, at which point the session finished. The breakpoint was defined as 300 seconds since the last time the key had been pecked by the hen. Hens 74, 75 and 76 remained in the home cage for that day where they were fed the base diet. Experimental sessions were conducted seven days a week.

On day six hens 74, 75 and 76 were exposed to the PR schedules while 71, 72, 73 remained in the home cages and were fed the base diet (at least 50 cc). This alternation of hens continued until each hen had had three sessions with each reinforcer type, while being fed each maintenance diet. The base diet and the food in the chamber varied across conditions. The procedure was repeated until all conditions had been experienced. An outline of each condition is given in Table 2.1.

Table 2. 1. Sequence of experimental conditions. Not inclusive of sessions undertaken during training.

Condition	Base Diet	Magazine Food	Abbreviation
1	P	W	P/W
2	P	PW	P/PW
3	P	P	P/P
4	P	W	P/W
5	W	W	W/W
6	W	PW	W/PW
7	W	P	W/P
8	PW	W	PW/W
9	PW	PW	PW/PW
10	PW	P	PW/P

Results

Ten conditions with three series each were undertaken. The data was averaged across the three series for each condition. As the P/W condition was replicated twice (condition one and condition four) and no consistent differences were found between replications, the averages for condition one and condition four were then averaged together, resulting in the P/W condition being the average of six series, not three and condition four being eliminated from subsequent analysis.

Overall Response Rates

The overall response rates were calculated as the total number of responses per ratio divided by the key time (total time spent in each ratio minus the time the magazine was up). Figures 2.1 and 2.2 present the overall response rates for each condition, averaged over Series 1, 2 and 3, plotted against the natural log of the PR ratio for all hens, the series were averaged as there was found to be no consistent differences between them. It should be noted that Figure 2.1 and 2.2 present the same data. However Figure 2.1 presents the three maintenance diets (P, W and PW) on the left to right panels with the overall response rates calculated for each reinforcer type plotted. Figure 2.3 presents the three reinforcer types (W, PW and P) on the left to right panels with the overall response rates calculated for each maintenance diet plotted.

The left panel of Figure 2.1 shows that for Hens 71, 73, 75 and 76 the response rate functions were bitonic. Overall there was little discernable difference between the overall response rates when the maintenance diet was P (conditions P/W, P/PW and P/P) for any hen. The peak in overall response rate generally occurred between PR8 to PR32 for all hens. For Hens 71, 73 and 75 the overall response rate generally increased as the response requirement increased and then decreased over the last 2-3 PR ratios. For Hen 72 the overall response rate decreased slightly as the PR ratio got higher. Hen 74 showed an increase in overall response rate for the P/W condition but did not provide enough data under the P/PW and P/P conditions for analysis. In all conditions Hen 76, started with a very high overall response rate for PR1, which then decreased sharply but increased again, then decreased over the last 2-3 PR ratios.

The middle panel of Figure 2.1 shows that when the maintenance diet was W (W/W, W/PW and W), there was little discernable difference between the overall response rates for any hen. For Hens 71, 73, 74 and 76 as the response requirement increased the overall response rates generally increased and then decreased over the last 2-3 ratios. Once again the peak in the overall response rate occurred between PR8 to PR32. The exceptions were Hen's 72 and 75 where the overall response rate decreased slightly as the response requirement got higher.

The right panel of Figure 2.1 shows that when the maintenance diet was PW (PW/W, PW/PW and PW/P), there was little discernable difference between the overall response rates for all hens. For all hens as the response requirement increased the overall response rate generally increased and then decreased over the last ratios. The peak in the overall response rates was again between PR8 to PR32.

Figure 2.2 reflects the same trends as Figure 2.1 and shows that for all three reinforcer types the functions were generally bitonic. Figure 2.2 shows that for all hens the overall response rates were generally the same at the lower PR ratios for all hens.

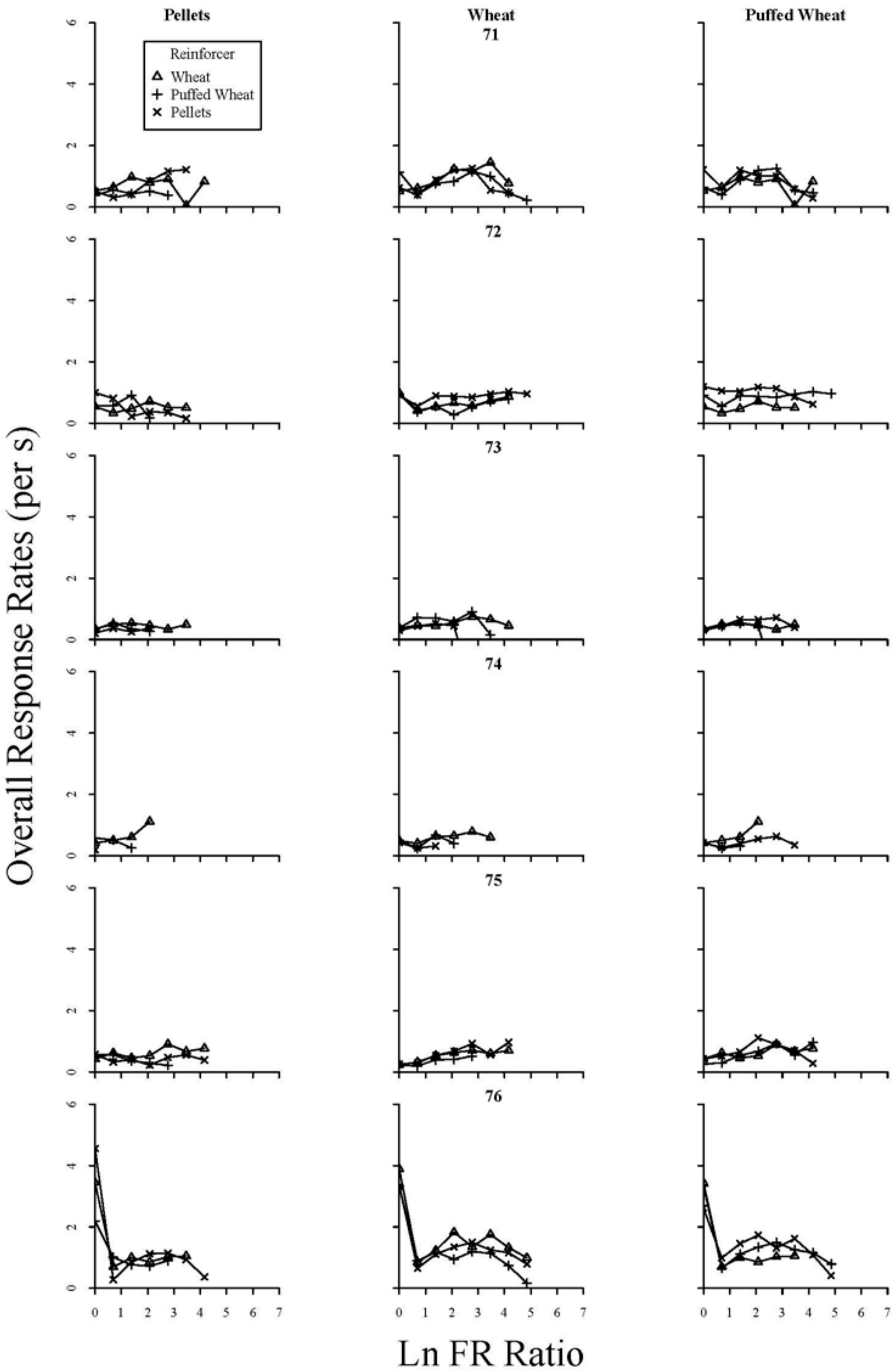

Figure 2. 1. The overall response rates (per s) obtained over all conditions, averaged across Series 1,2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three maintenance diets; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each reinforcer type; W, PW and P.

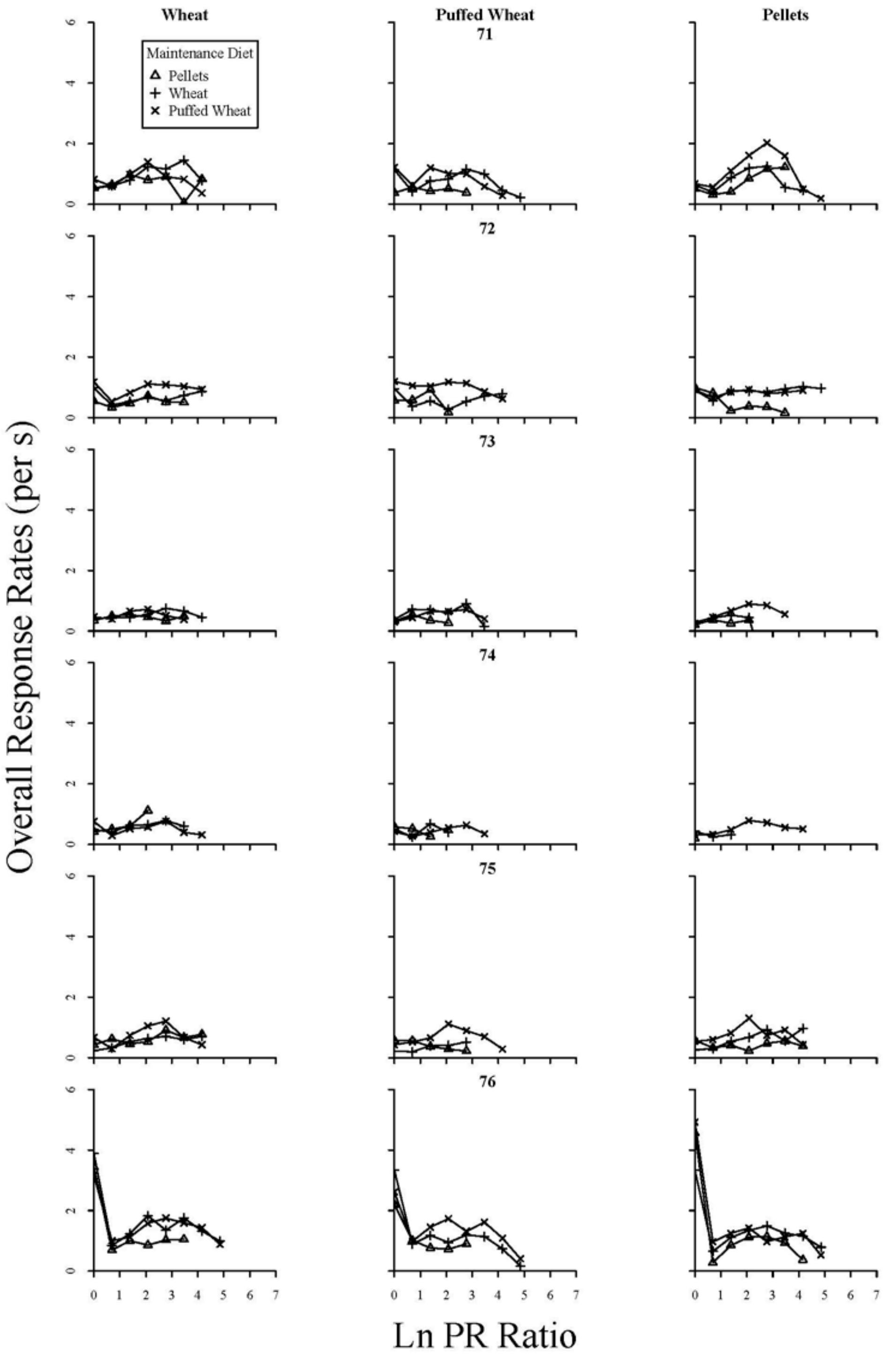

Figure 2. 2. The overall response rates (per s) obtained over all conditions, averaged across Series 1,2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three reinforcer types; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each maintenance diet; W, PW and P.

Running Response Rates

The running response rates were calculated as the total number of responses per ratio divided by the run time (where the run time = the key time with the post-reinforcement pause excluded). No running response rate can be calculated for the ratio of 1. Figures 2.3 and 2.4 present the running response rates for each condition, averaged over Series 1,2 and 3 and plotted against the natural log of the response requirement for all hens. The series were averaged as there was found to be no consistent differences between them. It should be noted that Figure 2.3 and 2.4 present the same data. However Figure 2.3 presents the three maintenance diets (P, W and PW) on the left to right panels with the running response rates calculated for each reinforcer type plotted. Figure 2.4 presents the three reinforcer types (W, PW and P) on the left to right panels with the running response rates calculated for each maintenance diet plotted.

Figure 2.3 and 2.4 both show that as the response requirement increased the running response rate decreased for all hens. Overall the running response rates tended to decrease at approximately the same rate across all conditions for all birds.

The left panel of Figure 2.3 shows that when the maintenance diet was P (P/W, P/PW and P/P). Hen 71 had the clearest differences in running response rate as the running response rate was the highest for P/P, followed by P/W and then P/PW. For Hen 76 the running response rate for P/P was mostly higher than for P/W followed by PW/PW. Hens 72,73,74 and 75 had no clear differences between running response rates for conditions P/W, P/PW or P/W.

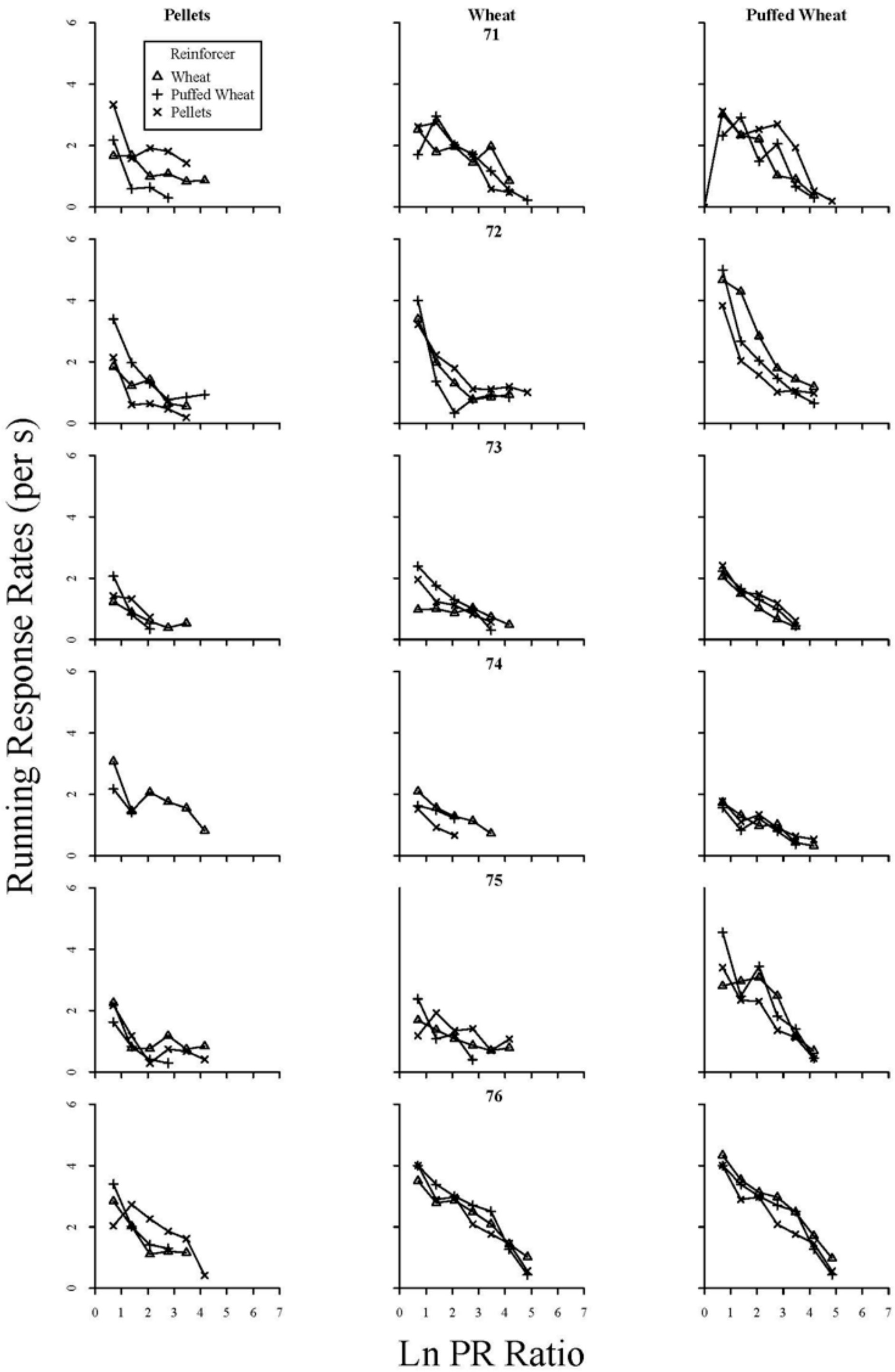

Figure 2. 3. The running response rates (per s) obtained over all conditions, averaged across Series 1 ,2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three maintenance diets; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each reinforcer type; W, PW and P.

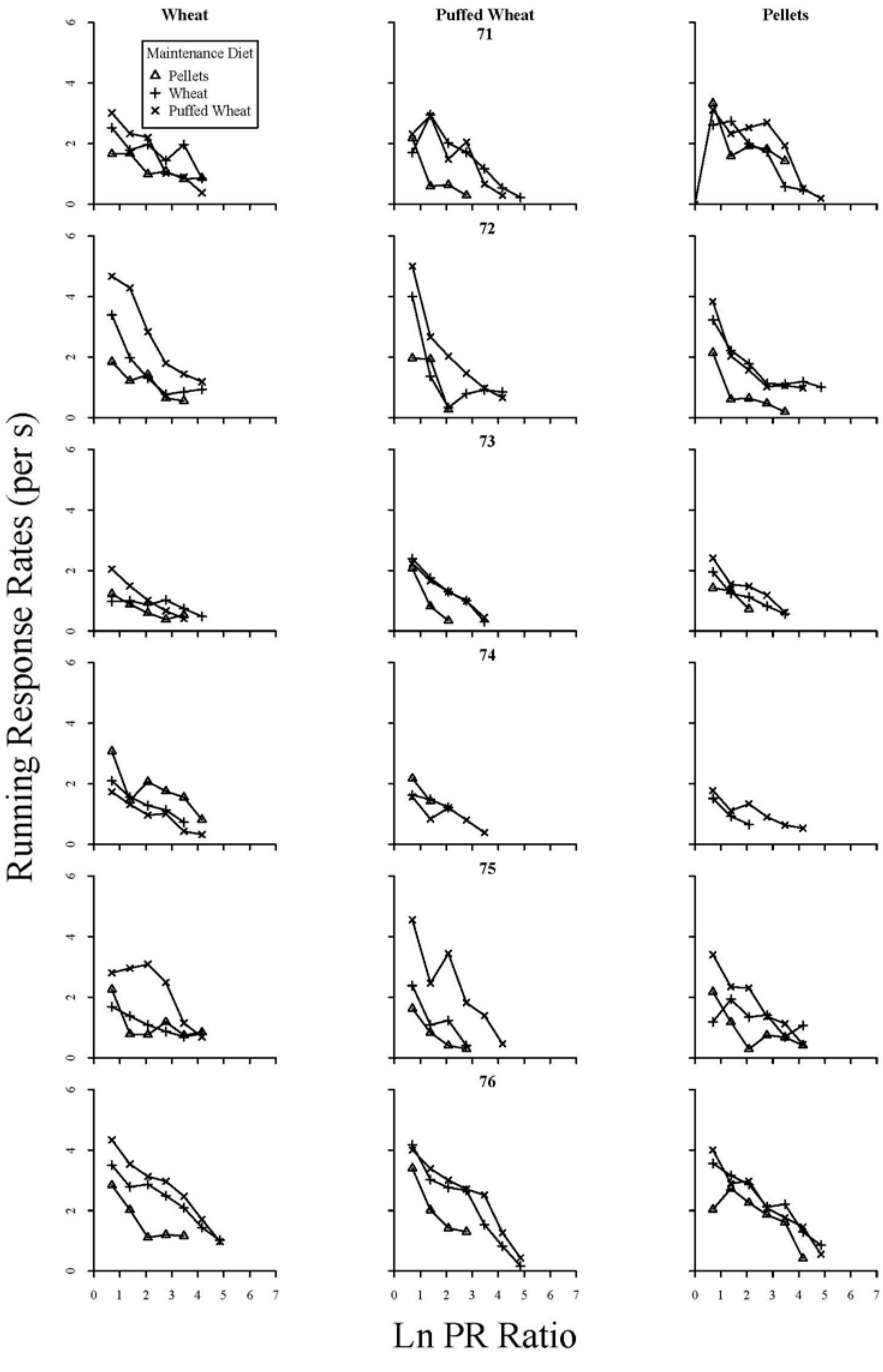

Figure 2. 4. The running response rates (per s) obtained over all conditions, averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three reinforcer types; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each maintenance diet; W, PW and P.

The left panel of Figure 2.3 shows for Hens 72,73 and 76, the running response rate for the second ratio (the first data point shown on the graph), was highest when the condition was P/PW. For Hens 74 and 75 the running response rate for the second ratio was highest for P/W. For Hen 71 the running response rate for the second ratio was highest when the condition was P/P.

The middle panel of Figure 2.3 shows that when the maintenance diet was W (W/W, W/PW and W/P), for Hens 71,72,73,75 and 76 there were no clear differences between running response rates for any condition. Hen 74 had a higher running response rate for W/W than for W/P.

The right panel of Figure 2.3 shows that when the maintenance diet was PW (PW/W, PW/PW and PW/P), for Hens 71,73,74,75 and 76 the running response rates were generally the same for PW/W, PW/PW and PW/P. Hen 72 had the highest running response rate for PW/W followed by PW/PW and then P/PW.

The left panel of Figure 2.4 shows that when the reinforcer type was W (P/W, W/W and P/W) Hens 72,73,75 and 76 had higher running response rates for PW/W than P/W or W/W. Hens 72 and 76 also had the lowest running response rates for P/W. For Hen 71 there were no clear differences between running response rates for any of the conditions. For Hen 74 the running response rate was highest for P/W.

The middle panel of Figure 2.4 shows that when the reinforcer type was PW (PW/W, PW/W and PW/W) Hens 72 and 75 had the highest running response rates for PW/PW. Hens 71, 73, 74 and 76 also had the lowest running response rates for P/PW. Hen 74 showed no clear differences between running response rates for P/PW, W/PW or PW/PW.

The right panel of Figure 2.4 shows that when the reinforcer type was P (P/P, W/P and PW/P) Hens 71 and 73 had no clear differences between running response rates for the different maintenance diets. Hens 74 and 75 had the highest running response rates for PW/P. Hens 72, 75 and 76 had the lowest running response rates for P/P. Overall running response rate across hens was not affected in a consistent way by reinforcer type or maintenance diet type.

Post Reinforcement Pauses

The PRP times were calculated as the time taken by the hen to make the first response after receiving a reinforcer. The Y axis was set to show 30 s despite not all data fitting within this range, this was done as a few PRP times were very high and including them would have resulted in the trends of the majority of the data being obscured.

Figures 2.5 and 2.6 present the PRP times for each condition, averaged over Series 1, 2 and 3, plotted against the natural log of the PR ratio, the series were averaged as there was found to be no consistent differences between them. It should be noted that Figure 2.5 and 2.6 present the same data. However Figure 2.5 presents the three maintenance diets (P, W and PW) on the left to right panels with the PRP times calculated for each reinforcer type plotted. Figure 2.6 presents the three reinforcer types (W, PW and P) on the left to right panels with the PRP times calculated for each maintenance diet plotted.

Figure 2.5 and 2.6 both show that for all hens, over all conditions, as the response requirement increased the PRP times increased. The left panel of Figure 2.5 shows that when the maintenance diet was P (P/W, P/PW, P/P) Hens 71,73,75 and 76 had the highest PRP times for P/P.

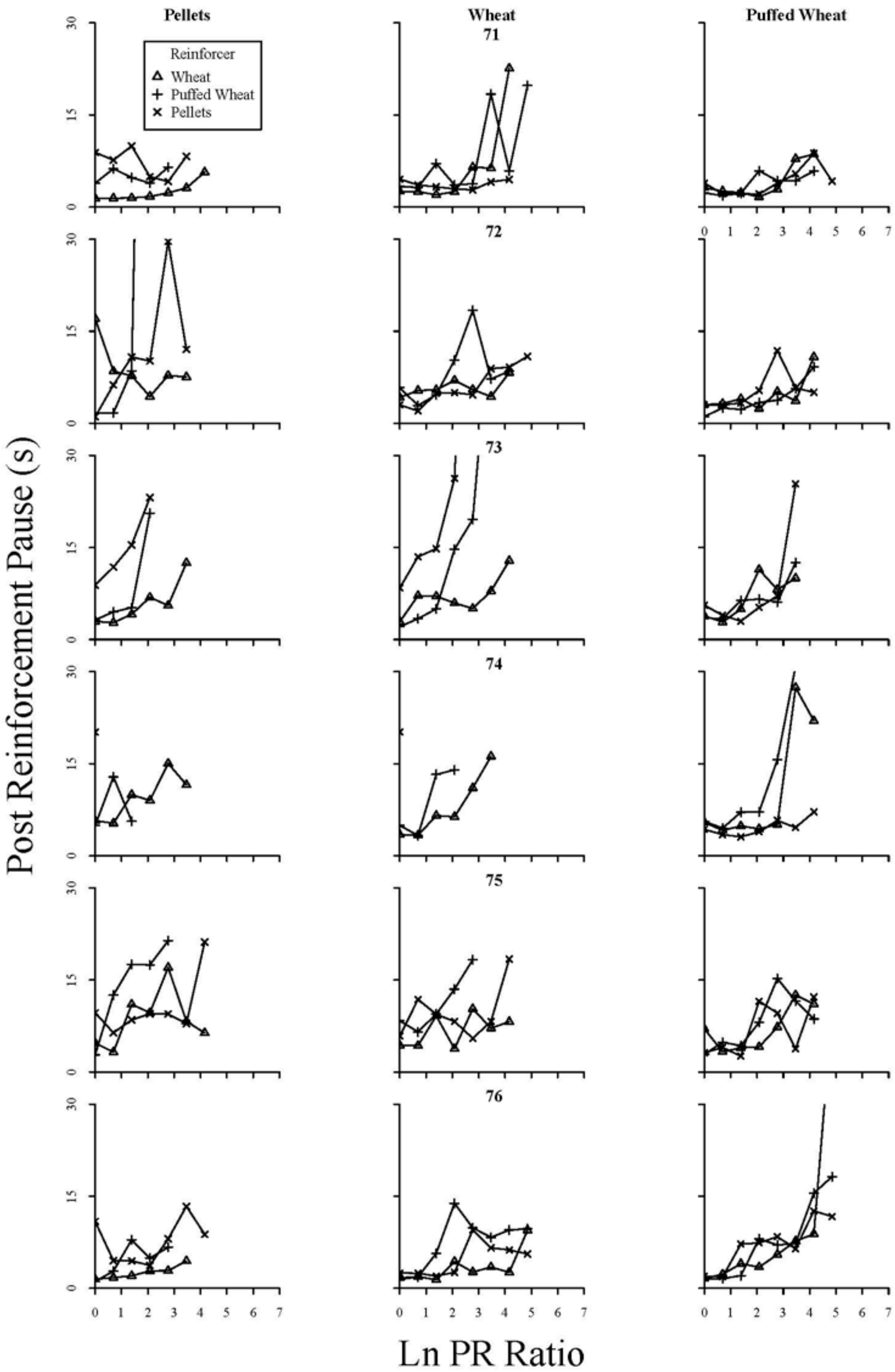

Figure 2. 5. The PRP times (s) obtained over all conditions, averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three maintenance diets; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each reinforcer type; W, PW and P.

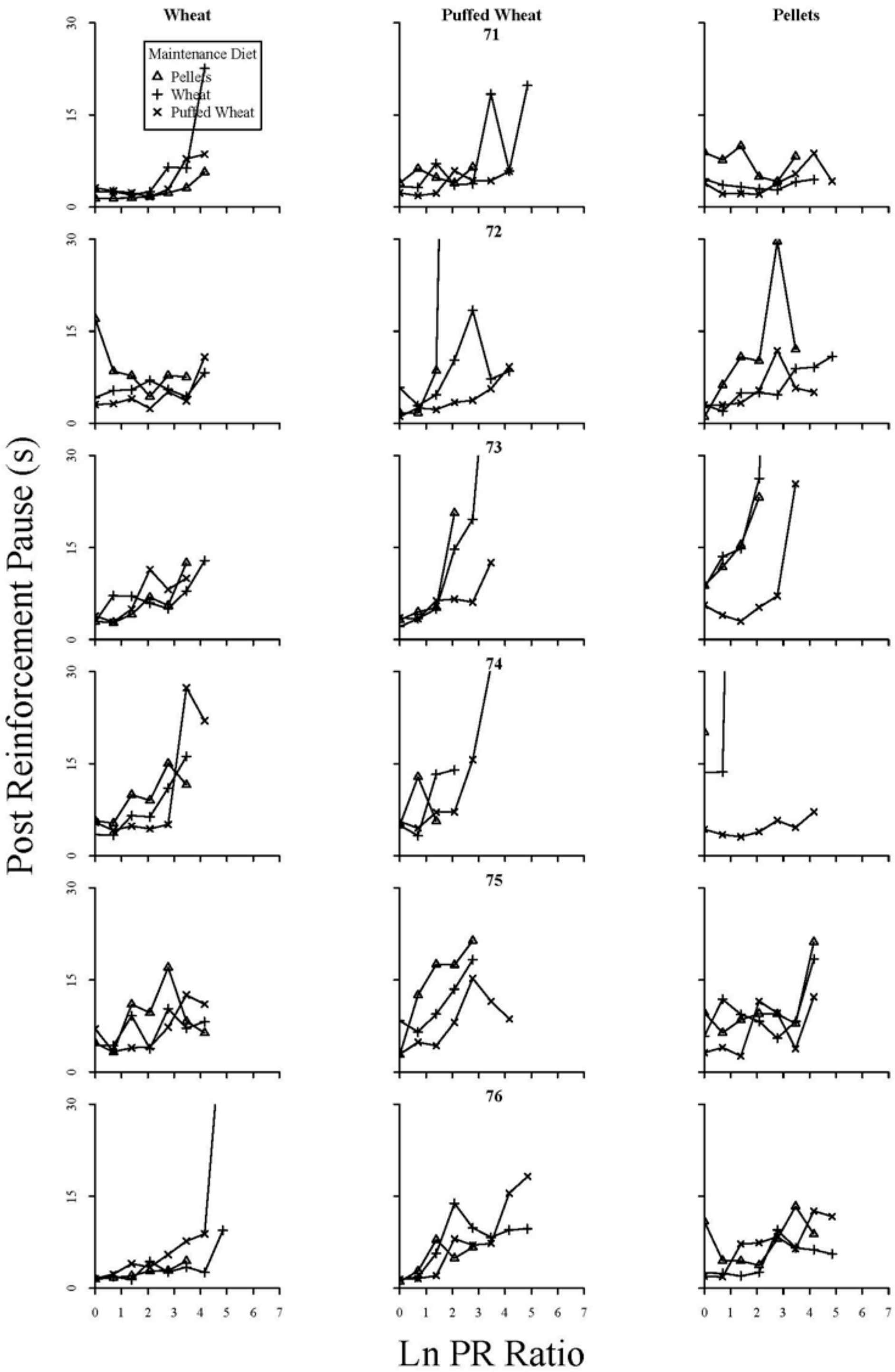

Figure 2. 6. The PRP times (s) obtained over all conditions, averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three reinforcer types; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each maintenance diet; W, PW and P.

No clear differences in the PRP times were able to be observed for Hens 72 and 74 between P/W, P/PW or P/P.

The middle panel of Figure 2.5 shows that when the maintenance diet was W (W/W, W/PW, W/P) Hens 72, 74, 75 and 76 had the highest PRP times for PW/W. Hen 73 had the highest PRP times for W/P, there were no clear differences between W/W, W/PW or W/P observable for Hen 71.

The right panel of Figure 2.5 shows that when the maintenance diet was PW (PW/W, PW/PW) there were no clear differences observable between PRP times, for any of the hens.

The left panel of Figure 2.6 shows that when the reinforcer type was W (P/W, PW/W and W/W) there were no clear differences observables between PRP times, for any of the hens.

The middle panel of Figure 2.6 showed that when the reinforcer type was PW (P/PW, W/PW, PW/PW) for Hens 71, 72, 73, 74 and 76 there were no clear differences observable between PRP times. Hen 75 had the highest PRP times for P/ PW followed by lower times for W/PW and then PW/PW.

The right panel of Figure 2.6 shows that when the reinforcer type was P (P/P, W/P, PW/P), there were no clear differences between PRP times shown for Hens 71,73,74 and 76, for conditions P/P, W/P or PW/P. Hens 72 and 75 had the highest PRP times for P/P. Overall PRP times were not affected in a consistent way by reinforcer type or maintenance diet type.

Demand Functions

The consumption rates were calculated for each response requirement in a PR as the total number of reinforcers earned in a ratio divided by the key time in that ratio. The functions fitted in Figures 2.7 and 2.8 are the best fits provided by Equation 1. The lines were fitted using R 2.10.1 statistical software via curvilinear regression and the method of least squares. Figures 2.7 and 2.8 present the natural logarithims of the consumption rate (per s) averaged across Series 1, 2 and 3, plotted against the natural log of the PR ratio scale for all hens, the series were averaged as there was found to be no consistent differences between them. It should be noted that Figure 2.7 and 2.8 present the same data. However Figure 2.7 presents the three maintenance diets (P, W and PW) on the left to right panels with the consumption rates calculated for each reinforcer type plotted. Figure 2.8 presents the three reinforcer types (W, PW and P) on the left to right panels with the consumption rates calculated for each maintenance diet plotted.

Table 2.2 shows the parameters of the equation as well as the residual standard error (*RSE)*, the predicted maximal peaks of response output (P_{max} - calculated using Equation 2) and the percentage of variance accounted for (%VAC*)*. Demand functions were unable to be calculated for conditions P/PW, P/P and W/P for Hen 74 and for condition P/PW for Hen 73 as the hens did not work enough.

The functions in Figures 2.7 and 2.8 generally show mixed elasticity across all conditions for all birds. The left panel of Figure 2.7 shows that when the maintenance diet was P (P/W, P/PW, P/P) for Hens 71 and 72 there were differences in the shapes and location of the curves. Hen 71 had a higher intercept for P/W than P/PW and P/P. Hen 72 also had a higher intercept for P/PW followed by P/P and then P/W. There were no systematic differences between the shapes of the curves shown on either Figure 2.7 or Figure 2.8 for any other maintenance diet or reinforcer type, for any other hen.

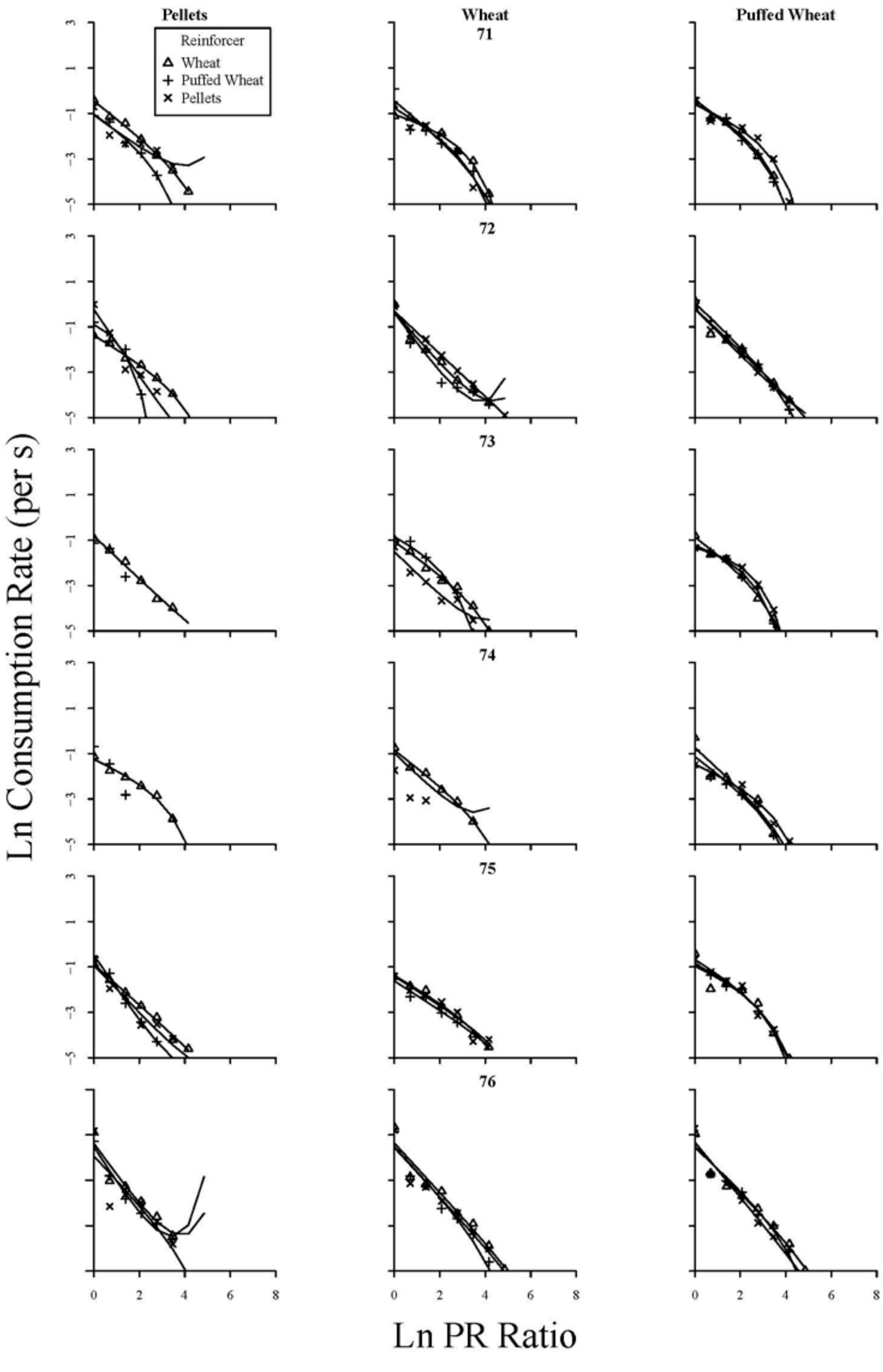

Figure 2. 7. The natural logarithims of the consumpition rate (per s) obtained over all conditions, averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three maintenance diets; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each reinforcer type; W, PW and P. The lines are the best fits of Equation 1.

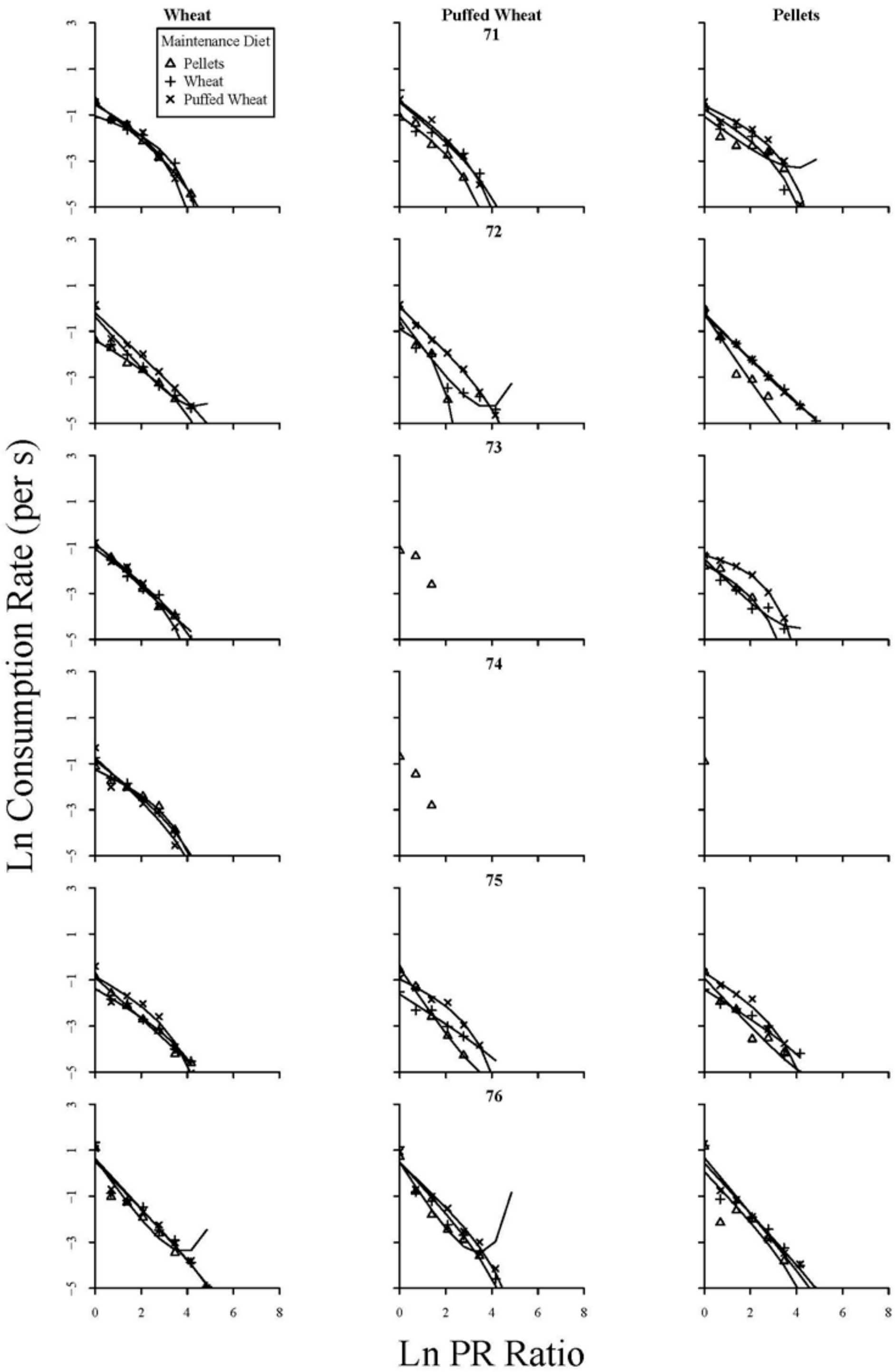

Figure 2. 8. The natural logarithims of the consumption rate (per s) averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. This figure depicts the three reinforcer types; W (left), PW (middle) and P (right) with the rates obtained for that reinforcer per maintenance diet; W, PW and P, plotted (see legend). The lines are the best fits of Equation 1.

Table 2.2 shows that the fitted parameter *a*, which shows the rate of change of elasticity for the demand functions, was mostly positive and close to zero. There were no systematic differences observed in the *a* values across conditions for all hens.

Parameter *b* represents the initial slope (initial elasticity) of the demand functions. The *b* parameter values shown in Table 2.2 suggest that for the majority of hens the initial demand for all reinforcer types across all maintenance diets was inelastic (less steep than -1.0). There are two cases where the *b* value was -1 which indicated initial unit elasticity. These were for Hen 71 for the W/W condition and Hen 73 for the PW/W condition. Aside from those two instances Hens 71 and 73 displayed inelastic initial demand for all other conditions. Hen 72 showed elastic initial demand for the P/W, P/PW, W/P, PW/W and PW/PW conditions and inelastic initial demand for P/P, W/W, W/P, W/PW and PW/P. Hen 74 showed elastic initial demand for all conditions the demand function could be applied too. Hen 76 had elastic initial demand for all conditions aside from PW/PW. The average *b* value for all hens for each reinforcer type was the largest when P was the reinforcer, -0.82, followed by W, 0-79 and PW, -0.72. The average *b* value for all hens for each maintenance diet was the largest when P was the maintenance diet, -0.91, followed by W, 0-84 and PW, -0.71. Hen 74 and 73's data was omitted from these averages where it was missing. The *b* values that were the largest for Hens 71 through 76 were the conditions of W/W, PL/PL, W/PW, PW/W, PL/PW and PL/PW respectively. The *b* values that were the smallest for Hens 71 through 76 were for PW/PL, PL/PW, PW/PL, W/PW PW/PW and PW/PW respectively.

Table 2. 2. The parameters a, b, and ln L provided by Equation 1 for each condition and the standard errors of the estimates (se), the percentages of variance accounted for by the lines (%VAC) and the P_{max} values. The values are the average of the functions fitted across Series 1, 2 and 3.

Hen	Condition	Ln *L*	*b*	*a*	*RSE*	P_{max}	*%VAC*
71	P / W	-0.45	-0.78	0.012	0.10	18.3	99.6
	P / PW	-0.98	-0.67	0.055	0.19	6.0	98.4
	P / P	-1.08	-0.74	-0.013	0.41	-20.0	87.0
	W / W	-1.01	-1.00	-0.027	0.84	0.0	73.5
	W / PW	-0.44	-0.82	0.016	0.46	11.3	96.5
	W / P	-0.73	-0.58	0.032	0.38	13.1	96.1
	PW / W	-0.52	-0.54	0.044	0.23	10.5	97.8
	PW / PW	-0.37	-0.71	0.033	0.22	8.8	99.0
	PW / P	-0.57	-0.45	0.031	0.32	17.7	98.3
72	P / W	-1.36	-0.60	0.016	0.10	25.0	99.4
	P / PW	-0.48	-0.02	0.427	0.38	2.3	97.4
	P / P	-0.25	-1.48	-0.007	0.46	68.6	96.4
	W / W	-0.38	-1.16	-0.015	0.29	10.7	97.3
	W / PW	-0.41	-1.38	-0.030	0.41	12.7	95.2
	W / P	-3.14	-0.94	7.176	0.19	0.0	99.0
	PW / W	-0.20	-0.93	0.002	0.31	35.0	96.9
	PW / PW	0.05	-0.94	0.013	0.11	4.6	99.7
	PW / P	-0.22	-1.02	-0.003	0.14	6.7	99.4
73	P / W	-0.82	-0.94	-0.002	0.16	-30.0	99.0
	P / PW						

	P / P	-1.65	-0.48	0.074	0.29	7.0	93.8
	W / W	-1.05	-0.71	0.015	0.16	19.3	99.1
	W / PW	-0.77	-0.49	0.083	0.19	6.1	99.1
	W / P	-1.52	-1.00	-0.018	0.32	0.0	95.1
	PW / W	-0.83	-0.74	0.034	0.18	7.6	98.9
	PW / PW	-1.16	-0.33	0.073	0.13	9.2	99.3
	PW / P	-1.27	-0.21	0.065	0.04	12.2	99.9
74	P / W	-1.22	-0.46	0.031	0.15	17.4	98.5
	P / PW						
	P / P						
	W / W	-0.84	-0.76	0.015	0.17	16.0	98.7
	W / PW	-1.01	-0.34	0.033	0.15	20.0	99.1
	W / P						
	PW / W	-0.73	-0.90	0.015	0.45	6.7	95.2
	PW / PW	-1.11	-0.74	0.025	0.31	10.4	96.5
	PW / P	-1.45	-0.47	0.024	0.18	22.1	98.6
75	P / W	-0.89	-0.89	0.001	0.14	110.0	99.3
	P / PW	-0.50	-1.48	-0.020	0.18	24.0	99.3
	P / P	-0.93	-1.06	-0.005	0.38	12.0	95.8
	W / W	-1.36	-0.59	0.013	0.15	31.5	98.8
	W / PW	-1.62	-0.64	0.004	0.24	90.0	94.6
	W / P	-1.41	-0.63	0.005	0.33	74.0	93.8
	PW / W	-0.81	-0.55	0.031	0.45	14.5	94.1
	PW / PW	-0.92	-0.45	0.042	0.14	13.1	99.5
	PW / P	-0.64	-0.62	0.030	0.24	12.7	98.5
76	P / W	0.59	-1.41	-0.029	0.52	14.1	93.4

P / PW	0.42	-1.59	-0.051	0.29	11.6	97.9
P / P	0.08	-1.06	0.013	0.94	-4.6	85.4
W / W	0.63	-1.08	0.002	0.50	-40.0	95.3
W / PW	0.50	-1.08	0.014	0.48	-5.7	97.2
W / P	0.44	-1.09	0.001	0.53	-90.0	94.8
PW / W	0.50	-1.02	0.003	0.39	-6.7	97.0
PW / PW	0.46	-0.93	0.015	0.36	4.7	98.1
PW / P	0.67	-1.21	0.002	0.46	-105.0	96.7

Ln *L* represents the estimate of level consumption at minimal price. Ln *L* was small and negative for all hens aside from 76. For Hen 76 Ln *L* was small and positive. P_{max} shows the PR value at which the maximal response output can be seen. P_{max} is representative of the point where demand changes from inelastic to elastic. There were no systematic changes observed in P_{max} between any conditions for any hen. The positive P_{max} values ranged from 2.3 to 103. However for Hens 71, 72, 75 and 76 the P_{max} value was higher for the P/W condition than for the P/PW condition. The P_{max} value for Hens 73 and 74 could not be compared for those conditions as the hens had either not worked enough for P_{max} to be calculated or was a negative value.

The VAC% shows the percentage of variance accounted for by the fits of the line. Table 2.2 shows that mostly the functions fitted the data well with all but two fits accounting for over 90% of the data. The exceptions were for Hen 71for conditions P/P where the VAC% is 87% and condition W/W where the VAC% is 73.5%. The residual standard errors were also small across all conditions for all hens, except for the cases of the two exceptions mentioned above where they were marginally higher.

Table 2.4 shows the breakpoints (or highest PR value reached) for all sessions of data collected, for all hens. Table 2.4 also shows no systematic differences in breakpoint across conditions, except for the P/PW condition. All hens had the lowest or lowest equal breakpoints for the P/PW conditions. Hens 71, 72, 73 and 76 only had low breakpoints for the P/PW condition and no others. Hens 74 and 75 also had low breakpoints for the W/PW condition but no others. No hen's had low breakpoints for the PW/PW condition.

Consumption Rate Functions with Linear Regression

Figures 2.9 and 2.10 present same data as in Figures 2.7 and 2.8 In these figures the fitted lines are the best fits straight (essentially Equation 1 with *a* set = 0) fitted using linear regression and the method of least squares. Table 2.3 shows the parameters of the equation as well as the residual standard error (*RSE)* and the percentage of variance accounted for (%VAC*)*. There are no clear differences shown either Figure 2.9 or 2.10 in the steepness of the lines, between any conditions, for any bird. The slopes provided by the linear regression fits are all negative indicating that as price increased consumption decreased.

There were no systematic differences observed in the slopes provided by the equation across all birds. The intercepts provided by the linear regression fits were negative for Hens 71 to 75, there was one exception for Hen 71 and that was condition PW/P where the intercept was positive. For Hen 76 the intercepts were positive for all conditions. Table 2.2 shows that mostly the functions fitted the data well with all but one fit accounting for over 80% of the data. There was one exception for Hen 71 and that was condition W/W where the VAC% was 73.5 %. The *RSE* is small and positive for all hens.

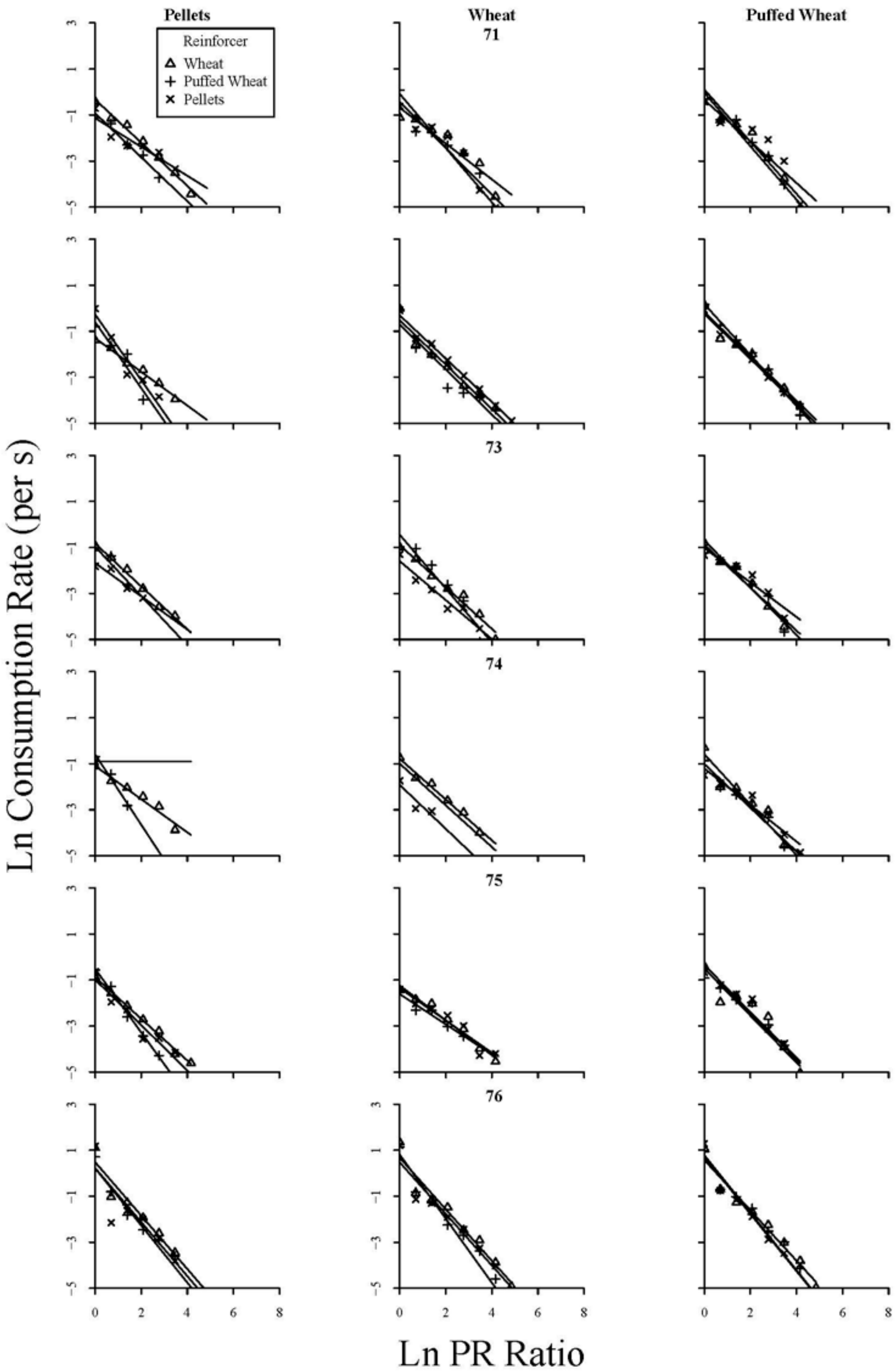

Figure 2. 9. The natural logarithims of the consumption rate (per s) obtained over all conditions, averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. The data from the three maintainence diets; P (left panel), W (middle panel) and PW (right panel) are shown with the rates obtained for each reinforcer type; W, PW and P. The lines were fitted through linear regression.

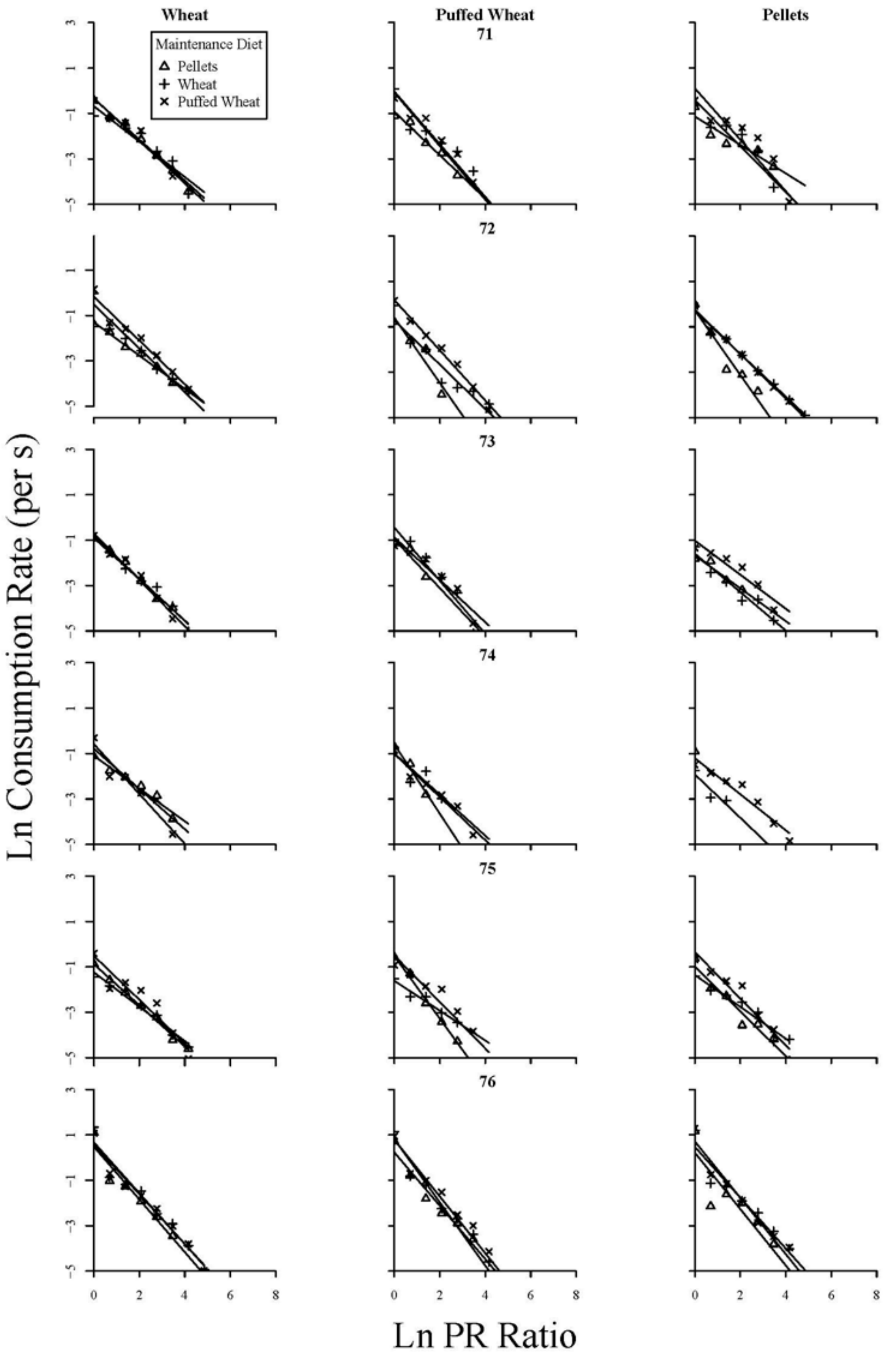

Figure 2.10. The natural logarithims of the consumption rate (per s) averaged across Series 1, 2 and 3 and plotted against the natural logarithims of the response requirement for all hens. This figure depicts the three reinforcer types; W (left), PW (middle) and P (right) with the rates obtained for that reinforcer for each maintainence diet; W, PW and P, plotted (see legend). The lines were fitted through linear regression.

Table 2. 3. *The intercept and the slope provided by a linear regression function fitted to the Ln consumption rate for each condition versus the Ln PR ratio. Also shown are the standard errors of the estimates (se) and the percentages of variance accounted for by the lines (%VAC). The values are the average of the functions fitted across Series 1, 2 and 3.*

Hen	Condition	Intercept (ln *L*)	Slope (*b*)	*RSE*	*%VAC*
71	P / W	-0.33	-0.94	0.171	98.8
	P / PW	-0.92	-0.96	0.208	97.1
	P / P	-1.13	-0.63	0.361	86.4
	W / W	-0.68	-0.78	0.419	90.3
	W / PW	-0.08	-1.18	0.580	93.3
	W / P	-0.42	-1.01	0.513	91.2
	PW / W	-0.35	-0.90	0.481	94.8
	PW / PW	-0.04	-1.16	0.317	94.4
	PW / P	0.10	-1.13	0.447	94.8
72	P / W	-1.30	-0.73	0.124	98.6
	P / PW	-0.60	-1.43	0.530	89.8
	P / P	-0.27	-1.43	0.400	96.4
	W / W	-0.52	-0.96	0.316	96.2
	W / PW	-0.71	-0.98	0.517	90.6
	W / P	-0.31	-0.94	0.174	99.0
	PW / W	-0.18	-0.96	0.823	86.4
	PW / PW	0.18	-1.11	0.283	96.9
	PW / P	-0.24	-0.98	0.182	99.0

73	P / W	-0.83	-0.93	0.139	99.0
	P / PW	-0.96	-1.07	0.407	87.0
	P / P	-1.68	-0.72	0.219	92.9
	W / W	-0.90	-0.91	0.232	97.6
	W / PW	-0.45	-1.17	0.494	92.2
	W / P	-1.59	-0.85	0.298	94.4
	PW / W	-0.70	-1.02	0.129	99.4
	PW / PW	-0.88	-0.93	0.247	97.3
	PW / P	-1.02	-0.75	0.425	91.0
74	P / W	-1.10	-0.72	0.220	95.7
	P / PW				
	P / P				
	W / W	-0.79	-0.89	0.167	98.3
	W / PW	-1.00	-0.91	0.597	73.5
	W / P	-1.92	-0.95	0.438	82.0
	PW / W	-0.59	-1.10	0.366	89.8
	PW / PW	-1.01	-0.95	0.442	94.3
	PW / P	-1.21	-0.79	0.301	95.4
75	P / W	-0.88	-0.91	0.122	99.3
	P / PW	-0.52	-1.38	0.152	99.2
	P / P	-0.98	-0.99	0.346	95.6
	W / W	-1.24	-0.76	0.205	97.3
	W / PW	-1.61	-0.66	0.199	94.6
	W / P	-1.36	-0.70	0.303	93.5
	PW / W	-0.51	-0.96	0.336	93.8
	PW / PW	-0.50	-1.02	0.548	89.3

	PW / P	-0.35	-1.03	0.523	91.1
76	P / W	0.48	-1.16	0.481	92.5
	P / PW	0.22	-1.17	0.380	95.3
	P / P	0.21	-1.24	0.860	84.9
	W / W	0.67	-1.12	0.303	93.5
	W / PW	0.81	-1.39	0.459	95.2
	W / P	0.47	-1.12	0.562	95.4
	PW / W	0.58	-1.09	0.421	94.1
	PW / PW	0.78	-1.25	0.489	95.6
	PW / P	0.71	-1.24	0.423	96.7

Table 2. 4. *The highest ratio reached in each PR series in each condition for each hen.*

Condition	Mainten-nance Diet	Reinfo-rcer	Series	Hen Number 71	72	73	74	75	76
1	P	W	1	128	64	64	64	128	256
			2	64	32	32	64	64	32
			3	16	16	16	16	64	32
2	P	PW	1	16	8	8	4	16	16
			2	2	8	8	4	8	8
			3	32	16	32	1	32	32
3	P	P	1	32	128	8	0	32	64
			2	32	32	8	4	64	64
			3	64	16	64	32	64	64
4	P	W	4	64	128	128	16	64	128
			5	64	64	64	64	64	128
			6	64	128	128	32	64	128
5	W	W	1	64	64	128	64	64	256
			2	64	128	64	16	64	128
			3	128	64	128	16	64	128
6	W	PW	1	64	64	64	8	8	64
			2	128	32	128	2	64	128
			3	128	64	64	4	64	128
7	W	P	1	32	64	64	8	32	128
			2	128	128	64	32	32	128
			3	64	128	32	16	16	128
8	PW	W	1	32	64	16	64	64	128

			2	128	64	32	32	64	128
			3	64	64	64	64	128	128
9	PW	PW	1	64	64	64	32	64	128
			2	64	64	32	16	64	128
			3	64	64	32	64	64	64
10	PW	P	1	128	128	32	128	64	128
			2	128	64	32	64	128	256
			3	64	64	32	8	64	128

Figure 2.11 shows the weights of the hens over the conditions of the experiment when the hens worked on the PR schedules. The vertical dashed lines represent each condition. The black horionzal line represents 5% above the hens's target weight and the dashed horionztal line represents 5% below the hen's target weight. The horizontal line through the data represents the hens target weight (80 % of its free-feeding body weight). The clear circles represent the hen's weight on that day. For the majority of the experiment the hens were within ± 5% of their individual target weights. Hen 74 began to lose weight over the last three conditions of the experimental period as she would not consume PW. The increase in the weight of Hen 74 over the last two days of the experiment is because she was given supplemental feed of P due to her rapid weight loss.

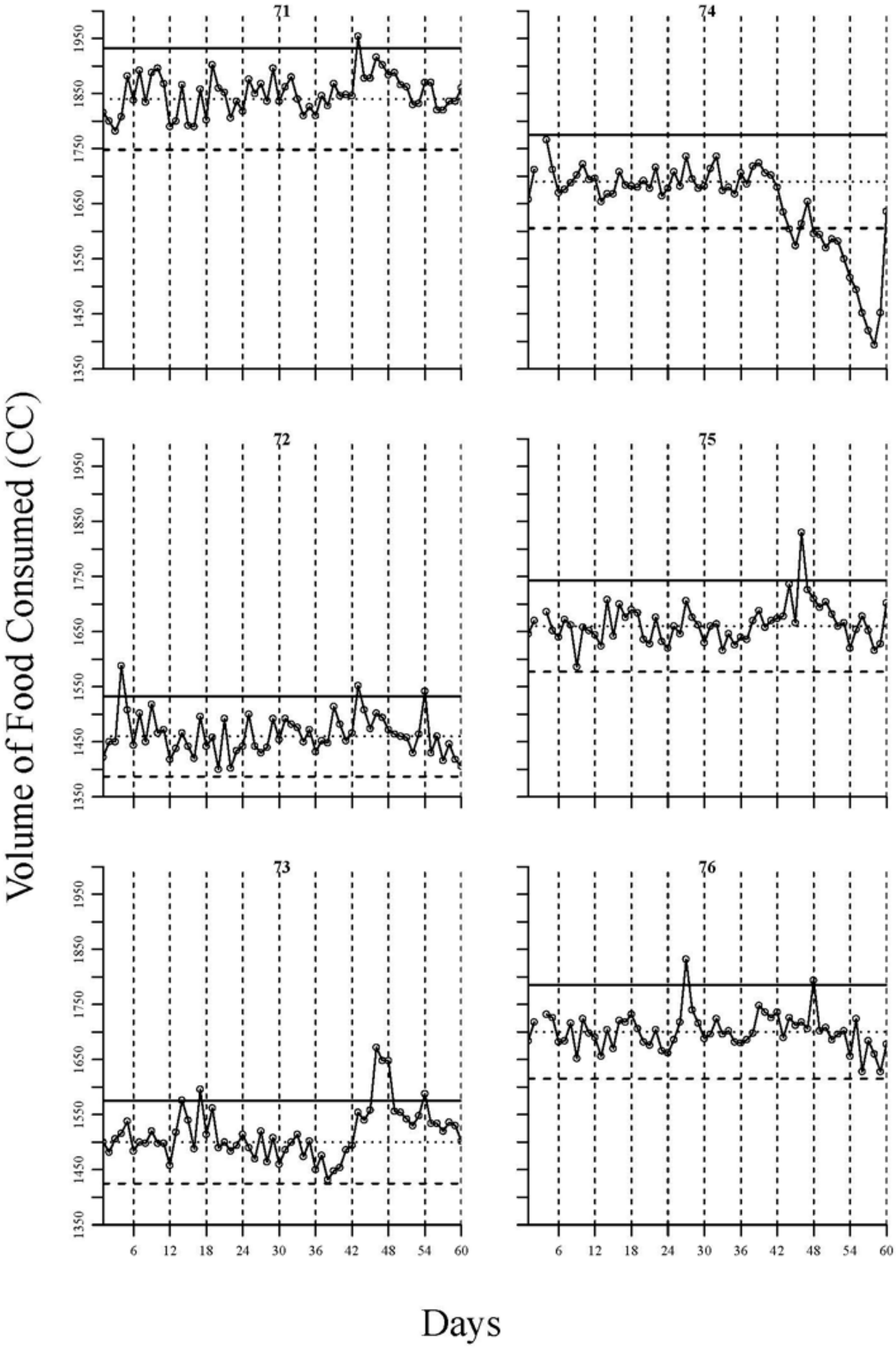

Figure 2. 11. The weights of all hens over the 60 days when data was collected. The vertical dashed lines represent each condition. The black horionzal line represents five % above the hens's target weight and the dashed horionztal line represents five % below the hen's target weight. The clear circles represent the hen's weight on that day.

Discussion

The aim of Experiment 2 was to investigate whether feeding hens a range of foods (W, PW and P) as different maintenance diets would change demand for the foods (W, PW and P) when hens were working on a PR schedule with a doubling response requirement. Overall the results showed that there were no systematic differences in demand functions, parameter values, overall response rates, running response rates or post reinforcement pauses between any condition for any hen, indicating that there was no relationship between maintenance diet and motivation of the hens to obtain the various reinforcers.

It was expected that hens may have shown a higher demand for W over PW when P was the maintenance diet. This was expected because Foster et al. (2009) used concurrent schedules to assess preference for three foods (W, honey puffed wheat and PW) and found that hens indicated a bias for W over PW when fed a P maintenance diet. The higher demand for W over PW was also expected because Experiment 1 found that four hens had no preference for PW and three hens had a preference for W. However, as stated above the different preferences did not affect the demand and the demand functions were not different over the varying conditions. The only consistent difference found across hens was that the breakpoints and the P_{max} values (for the hens these could be calculated for) for the P/PW condition were either the lowest or the lowest equal for all hens.

The overall response rates were very similar to results reported by Foster, Temple, et al. (1997) who stated that the response rates obtained with hens working under PR schedules tended to be high for the small ratios, this can most clearly be seen for Hens 71, 72 and 76 during Experiment 2. Foster et al. (2009) reported that overall response rates tended to be slower at the smaller FR's for less preferred foods. This was not the case for responding under the PRs here as overall response rates were generally the same for all foods at the lower ratios values. One reason for this could be because the data from Experiment 2 was only obtained from one ratio value for each PR. The data obtained for the low PR values also was also obtained from very early within a session. As the data was obtained so early within the session, and was not an average or median and was from a singular ratio this may explain why the response rates were not slower at the smaller FR's for foods the hens were found to prefer from Experiment 1.

The running response rates obtained during Experiment 2 started high for all hens and decreased steadily as the ratios increased, this was very similar to results reported by Foster, Blackman and Temple (1997) and Foster et al. (2009) for FR schedules. The results for Experiment 2 were that two out of six hens had higher running response rates for the P/W condition and one hen had a higher running response rate for the P/PW condition. Foster et al. (2009) also reported that four out of six hens had similar running response rates for PW and W, and that two out of six hens had higher running response rates for PW, than W. Three hens showed no discernable differences between running response rates for the P/PW and P/W conditions. Therefore the running response rates obtained under PR schedules were similar to FR schedule performance of hens. It is interesting that similar results were obtained under PR schedules to FR schedules. This is because as mentioned previously, the data obtained in Experiment 2 was only obtained for one ratio at each PR, averaged over three series, whereas the data obtained in FR experiments is usually an average or median from many more exposures of the animal to that ratio.

In Experiment 2 the PRPs increased as the ratio increased; these results were very similar to those reported by Felton and Lyon (1966) and Foster, Blackman and Temple, (1997) for FR schedules. In these studies the PRP times tended to decrease as the ratio requirement increased with both open and closed experimental economies. However, Foster et al. (2009) found that PRP times were longer for the more preferred food (W), this differed to the results of Experiment 2 as no discernable differences were found between PRP times for any reinforcer type even though W was found to be a preferred food by four hens in Experiment 1.

Both the *a* values (the rate of change of elasticity) and the *b* values (the initial slopes) from Experiment 2 were found to be similar to Foster, Blackman and Temple (1997). The average *a* value for all hens from Experiment 2 when W was the reinforcer was 0.009. The average *a* value for the five hens that participated in the Foster, Blackman and Temple (1997) study in the open economy condition was 0.015. Foster, Blackman and Temple (1997) found that under the open economy condition the values of *a* for a W reinforcer were small and some were negative (indicating that the demand function curved upwards). This was very similar to the results found in Experiment 2, as the *a* values were all small and around one fifth were negative. The *b* values calculated for Experiment 2 ranged from -1.59 to -0.02. The *b* values found by Foster, Blackman and Temple (1997) under the open economy condition ranged from -1.60 to -0.33 for a W reinforcer.

It is interesting that Foster, Blackman and Temple (1997) used FR schedules and the same species, and found a similar range of *a* and *b* values despite using only one reinforcer type and maintenance diet. This supports the conclusion that the results of this present experiment do not show any systematic effects of reinforcer type or maintenance diet. It appears that any changes in demand functions between birds are idiosyncratic and not under the control of either the reinforcer type or the maintenance diet.

One possible explanation for the lack of differences found between the different maintenance diets and reinforcer types is the effect of pre and post feeding. It was necessary for Experiment 2 to be conducted in an open economy as the hens had to be pre-fed the with the appropriate maintenance feed in order for the provision of feed to be considered as an establishing operation. All the hens in Experiment 2 were pre-fed at least 18 hours before a session was due to begin. Other studies (Ladewig et. al, 2002; Ferguson & Paule, 1997) have not found pre-feeding animals at this much earlier time to have an effect on demand for water and food with rats. Ladewig et al. (2002) found that demand slopes for a water reinforcer were steepest when water was provided immediately before and after an experimental session and the slopes were shallowest when additional water was not provided at all (closed economy). They concluded that the availability of a commodity used as a reinforcer outside of the test situation can significantly affect demand for the reinforcer dependant on what time access to the commodity is given.

The hens also received supplemental post feed 0-6 hours after an experimental session if they were found to be underweight or had when they had not earned more than ten reinforcers in a session. On no occasion did a hen earn more than ten reinforcers, therefore post feed was given after every experimental session. It is conceivable that the timing of post feed during Experiment 2 may have had an effect on the individual hens demand for food. As the hens were ran in the same order each day at roughly the same time it is possible that the hens may anticipate post feed at a certain time and like Ladewig et al. (2002) the demand for the reinforcer may have been affected by the expected delivery of post-feed.

Ferguson and Paule (1995) also investigated the effect of pre-feeding, however unlike the rats in Ladewig et al. (2002) and like the hens in Experiment 2 the rats in Ferguson and Paule (1995) were maintained below their free-feeding bodyweight on PR schedules. Ferguson and Paule found no significant effect of pre-feeding intervals ranging from 0.25 to 6 h before they conducted the PR session. They concluded that this was related to the fact that the rats' were maintained below their free feeding body weight. Ferguson and Paule went on to conduct another study, Ferguson and Paule (1997), to investigate this idea.

Ferguson and Paule (1997) found that when rats were maintained between 75% and 100% of free-feeding body weight, there were significant differences in PR schedule performance relative to the percentage of free-feeding body weight the rats were maintained at. In other words PRP times were higher and response rates and number of reinforcers earned were lower when the body weights of the rats were higher. A PR 1+1 schedule was used in this experiment, where the response requirement increased by 1 after each reinforcer.

It is suggested that the hen's weights during Experiment 2 could have masked any pre-feeding effects on the type of maintenance diet fed, similar to how Ferguson and Paule (1995) found no effect of pre-feeding on rats that were maintained below their free-feeding body weight. The body weights of the hens in the present experiment were all relatively stable (within 75% to 85% of their free-feeding body weights) throughout. It is possible that there were no significant differences in the demand curves for each reinforcer type as the hens were all maintained at a low enough weight for all food types to have the same reinforcing effectiveness. Given that even though body weight was relatively stable for the hens during Experiment 2 it still varied to a degree**.** It is also possible that the slight differences found in the parameter values produced from the demand curves could have been influenced by the varying body weight of the hens on the days the PR data was obtained. It is suggested that any future study only use data from the experimental sessions ran on the days when the hens were within a stricter specified body weight range, to account for any effects that body weight may have on demand.

As the hens in Experiment 2 had consumed the pre-feed well before the experimental sessions were conducted, the effect of type of pre feed may have been overridden by the time distance away from the experiment session that it was given. Bokkers et al. (2004) investigated the effect food deprivation would have on PR schedules (that increased by two or four each time) breakpoints. They fed either 50% or 75% of the amount of food a broiler hen would eat ad-libitum, prior to conducting the experimental session. As in the present experiment all hens in the Bokkers et al. (2004) had consumed the pre-feed by 18 hours before experimental sessions were conducted. The results showed that there was a significant difference in the breakpoints reached between the 50% group and the 75% group for the first week of experiments only. It is surprising that having less food available outside of the experimental chamber to the hens had no strong effect on the PR schedule behaviour in the Bokkers et al. (2004) study. However this author suggests that as the hens in Bokkers et al. (2004) had consumed the reduced amounts of feed well before the experimental session began, the animals may have been hungry enough that the amount of pre-feed they had consumed no longer had relevance to their PR schedule behaviour. The same explanation is also suggested as the reason that there was no effect on type of maintenance diet found in Experiment 2.

One possible reason for the finding that all hens had the lowest or lowest equal breakpoints and P_{max} values for the P/PW condition is that satiation may have affected the hen's responding for PW. PW is a much less dense food than W or P. It is possible that in the 2 s reinforcer time the amount consumed of PW contributed more to the filling of the hen's crop than the amount consumed of W or P in the same amount of time. As the only measure of amount eaten was the number of reinforcers earned this may not have been appropriate as there was no way to gain a comparable measure of the amount of each type of food eaten across conditions. It is suggested that any future study should weigh the amount eaten of each reinforcer and then convert the weight back into volume and see if there is any relationship between the volume eaten of each food and the breakpoint an animal will work to.

One finding that does not support the idea that PW contributes more to the satiation of a hen is the finding that hens did not work to lower breakpoints when fed a PW maintenance diet than when fed a W or P maintenance diet. As the amount of PW fed as the pre-feed was given in the equivalent weight of the amount of P the hens would normally receive the hens ended up eating a significantly larger volume of food than they would normally receive. The weights of all hens except for Hen 74 (who would only consume a small amount of PW) did increase at the beginning of the first condition that had PW as the maintenance diet, however as the amount of post-feed was lowered in accordance with the normal rule, the body weights stabilised and were stable by the time the PR sessions began and the hens' body weights remained relatively stable within ± 5% of their 80% free feeding body weight. It is also interesting that no hens worked to lower breakpoints for the PW/PW condition despite the fact that the hens had received large amounts of pre-feed which may have already contributed to their satiation levels if volume is important for this. This suggests that perhaps the volume of PW as a reinforcer was not as important as previously suggested and therefore the weight of each reinforcer eaten was not needed as a measure during Experiment 2. However knowing the weight and therefore the volume of each reinforcer consumed durting the experimental sessions would clarify if the volume of PW is an issue.

Foster, Blackman and Temple (1997) investigated the performance of hens under FR schedules in open versus closed economies in short and long sessions. They found that when sessions were short, overall response rates and rates of reinforcers earned, decreased with increasing FR requirements. The short session closed economy was found to have similar results to the short session open economy sessions where the FR was increased daily and sessions were only run when the hens were at approximately 80% of the hen's free-feeding body weight. As availability of feed outside of the experimental session is suggested to be a possible reason for the finding that neither reinforcer type nor maintenance diet had an effect on demand for reinforcers. It is suggested that the next experiment try and replicate the open economy conditions used by Foster, Blackman and Temple (1997) in order to see if an effect of reinforcer type will be found.

In summary the type of food fed as a maintenance diet did not act as an establishing operation and change demand for any reinforcer type. The only consistent finding across all hens was that all hens worked to lower breakpoints for the P/PW condition than any other condition. It is suggested that low body weight and the provision of post-feed may be the reasons why no differences were found.

It is proposed that a further experiment should be undertaken replicating the P maintenance diet conditions (W/P, PW/P, P/P) using a FR schedule of reinforcement which doubles over subsequent sessions. FR schedules have been found to generate similar demand functions to PR schedules with hens (Foster et al. 1997). In addition Foster, Blackman and Temple (1997) found that short session closed economy experiments were found to have a similar result to experiments conducted in an open economy where the FR was increased daily and hens were maintained at approximately 80% of their free-feeding body weight. Therefore it is proposed that the hens should only be allowed to earn a maximum of 40 reinforcers or to work for a maximum of 40 minutes in order to keep session length short. In addition as hens are required to be fed outside of the experimental sessions and therefore, the experiment must be maintained in an open economy, it is also proposed that hen's body weights should be monitored similar to the open economy condition conducted by Foster, Blackman and Temple (1997). The reason for only replicating the P maintenance diet is that different biases for PW and W, when hens' were fed a P maintenance diet, have been obtained under concurrent schedules (Foster et al., 2009).

Experiment 3: FR Demand Experiment

Introduction

In this next experiment, hens responded under FR schedules in which the response requirement doubled after each session. Three different reinforcers (W, PW and P) were used. The hens responded for each of the three different reinforcers while their body weights were maintained at 80 % + or – 10% of their free feeding body weight by P. As there was not enough time to fully replicate Experiment 2 only P was used as a maintenance diet because Foster et al. (2009) found a bias toward W over PW, using concurrent schedules when hens were fed a maintenance diet of P. Hens could work to a maximum of 40 reinforcers or 40 minutes as Foster et al. (2009) found the difference biases with 40 minute sessions. Another reason for only allowing hens to earn a maximum of 40 reinforcers was because in the past hens responding on low FR schedules have had a tendency to earn large amounts of reinforcers and thus become greater than their target weight and not require post feed.

Equation 1 was fitted to the data, the parameter estimates and the values of P_{max} were used to assess whether demand differed over the different reinforcer types. The overall response rates, running response rates, post-reinforcement pauses for each response requirement were also examined.

Method

Subjects

Hens were the same five Brown Shaver hens numbered 72-76 that took part in Experiment 1 and 2.

Apparatus

The same experimental chamber and food hopper that were used during Experiment 2 were also used throughout this experiment. When the key was pecked, responses were recorded by custom built operant behaviour hardware (ATmega18L microcontroller) and software (programmed using BASCOM and MikroElectronica). A response was recorded when the key was pushed in and then released only while the key was lit, responses to the darkened key were not recorded. Entries of the hen's heads into the magazine were recorded when a sensor was operated in the magazine and the time of such entries recorded in within the hardware.

Procedure

As all hens had completed Experiment 2, no key pecking training was necessary. There were three conditions in the experiment. At the start of each condition, the hens were fed a base diet of commercial laying P via food containers in their home cages for four days, the hens were not run during this period. The amount of food given was adjusted to maintain the hens at ± 5 % of the 80 % free-feeding body weight but was always a minimum of 50 cc. Hens remained in their cages throughout this time except for daily weighings. On the fifth day all hens were exposed to a FR1 (Fixed-ratio of 1 response) schedule. Hens responded for 2-s access to one of the three feeds (W, P or PW), depending on the condition. When a session started the response key would light up white and it remained on until a peck was made. Once the response requirement in effect was fulfilled the key light went off and the magazine hopper was raised for 2 s.

Sessions terminated when 40 reinforcers had been earned or 2400 s had elapsed. On the sixth session, provided the hen had earned at least one reinforcer under the FR1 schedule in the fifth session, the hens were exposed to a FR2 schedule, the FR then doubled each session until no reinforcers were received. When this occurred the FR was repeated the next session, if on this second session under a particular FR no reinforcers were obtained the FR schedule was changed to FR20 and would remain so until all birds were ready to begin the next series of FR's. As shown in Table 3.1, each condition involved one of the foods as the reinforcer and two FR series. The number of session in series depended on the highest FR reached. If the highest FR was 128 then there were at least 10 sessions, FR 256 involved at least 11 sessions, FR 512 at least 12 sessions, and FR 1024 at least 13 sessions. The highest FR values at which at least one reinforcer was obtained for each series in each condition are shown in Table 3.1 for each hen.

Table 3. 1. *The condition order, the magazine food and highest FR reached in each FR series in each condition for each hen.*

Condition Order	Series	Reinforcer Type	Hen Number				
			72	73	74	75	76
1	1	W	512	128	256	512	1024
	2	W	256	128	512	512	512
2	1	PW	512	28	64	256	256
	2	PW	256	64	64	512	512
3	1	P	128	32	64	128	256
	2	P	256	128	1	1024	256

Results

Examination of the data from each FR series in each condition showed no consistent differences across hens. Thus the data presented are the means across the two series of each condition.

Overall Response Rates

The overall response rates were calculated as the total number of responses in a ratio divided by the key time (total time spent in a ratio minus the time the magazine was operative). Figure 3.1 presents the median overall response rate for each FR value, averaged across Series 1 and 2, plotted against the natural log of the FR value. The response rate functions for Hens 72, 75 and 76 are bitonic. For Hens 72 and 75 the overall response rate generally increased as the response requirement increased and then decreased over the last 2-3 FR ratios, these functions can also be described as bitonic but not as markedly so. The peak in overall response rate generally occurred between FR8 to FR32 for all hens. There was with little discernable difference between the overall response rates from any of the foods for any hen..

Running-Response Rates

The running-response rates were calculated as the total number of responses in a ratio divided by the run time (where the run time = the key time with the PRP time excluded). Figure 3.2 presents the median running response rate for each FR averaged across Series 1 and 2, plotted against the natural log of the FR value. As the response requirement increased the running-response rate decreased for all hens. Overall the running-response rates tended to decrease with approximately the same steepness for conditions W and PW for all hens. All hens displayed a zig-zag pattern in running-response rates for the P condition with the

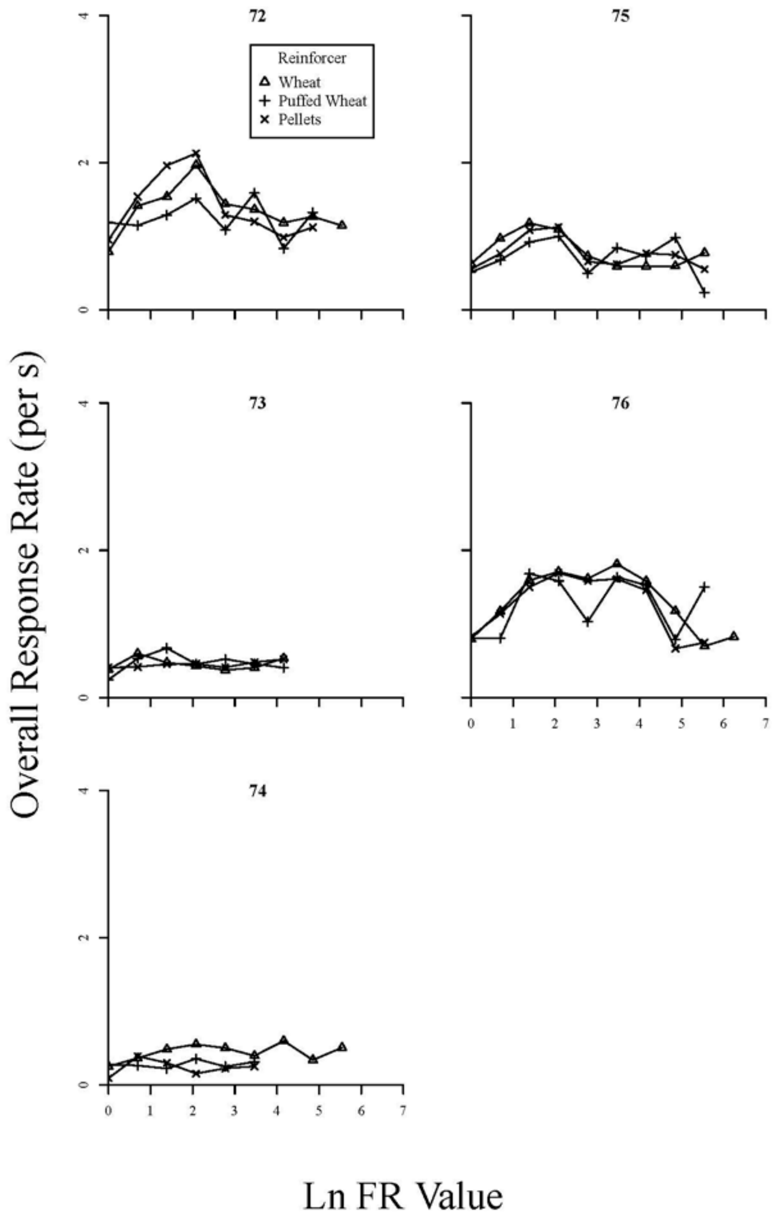

Figure 3. 1. The median overall response rate (per s) from each ratio, for each FR averaged across Series 1 and 2 and plotted against the natural log of the response requirement for all hens.

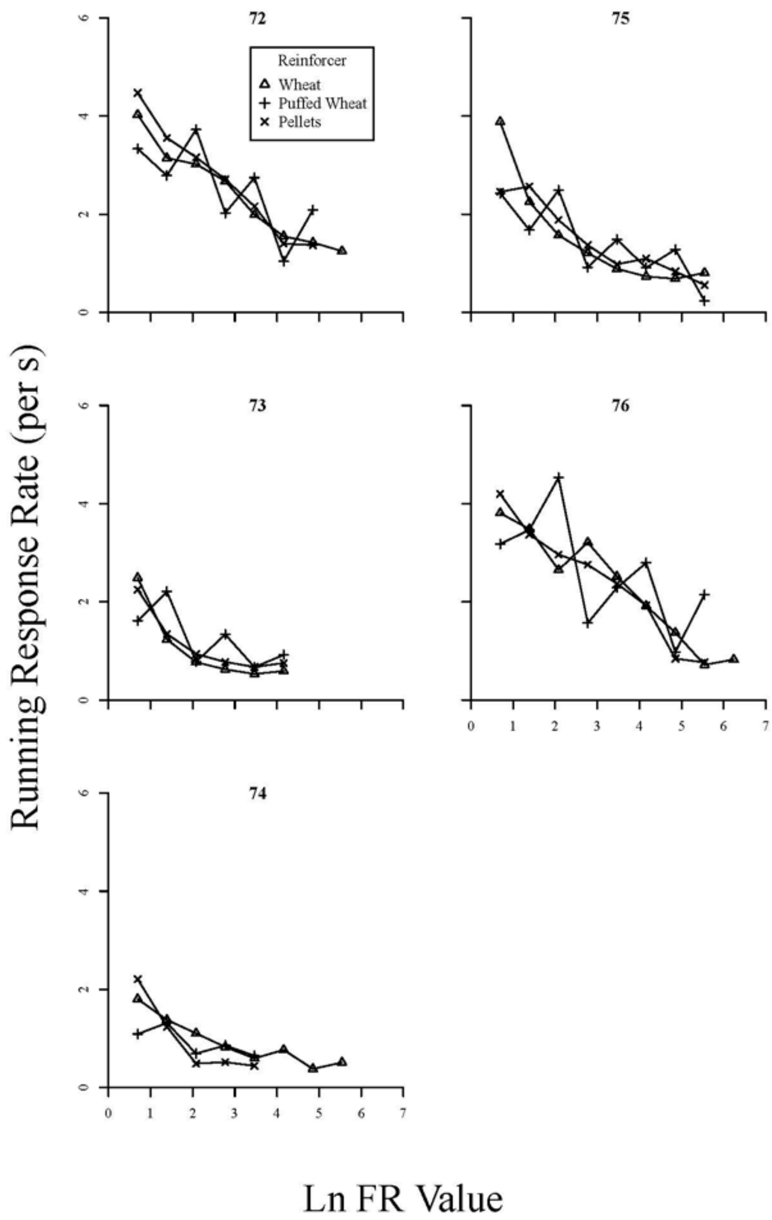

Figure 3. 2. The median running-response rate (per s) for each FR averaged across Series 1 and 2 and plotted against the natural log of the response requirement for all hens.

running-response rate decreasing over FR value, then increasing over the next FR value and then decreasing.

Post-Reinforcement Pauses

The PRP times were calculated as the time to the first response after receiving a reinforcer. Figure 3.3 presents the median PRP time for each FR, averaged across Series 1 and 2, plotted against the natural log of the FR value. As FR value increased PRP times increased for Hens 73, 75 and 76 over all conditions. For Hens 72 and 74, PRP times increased steadily until the last 2-3 FR values, when the PRP times decreased. Hen 74 had the highest PRP times for P then for PW and then W. Hen 76 has lowest PRP times for the last three FR values for the W condition. Overall there were no consistent differences in PRP times for any bird across conditions.

Demand Functions

The consumption rates were calculated as the median of the estimated rate of reinforcer delivery (based on the time it took to complete the ratios) over a session. The functions fitted in Figure 3.4 are the best fits of Equation 1. The lines were fitted by curvilinear regression and the method of least squares. Figure 3.4 presents the natural logarithims of the median consumption rate for each FR, averaged across Series 1 and 2, plotted against the natural log of the FR value for all hens. Table 3.2 shows the parameters of the fitted equations as well as the residual standard errors (*se)*, the predicted maximal peaks of response output (P_{max} - calculated using Equation 2) and the percentages of variance accounted for (%VAC).

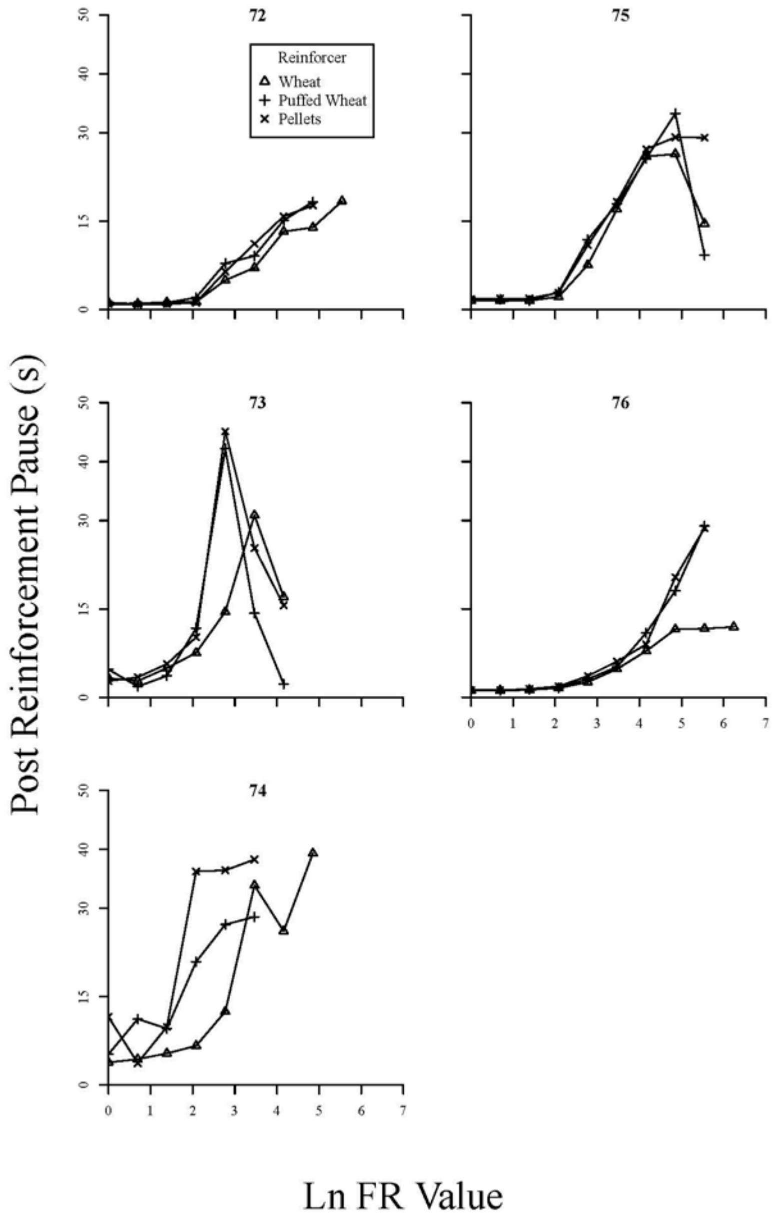

Figure 3. 3. The median PRP (s) for each FR averaged across Series 1 and 2 and plotted against the natural log of the response requirement for all hens.

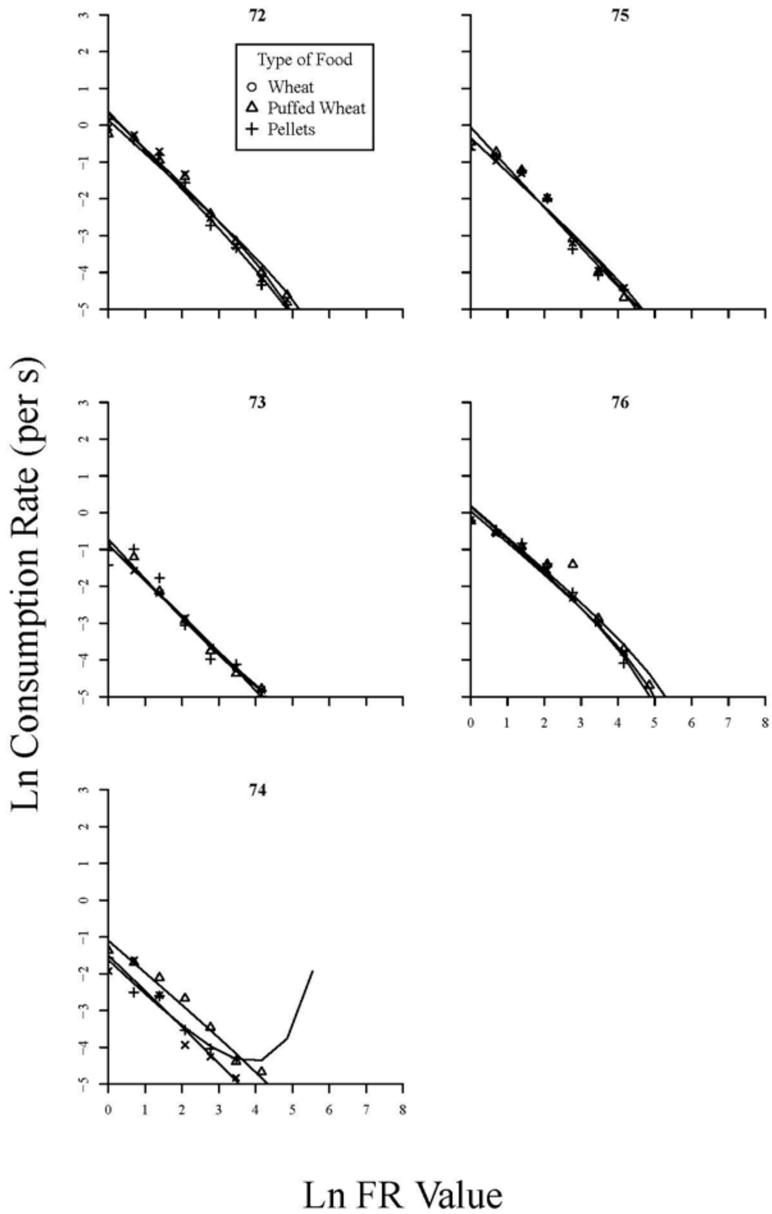

Figure 3. 4. The natural logarithims of the median consumption rate (per s) from each ratio, for each FR, averaged across Series 1 and 2 and plotted against the natural log of the response requirement for all hens. The lines are the best fits of Equation 1.

Table 3. 2. *The parameters* a, b*, and ln* L *provided by Equation 1 for each condition, the residual standard errors (*RSE*), the P_{max} values, and the percentages of variance accounted for by the lines (*%VAC*). The values are the average of the functions fitted across Series 1 and 2.*

Hen	Food	Ln *L*	*b*	*a*	*RSE*	P_{max}	*%VAC*
71	W	0.14	-0.90	0.00	0.25	39.8	98.7
	PW	0.37	-1.04	0.00	0.23	-17.8	98.9
	P	0.31	-0.95	0.01	0.31	11.2	97.8
72	W	-0.73	-1.09	-0.01	0.20	13.6	98.9
	PW	-0.88	-0.95	0.00	0.50	17.4	92.9
	P	-0.88	-0.99	0.00	0.06	-5.3	99.9
73	W	-1.10	-0.87	0.00	0.27	72.3	98.3
	PW	-1.65	-0.95	-0.02	0.22	-2.5	97.3
	P	-1.50	-0.96	0.00	0.49	16.4	91.9
74	W	-0.05	-1.09	0.00	0.28	110.6	98.6
	PW	-0.34	-0.92	0.01	0.36	14.6	98.0
	P	-0.34	-0.92	0.00	0.25	24.3	99.1
75	W	0.19	-0.86	0.00	0.46	45.1	96.9
	PW	0.17	-0.87	0.01	0.36	17.9	98.0
	P	0.05	-0.84	0.01	0.27	28.0	98.7

The functions in Figure 3.4 generally show mixed elasticity across all conditions for all birds. There were no systematic differences between the shapes of the functions for any condition, for any hen. Table 3.2 shows that the parameter *a*, the rate of change of elasticity of the demand functions, was mostly positive and close to zero. There were no systematic differences observed in the *a* values across conditions for all hens. Parameter *b*, the initial slope (initial elasticity) of the demand functions, was, for the majority of hens and for all three reinforcer types, greater than -1.0 (and so inelastic). The exceptions were Hen 71 with elastic initial demand for PW and Hens 72 and 74 with elastic initial demand for W. Ln *L*, the estimate of level consumption at minimal price, was small and negative for Hens 72, 73 and 75. For Hens 71 and 76 ln *L* was small and positive. There were no systematic changes observed for P_{max}, the FR value with maximal response output, across conditions for any hen. The positive P_{max} values ranged from 11.2 to 110.6. However, for Hens 73, 74, 75 and 76 the P_{max} value was higher for the W than for PW. Table 3.2 shows that the functions fitted the data well with all fits accounting for over 90% of variance in the data.

Consumption Rate Functions with Linear Regression

Figure 3.5 presents the same data as in Figure 3.4. In this figure the fitted lines are the best fits straight (essentially Equation 1 with *a* set = 0), fitted using linear regression and the method of least squares. Table 3.4 shows the parameters of the equation as well as the residual standard error (*RSE*) and the percentage of variance accounted for (%VAC). There are no clear differences in the slopes (*b*) of the lines across conditions for any hen. The slopes are all negative, indicating that as price increased consumption decreased. There were no systematic differences observed in the intercepts across all hens. The intercepts (ln *L*) were negative for Hens 73 to 75. For Hen 71 and 76 the intercepts were positive for all conditions. Table 3.2 shows that mostly the functions fitted the data well with all fits accounting for over 90% of the data variance. The *RSE*s were small for all hens.

Figure 3.6 shows the weights of the hens over each condition of this experiment. The vertical dashed lines represent condition changes. The black horionzal line represents 5 % above the hen's target weight and the dashed horionztal line represents 5 % below the hen's target weight. The horizontal line through the data represents the hens target weight (80 % of its free-feeding body weight). The clear circles represent the hen's weight on that day. For the majority of the experiment the hens were within ± 5% of their individual target weights. Hen 74 began the W condition at a higher weight, over 5% above her free-feeding body weight, however, by the second series of the W condition her weight had decreased.

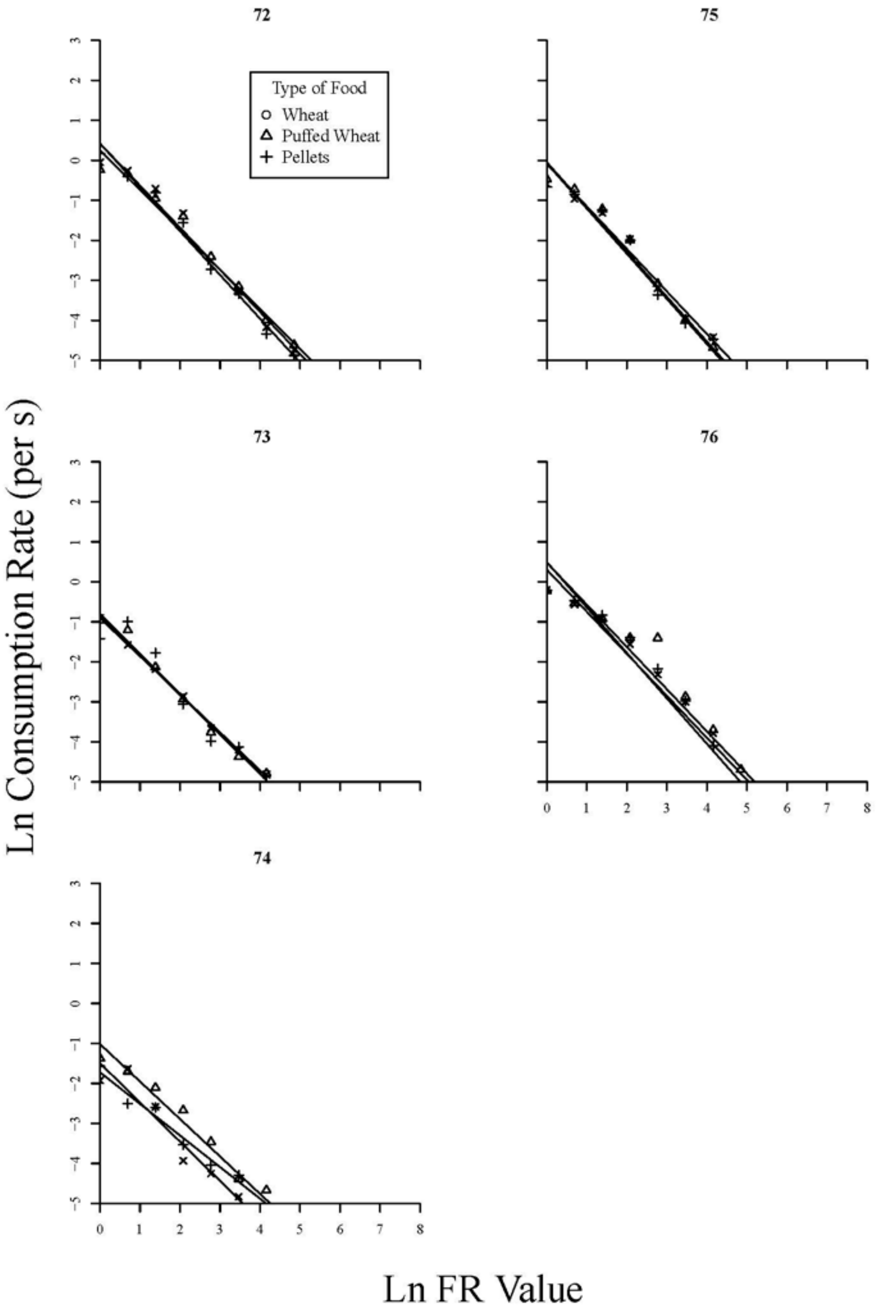

Figure 3. 5. The natural logarithims of the median consumption rates (per s) from each ratio, for each FR, averaged across Series 1 and 2 and plotted against the natural log of the response requirement for all hens. The lines were fitted through linear regression.

Table 3. 3. *The intercept (Ln L) and the slope (b) provided by a linear regression function fitted to the natural logarithm of the median consumption rate for each condition plotted against the natural logarithm of the FR value. Also shown are the residual standard errors (RSE) and the percentages of variance accounted for by the lines (%VAC).*

Hen	Reinforcer	Intercept (ln *L*)	Slope (*b*)	*RSE*	*%VAC*
71	W	0.25	-0.99	0.265	98.3
	PW	0.42	-1.09	0.221	98.8
	P	0.42	-1.05	0.311	97.5
72	W	-0.80	-1.00	0.194	98.6
	PW	-0.85	-0.99	0.451	92.8
	P	-0.91	-0.95	0.063	99.8
73	W	-1.02	-0.94	0.264	98.1
	PW	-1.72	-0.79	0.222	96.4
	P	-1.49	-0.98	0.423	91.9
74	W	-0.09	-1.06	0.265	98.5
	PW	-0.08	-1.13	0.446	96.3
	P	-0.05	-1.12	0.405	97.4
75	W	0.48	-1.05	0.537	95.0
	PW	0.49	-1.14	0.496	95.6
	P	0.30	-1.05	0.380	96.9

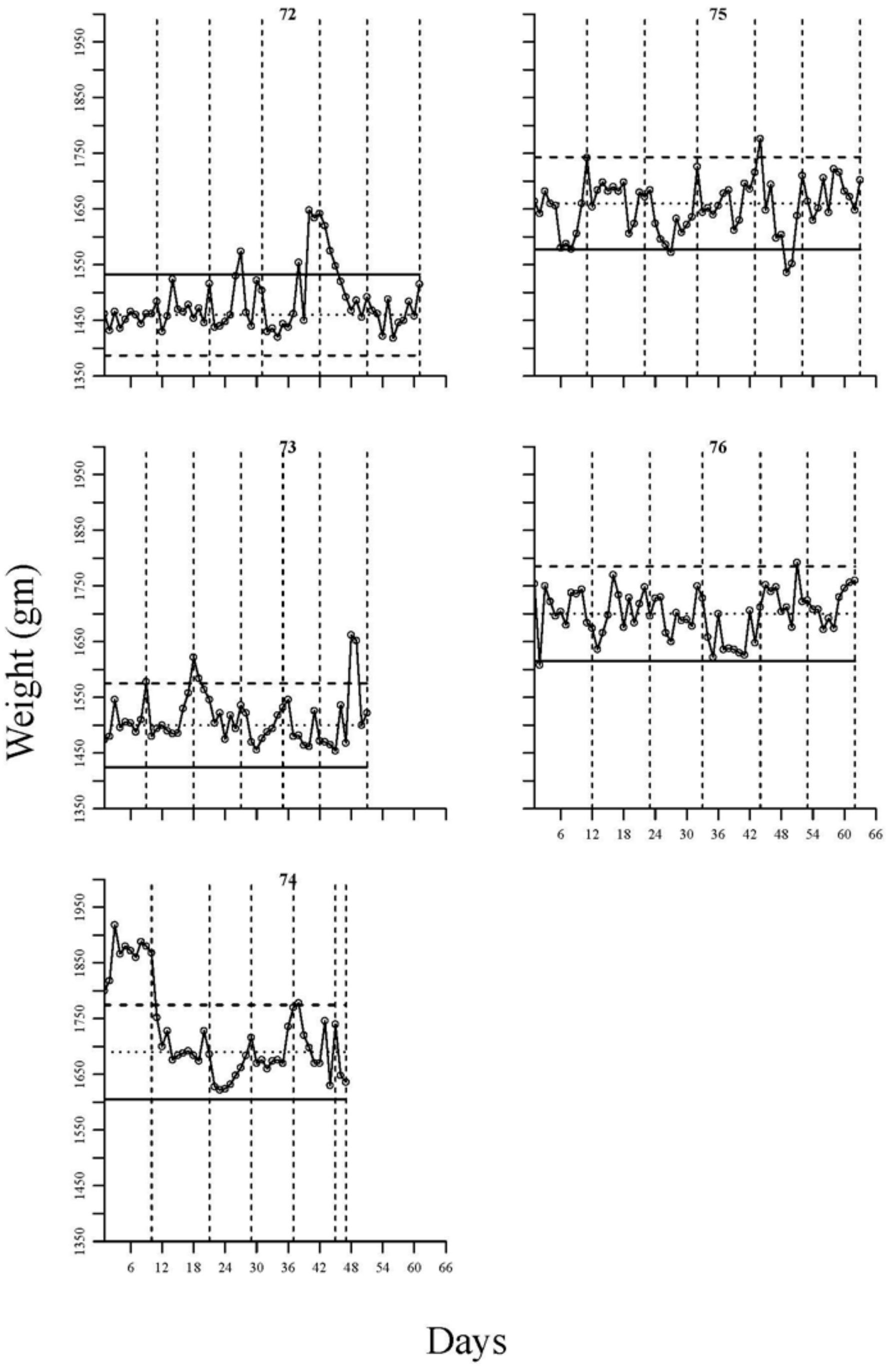

Figure 3. 6. The weights of all hens over the 66 days of data collection. The vertical dashed lines represent condition changes. The black horionzal line represents 5 % above the hen's target weight and the dashed horionztal line represents 5 % below the hen's target weight. The clear circles represent the hen's weight on that day.

Discussion

The aim of Experiment 3 was to investigate whether there would be different demand for three reinforcer types (W, PW and P) while being fed a P maintenance diet, when hens were working on a FR schedule with a doubling response requirement over sessions and session length determined by number of reinforcers at small FR values. Overall the results showed that consumption rate of reinforcers decreased with an increase in the response requirement for all reinforcer types. There were no systematic differences in demand functions, parameter values, overall-response rates, running-response rates or post reinforcement pauses between any reinforcer type for any hen. The median overall response rates and the median running response rates displayed similar patterns and had similar values to the overall response rates and running response rates from Experiment 2 that were obtained with data from only one ratio. The PRP times from Experiment 2 were more variable than the PRP times from Experiment 3. However this could be due to the fact that the PRP times (as well as the overall response rates, running response rates and consumption rates) in Experiment 3 were in fact medians, so the PRP times displayed were not affected by any unusually high or low values.

One difference between Experiment 2 and Experiment 3 was that hens in Experiment 2 never earned over 10 reinforcers so received post feed every day. However hens in Experiment 3 did earn up until the maximum number of reinforcers at the low FR ratios. Therefore on those days a hen only received post feed if she was under target weight. Figure 3.6 shows that all hens received post feed approximately half of the time during Experiment 3. Therefore limiting the maximum number of reinforcers able to be earned to 40 did work to ensure the hens regularly received post-feed (and therefore exposure to the maintenance diet) throughout the experiment.

One possible alternative to ensure hens received exposure to the maintenance diet would have been to alternate the days the hens worked on the FR schedules. In such an arrangement a day of working would follow a day of not working where the hens would have been fed to compensate for not earning reinforcers that day. However, due to the length of time involved in collecting data by using FR schedules that increase over sessions it would not have been possible to use this arrangement during this study. It is proposed that a further experiment could use this arrangement to ensure all hens received the maintenance diet regularly.

It was proposed in Experiment 2 that the provision of post feed may have affected the demand, and also that the hens' weight may have been a reason no consistent differences were found between demand for the various reinforcer types. The hens weights throughout this Experiment 3 were relatively consistently within ± 5% of their 80% free-feeding body weight and so were similar to Experiment 2.

Overall the results using FR schedules obtained in Experiment 3 are similar to of the results using PR schedules obtained in Experiment 2. This reflects the findings of Foster et al. (1997) who found that similar demand curves were generated under both PR and FR schedules with hens. The results differ to those found under concurrent schedules by Foster et al. (2009) when a bias was found toward W over PW when hens were fed a P maintenance diet. It is possible that hens in the Foster et al. (2009) study did not receive post-feeding as the hens were able to work until 40 minutes of keytime had elapsed and therefore were more likely to earn more reinforcers and not require post-feeding.

As the results found were similar to Experiment 2 and the body weights and provision of post feed similar also, it is suggested again that the low body weight of the hens and the provision of post-feed may be the reasons why no differences were found between the reinforcer types.

General Discussion

The aim of this thesis was to investigate whether feeding hens differing maintenance diets would affect demand when hens worked under PR and FR schedules for either the same or a different reinforcer type. The results from the demand experiment were then compared to the results of a free-access preference assessment to assess whether hen's initial preference for the different feed types had an effect on demand for the feeds.

Experiment 2 and 3 were both found to have similar results despite differences in the way the experiments were run. Both experiments did not replicate the results of Foster et al. (2009) who found that under concurrent schedules hens displayed a bias toward W over PW when fed a P maintenance diet. It is suggested that low body weight and the open economy accounted for the lack of differences found between the varying conditions.

The results of the preference assessment showed that three hens (72,73 and 75) showed a preference for W, one hen for P (74) and two hens had no clear preferences (71 and 76). Hens 72, 73, 74 and 75 were also found to show the least preference for PW. This reflected findings by Foster et al. (2009) who found using concurrent schedules that hens demonstrated a bias toward W over PW.

The results of the PR demand experiment showed that there was no difference in demand for W, PW or P. There was also no difference in demand for the three reinforcer types when the maintenance diet of the hens was varied between W, PW and P. The results of the FR demand experiment which replicated the P maintenance diet condition of the PR experiment reflected the results from the same condition of the PR demand experiment.

For both the FR and PR experiments the amount of reinforcers earned decreased systematically with the increase in response requirement. As discussed earlier the overall response rates, running response rates and PRP times reflected trends in behaviour seen in animals working under FR and PR schedules in the past. The demand curves generated by both the FR and PR schedules were similar, this finding reflected results found by Foster et al. (1997) who concluded that FR and PR schedules generated comparable not but identical demand curves when both used with hens.

The preferences obtained from the preference assessment did not result in different demand for the foods in the demand experiments. However, all hens did work to lower breakpoints during the P/PW condition of Experiment 2. The exception for showing different behaviour for the different reinforcer types was Hen 74. Hen 74 demonstrated she had no preference for PW during the preference assessment and this preference was reflected later on as during the P/PW condition Hen 74 did not work to a high enough ratio for the demand function to be calculated (the highest ratio completed under this condition was 4,4 and 1, for Series 1, 2 and 3 respectively). Hen 74 also worked to low ratios for the W/PW condition (8, 2 and 4, for Series 1, 2 and 3 respectively). For the PW/PW condition Hen 74 worked to higher ratios (32, 16 and 64, for Series 1, 2 and 3 respectively). It is also important to note that Hen 74 stopped eating the maintenance diet of PW during the PW/W, PW/PW and PW/P conditions. However even though Hen 74 stopped eating the maintenance diet and lost weight she did not work to higher ratios for the PW/W or PW/P condition than observed in the W/W, P/W, W/P or P/P conditions. Hen 74 did work to higher ratios (128, 64 and 8, for Series 1, 2 and 3 respectively) for the PW/P condition, compared to the P/P condition (0, 4 and 32, for Series 1, 2 and 3 respectively) and the W/P condition (8, 32 and 16, for Series1, 2 and 3 respectively). Hen 74 did not however demonstrate differences between the overall response rates, running response rates or PRP times for any condition, indicating that these were not controlled by her preferences for the reinforcer types.

Aside from Hen 74 for all other hens the results showed that the different preferences that were obtained during Experiment 1, were not related to different demand for the reinforcers under PR or FR schedules. In addition the different maintenance diets fed when the hens were working under the PR schedule did not affect demand for the same food when used as a reinforcer or for a different food used as a reinforcer. It is proposed that either the low body weight of the hens ± 5% of their individual 80% free-feeding body weight or the provision of feed outside of the experimental sessions are possible reasons that similar results were obtained for all reinforcer types, for all maintenance diets, in both PR and FR schedules.

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