Behavioural Economics: The Inferior-Good Effect

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Abstract

These experiments used 15 domestic hens to investigate the inferior-good effect, a decrease in consumption of a commodity as income increases. Experiment 1 investigated plain and salted wheat to serve as superior goods (opposite to inferior goods) and inferior goods. Hens consumed mostly plain wheat when given ad-libitum access so it was the intended superior good and salted wheat was the intended inferior good. In the next experiments, 3 s of plain wheat and 10 s of salted wheat were available for single responses on 2 keys during discrete trials. Income changed by changing the inter-trial interval (ITI) of fixed-length sessions or the total number of trials. Experiment 2 partially replicated the Silberberg et al. (1987) procedure, using the ITI income analogue for 6 hens. When income increased, 4 hens sometimes responded less on the salted-wheat key (demonstrating the inferior-good effect), 2 of these hens and a 5th hen sometimes responded more on both keys but proportionally more on the plain-wheat key (termed here as a relative inferior-good effect). Experiment 3a partially replicated the Hastjarjo et al. (1990a) procedure using the total-trials analogue for 7 other hens. The inferior-good effect occurred across some conditions for 2 hens while other hens tended to respond on the plain-wheat key, suggesting lack of contingency contact. When a 60-s ITI was added in Experiment 3b, variability increased for most hens, but only 1 hen showed the effect, 1 of the hens that did so in Experiment 3b. These 6 hens' (1 died) 80% bodyweights were re-assessed in Experiment 4 and hens were below 80% during Experiments 3a and 3b, suggesting that the lack of the inferior-good effect was not due to some hens being at high weights. The ITI analogue was used for these

6 hens in Experiment 5 and the effect occurred for 2 hens. Experiment 6 added forced-choice trials to the total-trials analogue (with 60-s ITI) to guarantee contingency contact. The inferior- and/or relative-inferior-good effect occurred for 3 hens. Across Experiments 2 through 6, body weights were usually heavier in high-income conditions and a within-session pattern of early-salted-late-plain responding occasionally occurred. “Crop capacities” of 5 Experiment-2 hens and a new hen (1 died) were assessed in Experiment 7 and there was no relation between this measure and inferior-or relative-inferior-good effects. Experiments 8 and 9 examined effects of pre- and post-feed in low-income conditions using the ITI analogue. When hens were pre-fed, responding for 5 of 7 hens resembled responding in high-income conditions of Experiment 2 with more plain-wheat responding and similar or less salted-wheat responding in some conditions (behaviour similar to the inferior- and relative-inferior-good effects, but without the income change). A similar pattern was found for 4 of 5 hens when hens were post-fed in Experiment 9, suggesting that food in the digestive tract may have played a role, and perhaps not the income manipulations themselves, where it (or other component of body weight) may have abolished quantity (i.e., the intended-inferior-good) as a reinforcer. Although these experiments occasionally demonstrated inferior- and relative-inferior-good effects, but less convincingly than published studies, the effects of income may have been non-specific. The usefulness of the inferior-good concept and other income-related economic concepts are thus challenged.

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Behavioural Economics: The Inferior-Good Effect

According to a prominent economics textbook, economics is, “the study of how societies use scarce resources to produce valuable commodities and distribute them among different people” (Samuelson & Nordhaus, 2005, p. 4). Economics can be further split into macro- and micro-economics where the former involves entire economies of many individual entities and the latter involves these entities themselves. If these entities are individual organisms, then economics begins to overlap other disciplines that study the behaviour of individuals. One such discipline is behaviour analysis, which is termed *the science of behaviour* (Association for Behavior Analysis International, 2006). B. F. Skinner was a pioneer of the science of behaviour and coined the term *behaviour analysis* (see Skinner, 1938, 1953, 1974).

Adam Smith, a philosopher, is often considered the founder of microeconomics (Samuelson & Nordhaus, 2005). In *The Wealth of Nations*, Smith (1776) stated that, “economic benefit comes from the self-interested actions of individuals” (Samuelson & Nordhaus, p. 5). Later, Jeremy Bentham, a philosopher influenced by Smith’s work, outlined a concept called *utility* as the, “property in any object...to produce pleasure, good or happiness or to prevent...pain, evil or unhappiness,” in *An Introduction to the Principles of Morals* (Samuelson & Nordhaus, p. 87). These beginnings of modern economics sit well with Skinner’s account of behaviour; namely, that the behaviour of an individual can be controlled by its consequences. In *Science and Human Behaviour* (1953), Skinner claimed that economic data should be understandable by a science of behaviour that accounts for the behaviour of individuals; however, “economic theory is not, as yet, derivable from current behavior principles...a complete behavioral account could profitably adapt and borrow from economics" (Hursh, 1980, p. 219).

Metaphors and analogies are part of every-day language and may help us make sense of the world (e.g., see Lakoff & Johnson, 2003). In applied settings, for example, Goldiamond and Dyrud (1968) used metaphorical language in changing patient behaviour outside of psychotherapy sessions. Also, the idea of borrowing from other disciplines through metaphor and analogy is not new. Bionics is the, "application of biological principles to the study and design of engineering systems, especially electronic systems" (The American heritage dictionary of the English language, 2000). Goldiamond and Dyrud used this approach to help understand how verbal behaviour controls other behaviours by applying knowledge gained through the study of psychotherapy. Hursh (1984) pointed out other behavioural work that has drawn from other disciplines:

> the practice of looking to another discipline for useful ways to analyze behavior is certainly not without precedent. Consider Descartes' (1662/1965) hydraulic analogy, John Stewart Mill's (1843/1965) chemical analogy, Kurt Lewin's (1951) analogy to physical field theory, and, more recently, analogies to physics (Bevin, Mandell, & Atakm 1983) and control theory in engineering (McFarland, 1971). (p. 435)

Additionally, Skinner applied natural selection in species (Darwin, 1859) to two other levels of analysis: the behaviour of individuals and the behaviour of social systems (Skinner, 1981, 1984). Rachlin (1971) identified the similarities in usefulness between the generalised matching law and the First Law of Thermodynamics. Metaphors and analogies, however, can break down. For example, behavioural momentum, a metaphor linking behaviour with Newtonian physics (Nevin & Grace, 2000) has been thoroughly critiqued (e.g., see Baum & Mitchell, 2000; Catania, 2000).

In an article outlining the amalgamation of behaviour analysis and economics into *behavioural economics*, Hursh (1984) suggested that, "the value of economic concepts for behavioral psychology rests on (1) their empirical validity when tested in the laboratory with individual subjects and (2) their utility when compared to established behavioral concepts" (p. 435-436). So, if behaviour analysis is to borrow concepts from economics, they need to be shown to do what they claim to do and they need to be shown to do what current behavioural concepts cannot do. Hursh (1980) suggested that economic concepts are indeed both empirically valid and useful. He offered the following four points:

> 1) a behavioral experiment is an economic system and its characteristics—open or closed—can strongly determine the results; 2) reinforcers can be distinguished by a functional property called elasticity; 3) reinforcers may interact as complements as well as substitutes; 4) no simple choice rule, such as strict matching, can account for all choice behavior. (p. 219)

Each point was supported with empirical examples from human and non-human experiments suggesting, overall, that at least the economic concepts mentioned above are useful for behaviour analysis (for an overview of behavioural-economic concepts, see Madden, 2000). To illustrate these points, a simple example will be discussed.

Imagine a basic economic system whereby a person earns an income for working a certain number of hours. In this system, only two foods are available: minced meat and steak. Minced meat costs less than steak, but steak tastes better. Additionally, water might be available for free. If all income is spent on minced meat, some of the meat is wasted; if all is spent on steak, not enough steak is available for survival. This person might buy various amounts of minced meat and steak over time, but their behaviour would probably become predictable. It would be equally easy to imagine a behavioural experiment whereby a non-human spends time responding in an experimental chamber by engaging in responses such as lever pressing or key pecking. There may be a fixed number of trials per session where responding could be allocated across any of the alternatives within the parameters of the experiment. A small amount of more-preferred food might be delivered for one kind of responding and large amount of less-preferred food might be delivered for another. If all responses are allocated to the operandum producing the large amounts of less-preferred food, some is wasted; if all are allocated to the operandum producing the small amounts of more-preferred food, the organism will starve. Like the human's behaviour, the behaviour of the non-human would become predictable.

Both of these examples could be described using either behavioural or economic concepts. Behaviourally, both organisms are put in a situation where responding can be reinforced by two reinforcers of differing values and magnitudes or under two different schedules of reinforcement. Economically, both individuals are in a closed economy where two commodities of differing utility can be purchased at two different prices. Behaviourally, sessions are limited to a certain number of trials or certain duration of time which, in turn, limits the numbers of reinforcers that can be delivered; economically, income limits the amounts of commodities that can be purchased. In this case, the behavioural experiment can be regarded as an economic system. If similar commodities (reinforcers) were available outside of the economy (session), as in an open economy, or if prices or income changed, then purchasing would change as suggested by Hursh's first point (1980). Each of these economic concepts has been studied in behavioural experiments.

If an individual is working because they receive a pay cheque that can then be used to purchase commodities, w*orking* can be considered an operant relation between a response (working) and a reinforcer (money, a conditioned reinforcer because it can be used to purchase commodities). When the relation occurs predictably, it can be described as one or more of many kinds of schedule of reinforcement (Ferster & Skinner, 1957). In such an experiment, an analogue of commodity price, then, is the schedule requirement for the delivery of one reinforcer. If the response requirement is increased, it is analogous to increasing the price of the reinforcer because more responses or effort is, required to obtain a single reinforcer; the opposite is true if the response requirement is decreased. In simple behavioural experiments, price, then, can range from zero responses or effort (free) to a small number of responses or effort (inexpensive) to a large number of responses or effort (expensive) to an infinite number of responses or effort (unattainable). So, in these simple arrangements, reinforcers can be delivered non-contingently (free), under a rich schedule or low operandum-force requirement (inexpensive), under a lean schedule or high force requirement (expensive) or withheld as in an extinction schedule (unattainable).

Researchers have manipulated price using different schedules of reinforcement and different kinds of operandi. Several experiments have involved manipulations of the number of responses required to attain reinforcers—fixed ratio (FR) schedules of reinforcement. FR schedules have been manipulated for lever pressing by rats (Bauman, 1991; Bauman, Raslear, Hursh, Shurtleff, & Simmons, 1996; Boice, 1984; Collier, Johnson, & Morgan, 1992; Lea & Roper, 1977; Mathis, Johnson, & Collier, 1996), key pecking by domestic hens (Foster, Blackman, & Temple, 1997), door pushing by domestic hens (Sumpter, Temple, & Foster, 1999), and button pressing by humans (Tustin, 1994). Roper (1975) altered the price of food for rats by changing the operandum-reinforcer distance along with the FR requirement for lever pressing. Hursh and Natelson (1981) changed the price of food and electronic brain stimulation (EBS) for rats by changing the variable-interval (VI) requirement for lever pressing. That is, food or EBS was available following the first lever press after a variable length of time following the last reinforcer delivery, a schedule usually resulting in moderate response rates. In this experiment, price was the average number of lever presses per reinforcer. So, price may be analogous different kinds of response requirements.

Another characteristic of an economy that has been said to change behaviour is the utility of the commodities purchased. Samuelson and Nordhaus (2005) offer a more quantitative definition of utility than that Jeremy Bentham's given earlier, "more precisely, it refers to how consumers rank different goods and services. If basket A has higher utility than basket B for Smith, this ranking indicates that Smith prefers A over B" (p. 84). This kind of utility is termed *ordinal utility* and differs from *marginal utility* which specifies the additional utility gained through the consumption of an additional unit of a commodity. Typically, as commodities are purchased marginal utility decreases for each subsequent unit—the law of diminishing marginal utility. The utility of commodities, then, can vary between commodities as well as with each additional unit of a commodity consumed and can therefore seemingly affect commodity consumption. However, it is not a property of the commodity or the individual consuming it, but a construct (Samuelson & Nordhaus, 2005). If basket A is said to be preferred over B because an individual was seen consuming A when given a choice, it is similar to saying that A has a higher ordinal utility than B. The concept is probably better understood as describing the relation between at least two commodities and an individual’s behaviour even though commodities themselves are discussed as “having utility.”

The concept, *value*, has been used in behaviour analysis and is sometimes used to describe reinforcers; however, like utility, it is a construct that is better understood as a descriptor of the relation between at least two reinforcers and an individual’s behaviour—behaviour in a choice situation. Nevertheless, reinforcers are sometimes discussed as “having value.” Premack (1965) identified four equivalent methods for measuring value: a more-valuable reinforcer reinforces responding for a longer duration than does a less-valuable reinforcer, it reinforces consumption of a less-valuable reinforcer, it causes a larger increase in response rate than does a less-valuable reinforcer, and, in a choice situation, it is chosen over a less-valuable reinforcer. Other similar measures of value have been based on the number of responses emitted (Neuringer, 1969; Taylor, 1975), the proportion of reinforcers obtained (Carder, 1972; Carder & Berkowitz, 1970; Carlson & Riccio, 1976; Hothersall, Huey, & Thatcher, 1973; Jensen, 1963; Kleinman, 1976; Mitchell, Scott, & Williams, 1973; Morgan, 1974; Paclawskyj & Vollmer, 1995; Singh, 1970; Tarte & Snyder, 1973), the latency of approach to reinforcers (Jensen, Leung, & Hess, 1970; Koffer & Coulson, 1971; Pace, Ivancic, Edwards, Iwata, & Page, 1985), and the reinforcer chosen in choice situations involving two stimuli (paired-stimulus method) (Fisher et al., 1992) or several stimuli (multiple-stimulus method) (DeLeon & Iwata, 1996; Windsor, Piche', & Locke, 1994). Basket A, then, might be considered to be more preferred, to have a higher ordinal utility, or to have a higher value than basket B. This statement would be supported if, in a behavioural experiment, the two baskets were related as described by Premack, if more responding or a higher proportion of responses occurred for A than for B, if approaches to A were faster than approaches to B, or if A was consistently consumed over B when given access to both or both amongst several others.

A large body of research on the study of choice overlaps the above studies on value—studies investigating the matching law through the use of concurrent schedules of reinforcement (for a review, see Davison & McCarthy, 1988; Herrnstein, Rachlin, & Laibson, 1997). Several of these studies have used concurrent variable-interval (VI) schedules, where reinforcers were delivered on each schedule following the first responses after variable intervals of time that averaged to a specified interval (Ferster & Skinner, 1957). The study showed that ratios of pigeons' numbers of responses on the two keys under two different VI schedules were equal to ratios of reinforcement rates for the two keys (Herrnstein, 1961). That is, pigeons' response ratios *matched* reinforcement-rate ratios. They did not, for example, simply respond only on the key delivering reinforcers the most frequently. The same relation was also found for and expressed in terms of time allocation such that time ratios matched reinforcement-rate ratios (Baum & Rachlin, 1969). Additionally reinforcer amount and immediacy were found to affect response and time ratios (Baum & Rachlin) in a similar fashion (more amounts or faster immediacy resulted in more time or responses). Here, the time allocation, T, on each alternative, *1* and *2*, are proportional to the multiplication of reinforcer rate, r, amount, a, and immediacy, i:

$$\frac{T_1}{T_2} = \frac{r_1 a_1 i_1}{r_2 a_2 i_2} . \tag{1}$$

The authors suggest that the right side of the equation plus any other variables that might affect time allocation or responding might be defined as value, V. So:

$$\frac{T_1}{T_2} = \frac{V_1}{V_2} . \tag{2}$$

Rachlin (1971) built on Baum and Rachlin's (1969) Equation 1 by including an extra parameter, *X*, representing, "parameters of reinforcement other than rate, amount, and immediacy," (p. 249). The equation became:

$$\frac{T_L}{T_R} = \frac{R_L}{R_R} \bullet \frac{A_L}{A_R} \bullet \frac{I_L}{I_R} \bullet \frac{X_L}{X_R} = \frac{V_L}{V_R} . \tag{3}$$

Here *R*, *A*, and *I* are reinforcement rate, amount, and immediacy, as in Equation 1, and the *L* and *R* subscripts denote left and right (which would be synonymous to the *1* and *2* subscripts from Equations 1 and 2). Equation 3 adds an additional expression representing the ratio of reinforcement values, *V*, and posits equality between the ratios of time allocation, the reinforcer dimensions of the middle expression, and value. Killeen (1972) pointed out that Equation 3 was a combination of three equations: Equations 1 and 2, and the part of Equation 3 without the ratio of values on the right side of the equation. Killeen cautioned that the latter two equations give two independent ways of defining the ratio of values and that their equality, as suggested by Equation 3, may not always be the case. He then suggested that *value* might name the subjective concatenation of reinforcer dimensions above, but should not be thought of as a new variable. He further suggested that value described in this way was one way of defining utility. So here, the two concepts overlap and judgments on value or utility are linked to time allocation or responding such that more time or more responding is associated with higher value and utility. Also, the equations suggest that knowing the parameters of reinforcement described by *value* or *utility* should allow for predictions of time allocation and response rates.

Another parameter of reinforcement that has been shown to effect responding is reinforcer quality. For example, Miller (1976) showed that different food types resulted in different time allocations and response rates in pigeons; Hollard and Davison (1971), found differences between EBS and food in pigeons; Neef, Mace, Shea, and Shade (1992), for money and tokens in children; Petry and Heyman (1995), for ethanol and sucrose in rats; and Belke, Pierce, and Duncan (2006) for sucrose and wheel running in rats. So, at least the following parameters of reinforcement (which might collectively be referred to as *value* as suggested by Equation 3) have been shown to affect time allocation and/or response rates: rate, amount, immediacy, and quality. Further, it has been acknowledged that other variables not-yet-described could also affect time allocation and response rates as well (Baum & Rachlin, 1969; Rachlin, 1971).

In Hursh's (1980) point 2), he indicated that *elasticity* is a property of reinforcers which can distinguish one from another. In short, it is a way of quantifying qualitatively-different commodities (reinforcers) and there is no similar concept in behaviour analysis. More specifically, Hursh was referring to *demand elasticity* (sometimes called *price elasticity*). Demand elasticity is the absolute value of percent change in quantity of a commodity demanded divided by the percent change in its price (Samuelson & Nordhaus, 2005). So, if $\%\Delta Q$ is percent change in quantity demanded and $\%\Delta P$ is percent change in price, then the demand-elasticity coefficient, E_D, can be shown by the following equation:

$$E_D = \left|\frac{\%\Delta Q}{\%\Delta P}\right|. \tag{4}$$

Demand elasticity can also be portrayed graphically by plotting demand curves, simply the quantity demanded plotted across increasing prices (for behaviour analysis, or vice versa for economics). A property of demand curves is *the law of downward-sloping demand* which states that the quantity of a commodity demanded decreases as price increases; the rate at which the quantity demanded decreases with price differs from commodity to commodity (Samuelson & Nordhaus, 2005). So, demand-elasticity coefficients and shapes of demand curves can provide information that can be used to distinguish reinforcers or commodities from one another.

When demand elasticities of two reinforcers or commodities differ, it means their demand-elasticity coefficients differ and that their demand curves would look different. When demand functions are plotted in log-log coordinates, the demand-elasticity coefficient is equal to the slope of the resulting line or to the slope of any of the tangent lines for points on the resulting curve. If the coefficient is less than one, demand is termed *inelastic*, so less sensitive to price changes; greater than one, *elastic*, so more sensitive to price changes; equal to one, *unit*, so proportionally sensitive to price changes (for a more thorough description, see Hursh, 1980). If the coefficient is zero, then demand is not affected by price. Along the continuum of elasticity, commodities that are inelastic tend to be necessities while commodities that are elastic tend to be luxuries (Hursh, 1980). People would probably continue to buy food, a necessity, at high prices, but the purchase of movie tickets, a luxury, would probably decrease with increases in price. When commodities are compared, their elasticity coefficients and demand functions can be compared and statements about demand elasticity in relation to the other commodity can be made. For example, “A is more elastic than B,” suggests that A’s coefficient is greater than B’s, that A’s demand curve is steeper than B’s, that price increases affect A more than B, and that that A is more of a luxury and B is more of a necessity.

At least the following could affect demand elasticity: the nature of the reinforcer, the response-reinforcer distance, the species consuming the reinforcer, the availability of other reinforcers, and the type of economy (open or closed) (Hursh, 1984; Lea & Roper, 1977). When food and EBS were available under VI schedules, demand for food did not decrease as much as EBS when price was increased by increasing the VI (Hursh & Natelson, 1981). In other experiments, researchers found differences in demand elasticity between food and saccharin for monkeys (Hursh, 1991), between root beer and Tom Collins mix for rats (Rachlin, Green, Kagel, & Battalio, 1976), between food and sucrose for rats (Lea & Roper, 1977), and across a variety of food ranging from coffee to dairy products to wine for people (Lea, 1978). Roper (1975) demonstrated changes in demand elasticity when response-reinforcer distances were manipulated for mice responding under a FR schedule with nest material and food as reinforcers. As the response-reinforcer distance became longer, the demand elasticity increased. Elasticities ranged from inelastic (when the operandum-reinforcer distance was relatively short) to unit (when the operandum-reinforcer distance was relatively long). Boice (1984) compared water-consumption demand functions for two species of packrats and found elastic demand for packrats from a dry habitat and inelastic demand for packrats from the wet habitat. Boice explained the difference:

> When the terms of foraging were made easy, much as they might be in an occasional desert rainfall, [the packrats from the dry habitat]…gorged themselves. When terms were made difficult, as they ordinarily might be in nature, [the packrats from the dry habitat]…earned relatively little drinking water….[The packrats from the wet habitat] earned water in moderate amounts when terms were easy, just as they might in nature. When access to water was difficult, they expended extra efforts rather than tolerate water deprivation, presumably because they had less efficient mechanisms of water concentration…than did the sample of [packrats from the dry habitat]" (p. 117, brackets mine).

Finally, Hursh (1984) reviewed literature showing that in closed economies, where all food is consumed during experimental sessions, response rates for monkeys, pigeons, and rats under VI schedules were inversely related to reinforcement rate, suggesting inelastic demand; but in open economies, where food was available outside of sessions, response rates decreased slightly with decreases of reinforcement rate, suggesting elastic demand. So, demand elasticity has been shown to change in various circumstances. It is, therefore, not a reinforcer or commodity property, but a concept that captures the relation between consumption and price which changes depending on context (Hursh, 1980). In this respect, it is similar to value and utility. None of these concepts can be shown to be an intrinsic property of a commodity or reinforcer. Much like naming a consequence a *reinforcer*, judgements on value and utility are based on observations of the effect of a stimulus on behaviour. Demand elasticity is not the same as value or utility because it relates to the rate of change in consumption as price increases while value relates to the overall level of consumption or to intensity of demand (the demand for a commodity at a minimal price, see Hursh, 1984) and utility relates to something similar to value. The research above affirms Hursh's (1980) point 2), that demand elasticity can distinguish reinforcers. The research shows the concept to be empirically valid and it is also useful as no behavioural concepts capture what the concept captures.

Hursh's (1980) point 3) states that reinforcers can interact as complements and substitutes. Concurrently-available reinforcers can be substitutes for, complements of, or independent of each other (DeGrandpre, Bickel, Higgins, & Hughes, 1994; Hursh, 1980, 1984). Substitutes are at one end of a continuum: as the price for commodity A increases the consumption of a substitutable commodity (B), at a fixed response requirement, increases. Complements are at the other end: as the price for commodity A increases the consumption of a complimentary commodity (C), at a fixed response requirement, decreases.

Between these two ends are independents: as the price for commodity A increases the consumption of an independent good (D), at a fixed response requirement, remains the same. Hursh (1980) offered and example, "public officials hope to reduce commuting by private vehicle by increasing the supply of the *substitute*, public transportation, and by reducing the supply of the *complement*, cheap downtown parking" (p. 234). These officials would probably be unsuccessful in their efforts if their strategy was to increase or decrease the supply of an *independent*, say public toilets.

Substitutability has been investigated with rats for food pellets and sucrose pellets, ethanol mix and sucrose mix, and sucrose and wheel running (Bauman et al., 1996; Belke et al., 2006; Lea & Roper, 1977; Petry & Heyman, 1995); with pigeons for leisure time and food (J. K. Green & Green, 1982; L. Green, Kagel, & Battalio, 1987); with rhesus monkeys for food pellets and water (Hursh, 1978); and with people for nicotine gum and cigarrettes, visual stimuli and attention, and various drugs (Bickel, DeGrandpre, & Higgins, 1995; Shahan, Odum, & Bickel, 2000; Tustin, 1994). Several other studies can be found in a review of the literature (L. Green & Freed, 1993). The concept of substitutability, then, has been empirically validated in the laboratory across several species and reinforcers. No behavioural concepts capture the relation between reinforcers as such, so the concept is probably useful for behaviour analysis as Hursh (1980) suggested in his point 3).

Hursh's (1980) final point, point 4), indicated that a simple choice rule such as strict matching was inadequate to account for all choice behaviour. In papers that have discussed matching outcomes in choice situations, the underlying behavioural process has sometimes been called *melioration*. Herrnstein and

Vaughan (1980) defined melioration as follows, “the process itself appears to be psychologically simple, requiring the subject to detect nothing more than signed differences in local reinforcement rate and to reallocate behaviour to the higher local rate” (p. 164). Given that reinforcer amount (magnitude) (e.g., Catania, 1963; Neuringer, 1967) and immediacy (e.g., Chung & Herrnstein, 1967) have also been shown to affect behaviour, the process could involve detecting these differences as well. Presumably the process would also involve detecting differences in reinforcer quality. Another view of the underlying behavioural process in choice situations has been called *maximisation* (note that the term has been used to describe both the process and the outcome and, similarly, in some papers *matching* has been used to describe the same underlying process as *melioration*). Maximisation is derived from economic theory and asserts that individuals maximise utility (Samuelson & Nordhaus, 2005); it is a predominant view in behavioural economics (e.g., see Rachlin, Battalio, Kagel, & Green, 1981). According to maximisation, all behaviour is choice behaviour and choices are made such that a set of properties in an organism’s environment (utility) is maximised by the choice (Rachlin et al.). So, organisms don’t simply allocate time or responding by matching relative rates of reinforcement (or amounts, immediacy, etc.), instead, time allocation and responding occurs such that overall utility is maximised. Organisms, thus, behave rationally. Within economics, though, maximisation is more of an assumption than an empirically-tested phenomenon.

In behaviour analysis, an overwhelming majority of experiments testing between melioration and maximisation show melioration to hold better than maximisation (Herrnstein et al., 1997). Although maximisation was occasionally found, matching was found for these experiments as well and both outcomes tended to be describable in terms of melioration. For example, Vaughan and Herrnstein (1997) described maximisation as follows:

> All choices are viewed as depending on their relation to once central dimension, overall utility. Equilibrium is supposedly reached when no possible redistribution of activities can increase overall utility. In contrast, melioration portrays an organism as a set of competing response tendencies, a system that is "rational" only in certain special environments (Vaughn, 1984). If one response pays off more than another, the first will increase even if the overall payoff thereby suffers. At equilibrium, all surviving responses pay off at the same average rate. Response categories that do not achieve that high a rate of pay disappear. A meliorating organism is a maximizing organism if it has an infinite capacity to redefine response categories to suit prevailing contingencies of reinforcement, for then the optimal distribution of responses in any situation would be treated as a single response category in its own right, and it would be chosen exclusively as a result of melioration (see Chapter 4). For a creature capable of learning new response configurations, melioration pushes towards maximization. However, no evidence has been provided for infinite response plasticity in any species. To the extent that the topography of response categories is not entirely determined by contingencies of reinforcement, a meliorating organism may fail to maximize. (p. 205)

Similarly, Heyman and Tanz (1995) suggested that matching and maximisation are both outcomes of the same underlying process whereby each is a point on a continuum. Finally, Rachlin, Green, and Tormey, (1988), suggested that, "neither is a fundamental law of human nature and to view both principles for what they are—useful tools by which the structure and function of behavior may be examined" (p. 122). This statement is consistent with Hursh's (1984) comments supporting the empirical validity and usefulness of economic concepts, but the literature described above does not support the empirical validity of maximisation, calling into question the usefulness of the concept compared to established behavioural concepts. Although maximisation is not supported, Hursh's (1980) point 4) may still be correct: matching may not account for all choice behaviour. For Premack's (1965) work and for melioration, value was supposedly scalable independent of the context (Rachlin, Kagel, & Battalio, 1980). Inspection of Equations 1, 2, and 3 reveals no parameters that account for context either. So, changing a reinforcement parameter such as the total number of trials per session or the length of the session should not affect behaviour.

However, numbers of trials per session and session length have indeed been shown to affect behaviour. Changing these parameters as such might be conceived of as changing overall reinforcement such that more trials or longer sessions result in more reinforcement while fewer trials or shorter sessions result in less. Experimenters have investigated the effects of these kinds of manipulations, which can be considered analogous to income changes (for a review, see Tsunematsu, 2001). For example, the effects of these changes has been investigated on drug consumption in people (DeGrandpre, Bickel, Rizvi, & Hughes, 1993); on phencyclidine (PCP), saccharin, and water consumption in rhesus monkeys (Carroll & Rodefer, 1993); on food, saccharin water, sucrose, and wheel-running in rats (Belke et al., 2006; Collier, 1981; Hastjarjo & Silberberg, 1992; Hastjarjo, Silberberg, & Hursh, 1990b; Shurtleff, Warren-Boulton, & Silberberg, 1987); and on food and leisure time in pigeons (J. K. Green & Green, 1982; Shurtleff & Silberberg, 1990; Wakita, Kawamura, & Watanabe, 1994). These findings pose a problem for melioration due to the lack of income-related parameters in Equations 1, 2, and 3. On the surface, maximisation, though, can account for these effects of income.

Rachlin et al. (1981) described maximisation as follows:

> In maximization theory, a rat in a Skinner box is seen not as being rewarded for pressing the bar by receiving food, but as choosing between various packages that contain so much food and so many bar-presses. Maximization theory assumes that the rat will choose the package (from all available packages) that it most prefers and that this preference, once demonstrated, will be consistent with future choices. (p. 373)

When income changes, a different package would result for the rat such that the highest possible utility, given the new income constraint, results. This package has been referred to as a *bliss point*, the most-preferred distribution of activites (Kagel, Dwyer, & Battalio, 1985). A large problem exists for utility, though. Utility seems to be assumed rather empirically supported and assertions about utility seem to be made post hoc (for a critique, see Herrnstein et al., 1997). Value has at least been quantified in Equations 2 and 3 so that the specific variables encompassed by the term can be manipulated to test effects on behaviour. The same cannot be said for utility, "the underlying contingencies of utility are neither discovered (as in biology), nor programmed (as in behaviour analysis), with only rare exceptions" (Vaughan & Herrnstein, 1997, p. 223) So, Hursh's (1980) fourth point suggesting the inadequacy of strict matching may still hold (due to the income-related experiments described above), but maximisation and utility do not seem to be empirically valid or more useful than established behavioural concepts.

Economics utilises four concepts that capture the relation between changes in income and changes in commodity consumption and there are no concepts in behaviour analysis that overlap these economic concepts. The concepts are inferior, normal, superior, and Giffen goods and their classification requires an observation of how consumption changes when income changes or calculation of an income-elasticity coefficient. Silberberg, Warren-Boulton, and Asano (1987) provided a concise description of three of these concepts:

> Goods are categorized as "normal" or "inferior" over any given income range, depending on whether consumption of that good increases or decreases as income increases. For a good that is "normal" over a given income range, an increase in income over that range results in increased consumption of that commodity. If that increase is more than proportionate to income, that good is a "superior" good over that income range. At the other extreme, if an increase in income results in an absolute fall in the amount consumed, the good is "inferior" over that income range. If all a of a given income is spent on only two goods, it follows arithmetically that both goods can be normal; if one is superior, the other can be normal or inferior; and if one is inferior, the other must be superior. (p. 292)

An example of the above might be minced-meat, as an inferior good, and steak as a superior good. Someone who is relatively poor may consume more minced meat than steak on a weekly basis because given their income constraint, exclusive purchasing of the better-tasting steak would result in starvation. Following an increase in income, if the consumption of minced meat decreases and if there is a more-than-proportional increase in consumption of steak, then these goods fit the criteria for inferior and superior goods. Under both of these income conditions, economists would say that the person is maximising utility (a package of better-tasting but small amounts of steak and worse-tasting but big amounts of minced meat) given each income constraint. Another individual earning a certain income may behave differently. If, following an increase in income, consumption of both goods increases, then both would be considered normal goods. Presumably, both individuals would be able to survive on their packages of minced meat and steak in each income condition.

Giffen goods are a special case of inferior goods. An inferior good is a Giffen good if its consumption increases when its price increases—a violation to the law of the downward-sloping demand (Samuelson & Nordhaus, 2005). Hastjarjo, Silberberg, and Hursh (1990a) offered the following example of a Giffen good:

> To illustrate how an inferior good can become a Giffen good, imagine that a hypothetical consumer earns \$8/day and that his large family requires 6 kg of food daily to maintain their body weights. Every day this consumer exhausts his income by buying 5 kg of potatoes at \$1/kg and 1 kg of hamburger [minced meat] at \$3/kg. One day our consumer gets a \$4 raise in salary. With \$12 in hand, he now purchases 3 kg of hamburger (\$9) and only 3 kg of potatoes (\$3). Because he has purchased fewer potatoes despite his increase in income, potato is an inferior good. To transform this inferior good into a Giffen good, imagine that the grocer now raises the price of potatoes to \$2/kg. Because our consumer needs 6 kg of food to feed his family, he can no longer afford to purchase any hamburger. Instead, he must spend his income exclusively on potatoes. Paradoxically, in response to an increase in the price of potatoes, our consumer is forced to buy more potatoes. (p. 266-267, brackets mine).

As in the earlier example of inferior and superior goods, according to economists this individual would be maximising utility given the new price constraint. However, as discussed earlier, it does not help to claim that behaviour changes when price or income changes because the changes maximise utility because utility cannot be quantified in the same way that value has been quantified. Also, melioration cannot account for any of these four goods because Equations 1, 2, and 3 do not contain parameters for analogues of income and because the equations predict that increases in price (i.e., decreases in reinforcement rate) always result in decreases in time allocation or response rates.

The equation for calculating income-elasticity coefficients is the same as Equation 4, except the denominator specifies the percentage change in income instead of price and the absolute value is not taken, so negative coefficients may result. So, if $\%\Delta Q$ is percent change in quantity demanded and $\%\Delta I$ is percent change in income, then the income-elasticity coefficient, E_I, can be shown by the following equation:

$$E_I = \frac{\%\Delta Q}{\%\Delta I} . \tag{5}$$

Given the description of the goods above, mathematically it follows that the commodity is an inferior good if E_I is negative; independent (the consumption of the good does not change when income changes) if zero; normal if between zero and one; superior if greater than one; not consumed before and after income changes undefined. If a commodity is not consumed before an increase in income but consumed after, then E_I is infinite and positive (a superior good); if consumed before an increase in income but not consumed after, then E_I is infinite and negative (an inferior good).

Although the reinforcers used in previous income studies could be categorised as inferior, normal, superior, or Giffen goods by inspecting the data and categorising as such, a literature search for research directly investigating inferior-goods with non-humans resulted in three experiments. These experiments demonstrated inferior goods, then Giffen goods with non-humans using different foods; one study used monkeys, Japanese macaques, as subjects (Silberberg et al., 1987), and two studies used rats (Battalio, Kagel, & Kogut, 1991; Hastjarjo et al., 1990a). Methods of all three studies differed with respect to income, price, and substitutability. Silberberg et al., and Battalio et al., manipulated income by changing the total number of discrete trials per session while Hastjarjo et al. manipulated income by changing the inter-trial interval (ITI) between discrete trials during fixed-length sessions. The inferior-good experiments of all three studies utilised different prices for each of the two reinforcers by programming different quantities of each per response, but substitutability of each pair of reinforcers differed. Battalio et al. used quinine (a bitter-tasting chemical) solution and root beer for rats, Hastjarjo et al. used food pellets and food pellets adulterated with quinine for rats, and Silberberg et al. used food pellets and food pellets adulterated with tinctura amara (a bitter-tasting Chinese herb) for monkeys. All of these studies demonstrated inferior and Giffen goods for some of their subjects but results for the Giffen goods were slight in at least two of the studies (Battalio et al.; Silberberg et al.). Inferior goods were the larger, adulterated foods and superior or normal goods were the smaller, presumably-better-tasting foods. The only study that presented income-elasticity coefficients was Battalio et al. Their intended-inferior-good elasticities (*intended* because inferior goods were not demonstrated for all subjects) ranged from -1.85 to 0.44.

The current series of experiments was intended to identify the variables that determine the occurrence or non-occurrence of inferior goods (goods with negative income elasticities) using domestic hens as subjects. Following from Hursh's (1980) point 4), it has been shown that established behavioural concepts (especially matching or melioration) do not account for behaviour that changes with changes in income, so the concepts of inferior, normal, and superior goods are candidates for being useful concepts for behaviour analysis that have already been validated. So the current series of experiments was also intended to further test the validity of the concepts as the variables controlling the occurrence or non-occurrence of inferior goods are identified. Within the small amount of literature that did address inferior goods, the explanation of the phenomenon has been nebulous. Amongst the three inferior- and Giffen-good studies, none explained the effects beyond stating that income affected consumption and that such an effect was predictable given the economic concepts outlined above. It is interesting that utility was not mentioned in any of these studies, but it would not have helped explain the phenomenon anyway, as discussed earlier. It is noteworthy that the matching literature tends to involve a variety of free-operant procedures (Davison & McCarthy, 1988) while the three inferior- and Giffen-good studies involved discrete trials. The possible relation of melioration and matching to the inferior- and Giffen-good studies, then, needs some further elaboration.

As Equation 1 involves ratios of response rates, it cannot be applied to discrete-trial data. Equations 2 and 3 involve ratios of time allocation instead of response rate, but no research could be found that discussed these equations in terms of discrete-trial responding. There were at least two studies that mimicked the contingencies of concurrent VI schedules utilising discrete trials (Nevin, 1969;

Shimp, 1966) with pigeons and both found matching as in other studies employing concurrent VI schedules, but these studies were much different from the inferior- and Giffen-good studies. It will therefore be assumed that in the inferior- and Giffen-good studies, responses on inferior- and superior-good operandi was reasonably correlated with time allocation, allowing Equations 2 and 3 to be hypothetically applied to these studies. If the equations balance, an underlying melioration process might be inferred. In the inferior-good experiments of these studies, reinforcers only differed with respect to amount and quality, so Equation 3 might be modified to express only these differences as their programmed rate, immediacy, and other parameters of reinforcement were identical. The ratio involving quality, *Q*, would reflect the difference in reinforcer qualities (based on H. L. Miller, 1976):

$$\frac{T_L}{T_R} = \frac{A_L}{A_R} \bullet \frac{Q_L}{Q_R} = \frac{V_L}{V_R} . \tag{6}$$

It can be seen that if this equation were applied to the data of the inferior- and Giffen-good studies, time allocation would have changed with income changes while the variables in the equation would have remained constant. Hence, the equation does not suffice in accounting for the effects of income changes, so an underlying melioration process is not supported.

Nevertheless, all three of the inferior- and Giffen-good studies showed shifts in responding with changes in income and (changes in price, in for the Giffen-good experiments) for at least some subjects. Inferior goods were demonstrated for 4 of 5 subjects in Battalio et al. (1991), for 4 of 4 subjects in Hastjarjo et al. (1990a), and for 2 of 2 subjects in Silberberg et al. (1987). The Silberberg et al. monkey study and the Hastjarjo et al. rat study were chosen for partial replication and further study because their methods provided the most detail and because the Hastjarjo et al. procedure was somewhat similar to Battalio et al. procedure. In light of the problems associated with considering value or utility to be an intrinsic property of reinforcers, the word *effect* will be added to these concepts when referring to behaviour. For example, minced meat may be an inferior good, but the individual's decrease in purchasing minced meat (behaviour) following an increase in income would be termed the *inferior-good effect*. As no inferior-good studies were found for domestic hens, the first step was to identify two candidates for the intended inferior and superior goods. The next steps were to partially replicate the inferior-good phases of the Silberberg et al. and Hastjarjo et al. studies and the final steps were to create new experiments intended to identify variables important for the inferior-good effect based on the results of the partial replications. It was predicted that the results of the partial replications would be similar to the results of the original experiments: that the intended inferior-good would decrease in consumption and that the intended superior-good would increase in consumption with increases in income. The results of all experiments will be discussed to identify some of the variables important for the inferior-good effect; to provide a more adequate explanation of the effect then what has been given in the literature; and to evaluate the empirical validity and usefulness of inferior-, normal-, and superior-good concepts for behaviour analysis.

Experiment 1: Preference Assessment (Group 7)

In experiments investigating inferior goods, Silberberg et al. (1987) adulterated monkey chow with a Chinese herb, tinctura amara, to create an inferior good for monkeys; Battalio et al. (1991) mixed water with root beer or quinine to create a superior and inferior good, respectively, for rats; and Hastjarjo et al. (1990a) adulterated food pellets with quinine to create an inferior good for rats. The subjects in the current series of experiments were domestic hens, a novel species in the investigation of inferior goods that warranted an investigation into the types of foods that might serve as inferior and superior goods. The purpose of this experiment was to select two foods that might serve as superior and inferior goods in subsequent experiments.

The current experiment utilised Silberberg et al.'s (1987) guidelines for selecting two different foods to investigate the inferior-good effect in monkeys.

> In selecting a commodity pair to serve as superior and inferior goods, we were guided by three characteristics…(a) these goods are close substitutes in at least some essential dimension (caloric value); (b) they differ significantly in value in some other, less essential dimension (taste); and (c) the less valued good is significantly cheaper than the more valued good. (p. 293)

If the same food is used for both types of commodities and if the apparatus can be manipulated to change the price of each food, then guidelines (a) and (c) would be satisfied. It was necessary, then, to identify a means of adulterating the taste of each food so that guideline (b) is satisfied.

A relevant study by Balog and Millar (1989) examined the effects of five different flavoured diets on feed consumption, weight gain, and feed efficiency when broiler chicks were offered these flavours during various experimental arrangements. The control diet was a corn-and-soybean-based mash while the experimental diet contained the same mash with one of the following powdered flavourings: quinine hydrobromide (bitter), citric acid monohydrate (sour), common salt (salty), saccharin (sweet), and aspartame (sweet). Experimenters found that the control feed was consumed more than the experimental feed. The consumption of the experimental feed increased in the following order: salt, quinine, saccharin, citric acid, and aspartame. Group weight gains, across the five groups, increased in the following order: salt, quinine, saccharin, aspartame, and citric acid. So, the salt feed tended to be consumed less than all other feeds and was associated with the lowest weight gains. Based on these findings, salt is a flavouring that is likely to decrease the consumption of food by hens.

In the current experiment, individually-housed hens had access to plain and salted wheat ad libitum. The more-consumed wheat may be deemed *more preferred* while the less-consumed food may be deemed *less preferred*; however, the word *preference* will be avoided in favour of the specific measure upon which preference is inferred (e.g., weight consumed). In subsequent experiments the more-consumed food may serve as the intended superior good while the less-consumed food may serve as the intended inferior good. The results of Balog and Millar (1989) suggested that more plain wheat would be consumed than salted wheat.

Method

Subjects

Subjects were 6 Brown Shaver hens (*Gallus domesticus*) with prior experimental experience numbered 71, 72, 73a, 74, 75, and 76a (the Group-7 hens). All hens were approximately two years old at the onset of the experiment. The experiment occurred in the hens' home cages located in a room with approximately 45 other hens under 12hr dark/light cycles. Water was continuously available and all food was consumed from the experimental apparatuses attached to the home cages. All hens began the experiment at approximately 80% of their body weight (when egg laying was infrequent and comb size was relatively small). Each hen's 80% body weight was calculated and then achieved following a period of free access to pellets during which body weights became stable (i.e., at 100% body weight). Following this body weight assessment, the laboratory technician further reduced birds' "80%" weights if egg laying still occurred frequently or if comb size was relatively large so that birds were roughly similar with respect to body state. Following this experiment and between and during subsequent experiments, this "80%" body weight was used as a threshold to calculate the volume of post-session food required to maintain body weight and will be referred to as the *post-feed threshold*. For the duration of the current experiment, hens were weighed approximately every other day and given grit approximately twice and vitamins approximately once weekly.

Apparatus

Two wheat dispensers were attached side by side to the front section of each home cage. The green plastic trough openings for each dispenser were 5 x 5 x 5 cm, were 3 cm apart, and were 20 cm from the floor of the cage. Each trough was supplied with salted or plain wheat from an inverted 750-ml brown opaque plastic bottle situated at the rear of the trough. When the dispensers were full, hens had access to approximately 510 g of each type of grain daily. Pecks to the back section of the inside of the trough allowed a small amount of wheat to pass through the neck of the bottle and into the trough where it could be consumed. Water was always available through a Hart Trigger Cup in front of each set of troughs.

Wheat was flavoured with salt by dissolving salt in water, adding the mixture to the wheat, and drying the mixture in a drying chamber. The salt weight was 5% of the wheat weight and was mixed with just enough water to completely dissolve the salt. The solution was then mixed with approximately 2 kg of wheat and allowed to dry in an oven pan at approximately 80° C for approximately 48 hr.

Experimenters weighed hens by placing each hen into a plastic, cone-shaped sleeve and weighing the hen and sleeve with a Salter 235 6S analogue hanging scale with a resolution of 20 g and a maximum of 5000 g. Experimenters weighed the food dispensers with a Wedderburn EEW-10K digital table scale with a resolution of 1 g and a maximum of 11,000 g.

Procedure

Hens consumed their entire daily ration of food by consuming salted and plain wheat from two identical dispensers in their home cages during fourteen 24-hr sessions. At approximately the same time daily, experimenters noted wheat spillage on the floor and waste tray, removed and recorded the weight of each dispenser, added wheat and reweighed dispensers if necessary, calculated the weight of salted wheat and plain wheat consumed, and replaced each dispenser.

Dispenser position (left or right) changed daily and was random, but the same across hens.

Results

Figure 1 shows the change in weight of the salted and plain wheat dispensers for each hen and Table 1 shows the sums of these weights across the 14 sessions for each hen. Experimenters noted spillage for all hens, so measured changes in dispenser weight may not have been the actual weights consumed. When change in dispenser weight measured 250 g or over, the session's data for that hen was not included in the analysis because it was assumed that some of the wheat was spilled. All other change-in-dispenser weights were assumed to be weights consumed. Across all hens and all sessions, more plain wheat (5258 g) was consumed than salted wheat (1587 g). Hens 71, 72, 73a, and 74 tended to consume plain wheat over salted wheat consistently while Hens 75 and 76a showed some variability in the weight of each wheat consumed. There was no

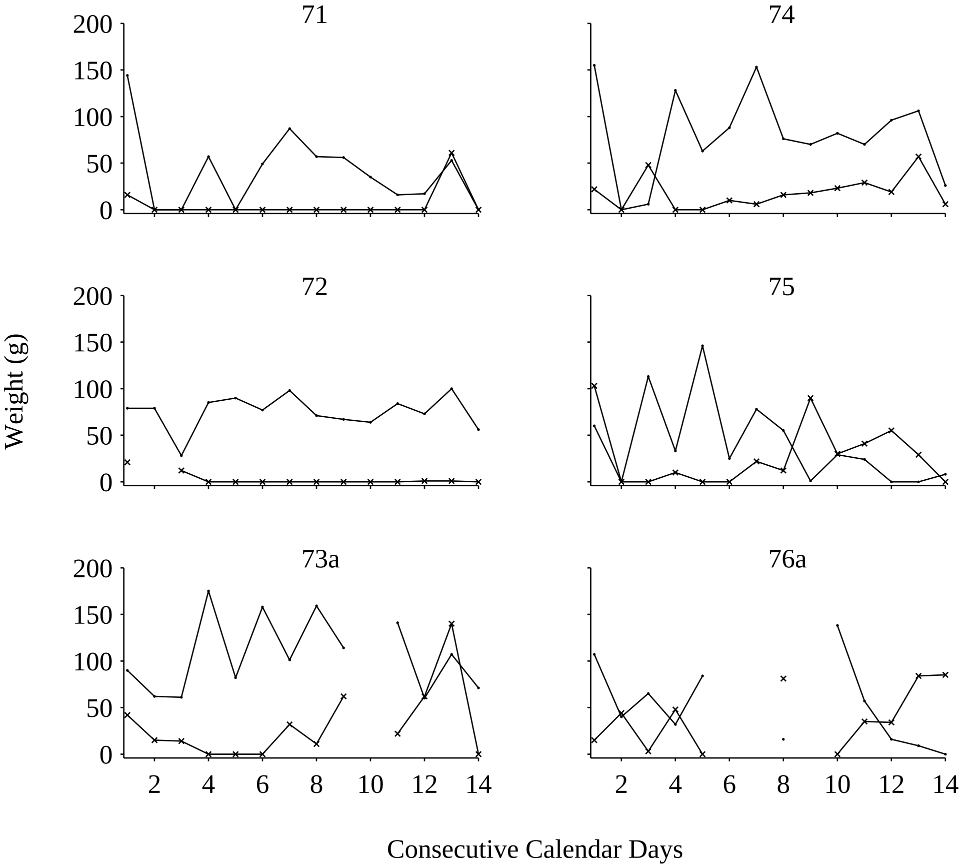

Figure 1. Experiment 1: Weight of plain-wheat (•) and salted-wheat (×) consumed across sessions.

relation between change in dispenser weight and dispenser position.

Table 1
Experiment 1: Total Weight (g) of Plain and Salted Wheat Consumed

Hen	Plain Wheat	Salted Wheat
71	571	77
72	1051	35
73a	1381	400
74	1119	254
75	572	392
76a	564	429

Discussion

The purpose of this experiment was to measure hens' consumption of two types of wheat so that in later experiments one might serve as an inferior good and the other might serve as a superior good. Across all hens, plain wheat was consumed more than salted wheat. Additionally, because plain and salted wheat are identical calorically and nutritionally, but differ in taste and in consumption, they fit the criteria described by Silberberg et al. (1987) for being potentially superior and inferior goods, respectively. So both types of wheat were used to demonstrate the inferior-good effect in subsequent experiments.

The spillage problem made it difficult to make statements on the actual weights consumed. The problem might have been avoided by allowing shorter-term access with the same dispensers or providing spill-proof dispensers. Given that the plain-wheat dispenser weights changed over three times the amount that the salted-wheat dispenser weights changed, it will be assumed that the hens consumed more plain wheat than salted wheat. There was no noticeable difference in the change in weight of wheat delivered from left or right dispensers, so it is likely that the salt or lack of salt was the controlling variable in consumption differences and not dispenser position.

Experiment 2: Long/Short ITI (Group 7)

The current experiment was a partial replication of the Silberberg et al. (1987) inferior-good study with monkeys. In their study, experimenters changed the ITI between discrete trials during fixed session lengths (an analogue of income) where large bitter pellets or small standard pellets were available for key presses during 1-hr sessions. The large bitter pellets were shown to be inferior goods because monkeys consumed them more often when income was low (i.e., when ITI was long and few trials occurred in each session) and less often when income was high (i.e., when ITI was short and many trials occurred in each session).

There were no published experiments of this kind where hens have served as subjects, so the specific income and price parameters as well as the commodity pair that might result in an inferior-good effect were unknown. For this reason, parameters were based on Silberberg et al. (1987) and the commodity pair (plain and salted wheat) on the results of Experiment 1. Silberberg et al.'s price difference between the two types of pellets was a magnitude of three whereby a single key press resulted in either 1.2 g of the intended superior good or 3.6 g of the intended inferior good. So, in the current experiment, plain wheat was made available for 3 s and salted wheat was made available for 10 s (three presentations of 3 s with .5 s between presentations). Their rationale for ITI duration was as follows:

> ITI durations for the high- and low-income conditions were based on a preexperimental estimate of the amount of food each subject required to maintain body weight. In the high-income condition, each subjects' ITI was 15 s, a frequency estimated to ensure body weights could be maintained by exclusive choice of either food. In the low-income condition, the ITI duration was 60 s and 70 s for 1-T276 and 6-T441, respectively. At these ITI durations, it was estimated that each subject could maintain its body weight only by a nearly exclusive choice of the large, bitter-tasting food. (p. 293)

Appropriate ITIs for subjects in the current experiment were calculated in a similar way. The weight of each hen's daily pellet intake that maintained body weight at approximately 80% (as described in Experiment 1) was the preexperimental estimate. Estimates of the weight of wheat the hens would consume during 3-s magazine presentations were made by observing some hens responding under a fixed-ratio 1 (FR1) schedule, weighing the magazines before and after, and dividing the total weight consumed by the total number of responses. The number of presentations that would be needed to occur in the Low- and High-Income Conditions were calculated as described above. Finally, ITIs for each hen were programmed so that in a 20-min session during a Low-Income Condition, the hens could at least maintain their body weight by nearly exclusive consumption of the intended inferior good, and during a High-Income Condition, by exclusive consumption of either food.

The current experiment exposed hens to 20-min sessions of discrete trials where a peck on one key resulted in one 3-s presentation of plain wheat and a peck on the other key resulted in three 3-s presentations of salted wheat. Sessions occurred approximately daily. When the ITI varied from short to long (High-Income and Low-Income, hereafter called *Rich* and *Poor Conditions*, respectively) as described above, it was expected that responding on the salted-wheat key would increase while responding on the plain wheat key would decrease. Such a result would replicate the work of Silberberg et al. (1987) and show salted wheat to be an inferior good and plain wheat to be a superior good for these hens.

Method

Subjects

The 6 Group-7 hens from Experiment 1, numbered 71, 72, 73a, 74, 75, and 76a, were individually housed in home cages where water and grit was continuously available. Hens were maintained at approximately 80% of their free-feeding weight as described in Experiment 1. Post-session feedings of commercial laying pellets, whereby the volume was measured in cc, were given daily and when necessary depending on the hen's body weight in relation to its post-feed threshold (see Experiment 1). Hens under their post-feed threshold received yesterday's post-feed volume plus 10 cc; hens over their threshold received yesterday's post-feed volume minus 10 cc; hens equal to their threshold received yesterdays' post-feed volume. On days when sessions did not occur, hens were given 50 cc of pellets in addition to the pellets required to maintain body weight as described above. If an egg was laid in the experimental chamber and no reinforcers were earned, hens were given 50 cc of pellets.

Apparatus

The experimental chamber was made out of particle board and located in a room with several chambers emitting brief beeps and other noises. The inner chamber area was 56.5 x 41.5 x 50 cm and painted black. Two 3-cm-diameter response keys were located on a panel 38.5 cm from the floor and 7 cm from either side of the chamber. Left and right keys were illuminated green and red, respectively, and were operated by a force of at least 0.2 N. The reinforcer was 3-s access to plain wheat from the left magazine or 10-s access (three 3-s presentations with 0.5 s in between each presentation) salted-wheat (5% by weight, see Experiment 1) from the right magazine. The purpose of the 0.5-s between presentations was to allow more wheat to enter the magazine. Magazines were located behind a 8.5 x 12 cm feeder opening directly below each response key, 10 cm from the floor. During reinforcement, a magazine rose into its opening and was illuminated by a white light from within the opening. The beam of an infrared sensor spanned each magazine aperture and was broken when the hen's head and beak crossed it during food consumption. A similar opening was centred between the two magazine openings and contained a water dish and another infrared sensor. Blue and amber houselights were located on the ceiling of the chamber and provided general chamber illumination. A fan was located at the rear of the chamber. A DOS-based PC operated MED-PC 2© software that controlled the experiment via MED interfaces. The analogue hanging scale and cone from Experiment 1 were used to weigh subjects.

Procedure

Experimental sessions occurred approximately 6 days a week at approximately the same time every morning and lasted for 20 min. Following approximately 23 hr of food deprivation in their home cages, hens consumed most of their daily intake of food by consuming salted wheat and/or plain wheat during experimental sessions. During all sessions, water was always available while both salted wheat and plain wheat were concurrently available in a discrete-trial procedure such that key-pecks produced either salted wheat or plain wheat.

Hens were placed in the experimental chamber after being weighed. Sessions began with either the blue or the amber houselights illuminated (amber during the Poor Condition and blue during the Rich Condition) and with the green (left) and the red (right) keys illuminated concurrently. A peck on either key turned off the houselights and both key lights and operated the magazine and magazine light associated with that key. The left magazine, associated with the green, key always delivered plain wheat for 3 s while the right magazine, associated with the red key, always delivered salted wheat for 10 s (3 presentations of 3 s, with .5 s pause between presentations). Following magazine operation, the magazine light turned off and remained off with all other lights for the specified ITI after which the houselights were again illuminated along with the key lights as described above. Discrete trials continued until the sessions ended after 20 min.

In the Rich Condition, trials were separated by a short ITI while in the Poor Condition trials were separated by a long ITI. ITIs varied between hens, as described previously and are presented in Table 2 along with the order of conditions. Each hen was exposed to each of the two income conditions twice. Half of the hens began sessions in the Rich Condition while the other half of the hens began in the Poor Condition. Conditions changed when responding on both keys reached visual stability across all hens. This experiment terminated when all hens' responding had reached visual stability in all four conditions. The MED-PC 2© software monitored all session events including effective responses, ITI responses, time spent with head in each magazine, and time spent with head in the waterer.

Results

Programmed ITIs ranged from 75 s to 150 s in the Poor Conditions and from 25 s to 50 s in the Rich Conditions and are displayed in Table 2. The ITI of the first Poor Condition for Hen 71 was decreased from 105 to 95 s after 6 sessions because the hen was losing body weight and requiring excessive post-session feeding. This change in the ITI was intended to minimise the effect of post-session feeding on responding during the session (i.e., to keep the economy as *closed* as possible while adhering to ethical requirements regarding body weight). The ITI of the second Poor Condition for Hen 72 was increased from 105 to 150 s because there was no change in responding following the condition change from Rich to Poor. This increase in ITI was intended to shift responding towards the salted-wheat key; however, no such shift occurred. The maximum number of trials possible for each subject in each condition are also presented in Table 2. Trials ranged from 8 to 16 in the Poor Conditions and from 24 to 46 in the Rich Conditions. The ITI, and hence, the maximum number of trials for each hen was the same between its respective replications of Poor and Rich Conditions, except for Hens 71 and 72 for the reasons described above. For reasons unrelated to the experiment, Hen 76a died during its second Poor Condition.

Table 2
Experiment 2: Order of Conditions, Inter-Trial Intervals (s), Total Possible Trials (in Brackets) for Each Condition

	Successive Conditions			
Hen	Poor	Rich	Poor	Rich
71	105/95 s (12/13)	30 s (38)	95 s (13)	30 s (38)
72	105 s (12)	40 s (29)	105/150 s (12/8)	40 s (29)
73a	150 s (8)	50 s (24)	150 s (8)	50 s (24)
	Rich	Poor	Rich	Poor
74	25 s (46)	75 s (16)	25 s (46)	75 s (16)
75	40 s (29)	130 s (10)	40 s (29)	130 s (10)
76a	25 s (46)	90 s (14)	25 s (46)	90 s (14)

Silberberg et al. (1987) and Hastjarjo et al. (1990a) presented data from the last five sessions of conditions as part of their analyses of inferior-good effects, so this number was used as a benchmark for data presentation in this experiment and subsequent experiments. As Silberberg et al. ran each condition for only 12 sessions and Hastjarjo et al. ran conditions for 10 to 18 sessions, 5 sessions accounted for approximately 28 to 50% of sessions in each condition. The shortest condition in the current experiment was the first condition which lasted for 50 sessions; 28 to 50% of 50 sessions is 14 to 25 sessions. So, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. Table 3 shows the median number of responses for the last 20 sessions of each condition. Medians were used instead of means because, occasionally, the number of responses in some of these last 20 sessions differed markedly from the rest of the sessions and the use of medians decreased the effect of these *outliers* on the measure of central tendency. For all 18 income changes (3 changes per hen) across the four conditions for all 6 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the adjacent Rich Condition (i.e., the previous or next Rich Condition) on six occasions. In this analysis, medians, except for those of the first and last

Table 3
Experiment 2: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Rich	Poor	Rich	Poor	Rich	Poor	Rich
71	1.5	0	0	36	11.5	37.5	13	0
72	12	29	8	29	0	0	0	0
73a	0	8.5	0	16	8	14.5	8	8
	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
74	45	0.5	23.5	1	0	15.5	21.5	15
75	29	0	10	1	0	10	19	9
76a	44	4.5	45	9	0	9.5	0	5

conditions, were compared twice—once with the median for the previous condition and once with the median for the next condition. This inferior-good effect occurred for 1 condition change for Hens 71, 74, and 75 and for all 3 condition changes for Hen 76. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Rich Condition on 16 occasions. Hen 71 was the only hen that did not show this plain-wheat pattern because the median number of plain responses in the first Rich Condition was zero.

Figure 2 shows the number of effective responses that occurred within each income condition. Responses were plotted across consecutive days rather than across sessions so that any effects of non-experimental days (when hens were fed 50 cc or more of pellets instead of consuming food in the experimental chamber) on responding might be apparent. The graphs show the same patterns as described by the medians described above. Additionally, responding tended to be similar within subjects between replications of each condition, except for Hens 71 and 74. Hen 71's first Rich Condition involved more salted-wheat responding and less plain-wheat responding than its second Rich condition and the opposite was true for Hen 74's Rich conditions. Hen 72 was the only hen that showed little variation in responding regardless of conditions; this hen tended to respond exclusively on the plain-wheat key.

Table 4 summarises responses across all conditions and shows the percentage of plain- and salted-wheat responses. Hens 71, 73a, and 74's responses occurred mostly on the salted-wheat key at 54 to 73% while Hens 72, 75, and 76's responses occurred mostly on the plain-wheat key with 2 to 44% of responses occurring on the salted-wheat key. Total responses on the plain-wheat key ranged from 1,478 for Hen 73a to 7,196 for Hen 76a; total responses on the salted-wheat key ranged from 109 for Hen 72 to 4,907 for Hen 74.

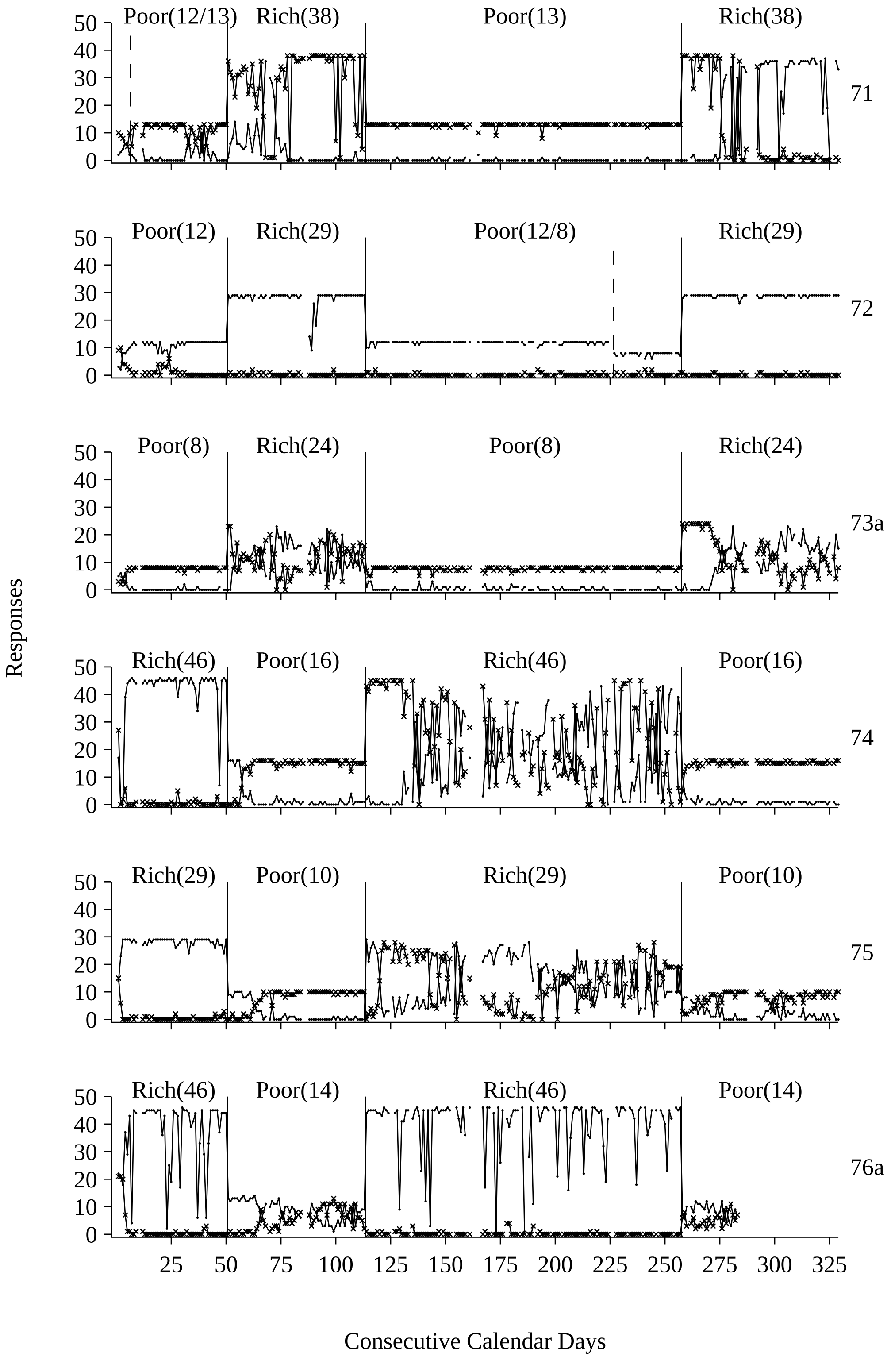

Figure 2. Experiment 2: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

Table 4
Experiment 2: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
71	1679	27	4610	73
72	5360	98	109	2
73a	1478	35	2763	65
74	4185	46	4907	54
75	3413	56	2684	44
76a	7196	93	545	7

Income elasticities for salted and plain wheat were calculated for each condition change using Equation 5. Percent change in demand was calculated by subtracting the median effective responses of the last 20 session of the previous condition from the median effective responses of the last 20 session of the next condition (see Table 3 for these values). Percent change in income was calculated similarly but by using the total number of available trials in each condition. In conditions where the ITI was changed (thereby, changing the total number of trials) this calculation used the number of trials in effect at the end of the condition. These elasticities are presented in Table 5 and represented in bar graphs in Figure 3. The table and figure show that for most income changes

Table 5
Experiment 2: Income Elasticities for Each Condition Change (U=undefined)

	Consecutive Condition Changes					
	Plain Wheat			Salted Wheat		
Hen	Poor/ Rich	Rich/ Poor	Poor/ Rich	Poor/ Rich	Rich/ Poor	Poor/ Rich
71	-0.5	U	∞	1.2	1	-0.5
72	1	1	1	U	U	U
73a	∞	1.5	∞	0.4	0.7	0
	Rich/ Poor	Poor/ Rich	Rich/ Poor	Rich/ Poor	Poor/ Rich	Rich/ Poor
74	1.5	24.5	1.5	-∞	0.2	0.5
75	1.5	∞	1.4	-∞	0.5	0.8
76a	1.3	3.9	1.2	-∞	-0.4	-∞

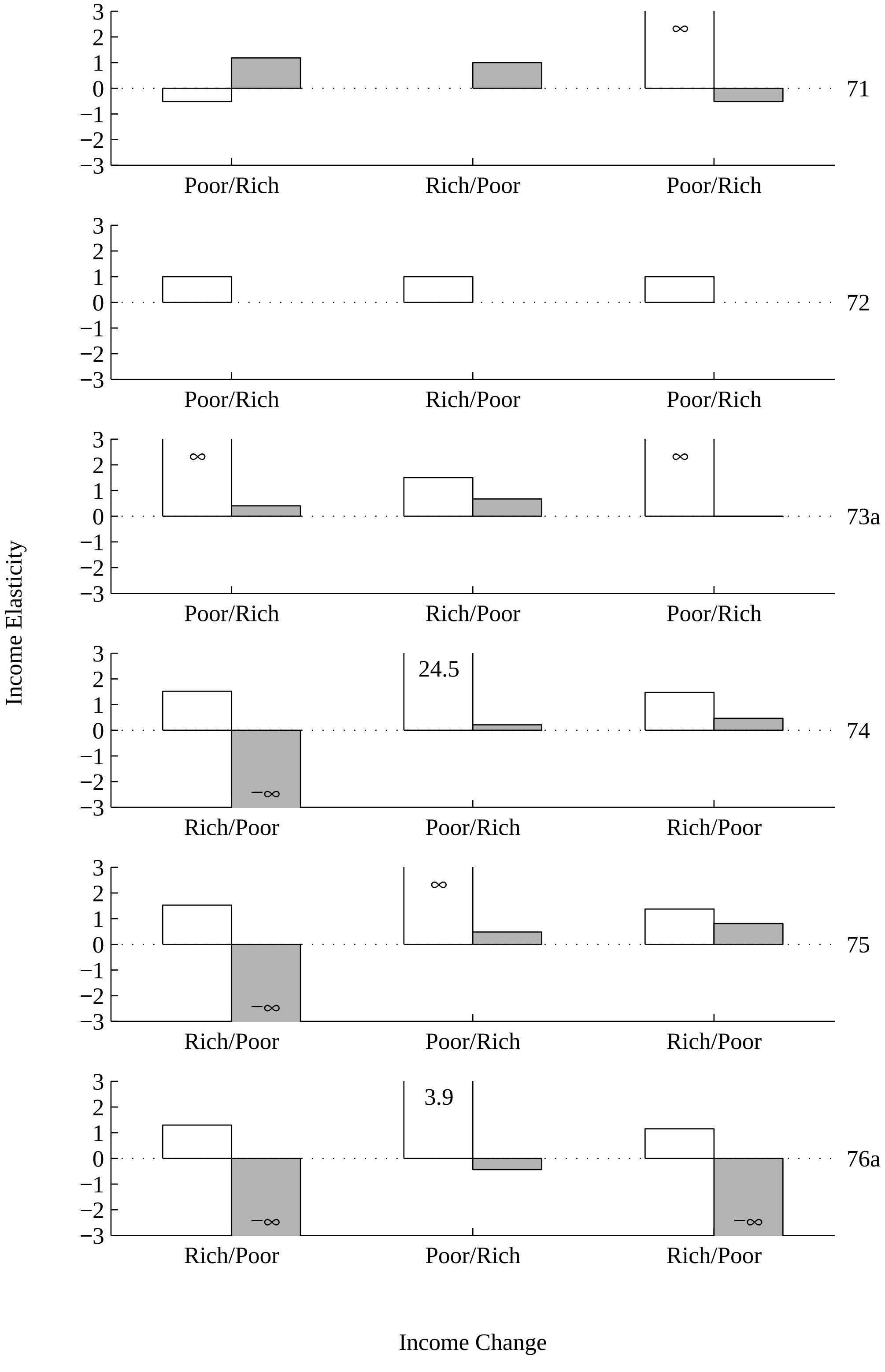

Figure 3. Experiment 2: Income elasticities for each condition change.

across all birds, plain-wheat elasticities tended to be positive while salted-wheat elasticities tended to be either positive and smaller or negative. Plain-wheat elasticities ranged from -0.5 to 24.5 and contained one undefined and four infinite values while salted wheat elasticities ranged from -0.5 to 1.2 with three undefined and four negative infinite values. Within birds, elasticities varied, but the relation between plain- and salted-wheat elasticity values followed the pattern described above for all hens except Hen 71. This hen was the only hen that showed the opposite pattern. Additionally, when the figure was plotted using the mean number of responses, patterns remained the same with only minor deviations from the original figure.

Figure 4 shows cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions for each major condition in successive 2-min intervals. Means were used because similar graphs by Silberberg et al. (1987) and Hastjarjo et al. (1990a) utilised means. In these graphs, linear functions with an infinite slope indicate exclusive responding on the salted-wheat key; zero, exclusive responding on the plain-wheat key; one, equal responding on both keys. Curvilinear, positively-accelerating functions indicate early-session responding on the plain-wheat key with a gradual shift to late-session responding on the salted-wheat key. The converse is the case for curvilinear, negatively-accelerating functions. The graphs do not show similar patterns across birds. All hens responded exclusively or nearly exclusively on one key or the other for these last 20 sessions in at least 2 out of their four conditions, consequently the graphs show little or no variability in responding as their slopes are either nearly zero or approach infinity. Of the 8 conditions (out of 24) that did

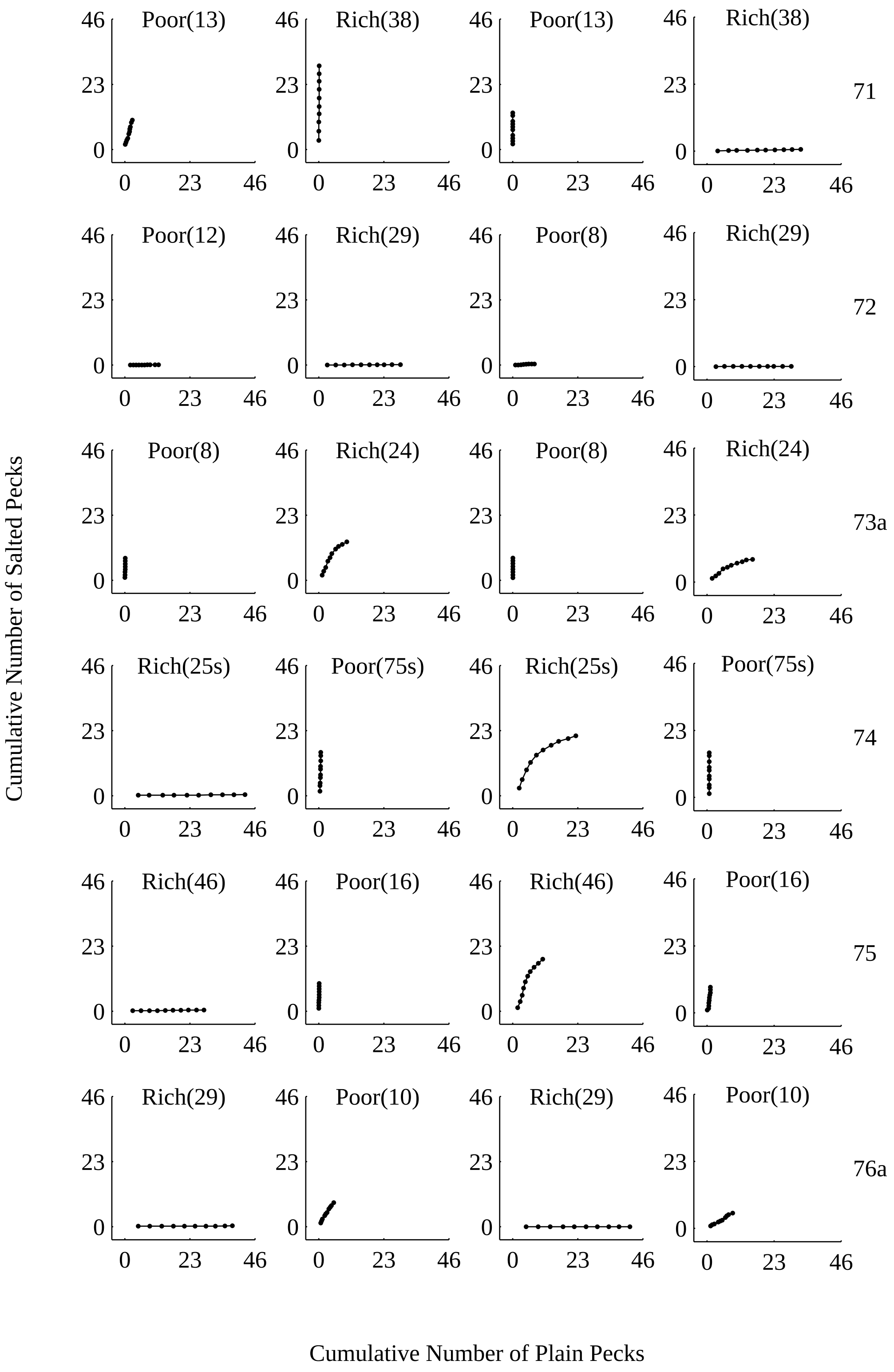

Figure 4. Experiment 2: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

involve varied responding, the pattern of responding on the salted-wheat key early in the session and plain-wheat key later in the session occurred on four occasions for each of the following hens in the following conditions: 73a for both Rich conditions, 74 for the second Rich Condition, and 75 for the second Rich Condition. The varied responding in the remaining four conditions involved responding on both keys that did not change during conditions for Hen 71's first Poor Condition, Hen 75's second Poor Condition, and both of Hen 76a's Poor Conditions.

Figure 5 presents the duration of time spent with the hen's head in each magazine (hereafter called *eat time*). The patterns were similar to the response patterns in Figure 2 except that for each response salted-wheat eat times were longer than plain-wheat eat times by a factor of approximately 3 because the salted-wheat magazine was available for 10 s whilst the plain wheat key was always available for 3 s. These eat times varied with and were similar to the responses for each wheat such that more responding on a key tended to be associated with longer eat times for the type of food associated with that key. The water infrared sensor had intermittent problems due to the water disrupting the beam, so these data were not analysed.

Hens' total number of responses that occurred on both plain- and salted-wheat keys during ITIs are plotted across sessions in Figure 6. All hens responded during the ITI for at least some sessions and there were differences in the number of ITI responses across subjects. Overall, 4 of the 6 birds (Hens 72, 74, 75, and 76a) shared a common pattern of responding with most ITI responses on both keys occurring during the first two of four conditions and occurring less often thereafter. Hen 71 rarely responded during the ITI across all conditions

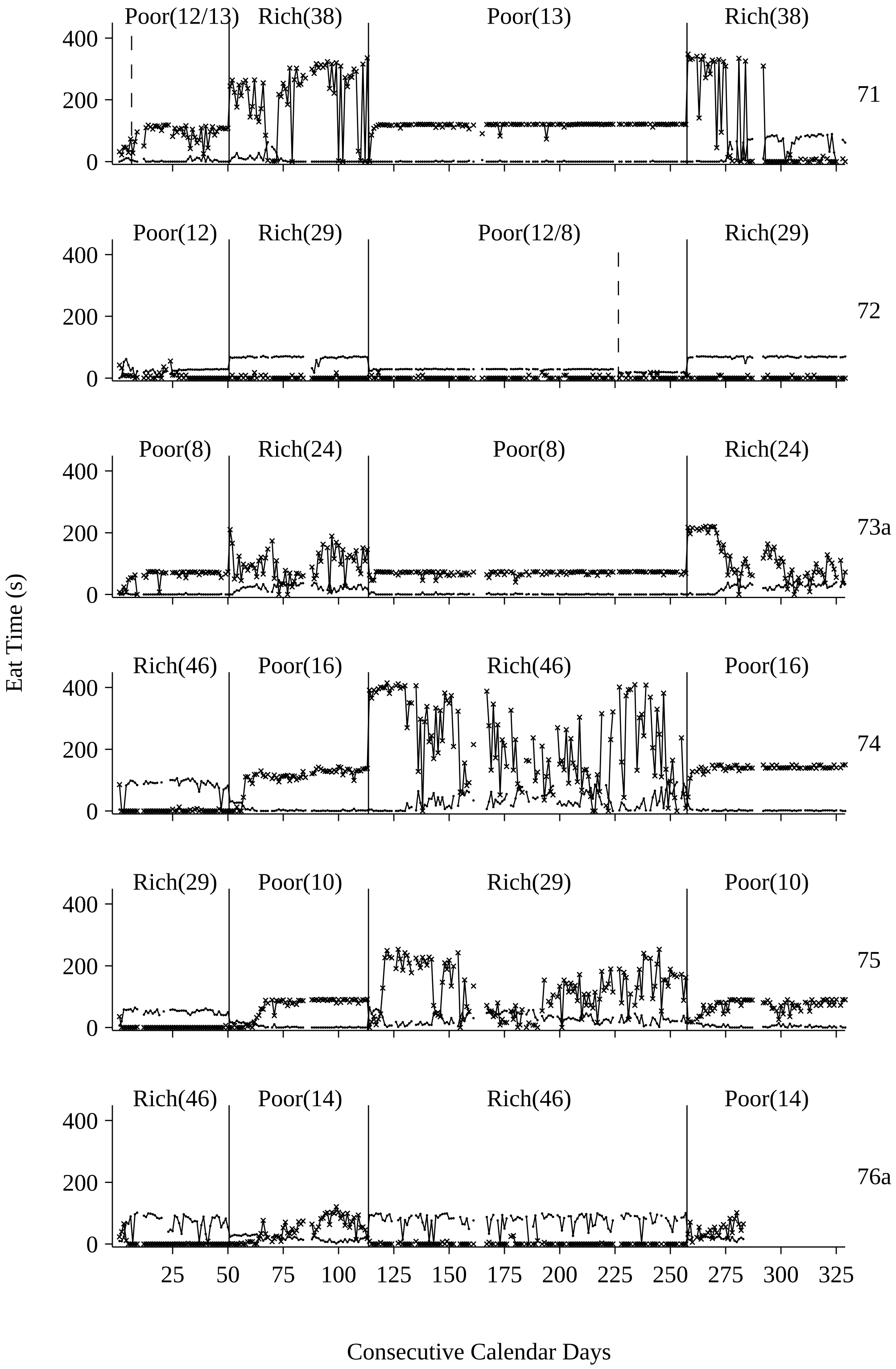

Figure 5. Experiment 2: Durations of eat times for the plain-wheat (•) and salted-wheat (×) magazines across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

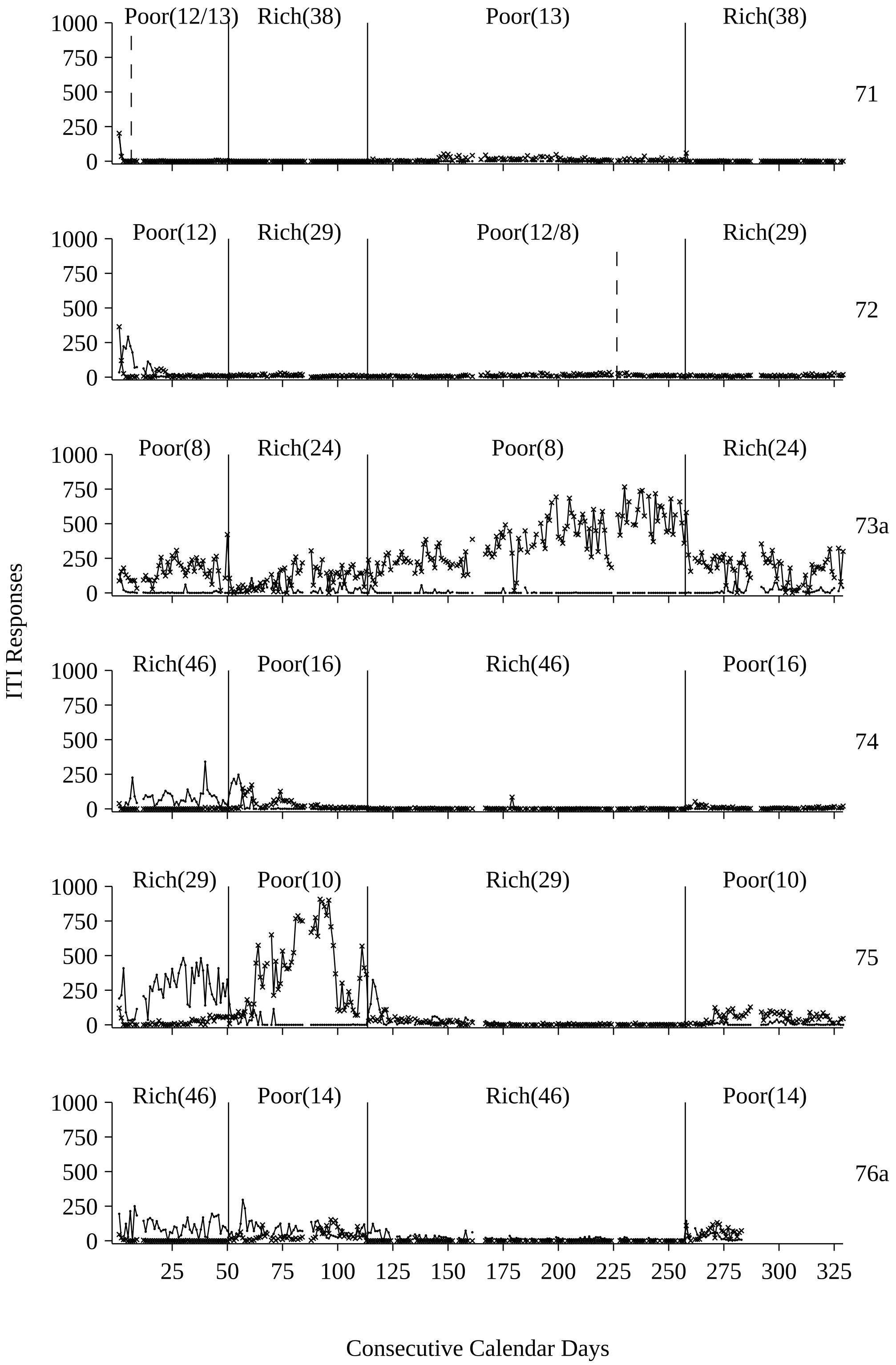

Figure 6. Experiment 2: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

while Hen 73's salted-wheat ITI responses increased across the first three conditions and decreased to frequencies comparable to those of the first condition as its plain-wheat ITI responses remained relatively infrequent across all conditions. Table 6 summarises ITI responses across all conditions and shows the percentage of plain- and salted-wheat ITI responses. Hens 74 and 76's ITI responses occurred mostly on the plain-wheat key while Hens 71, 72, 73a, and 75's ITI responses occurred mostly on the salted-wheat key. Total ITI responses on the plain-wheat key ranged from 267 for Hen 71 to 16,244 for Hen 75; total ITI responses on the salted-wheat key ranged from 2,870 for Hen 74 to 72,844 for Hen 73a.

Table 6
Experiment 2: Total ITI Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
71	267	13	1746	87
72	2783	43	3650	57
73a	3667	5	72844	95
74	5099	64	2870	36
75	16244	36	29156	64
76a	12428	76	3881	24

Figure 7 shows hens' pre-session body weights plotted across days and Table 7 shows pre-session body weight means for the last 20 sessions of each condition for each hen. Body weights of Hens 71, 72, 73a, 74, and 75 tended to be lower in the Poor Conditions than in the Rich Conditions while Hen 76a showed less variability in body weight across conditions. Within conditions, body weights tended to decrease then stabilise in 9 out of 12 Poor Conditions and increase then stabilise in 7 out of 12 Rich Conditions.

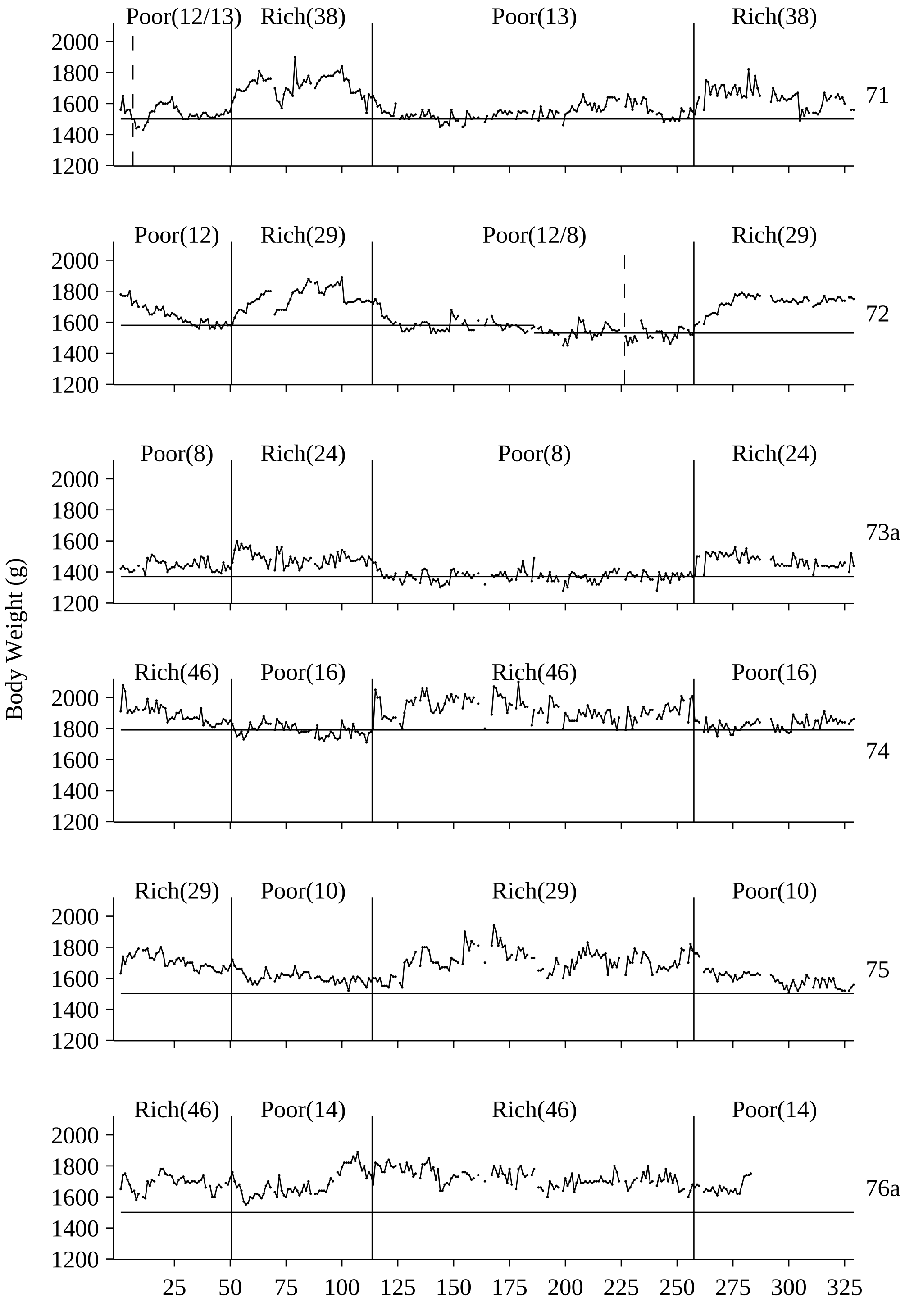

Figure 7. Experiment 2: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate ITI changes, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the maximum number of trials possible for each condition.

Table 7
Experiment 2: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions			
Hen	Poor	Rich	Poor	Rich
71	1526	1718	1530	1590
72	1586	1774	1523	1743
73a	1440	1487	1368	1442
	Rich	Poor	Rich	Poor
74	1848	1772	1924	1849
75	1667	1582	1703	1563
76a	1681	1782	1693	1661

Discussion

These results extend the results of the Silberberg et al. (1987) study that demonstrated an inferior-good effect with monkeys using a similar procedure. In their study, the 2 monkeys responded relatively more on the intended-inferior-good key in Poor Conditions versus Rich Conditions. This pattern occurred for all six condition changes (100%) across both monkeys. Income elasticities were not presented in Silberberg et al. so their can be no comparison to values from the current experiment; however, inspection of their graphs suggests that the intended inferior good's elasticities would be negative because responses for this food occurred relatively less in Rich Conditions and relatively more in Poor Conditions. Thus, the large bitter pellets fit the formal definition of an inferior good for these monkeys. Figure 3 and Table 5 show that Hens 71, 74, 75, and 76a in the current experiment sometimes pecked relatively more on the salted-wheat key in Poor Conditions (i.e., had negative income elasticities), but the pattern only occurred for 6 of 18 condition changes across all 6 hens. Strictly speaking, then, the inferior-good effect only occurred for 33% of all income changes in the current experiment. Although the inferior-good effect did occur 33% of the time in the current experiment, the effect was less robust than the 100% in the Silberberg et al. study.

However, an effect that might be considered to be weaker effect than the inferior-good effect did occur. Plain-wheat income elasticities were typically positive and for income changes where salted-wheat elasticities were also positive (and in one case, zero for Hen 73a), plain-wheat elasticities tended to be larger indicating that plain-wheat responding was more sensitive to income changes than salted-wheat responding. That is, when income increased, responding on both keys may have also increased but the increase in plain-wheat responding was usually larger than that of salted wheat. This difference in elasticity occurred for 5 hens (all but Hen 72) in 7 of 18 condition changes (39%) across all 6 hens and will be called the *relative-inferior-good effect* because relative to plain wheat, salted wheat was closer to fitting the inferior-good criteria. Regardless of what the effect is called, Silberberg et al. (1987) and the current study showed that changes in income differentially affected responding reinforced by two different foods. So in the current experiment, salted wheat was an inferior good for 33% of all condition changes (but only for Hens 71, 74, 75, and 76a) because it was of a lower value than plain wheat (as described in Experiment 1), cost less than plain wheat (hens received more of it for the price of 1 peck), and involved more responses with decreases in income (salted-wheat-responding increased with decreases in the total number of trials). For these 4 hens as well as Hen 73a, salted wheat was a relative inferior good because salted-wheat elasticities were smaller than plain wheat elasticities across 39% of condition changes. Overall, one or the other effect occurred for 5 hens (all except Hen 72) in 13 of 18 condition changes (72%) across all 6 hens.

Assuming that time allocation was strongly correlated with responding, Equation 6 may be applied hypothetically to the results of the current experiment. Figure 2, then, may be assumed to be similar to a time-allocation graph where time on both keys is plotted across consecutive calendar days. This assumption suggests that time allocation changed with overall reinforcement changes (income) while programmed rate, amount, and immediacy remained constant. Melioration, the process assumed to underlie the above equation, then, cannot adequately describe the data of the current experiment. This shortcoming has been highlighted by the other inferior-good studies (Battalio et al., 1991; Hastjarjo et al., 1990a; Silberberg et al., 1987), which state that the results cannot be readily explained by matching equations. "For example, according to matching theory, choice ratios will not change if the rates or amounts of reinforcement provided by each of two schedules is doubled or halved" (Silberberg et al., p. 292). However, the published and current inferior-good experiments show this prediction not to be the case. Eat times followed the same pattern as responding (and hypothetical time allocation) except eat-times for salted wheat were longer by a factor of approximately three due to the longer magazine presentation time (10 s instead of 3 s). These data suggest that birds did at least put their heads in the magazines following trials. So, salted wheat fits the criteria of an inferior or relative-inferior good for most hens and the data are not describable by Equation 6.

During the last five sessions of a Poor Condition, monkeys in the Silberberg et al. (1987) study responded on the inferior-good key early in sessions and on the superior-good key later in sessions. However, Figure 4 shows that this tendency was not as evident in the last 20 sessions for each major condition for hens in the current experiment. That is, although the pattern did occur for some hens in some conditions no hen consistently responded on the salted-wheat key early in the session and on the plain-wheat key later in the session. However, when it did occur for Hens 73a, 74, and 75, it occurred in these hens' Rich Conditions. So across all hens, within-session patterns in the Poor Conditions tended to show salted-wheat responding and in the Rich Conditions, either early-salt-late-plain or just plain responding with occasional plain and salted responding throughout sessions. Hen 71 was the only hen that responded nearly exclusively on the salted-wheat key in a Rich Condition. Silberberg et al. did not discuss the early-inferior-late-superior pattern beyond presentation of the results and it is currently unclear why the pattern did not occur in the current experiment when the across-session data were similar between experiments.

The results of the current study extend the body of literature that shows that changes in income (i.e., overall reinforcement) can affect behaviour. However, the specific way in which this relation occurs is still unclear. What differences between the two conditions contribute to the shift in responding? In the Silberberg et al. (1987) study and the current study, the only programmed change between Poor and Rich Conditions was the ITI duration (and the houselight colours in the current study), so the answer must bear on these variables. Additionally, two procedural differences between the Silberberg et al. study and the current experiment relate to these variables. The former study included a delay contingency during the ITI and it did not include houselight changes that accompanied condition changes.

First, in the monkey study Silberberg et al. (1987) programmed a 10-s delay to the next trial for ITI responses occurring in the last 10 s of ITIs. The rationale behind the contingency was not stated, but perhaps the experimenters predicted responding during the ITI, thus increasing the price of the resulting food. The delay contingency would have ensured that the price of each food remained the same across trials so long as ITI responses prior to the 10 s before each trial are not considered part of the price. ITI data were not reported in that study, so no comparison can be made with the data of the current study. All subjects in Experiment 2 responded during the ITI for at least the first several sessions and all subjects, except 73a, showed a decrease in ITI responding prior to or within their third condition. In subsequent conditions, ITI responses occasionally occurred, but at a lower frequency compared to responding during earlier sessions. In Hen 73a's second Poor Condition, ITI responses on the salted-wheat key increased from approximately 200 to approximately 600 across the entire condition. For all birds responding during the ITI in any condition, it may be argued that actual prices paid for the resulting food were higher than programmed prices. However, the validity of this argument depends upon how price is defined. There is no reason to specify 10 s over, say, 8 s as the length of time that separates price responses from ITI responses. For this experiment and subsequent experiments, the definition of price will be the programmed response requirement that results in a given duration of food.

The second procedural difference was that houselight changes accompanied condition changes in the current experiment. Unlike the Silberberg et al. (1987) study that did not programme stimulus changes with condition changes, the houselight colours in the current experiment changed from amber to blue between Poor and Rich Conditions, respectively. The rationale behind this change was that it would increase the chances of the inferior-good effect occurring. This assumption was based on the work of Heyman and Tanz (1995) who found that changes in overall reinforcement rate affected the concurrent-interval-schedule responding of pigeons most when these changes were accompanied by houselight changes. Birds in their study learned to maximise overall reinforcement rate in this way, a finding that is uncommon in studies that test between melioration and maximisation. In the current study, the houselight change that accompanied changes in overall reinforcement may have increased discriminability between the income conditions and increased the chances that condition changes would affect responding as described earlier. It is unlikely that the houselight colours themselves could have caused the observed changes in responding as there is no reason to assume colour would affect behaviour as such, so if the houselights did increase the discriminability of ITIs, then such influence would have been gained through their differential pairing with long and short ITIs.

If this pairing resulted in the houselights becoming part of the antecedent stimuli that affect responding, then an immediate change in responding in the first session of the replication of each condition would be expected. Some of the data in Figure 2 show this change. It did not occur for all hens, but this change is evident in places for Hens 75 and 76a. For Hen 75, in the last 20 sessions of the first Poor Condition the 10 responses were exclusively on the salted-wheat key in all but 4 sessions where 1 of the 10 responses occurred on the plain-wheat key. In the first session of the second Rich Condition (i.e., in the next session) all 29 responses occurred on the plain-wheat key. Similarly, for Hen 76a, in the last 20 sessions of the second Rich Condition responding was exclusive to the plain-wheat key (18 to 46 responses) and in the first session of the second Poor Condition (i.e., in the next session) responding occurred on both keys, with 6 occurring on the salted-wheat key and 7 on the plain-wheat key. In light of these findings, the ITIs and houselights may be understood as antecedent stimuli for responding on the two keys—either discriminative stimuli (S^Ds) or conditional stimuli.

According to Michael (1993), an S^D is:

> a stimulus condition that has been correlated with the *availability* of a type of consequence given a type of behavior. A correlation with availability has two components: An effective consequence...must have followed the response in the presence of the stimulus, and the response must have occurred without the consequence (which would have been effective as a reinforcement if it had been obtained) in the absence of the stimulus. (p. 195)

According to this definition, the ITIs and houselights fail as S^Ds because ITIs in the Silberberg et al. (1987) study and the ITIs and houselights in the current study were not correlated with the differential availability either kind of wheat; rather, both types of wheat were available in the presence of all ITIs. The key colours and/or positions, however, meet the criteria for S^Ds because each key colour and/or position was correlated with the differential availability of one kind of wheat. Note that it is not possible to determine what aspect of the keys was the S^D because key colours always remained in the same relative position.

The ITIs and houselights also fail as conditional stimuli in a four-term contingency. In order for conditional-stimulus control to occur, a reinforcer needs to be available only when a certain behaviour occurs in the presence of an S^D when a conditional stimulus, the fourth term, is present (Sidman, 1986). In the Silberberg et al. (1987) study, if the ITIs were conditional stimuli that varied between long and short durations, then the certain behaviours might have been responding on the standard-pellet and bitter-pellet response key; the S^Ds, the key positions or colours; and the reinforcers, the small standard pellet and the large bitter pellet. Given that responding on the standard-pellet key was most frequent during the short ITI, if the short ITI was a conditional stimulus for this responding, then the small standard pellet should have been available only when monkeys responded on the standard-pellet key in the presence of the short ITI. The same argument holds for responding on the bitter-pellet key during the long ITI. However, both kinds of pellets were available regardless of ITI duration, so there was no differential availability of these foods. In this respect, classifying the ITIs as conditional stimuli in the Silberberg et al. study does not hold, nor does it hold for the ITIs or houselights in the current study.

A way of reconciling the argument against ITIs and houselights as S^Ds or conditional stimuli is by defining Michael's (1993, p. 195) "type of consequence" and "type of behaviour" in a more temporally-extended manner. As such, the conceptualisation may be in line with both maximisation and melioration. A maximisation account of choice behaviour by Rachlin et al. (1981) has been described as choosing amongst packages containing different amounts of food and responding so that a set of properties in an organism's environment is maximised by the choice (utility is maximised); the preference for this package is said to continue once demonstrated. In the current experiment, the "type of consequence" and "type of behaviour", to use Michael's words, might have been the package encompassing amounts of plain and salted wheat as well as the activity required to access the food. It might be argued, then, that long and short ITIs and their associated houselights were S^Ds or conditional stimuli that were differentially correlated with the availability of the mostly-salted-wheat packages and the mostly-plain-wheat packages, respectively. Further, each package (that is, the package that is most-preferred or of the highest utility given each set of constraints) is only available under its particular ITI. Framed in this way, ITIs and houselights fit both of Michael's criteria for S^Ds as well as Sidman's (1986) description of conditional stimuli so long as behaviour is viewed in this temporally-extended way and so long as each package is considered to be the most preferred or of the highest utility given the specific constraints of that condition. This view is in line with maximisation; albeit, specifically what is maximised is still unknown and the packages being the most preferred is still a post-hoc explanation.

This view of stimulus control or conditional stimulus control over temporally-extended behaviour also fits with melioration. For example, Vaughan and Herrnstein (1997, p. 205) have defended melioration in experiments that show maximisation (see quote on p. 16). Here, melioration occurs between the *distribution of responses* and the other behaviour that can occur and bring about reinforcers. That is, the organism's distribution of responses matches the rate of reinforcement obtained with that distribution whilst other behaviour (including unmeasured behaviour) matches the rate of reinforcement obtained with that other behaviour. A problem with this account, though, is that matching occurring with the other behaviour needs to be assumed. In one respect, this account is tautological; however, it is useful in the same way that the First Law of Thermodynamics is useful—it tells, "when to look and when to stop looking...the matching law circumscribes our search for reinforcers in any situation" (Rachlin, 1971, p. 251).

The idea of patterns of responding as functional classes in concurrent procedures is described in the literature. Pigeons have learned sequences of responses that might be considered new response classes (Herrnstein, 1958; Herrnstein & Loveland, 1975; B. Schwartz, 1980, 1981). Herrnstein (1997) discussed these response classes by defining melioration as an outcome of evolution and places it on a continuum with maximisation. He then describes the relatedness between it and maximisation by alluding to temporally-extended response classes as follows:

> As evolution produces more easily conditionable and extinguishable response topographies and the capacity to detect correlations between behavior and its consequences over increasingly large time spans, melioration approaches maximization. Different species no doubt fall on different points along this continuum (p. 97).

Here, the continuum of temporally-extended behaviour implies the same temporally-extended distribution of responses as Vaughan and Herrnstein (1997). It is unclear where hens might be on this continuum, but it at least provides some support for melioration and its relation to the inferior-good effect as well as for ITIs and houselights as S^Ds or conditional stimuli.

Finally, in discussing their finding that pigeons could learn to maximise when houselight changes accompanied changes in overall reinforcement rate, Heyman and Tanz (1995) suggested a mediating process that might have resulted in their findings. They suggested that their contingencies strengthened sequences of responses to the point where they became functional units, a description similar to the temporally-extended accounts described above. They further suggested that maximisation and matching are both outcomes, rather than processes, that these outcomes depend upon how reinforcement contingencies are framed (factors such as stimulus conditions), and that a single underlying process is responsible for any outcome along the continuum.

So, temporally-extended behaviour patterns of hens in the current experiment may have come under stimulus control of the experimental conditions (houselights and/or ITIs) because those behaviour patterns either maximised utility, meliorated reinforcement, or followed a yet-to-be described behavioural process. Figure 4, however, does not show consistent within-session patterns such as early inferior-good responding and late superior-good responding as in Poor and Rich conditions (but more pronounced in Rich Conditions) for rats in Hastjarjo et al. (1990a) or as in Poor Conditions for monkeys in Silberberg et al. (1987), so it is difficult to assert the possibility of strengthened sequences of responses for all hens in all conditions.

An important difference is that Heyman and Tanz's (1995) hypothesised strengthened sequences of responses occurred during a free-operant procedure whilst the current study utilised a discrete-trial procedure. In the current study, effective responses were necessarily spaced by an ITI, so if sequences of responses were strengthened, they may have involved ITI responses as well as effective responses. ITI responses were not included in Figure 4, so each cumulative response in the graphs may be the end point of a systematic sequence of ITI responses. Including ITI responses in these figures may have revealed within-session patterns. Recall, though, that Silberberg et al. (1987) utilised a contingency during ITIs where the next trial occurred only when 10 s passed without an ITI response. Although the frequency of ITI responses was not reported, this contingency would have reduced ITI responses to low frequencies. They did, however, find a within-session pattern of early inferior-good responding and late superior-good responding for effective responses in Poor Conditions (no within-session data were given for Rich Conditions), suggesting that ITI responses were not part of a strengthened sequence of responses important for the inferior-good effect. Perhaps an unmeasured stereotyped response topography (e.g., pecking next to a key) occurred as part of temporally-extended behaviour patterns that came under stimulus control of the houselights and/or ITIs. Such a topography may have originally been reinforced by trial onset so long as the topography resulted in 10 s of no ITI responding. In this respect, the behaviour may have begun as superstitious behaviour (Skinner, 1992) and may have then become part of a temporally-extended behaviour pattern that maximised utility, meliorated reinforcement, or followed a yet-to-be-described process as suggested above.

In the current experiment, if ITI responses on either key were strongly correlated with effective responses on the same key, including ITI responses would not change within-session patterns. If ITI responses were weakly correlated, the pattern would change. For example, if a hen's effective responses occurred exclusively on the plain-wheat key, the resulting pattern would appear flat (the slope of the function would be zero). If this hen's ITI responses were also exclusive to the same key, adding these responses to the figures would not change the pattern, but it would increase the number of data points. If the ITI responses occurred on both keys or exclusively on the other key, then the pattern would change and the number of data points would increase. The resulting pattern would depend on what responses occurred and when. Comparison of the percentage of salted- or plain- wheat responses between Table 4 and Table 6 provides a rough indicator of the overall correlation between effective and ITI responses. Percentages differed by 20% or less for Hens 71, 74, 75, and 76a, and by more than 20% for Hens 72 and 73a. So, for these first 4 hens, effective and ITI responses were more strongly correlated then for these latter two hens. For all hens except Hen 74, the percentage of salted-wheat responses was higher for ITI responses than for effective responses, showing that these 5 hens responded on both keys but responded on the salted-wheat key proportionally more during the ITI than during trials. Overall, these data suggest that including ITI responses with effective responses in plots similar to Figure 4 would shift the slopes of the functions towards infinity for Hens 72 and 73a because of the large difference between effective and ITI responses on the salted-wheat key (but only if this difference occurred in the last 20 sessions of each condition). For the remainder of the hens, the similarities between effective and ITI percentages suggest only marginal changes in the slopes towards infinity (except for Hen 74). However, it is also possible that effective and ITI responses were not correlated during sessions, but varied in other ways that resulted in an overall strong correlation. If such a non-correlation occurred, it should be seen if Figure 4 is replotted with the ITI responses included. If effective and ITI responses were strongly correlated within each session for the last 20 sessions of each condition, then the addition of the ITI responses to Figure 4 should not change the patterns. If, on the other hand, these responses were weakly or not correlated within each of these sessions, then the addition of the ITI responses should change the patterns. Because percentages of effective and ITI responses differed by more than 20% for Hens 72 and 73a, within-session patterns for these hens should reflect a larger slope when ITI responses are added because a higher percentage of ITI responses were salted wheat than effective responses.

Figure 4 is replotted with the ITI responses included as Figure 8. As discussed above, the addition of the ITI responses did change within-session patterns for Hens 72 and 73a but did not substantially change patterns for Hens 71, 74, 75, and 76a (besides the increase in the number of data points) in these last 20 sessions of each condition. Hen 72's patterns changed with an increased slope, showing responding on both keys as the session progressed (but virtually all salted-wheat responses occurred during the ITI). Hen 73a's patterns changed as discussed above but only in the Rich Conditions, with increased slopes due to more salted-wheat responses occurring during the ITI than during trials. So, as the expected pattern of early salted-wheat responding and late plain-wheat responding did not reliably emerge with the addition of ITI responses, it is still difficult to determine the role of the pattern (if any) with respect to the inferior-good effect.

For 3 of the 5 birds showing the inferior- or relative-inferior-good effect, there was at least a slight tendency for birds' effective responses to occur on the

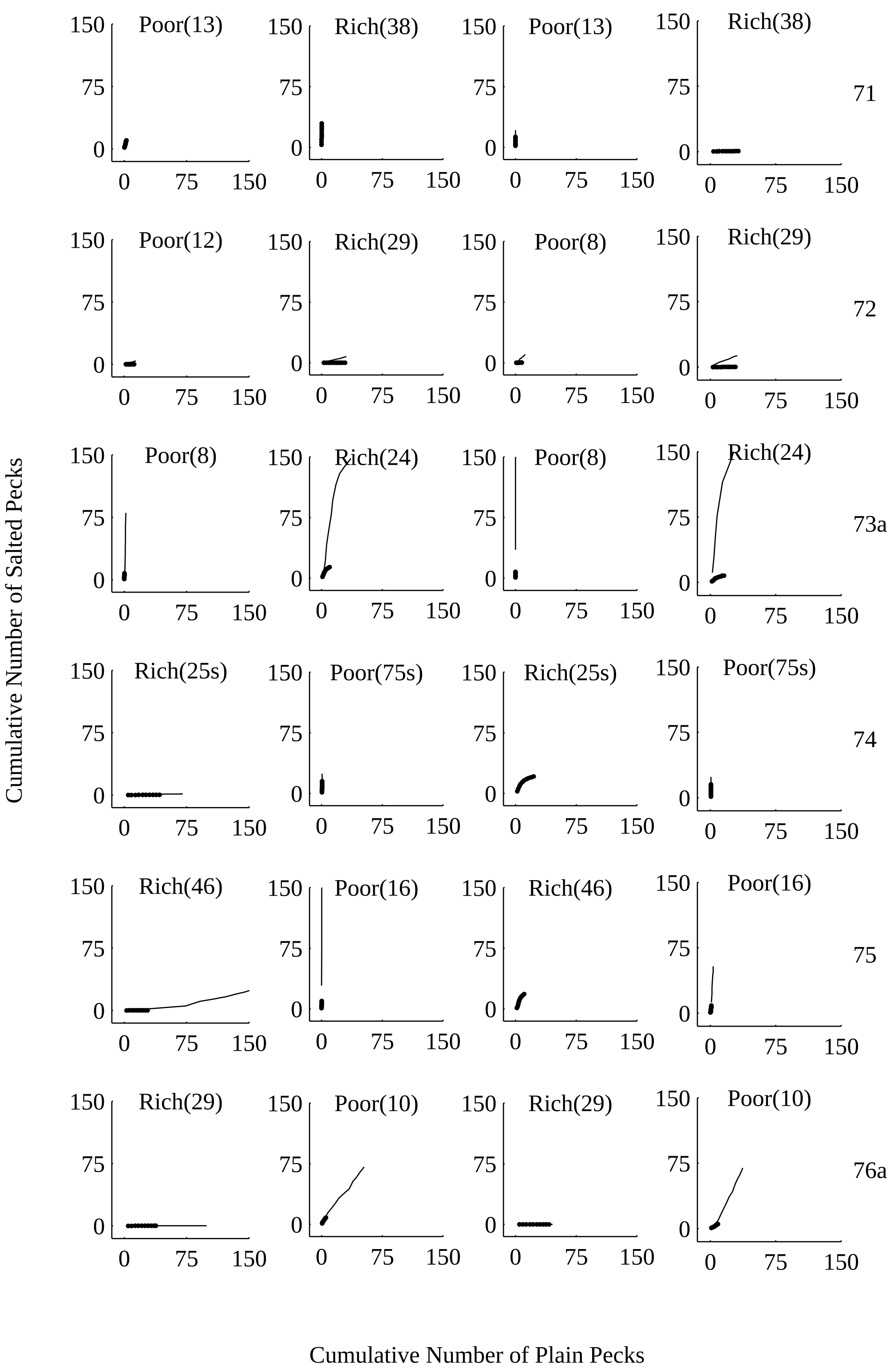

Figure 8. Experiment 2: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

salted-wheat key early in the session and on the plain-wheat key later in the session during some Rich Conditions. The inclusion of ITI responses did not change this pattern for the birds showing either effect. It is unknown why the pattern occurred for only some birds and in only some Rich Conditions. It may be that the patterns co-varied with an unmeasured variable. These within-session patterns resemble patterns in monkeys' Poor Conditions and in rats' Poor and Rich Conditions reported in the literature (Hastjarjo et al., 1990a; Silberberg et al., 1987), but are unexplained. The fact that they are common (and albeit, slight) across the published experiments and current experiment, even though procedures and species differed, suggests that they may play a role in inferior- and relative-inferior-good effects.

This experiment was a partial replication of Silberberg et al. (1987) and provided evidence of an inferior and relative-inferior-good effect in some hens. Silberberg et al. suggested that the effect could not be explained via matching theory because matching does not predict that behaviour will change when overall reinforcement rate changes. Instead, they suggest, "an economic approach can lead to a more comprehensive psychological account of choice" (p. 300). In particular, they refer to reinforcement maximisation as a process that better accounts for choice behaviour. The authors do not embellish beyond labelling the resulting behaviour with economic terms, namely that changes in consumption accompanied changes in income. This kind of recourse to the invisible maximised utility is common in economics, is not empirically testable, and remains an assumption at best (Vaughan & Herrnstein, 1997). It is a tautology, but differs from the tautology of the matching law (Rachlin, 1971) in that it suggests that one ought to look for utility when analysing behaviour. Of course, the major problem with utility is that it is a hypothetical construct whereas reinforcers are not—one will never find a utility function but one can test the effects of reinforcer parameters on behaviour.

The inferior-good effect still remains unexplained in the published literature. The current data do not confirm or refute melioration or maximisation; rather, both processes might account for the observed temporally-extended patterns of within-session behaviour as well as the shift in responding with condition changes. For melioration to hold, a further parameter that accounts for the observed changes occurring with changes in overall reinforcement need to be added to Equation 6 and a perspective of temporally-extended behaviour under stimulus control (or conditional stimulus control) would need to be taken. Maximisation, on the other hand, is difficult to disprove as it relies on unobservable utility functions. Procedurally, it is still unclear what the important variables are for the inferior-good effect. The next experiment partially replicated the inferior-good experiment with rats by Hastjarjo et al. (1990a). It investigated a way of achieving the effect via a different income manipulation that changed the total number of trials per session in variable-length sessions rather than changing the ITI in fixed-length sessions. The occurrence of the inferior-good effect or a relative-inferior-good effect would challenge the importance of the ITIs in the current experiment and in the published (Silberberg et al., 1987) experiment.

Experiment 3a: Few/Many Trials (Group 9)

The current experiment was a partial replication of the Hastjarjo et al. (1990a) study that showed an inferior-good effect in rats. Their experiment used combinations of bitter (quinine-adulterated) and standard pellets as commodity pairs where the combination of two standard and one quinine pellet was the intended inferior good while the other combination of two standard and four quinine pellets was the intended superior good. Like the Silberberg et al. (1987) study, Hastjarjo et al. did not present income elasticities. However, their graphs suggest negative elasticities for the two-standard-and-one-quinine pellet combination because less responses reinforced by this combination occurred in Rich Conditions than in Poor Conditions, thus the combination fulfilled the formal definition of an inferior good. Their study was similar to the monkey study by Silberberg et al., except that income was manipulated by changing the total number of trials in variable-length sessions where the ITI was always 60 s rather than changing the ITI between trials in fixed-length sessions. Both income manipulations resulted in more trials in the Rich Condition than in the Poor Condition. During sessions in the Hastjarjo et al. study, rats were exposed to a series of discrete trials where one lever delivered two standard food pellets and one quinine-adulterated pellet while the other lever delivered two standard food pellets and four quinine-adulterated pellets. The combination of two standard food pellets and four quinine-adulterated pellets was shown to be an inferior good because rats consumed it more often than the other combination when income was low (few trials occurred in each session) and less often when income was high (many trials occurred in each session). In this procedure the ITIs could not have been a S^Ds or conditional stimuli because they did not change when conditions changed. Instead, a 60-s ITI always followed trials, regardless of condition.

The fact that Hastjarjo et al. (1990a) found the inferior-good effect without changing the ITI between conditions challenges the idea of the change in ITI as an important part of the inferior-good effect (and as a S^D or conditional stimulus). The outcomes of both experiments were similar—changing overall reinforcement (income) resulted in changes in the distribution of responses across two operandi. If the ITI was an S^D or conditional stimulus in the Silberberg et al. (1987) study, the Hastjarjo et al. study should also have a similarly-functioning S^D or conditional stimulus if the two outcomes were due to similar processes (note that neither study changed houselights with condition changes). In the former experiment, a condition change could first exert discriminative control over behaviour only after the first trial in the current session at the time at which the current ITI differed from the previous condition's ITIs. In the latter experiment, the earliest that a condition change could have exerted control would have been during the trial following the number of trials programmed for the Poor Condition. In each experiment, these changes were the only discriminable changes that accompanied condition changes. If the reported changes in behaviour had indeed occurred due to these discriminable changes, the most parsimonious explanation would be that the ITI change necessitated a temporal discrimination while the total-trials change relied on a number-of-trials discrimination.

Gallistel and Gibbon (2000) state that studies investigating the importance of time with respect to learning date at least as far back as Pavlov's (1928) work on reflexes and Skinner's (1938) work on fixed-interval (FI) schedules. Pavlov showed that delays between the presentation of a conditioned stimulus, a ringing bell, and an unconditioned stimulus, meat powder (which resulted in salivation), resulted in similar delays to salivation when the conditioned stimulus was presented alone. Skinner showed that when reinforcers were available for a response following fixed intervals of time (an FI schedule of reinforcement), responding tended to occur most frequently near the end of the time intervals. Timing studies since then have been reviewed in several publications and generally show humans and non humans can respond differentially to temporal aspects of stimuli (Fantino, Preston, & Dunn, 1993; Gallistel & Gibbon, 2000; Gibbon, Malapani, Dale, & Gallistel, 1997; Killeen & Fetterman, 1988; R. R. Miller & Barnet, 1993; Staddon & Higa, 1991).

When tested under various experimental arrangements, humans and non-humans exhibit a pattern of time estimation (or differential responding to the temporal aspects of stimuli) with a property called *the scalar timing property*. This property is characterised by increasing variability in estimates (or accuracy) of the discriminated time as the time-to-be discriminated increases; however, the distribution of timing data is similar in all time ranges indicating that time sensitivity spans across a wide range of times (Cle'ment & Droit-Volet, 2006). Pigeons have differentially responded to stimuli durations ranging between 3 and 30 s (Reynolds & Catania, 1962) and between durations below 1 s (Fetterman & Killeen, 1992); rats between 1 and 6 min (Sams & Tolman, 1925), between 30, 60, and 120 s (Guilhardi & Church, 2005), between 5 and 45 s (Heron, 1949), and between intervals differing by as little as 10 s such as between 10 and 20 s (Anderson, 1932); monkeys between as little as 1.5 and 2.18 s (Woodrow, 1928); and hens between 4 and both 0 and 16 s as well as between 2 and both 0.25 and 8 s (Nakagawa, Etheredge, Foster, Sumpter, & Temple, 2004).

If hens' responding in Experiment 2 were under discriminative control of the ITI durations, behaviour would have needed to come under discriminative control of the ITIs in one of the following sets described in Table 2: 95 and 30 s, 150 and 40 s, 150 and 50 s, 75 and 25 s, 130 and 40 s, 90 and 25 s. Given that each set of ITIs differs by at a magnitude of 3 to 3.75 and that time sensitivity spans across a wide range of times, even if variability increases with the time durations a comparison of these magnitudes with the magnitudes used in the studies cited above might provide some support that the ITIs in each set could differentially affect responding. Magnitudes across the studies cited above varied greatly, and at least one study on rats showed that as the times to be discriminated became closer to one another (the magnitude changed from 9 to 2), accuracy suffered. For the studies cited above, magnitudes of difference between time durations that were found to be discriminable were as large as 1.45 in a monkey study (Woodrow, 1928) and as small as 10 in a pigeon study (Reynolds & Catania, 1962). The magnitudes for each set of ITIs in Experiment 2 fall within these magnitudes, but without more data on hens' threshold of temporal discrimination, it is only possible to assume that the ITIs differed enough for discriminative control to occur.

For humans, verbal behaviour in the form of counting can, and often does, play a mediating role in temporal discrimination (Cle'ment & Droit-Volet, 2006). Some timing literature suggests that adjunctive behaviour may occur as a mediating behaviour that facilitates time discrimination in non-humans (Killeen & Fetterman, 1988). For example, in a discrimination task, Machado and Keen (2003) reported that pigeons engaged in a stereotyped behaviour pattern of moving from one side of the experimental chamber to the other during the presentation of long and short temporal S^Ds. At the onset of the S^D, birds moved to the side associated with the short-duration key and then shifted to the long-duration side after a few seconds. Birds received food if, after the presentation of the temporal S^D, they responded on the short-duration key following short durations and on the long-duration key following long durations. Heuristically speaking, the description of this contingency was something like, "If *X* s pass, do *A*; if *Y* s pass, do *B*." The stereotyped pattern described above may have mediated the discrimination task such that the pattern began at the onset of the temporal S^D and ended with an effective response on the nearby key at the end of the temporal S^D. Here, the pattern was seemingly a necessary part of the effective response that resulted in presentations of food. The heuristic would then have become, "If you are at a relatively early point of adjunctive behaviour *Z* when the temporal S^D finishes, do *A*; if you are at a relatively late point, do *B*."

If the within-session patterns found for some birds in Experiment 2 and for both monkeys in Silberberg et al. (1987) functioned similarly to the pattern found by Machado and Keen (2003), the relation for these former experiments would need to be somewhat more complex because the patterns varied with each income condition. Here, two distinct session-long patterns are implied, one pattern for each income condition. Heuristically, "If relatively many seconds pass during the ITI (and/or if one colour houselight is on), respond on the inferior-good key for several trials and then shift to the other key; if relatively few seconds pass (and/or if the other colour houselight is on), respond on the inferior-good key for a few trials or not at all, then shift to the other key for the rest of the trials." An important difference between this hypothesised temporal-S^D-behaviour-pattern relation and the relation found in Machado and Keen (2003) is that latter required a short behaviour pattern spanning several seconds while the former would have required a behaviour pattern spanning 20 min (in Experiment 2) to 60 min (in Silberberg et al.). A maximisation account would state that this behaviour pattern maximised utility within each income constraint; a melioration account would state that the pattern meliorated reinforcement.

So, human and non-human behaviour can come under the control of temporal stimuli and the control can be mediated or facilitated by verbal behaviour, adjunctive behaviour, or stimuli that accompany time changes. The possibility of temporally-extended behaviour patterns (especially patterns taking more time then just a few seconds) coming under control of the temporal aspects of stimuli has not been well explained in the literature. Although such a relation seems plausible in explaining the relation between within-session patterns and the inferior-good effect, its complexity suggests that a more parsimonious account might be preferrable. Further, the answer to how a hen's temporally-extended behaviour pattern could come under the control of the number of trials in a session (as apposed to the ITI) is less clear. In the Hastjarjo et al. (1990a) rat study, the number of trials in the Poor Condition was 30 and in the Rich Condition, 150—they differed by a magnitude of 5. Assuming that the different ITIs of Experiment 2 were indeed discriminable, each trial would be followed by the hypothesised temporal S^D—the ITI. Hastjarjo et al.'s rats' behaviour would have had to come under control of a seemingly less-salient S^D—the occurrence or non-occurrence of the 31st and subsequent trials. It is difficult to see how this kind of control could occur without a mediating variable such as counting or a houselight change. Regardless, Hastjarjo et al. did find the effect.

The comparison between the Hastjarjo et al. (1990a) rat study, the

Silberberg et al. (1987) monkey study, and the hen study is between different species and between procedures that had other differences besides the ITI or its absence. The studies had different operanda, different foods that were presented in different ways, different numbers of trials, and perhaps other differences that make it difficult to pinpoint the important variables that control the inferior-good effect. The current experiment allowed comparison of the effects of the two different income manipulations on the behaviour of hens. By exposing hens to the same conditions as in Experiment 2, but by ending sessions following either a large or small number of trials (corresponding to Rich or Poor Conditions, respectively) with no ITI between trials. It was predicted that hens would consume more salted wheat in the Poor Condition than in the Rich Condition, confirming salted wheat as an inferior good for these hens. The occurrence of the effect would be consistent with Hastjarjo et al. (1990a) but would challenge the importance of the variable-length ITIs (as S^Ds or conditional stimuli) or would suggest that the effect occurred for different reasons in each experiment.

Method

Subjects

Subjects were 7 Brown Shaver hens (*Gallus domesticus*) with prior experimental experience numbered 91, 92a, 92b, 93, 94, 95, and 96 (the Group-9 hens). All hens were approximately one year old at the onset of the experiment. Hens were housed, maintained, and post fed in the same way as the hens in Experiment 2.

Apparatus

The analogue hanging scale and cone from Experiment 1 were used to weigh subjects but the scale was changed to UWE HS-3000 digital hanging scale with a resolution of 2 g and a maximum of 3000 g on Day 184. The experimental chamber had the same specifications as the experimental chamber in Experiment 2 except that amber houselights were on during Rich Conditions while blue houselights were on during Poor Conditions. Magazines were weighed with a Wedderburn EEW-10K digital table scale with a resolution of 1 g and a maximum of 11,000 g. The computer, software, and equipment from Experiment 2 controlled the experiment but the computer and software were changed to a Windows-based computer operating MED-PC for Windows 3© software on Day 149. All other apparatus specifications were the same as in Experiment 2.

Procedure

The procedure was similar to the procedure of Experiment 2, except no ITI occurred following pecks on either key. Instead, the next trial began immediately after reinforcer delivery and discrete trials continued until the sessions ended after a specified number of trials that varied across conditions and hens.

Approximately once per week, magazines were weighed before and after sessions so that the weight of plain and salted wheat consumed could be calculated.

In the Rich Condition with amber houselights, sessions ended after relatively many trials while in Poor Condition with blue houselights, sessions ended after relatively few trials. These houselights were arranged to be associated with opposite conditions to the houselights in Experiment 2. Total trials varied between hens and were based on estimates of wheat consumption necessary to maintain body weights on either exclusive consumption of salted wheat or plain wheat (for relatively few trials) or exclusive consumption of salted wheat (for relatively many trials) during daily sessions; this logic of estimating was the same as that of Experiment 2. Estimates were made by estimating the weight of daily wheat necessary to maintain body weight at 80% and by setting the total number of trials so that responding throughout the session on at least one of the keys yielded this weight of wheat (either salted or plain).

Each hen was exposed to each of the two income conditions twice. Half of the hens began sessions in the Rich Condition while the other half of the hens began in the Poor Condition. Conditions changed when responding on the two keys reached visual stability across all hens. This experiment terminated when all hens' responding reached visual stability in all four conditions. The MED-PC 2© software monitored all session events as in Experiment 2 but data from the water infrared sensor were not used due to the problems experienced in Experiment 2 (also, observations confirmed similar problems with the beam in the current experiment).

Results

Table 8 presents the maximum number of possible trials and order of conditions for each hen. Total trials ranged from 8 to 12 in the Poor Conditions and from 30to 40 in the Rich Conditions. For all hens, the total number of trials in some Poor Conditions was decreased (analogically decreasing income) because the inferior-good effect was not observed. Hen 92a died on the day following its first session in its first Rich Condition. During that session, the bird consumed forty 10-s presentations of salted wheat. The veterinarian hypothesised the cause of death to be excessive consumption of salt, as evidenced by swelling and redness in early parts of the bird's digestive tract. This event necessitated procedure changes in all experiments using salted wheat so access to salted wheat was limited to thirty 10-s presentations.

Table 8
Experiment 3a: Maximum Number of Trials for Each Condition

	Successive Conditions			
Hen	Poor	Rich	Poor	Rich
91	12/9	40	12/8	40
92a	12	40	.	.
92b	.	30	12/8	30
93	12	30	12/8	30
	Rich	Poor	Rich	Poor
94	40	12	30	12/8
95	40	12/8	30	8
96	40	12/8	30	8

As in Experiment 2, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. The median numbers of responses for these sessions are displayed in Table 9. For all 17 income changes (three changes for Hens 91, 93, 94, 95, and 96; two changes for Hen 92b, and no changes for Hen 92a as it died on the first day of its second condition) across the four conditions for all 7 hens, the median number of salted-

Table 9
Experiment 3a: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Rich	Poor	Rich	Poor	Rich	Poor	Rich
91	9	40	8	40	0	0	0	0
92a	0	.	.	.	12	.	.	.
92b	.	30	8	30	.	0	0	0
93	0	30	8	30	12	0	0	0
	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
94	40	0	30	7.5	0	12	0	0.5
95	40	8	30	8	0	0	0	0
96	40	8	30	8	0	0	0	0

wheat responses was higher in the Poor Condition than in the adjacent Rich Condition on four occasions. This inferior-good effect occurred for one condition change for Hen 93 and for all three condition changes for Hen 94. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Rich Condition on all 17 occasions.

Figure 9 shows the number of effective responses that occurred within each income condition across consecutive days. Generally, hens tended to respond either exclusively or mostly on the plain-wheat key, regardless of condition. This tendency is clear for Hens 91, 92b, 95, and 96. Hen 92a responded mostly on the salted-wheat key during its first and only Poor Condition. Hen 93 behaved similarly in its first Poor Condition and then responded almost exclusively on the plain wheat key for the rest of its conditions. Hen 94 showed the greatest variability across all hens. This bird responded almost exclusively on the plain-wheat key during its first Rich Condition; almost exclusively on either the plain-wheat or salted-wheat key during its first Poor

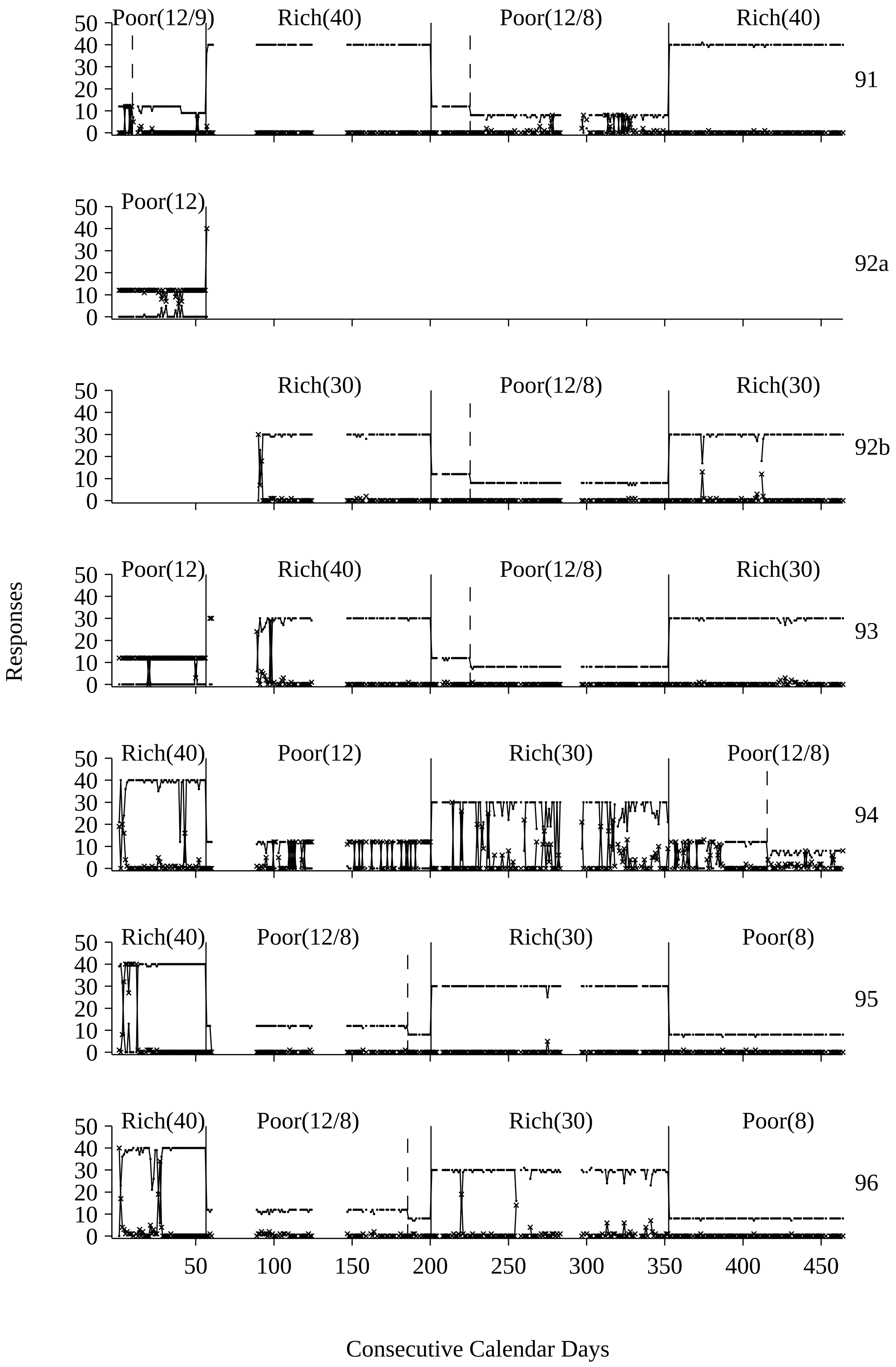

Figure 9. Experiment 3a: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

Condition; and then on both keys for its subsequent Rich and Poor Conditions. Table 10 summarises responses across all conditions and shows the percentage of plain- and salted-wheat responses. Hen 92a's responses occurred mostly on the salted-wheat key at 96% while Hens 91, 92b, 93, 94, 95, and 96's responses occurred mostly on the plain-wheat key with 2 to 17% occurring on the salted-wheat key. Excluding Hens 92a and 92b because these hens experienced less conditions than the others, total responses on the plain-wheat key ranged from 5,934 for Hen 93 to 8,306 for Hen 91; total responses on the salted-wheat key ranged from 183 for Hen 91 to 1,257 for Hen 94.

Table 10
Experiment 3a: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	8306	98	183	2
92a	27	4	673	96
92b	5886	98	102	2
93	5934	88	786	12
94	6204	83	1257	17
95	6872	95	326	5
96	6990	96	260	4

Income elasticities for salted and plain wheat were calculated as in Experiment 2 using Equation 5 with the median number of responses of the last 20 sessions of each condition (see Table 9 for medians). These elasticities are presented in Table 11 and represented in bar graphs in Figure 10. Income elasticities could not be calculated for Hen 92a because it experienced only one session in its second condition before it deceased. This bird was replaced with Hen 92b, so only two income elasticities could be calculated for this hen as it only experienced three conditions. For most income changes across all birds, plain-wheat elasticities tended to be either 1 or positively infinite (except for Hen 94's

Table 11
Experiment 3a: Income Elasticities for Each Condition Change (U=undefined)

	Consecutive Condition Changes					
	Plain Wheat			Salted Wheat		
Hen	Poor/ Rich	Rich/ Poor	Poor/ Rich	Poor/ Rich	Rich/ Poor	Poor/ Rich
91	1	1	1	U	U	U
92b	.	1	1	.	U	U
93	∞	1	1	-0.7	U	U
	Rich/ Poor	Poor/ Rich	Rich/ Poor	Rich/ Poor	Poor/ Rich	Rich/ Poor
94	1.4	∞	1	-∞	-0.7	-∞
95	1	1	1	U	U	U
96	1	1	1	U	U	U

first condition change where the income elasticity was 1.4) while salted-wheat elasticities tended to be either negatively infinite, -0.7, or undefined. Income elasticities of each wheat for each of the three condition changes were the same within birds for Hens 91, 92b, 95, and 96. For Hens 93 and 94, there was some variability in elasticities within birds, but values were positive for plain wheat and negative (or undefined for Hen 93) for salted wheat.

Cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key are shown in Figure 11. Each data point represents the mean number of responses for each successive trial across the last 20 sessions for each major condition. Most of the graphs show linear functions with slopes of approximately zero due to exclusive or nearly-exclusive responding on the plain-wheat key. The only function with a slope approaching infinity was Hen 92a in its first and only Poor Condition where nearly-exclusive responding on the salted-wheat key occurred. The only functions with slopes that fell somewhere between zero and infinity were for Hen 94's Rich Conditions. Responding in the first Rich Condition tended to occur on both keys throughout the session. A slight pattern of responding on the salted-wheat key early in the session and plain-wheat key later occurred in this hen's second Rich Condition.

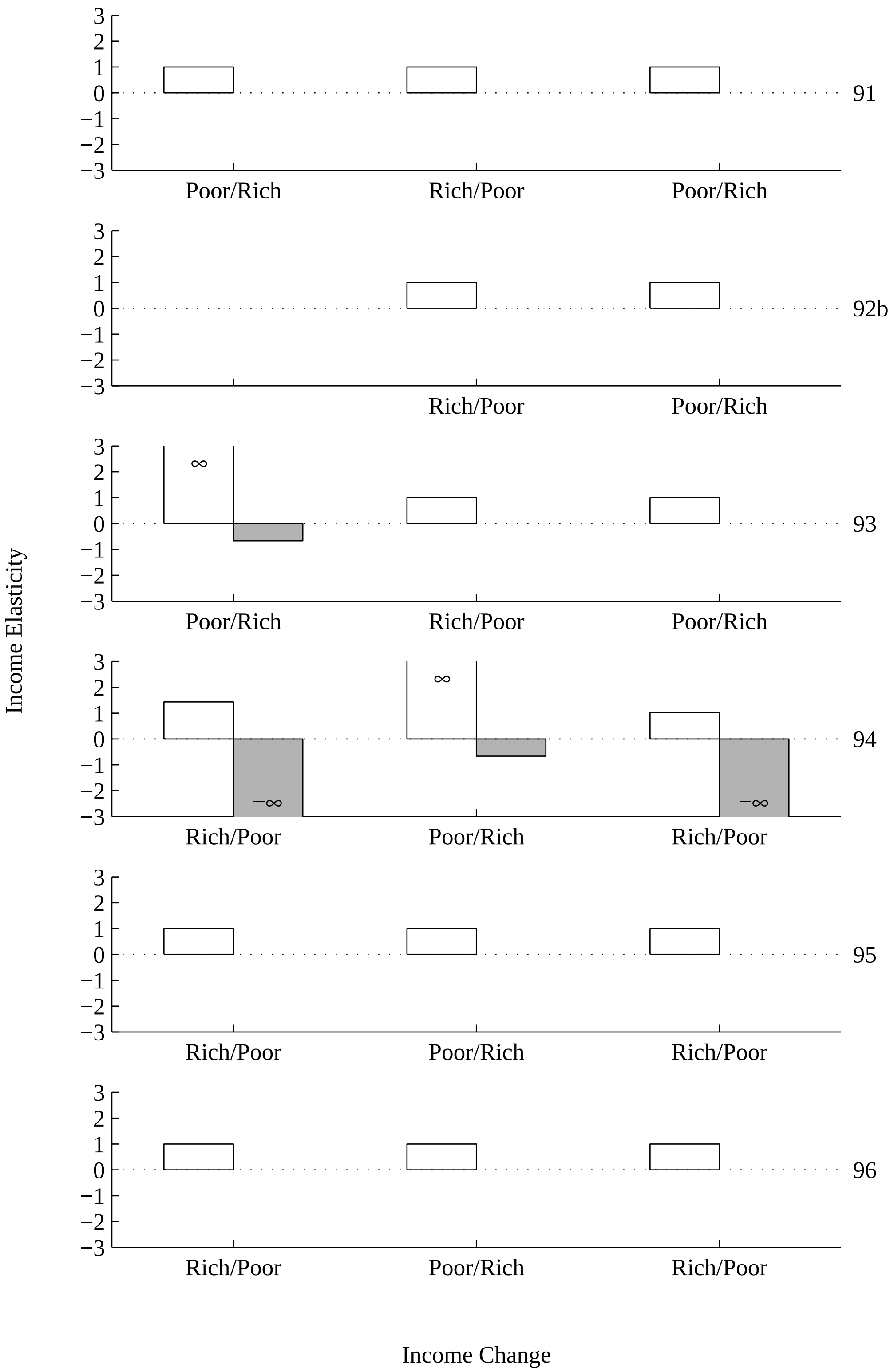

Figure 10. Experiment 3a: Income elasticities for each condition change.

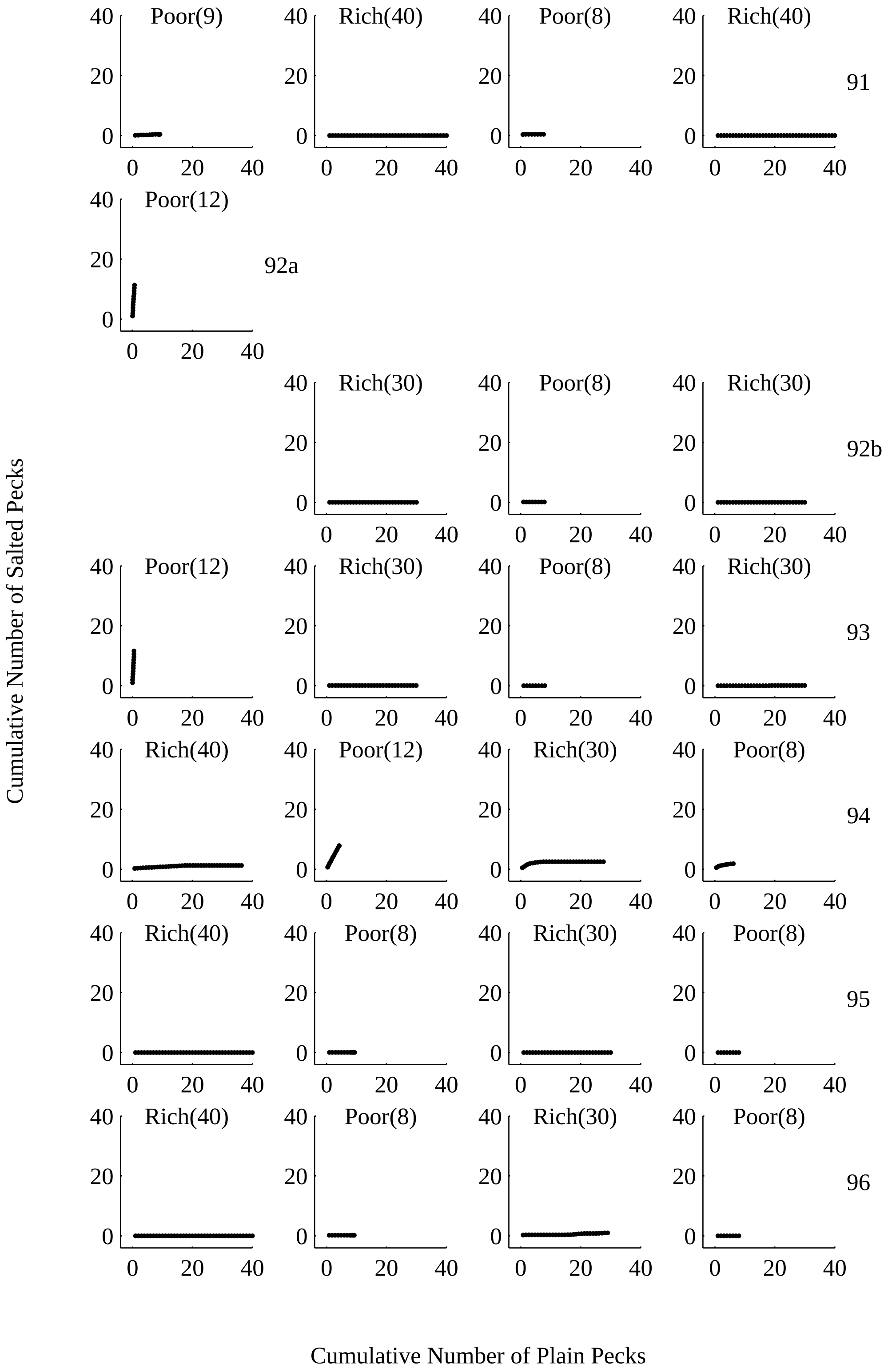

Figure 11. Experiment 3a: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses for each successive trial across the last 20 sessions of the condition.

The duration of eat time for each type of wheat is presented in Figure 12. As reported in Experiment 2, the patterns were similar to the response patterns in Figure 9 except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. Overall, more responding on a key tended to be associated with longer eat times for the type of food associated with that key. Pearson correlation coefficients (*r*) for eat times versus wheat weights as well as sample sizes are shown in Table 12. The coefficients can be interpreted as follows: .10 through .29, small; .30 through .49, medium; .50 through 1, large (Cohen, 1988). To avoid inflating the correlations, pairs of eat times and their respective wheat weights were omitted from analysis when they were both zero. Correlation coefficients were undefined for samples that had no variability in either eat time or wheat weight or for samples that had less than two pairs of data. undefined values occurred for plain wheat in Hen 93’s first Poor Condition and for salted wheat in some conditions for Hens 91, 92b, 93, 95, and 96. Correlations differed within and between birds as well as the two types of wheat, but no consistent differences were found. Statistical significance of the coefficients was tested using an alpha level of .05 to find that all significant correlations were large and positive: 9 out of 24 for plain wheat and 3 out of 24 for salted wheat or 8 out of 24 in the Poor Conditions and 4 out of 24 in the Rich Conditions. Sample sizes varied and ranged from 0 to 14. However, given the number of both significant and non-significant correlations, the significant correlations may have occurred through chance, so should be interpreted with caution.

There were occasions where responding occurred during the magazine presentations. Table 13 summarises these during-magazine responses across all conditions and shows the percentage of plain- and salted-wheat responses. All

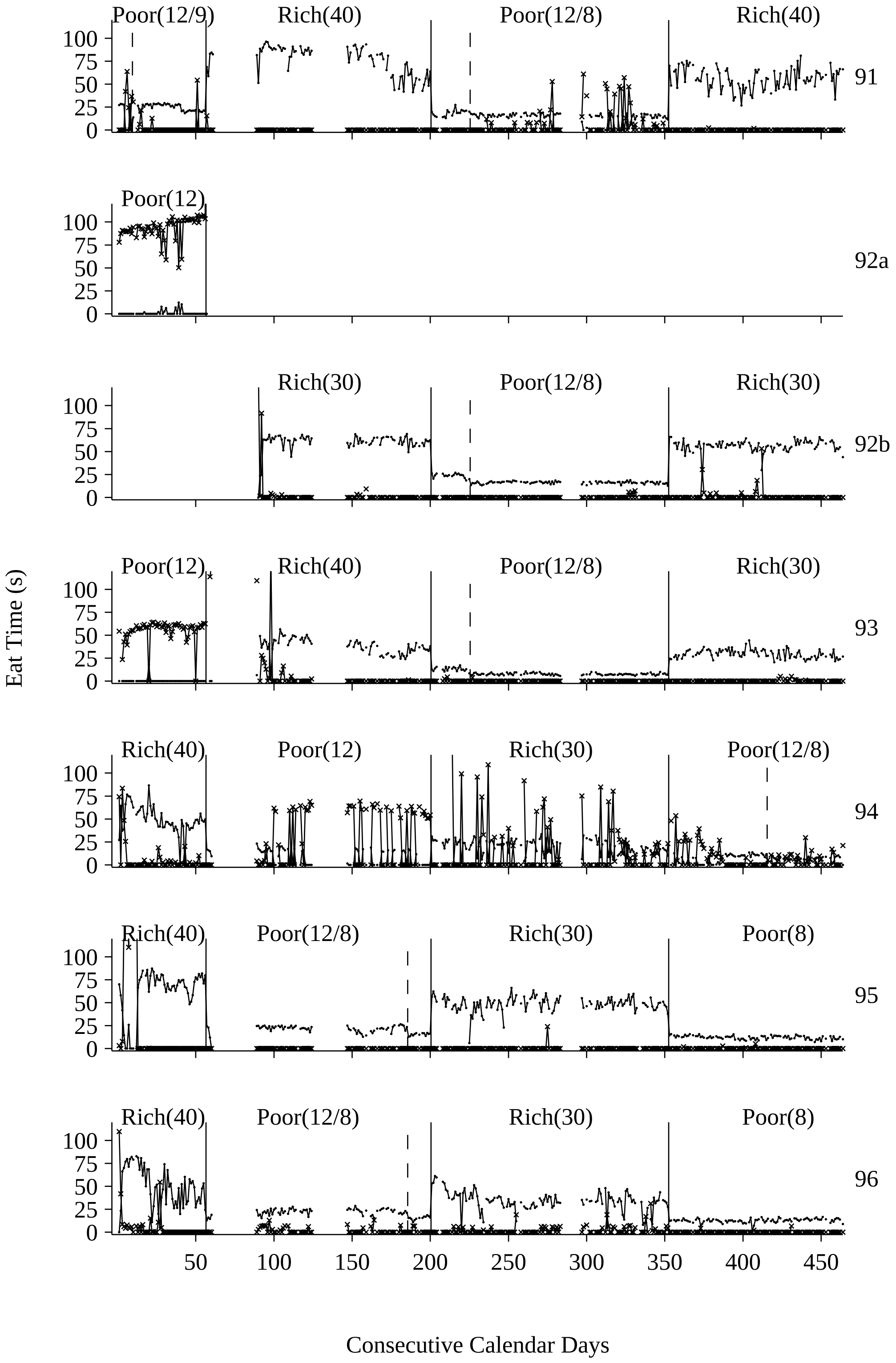

Figure 12. Experiment 3a: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

Table 12
Experiment 3a: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Rich	Poor	Rich	Poor	Rich	Poor	Rich
91	.89*	.46	.35	.54	U	U	.97*	U
	(7)	(14)	(7)	(7)	(1)	(0)	(4)	(0)
92a	1*	.	.	.	.58	.	.	.
	(3)				(9)			
92b	.	.27	-.24	.37	.	-1	U	U
		(12)	(9)	(7)		(2)	(0)	(0)
93	U	.34	.97*	.37	.23	.98*	U	U
	(0)	(13)	(9)	(7)	(9)	(4)	(0)	(1)
	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
94	.64	.94*	.95*	.84*	.94	.96*	1	1
	(8)	(6)	(9)	(7)	(4)	(9)	(2)	(2)
95	.76	.1	.59	.38	1	U	U	U
	(6)	(13)	(9)	(7)	(2)	(0)	(0)	(0)
96	.86*	.94*	.95*	-.18	.85	U	.60	U
	(9)	(13)	(8)	(7)	(3)	(0)	(5)	(1)

*p<.05

Table 13
Experiment 3a: During-Magazine Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	20	100	0	0
92a	0	-	0	-
92b	0	-	0	-
93	4	100	0	0
94	422	95	20	5
95	21	100	0	0
96	29	100	0	0

hens except Hens 92a and 92b responded on the plain-wheat key during some magazine presentations; these two hens never responded on either key during magazine operation. Across the entire experiment, these responses ranged between 4 and 29 for Hens 91, 93, 95, and 96 and totalled 422 for Hen 94. Hen 94 also responded 20 times on the salted-wheat key during magazine presentations, accounting for 5% of all of these responses. So, besides for Hen 94, during-magazine responses happened only occasionally. Hen 94's during-magazine responses showed that up to about 10 plain-wheat responses occurred per session in most sessions during the second Rich Condition and typically under

5 plain-wheat responses occurred in the second Poor Condition.

Table 14 shows pre-session body weight means for the last 20 sessions of each condition and Figure 13 shows hens' pre-session body weights plotted across days for each hen. Mean body weights of Hens 91, 92b, 94, 95, and 96 tended to be lower in the Poor Conditions than in the Rich Conditions. Hen 93's mean body weight also followed this pattern except for its first Poor Condition where its mean body weight was highest.

Table 14
Experiment 3a: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions			
Hen	Poor	Rich	Poor	Rich
91	1469	1576	1406	1573
92a	1823	.	.	.
92b	.	1537	1367	1506
93	1845	1690	1608	1695
	Rich	Poor	Rich	Poor
94	2005	1611	1842	1605
95	1957	1513	1750	1514
96	1755	1526	1684	1529

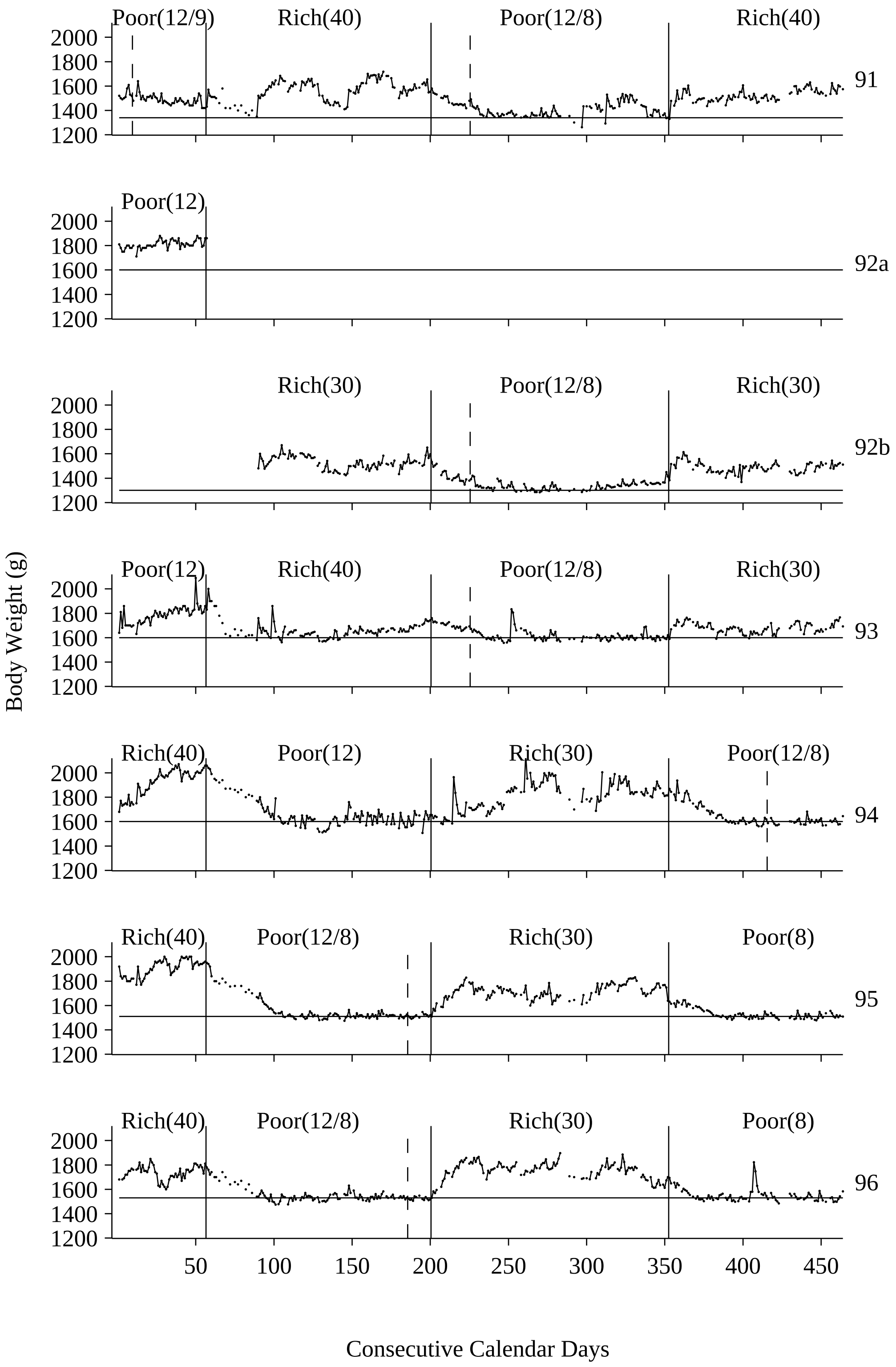

Figure 13. Experiment 3a: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate changes in the programmed number of trials, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the maximum number of trials possible for each condition.

Discussion

For most hens the results did not resemble the results of Experiment 2, the Silberberg et al. (1987) monkey study, or Hastjarjo et al. (1990a) rat study where subjects responded relatively more on the intended-inferior-good operandum in Poor Conditions versus Rich Conditions. This pattern occurred for all 6 condition changes for the 2 monkeys in Silberberg et al. (100%), for 6 of 18 condition changes for the 6 hens in Experiment 2 (33%), and for all 12 condition changes for the rats in Hastjarjo et al. (100%). Figure 9 and Table 9 show that all hens except Hens 93 and 94 tended to respond on one key, the plain-wheat key, exclusively (Hen 92a only experienced one condition so no statements could be made on income elasticity). Hen 94 responded more on the salted-wheat key in Poor Conditions (i.e., had negative income elasticities) than in Rich Conditions. This pattern also occurred for the first condition change for Hen 93. So, in the current experiment the inferior-good effect occurred only for 3 of 18 condition changes (17%) showing that salted-wheat responses did not change in the opposite direction to income changes as often as they did in Experiment 2, Silberberg et al., or Hastjarjo et al. The weaker, relative-inferior-good effect that was found when both elasticities were positive in Experiment 2 was not found in the current experiment. Under these circumstances in Experiment 2, plain-wheat elasticities tended to be larger indicating that plain-wheat responding was more sensitive to income changes than salted-wheat responding. This effect occurred for 5 of 6 hens in 13 of 18 condition changes (72%) in Experiment 2 but no such effect was found in the current experiment because plain-wheat income elasticities were always positive and salted-wheat elasticities tended to be undefined or negative. In the current experiment, then, salted wheat was an inferior good for

17% of condition changes (but only for Hens 93 and 94) because it was of a lower value and cost than plain wheat and it involved more responses with decreases in income.

The within-session patterns of early intended-inferior-good consumption and late intended-superior-good consumption found in Hastjarjo et al. (1990a), Silberberg et al. (1987), and for Hens 73a, 74, and 75 in Experiment 2 were only found in Hen 94's second Rich Condition in this experiment. The other hens tended to respond exclusively or nearly-exclusively on the plain-wheat key (save the first Poor Condition for Hens 92b and 93). It is noteworthy that Hen 94 was also the only hen to show the inferior-good effect across all three condition changes (with only Hen 93 also showing the effect, but for only one condition change). The occurrence of this pattern in the Rich Condition for the one bird showing the effect (in combination with the pattern's occurrence for other birds showing the effect or the relative effect in Experiment 2) suggests that the pattern may be important for the inferior- and relative-inferior good effects. However, exactly how the pattern and the effects might be related is still unknown.

The occurrence of during-magazine responses in Table 13 shows that on occasion, some hens either did not eat or stopped eating early and, instead, pecked a key (usually the plain-wheat key and rarely, except for Hen 94). Hen 94 responded the most during this 3- to 10-s window with 442 responses on both keys. When compared with the 7,461 effective responses on both keys in Table 10, these during-magazine responses were still relatively infrequent, accounting for approximately 6% of all responses for this bird. It is unknown why these responses began in the second Rich Condition. Hen 96 had the next-most-frequent during-magazine responses with 29 on the plain-wheat key and other hens had 0 or less. When Hen 96's 29 during-magazine responses are compared with its 7,250 effective responses, these during-magazine responses were even less frequent, accounting for only about 0.4% of all responses for this hen. Given the infrequent occurrence of during-magazine responses, the eat-time data showing that hens put their heads in the magazines, and the positive correlations between eat-time and amount consumed, it can reasonably be assumed that hens at least usually consumed plain or salted wheat following effective responses.

One difference between the procedure of this experiment and the procedure of Experiment 2 was the absence of an ITI in the current experiment. Other differences were that different hens were used in this experiment, the houselight colours were shifted to opposite conditions, and the specific number of trials per session for each hen in each condition differed from the trials per session in corresponding conditions in the previous experiment. Although individual physiological differences may account for some difference in behaviour between the current experiment and Experiment 2, it is unlikely that this difference alone would lead to the different outcomes of this experiment considering that 5 of the 6 hens in the previous experiment showed similar behaviour to each other. It is also unlikely that the swapping of houselight colours between experiments would be responsible for the different outcomes because there is no reason to assume that colour would have such a direct effect on behaviour. Finally, it is probably not the case that the difference between the number of trials between this experiment and Experiment 2 was the important factor that lead to different outcomes. Each hen in Experiment 2 had different numbers of trials in its respective Poor and Rich Conditions, but the effect was still observed. Further, the numbers of trials used in this experiment were comparable to the numbers of trials used in the previous experiment (see Table 8 and Table 22). So, something about the ITIs may have been important for the effect to occur in Experiment 2.

These results also did not replicate the results of the Hastjarjo et al. (1990a) study that demonstrated an inferior-good effect with rats using a similar procedure. One difference between the procedure of the Hastjarjo et al. rat study and the current experiment was the presence of 60-s ITIs in the former experiment while the next trial began immediately in the current experiment. The reasons for not using the fixed-length ITI in the current experiment were first, that there was no a priori rationale for why it might contribute to the effect and, second, that not including it would simplify the procedure. Another difference between the current experiment and Hastjarjo et al. was that Hastjarjo et al. included five forced-choice trials on both keys prior to each session. Likewise, these forced-choice trials were eliminated from the current study because there was no a priori rationale for them. Given that the effect occurred with the Hastjarjo et al. procedure but not with the current procedure, the fixed-length ITI and the forced choices require further investigation.

Most hens in the current experiment tended to respond exclusively on the plain-wheat key and some hens, such as Hens 91, 92a, 93, 94, and 95, occasionally responded exclusively on the salted-wheat key during sessions in both Rich and Poor Conditions. Responding on both keys during any session was rare for all hens except Hen 94. It may be the case that there was very little opportunity for hens responding to vary because only a single response was necessary for reinforcer delivery and because trials occurred immediately following reinforcer delivery. Hens may have developed a fixed pattern of responding on the plain-wheat key, making the birds’ behaviour insensitive to the contingencies on the salted-wheat key (because behaviour rarely came into contact with the contingencies). If the hens' behaviour rarely contacted the contingencies of the salted-wheat key, then there is no reason why the contingencies should have had any control over behaviour.

In the Silberberg et al. (1987) monkey study, the Hastjarjo et al. (1990a) rat study, and Experiment 2, a side-effect of the ITIs (variable and fixed) may have been that they provided time for behaviour to vary, thus increasing the chances of coming into contact with the contingencies of both keys. If the early-salted-late-plain within-session patterns found in Experiment 2 and in the published studies were important for the effect, then perhaps contingency contact facilitated the acquisition of these patterns which then enabled the effect to occur. In the current experiment, perhaps the effect did not occur because these within-session patterns were never established due to the lack of contingency contact. Alternatively, if within-session patterns are not important for the effect, then contingency contact may still be important for the reasons described earlier.

Another means of increasing variability may have been the 10 forced-choice trials occurring at the beginning of sessions in the Hastjarjo et al. (1990a) study as this aspect of the procedure ensured variability, at least in experience. If this variability is important for the inferior-good effect, then it is not surprising that the effect did not occur in the current experiment as it did not involve forced choices or ITIs during which behaviour could vary. Instead, Table 15 shows that sessions lasted between only 30 and 382 s during which responding tended to occur on only one key for the entire session while in Experiment 2 sessions lasted 20 min during which responding occurred on both keys for most birds.

In Experiment 2 the inferior-good effect or the relative-inferior-good effect

Table 15
Experiment 3a: Mean Session Lengths

	Mean Session Length (s)			
Hen	Poor	Rich	Poor	Rich
91	79	206	48	184
92a	168	.	.	.
92b	.	159	41	156
93	160	163	37	127
	Rich	Poor	Rich	Poor
94	260	95	180	56
95	295	79	135	30
96	382	48	154	47

occurred for 5 of 6 hens and it was hypothesised that temporally-extended behaviour patterns involving effective responses (and perhaps including ITI responses or other stereotyped behaviour) may have come under discriminative or conditional stimulus control of the ITIs and/or accompanying houselights because those behaviour patterns either maximised utility, meliorated reinforcement, or followed a yet-to-be described behavioural process. There was also evidence that houselights affected behaviour as behaviour shifted immediately following condition replications for Hens 75 and 76a. Alternatively, the ITIs in Experiment 2 may have been important for the inferior-good effect because they provided time for behaviour to vary and increased the chances of hens' behaviour contacting the contingencies of both keys. This latter hypothesis fits the data of Silberberg et al. (1987), Hastjarjo et al. (1990a), Experiment 2, and Experiment 3a but does not answer the question of how changes in overall reinforcement affected behaviour. The current experiment does not provide data to further the discussion on melioration and maximisation other than that changes in overall reinforcement did not affect responding, a finding consistent with melioration. However, this finding should be interpreted carefully given the possibility of the hens' behaviour not contacting the contingencies on both keys.

The next experiment added a 60-s ITI to the procedure of the current experiment, as in Hastjarjo et al. (1990a), to test the effect of the fixed-length ITI on responding. The occurrence of the inferior-good effect would suggest that the importance of variable-length ITIs was that they provided time for behaviour to vary, not that they provided stimulus control. Non-occurrence or rare occurrence of the effect would support the hypothesis that ITIs functioned as discriminative or conditional stimuli in Silberberg et al. (1987) and in Experiment 2. Further discussion on melioration, maximisation, stimulus control, houselight effects, within-session patterns, and the importance of time for responding to vary (and contact contingencies) would bear on these findings. Given that all birds in Experiment 2 responded during the ITI at least early in the experiment, it was expected that birds in the next experiment would also respond during the ITI. This responding was expected to result in more variability thereby increasing the chances of contacting the contingencies of both keys and increasing the chances of the inferior-good effect occurring as in Hastjarjo et al.

Experiment 3b: Few/Many Trials with ITI (Group 9)

One difference between the procedures of Hastjarjo et al. (1990a) and Experiment 3a was the absence of a 60-s fixed ITI in Experiment 3a. Where the former experiment resulted in the inferior-good effect, the latter did not. Experiment 3b added a 60-s fixed ITI to the procedure of Experiment 3a to ascertain its effect on responding. Because the ITI necessarily added more time to sessions, behaviour had more time to vary between trials, as in Experiment 2. If the effect of the fixed-length ITI is that it increased the chances that behaviour will contact the contingencies of both keys, then ITI responses should occur, but diminish across sessions, variability within sessions should increase, and the inferior-and/or relative-inferior-good effects should emerge.

Method

Subjects

Hen 92a died during Experiment 3a, so subjects were the other 5 Group-9 hens used in Experiment 3a and a new hen, Hen 92b. Hens were housed, maintained, and post-fed as in Experiment 2.

Apparatus

The equipment from Experiment 3a was used for this experiment.

Procedure

The procedure was identical to the procedure of Experiment 3a except a 60-s ITI was added. Hens 91, 92b, and 93 were subjected to the Poor Condition and Hens 94, 95, and 96 were subjected to a Rich Condition then a Poor Condition. The total number of trials per session was 12 in the Poor Conditions and was 30 in the Rich Conditions. In these Poor and Rich Conditions, houselights were aqua and red, respectively, so they differed in colour from the houselights used in Experiment 3a. The MED-PC 2© software monitored all session events as in Experiment 2 and data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a.

Results

For all hens except Hen 94, the total number of trials in the Poor Conditions was decreased (analogically decreasing income) from 12 to 8 because the inferior-good effect was not observed. As in previous experiments, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. The median numbers of responses for these sessions are displayed in Table 16. For the 3 hens that experienced a condition change (Hens 94, 95, and 96), the median number of salted-wheat responses was higher in the Poor Condition than in the Rich Condition indicating an inferior-good effect for only Hen 94. The median number of plain-wheat responses was lower in the Poor Condition than in the Rich Condition for all 3 of these hens.

Table 16
Experiment 3b: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions			
	Plain Wheat		Salted Wheat	
Hen	Poor		Poor	
91	3.5		4.5	
92b	8		0	
93	7		1	
	Rich	Poor	Rich	Poor
94	27	1	2	11
95	27.5	8	2.5	0
96	30	8	0	0

Figure 14 shows the number of effective responses that occurred within each income condition across consecutive days. For all hens except Hen 92b, responding was more variable in this experiment than during Experiment 3a. Hens 91 and 93 responded on the salted-wheat key more often during the Poor Condition in this experiment then in the last Poor Condition of Experiment 3a, save some variability for a minority of Hen 91's sessions. Hen 92b's almost-

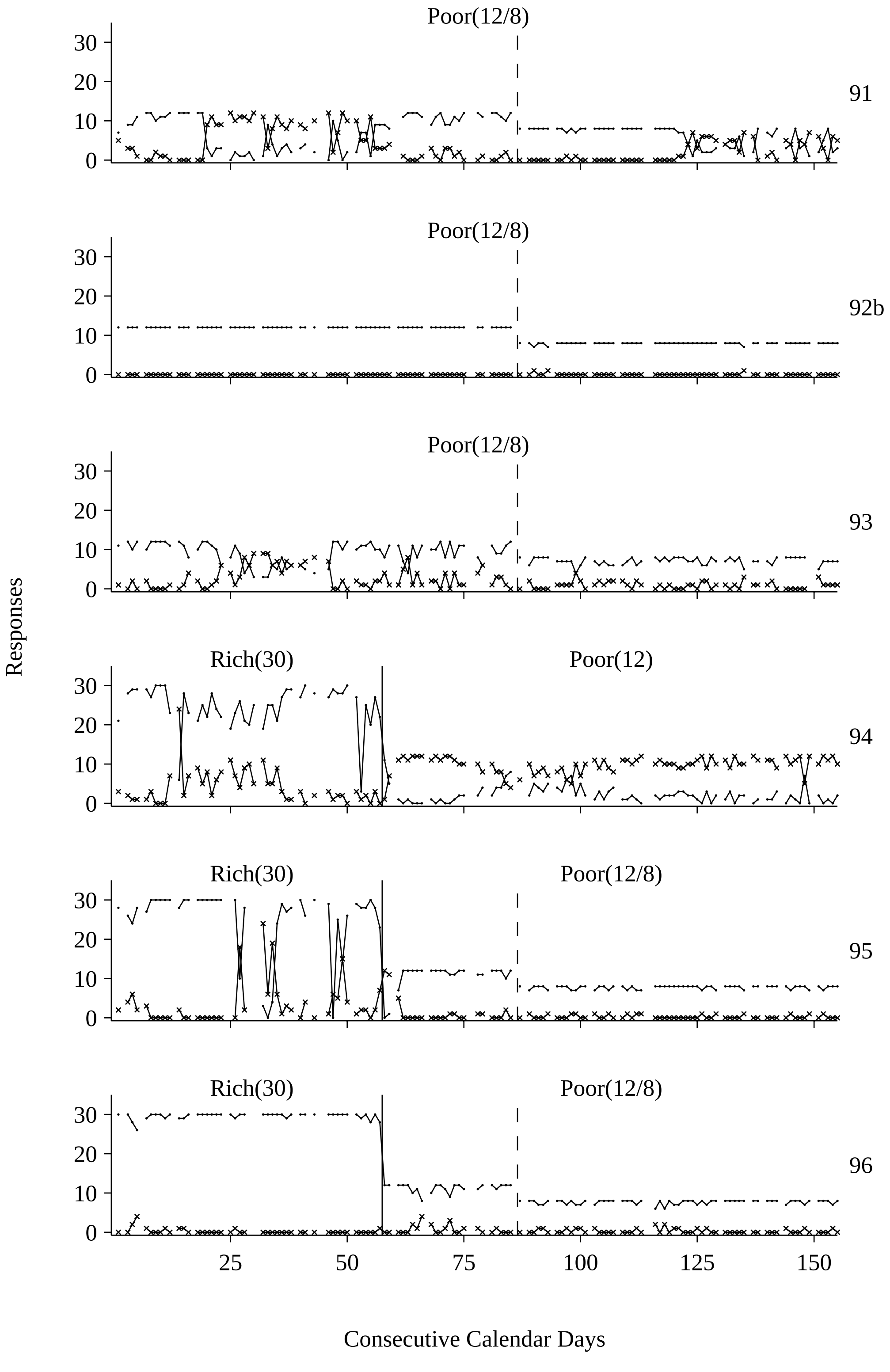

Figure 14. Experiment 3b: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

exclusive, plain-wheat-key responding was similar to responding in Experiment 3a. Hens 94 and 96 responded mostly on the plain-wheat key, but with some variability, during Rich Conditions and responding was similar to responding in the Rich Conditions of Experiment 3a. Hen 95's responding at the beginning of the Rich Condition was almost exclusively on the plain-wheat key and similar to its responding across all conditions of Experiment 3a. Then, across several sessions until the end of this condition, responding became more variable. This behaviour was unlike behaviour occurring in any condition across over 450 sessions during Experiment 3a. When Hens 94, 95, and 96's condition changed from Rich to Poor, Hen 94's responding shifted towards the salted-wheat key and was unlike responding in any condition of Experiment 3a while Hens 95 and 96 responded almost exclusively on the plain-wheat key as in most sessions across all conditions in Experiment 3a. Table 17 summarises responses across all conditions and shows the percentage of plain- and salted-wheat responses.

Table 17
Experiment 3b: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	849	66	431	34
92b	1289	100	3	0
93	1036	81	248	19
94	1316	57	983	43
95	1771	90	198	10
96	2009	98	46	2

All responses occurred mostly on the plain-wheat key with 0 to 43% or less occurring on the salted-wheat key for all hens. Total responses on the plain-wheat key ranged from 849 for Hen 91 to 2,009 for Hen 96; total responses on the salted-wheat key ranged from 3 for Hen 92b to 983 for Hen 94.

Salted- and plain-wheat income elasticities were calculated as in previous experiments using Equation 5 and the median number of responses of the last 20 sessions of each condition (see Table 16 for medians). These elasticities are presented in Table 18 and represented in bar graphs in Figure 15. Income elasticities could only be calculated for Hens 94, 95, and 96 because these hens experienced a condition change while the others did not. Plain-wheat elasticities were 1.6 for Hen 94 and 1 for Hens 95 and 96 while salted-wheat elasticities were -7.5, 1.4, and undefined, respectively. These plain-wheat income elasticities were comparable to the values found in Experiment 3a as all of these values were

Table 18
Experiment 3b: Income Elasticities

Hen	Poor/Rich	
	Plain Wheat	Salted Wheat
94	1.6	-7.5
95	1	1.4
96	1	U

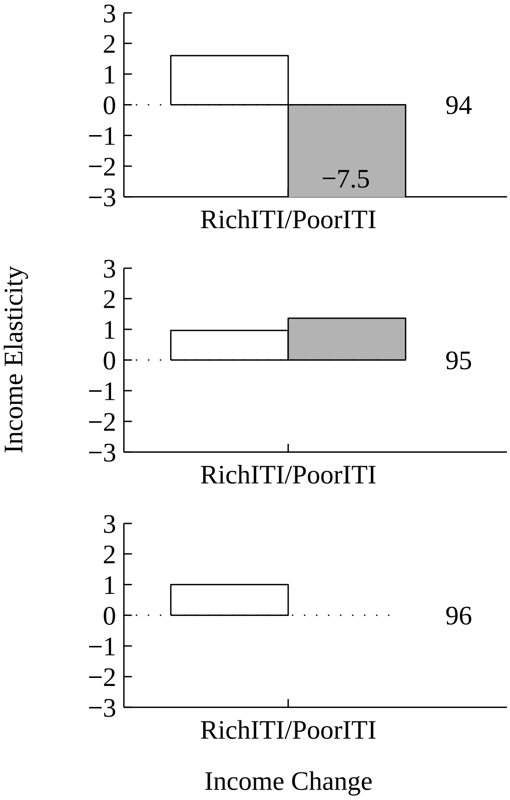

Figure 15. Experiment 3b: Income elasticities for each condition change.

positive and most were 1 or near 1 (see Table 11). Likewise, salted-wheat income elasticities were somewhat comparable to those found in Experiment 3a. Two of Hen 94's values were negatively infinite and one value was -0.7, so the -7.5 value from the current experiment is similar. All three of Hen 95's and 96's income elasticities for salted wheat were undefined in Experiment 3a, so the 1.4 and undefined values for Hens 95 and 96 are different and similar, respectively. Overall income elasticities in Experiment 3b were comparable to income elasticities in Experiment 3a for Hens 94, 95, and 96.

Figure 16 displays cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key. As in Experiment 3a, each data point represents the mean number of responses for each successive trial across the last 20 sessions for each major condition. Half of these functions were similar to most of the functions found in Experiment 3a: slopes at or near zero due to exclusive or nearly-exclusive responding on the plain-wheat key. The other half showed responding on both keys throughout the session for Hen 93's Poor Condition and Hen 94 and 95's Rich Condition, early plain-wheat responding and late salted-wheat responding for Hen 91's Poor Condition, and nearly-exclusive salted-wheat responding for Hen 94's Poor Condition. The pattern for Hen 91 differed from its nearly-exclusive plain-wheat responding across all conditions in Experiment 3a while the pattern for Hen 94 resembled at least the first Poor Condition in Experiment 3a, but showed more salted-wheat responding than both Poor Conditions from that experiment.

When ITI responses were added to the within-session responses in Figure 17, patterns were similar to their corresponding cumulative-within-session-response patterns changed for only Hen 93 and 96's Poor Conditions. The

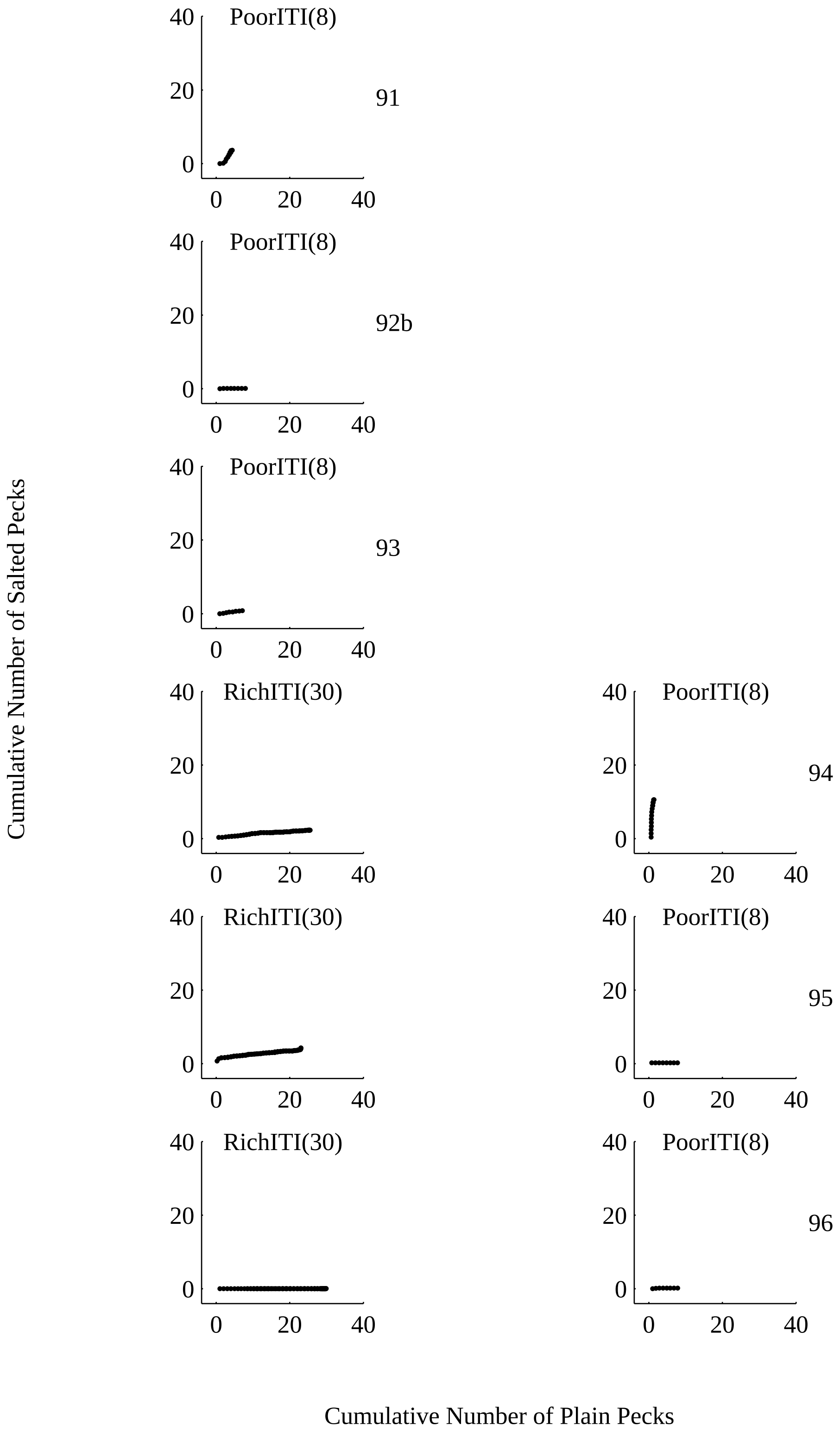

Figure 16. Experiment 3b: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses for each successive trial across the last 20 sessions of the condition.

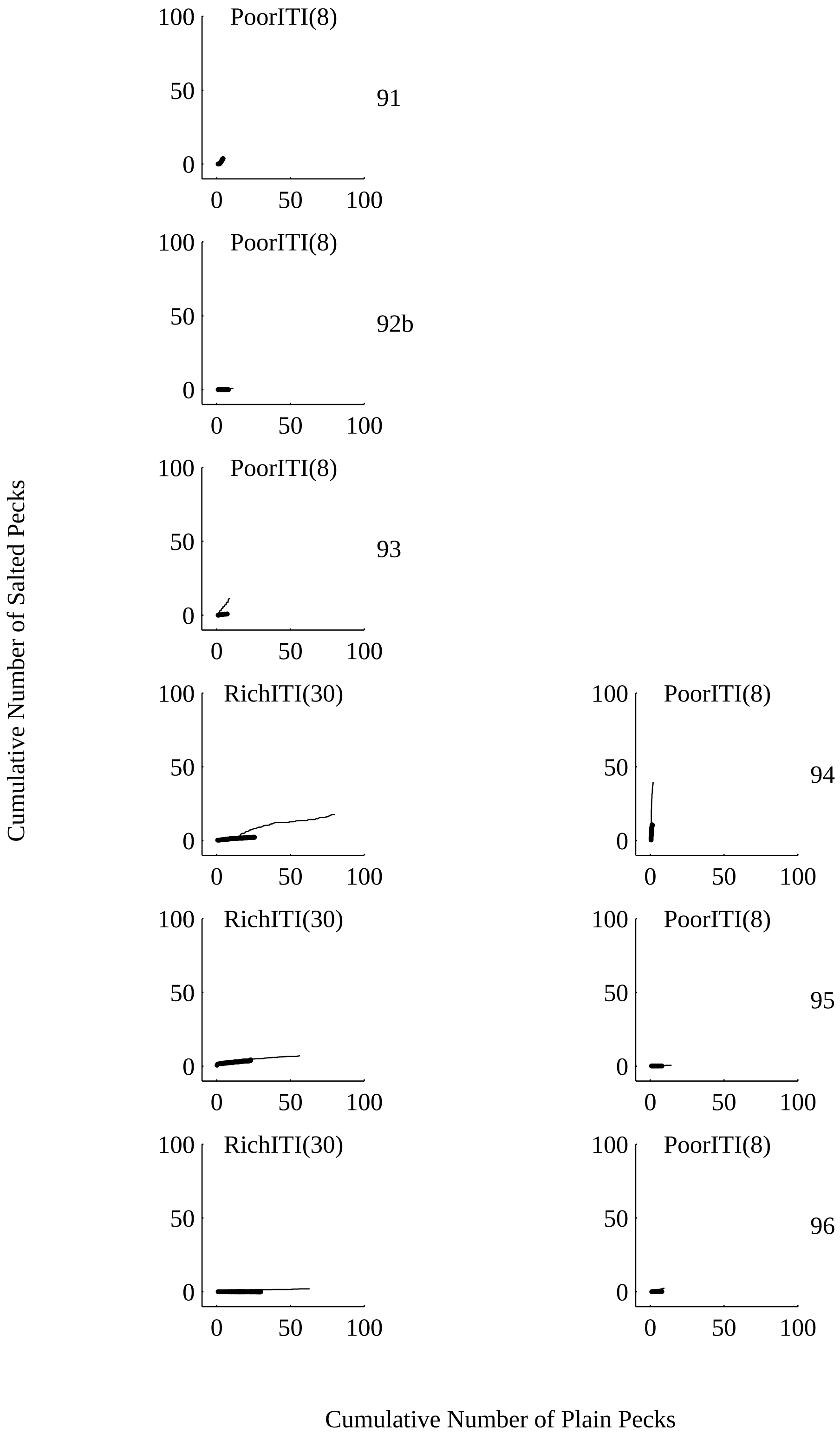

Figure 17. Experiment 3b: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

addition of ITI responses showed a pattern of responding on both keys throughout the session whereas not including the ITI responses showed nearly-exclusive responding on the plain-wheat key for these hens.

The durations of eat time for salted and plain wheat are presented in Figure 18. As in Experiments 2 and 3a, the patterns were similar to response patterns except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. Overall, more responding on a key tended to be associated with longer eat times for the type of food associated with that key. Pearson correlation coefficients for eat times versus wheat weights and sample sizes are shown in Table 19. When eat times and their respective wheat weights were zero, the pair was omitted from analysis to avoid inflating the correlations. Correlation coefficients were undefined for samples that had no variability in either eat time or wheat weight or for samples that had less than two pairs of data; undefined values occurred for salted wheat in Hen 92b's Poor Condition and Hen 96's Rich Condition. There were differences in correlations between birds and the two types of wheat, but no consistent differences were found. For the 3 hens exposed to both conditions, correlations were similar. Statistical significance of the coefficients was tested using an alpha level of .05. All significant correlations were large (Cohen, 1988) and positive: 8 out of 9 for plain wheat and 4 out of 9 for salted wheat or 9 out of 12 in the Poor Conditions and 3 out of 6 in the Rich Conditions. Sample sizes varied and ranged from 0 to 19.

Hens' salted- and plain-ITI responses are displayed in Figure 19. All hens responded during the ITI for at least some sessions and all hens responded more frequently early in the experiment. Hen 91 usually responded less than 10 times on either key during most sessions besides a burst of up to 126 salted-wheat ITI

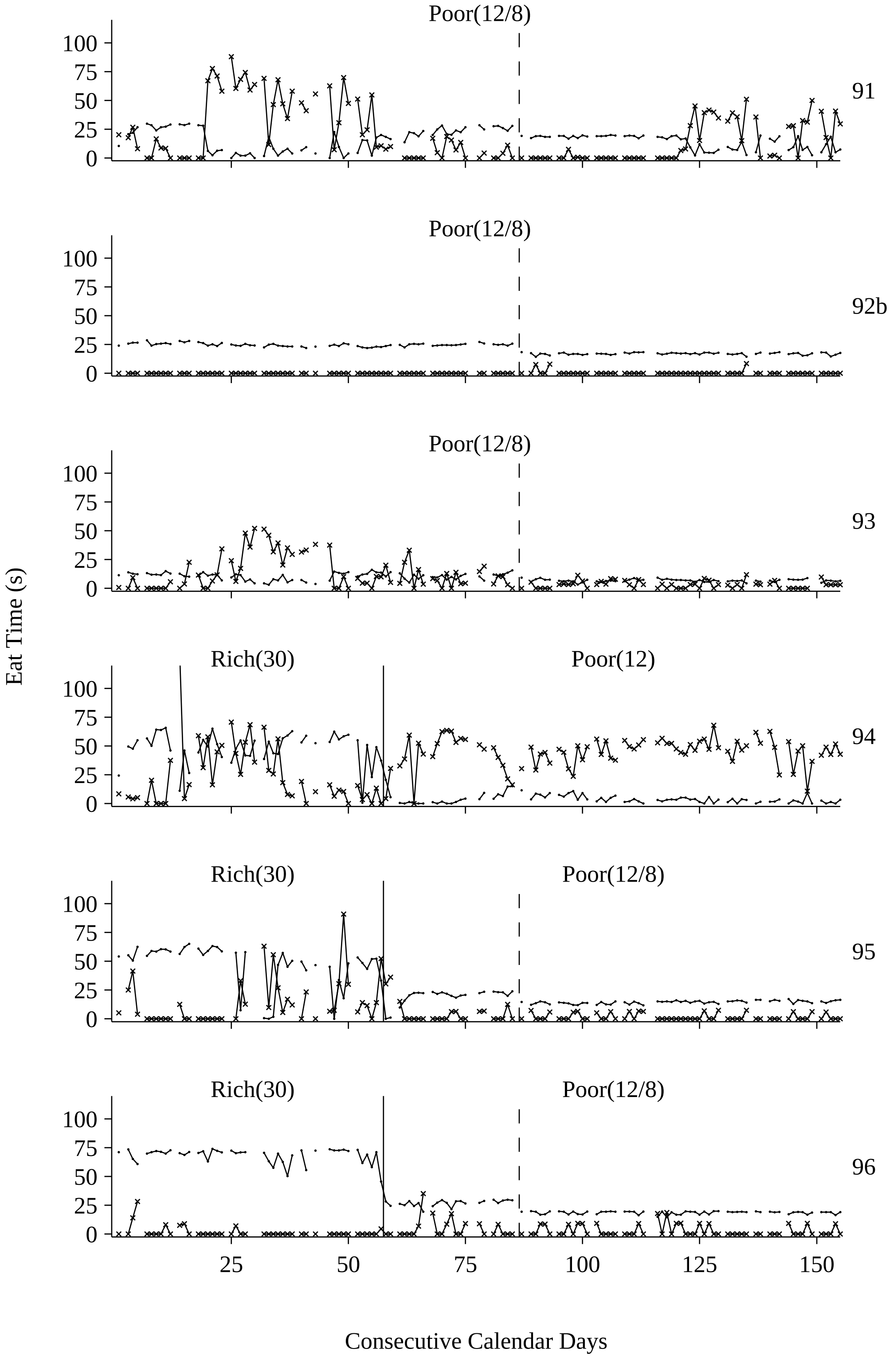

Figure 18. Experiment 3b: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

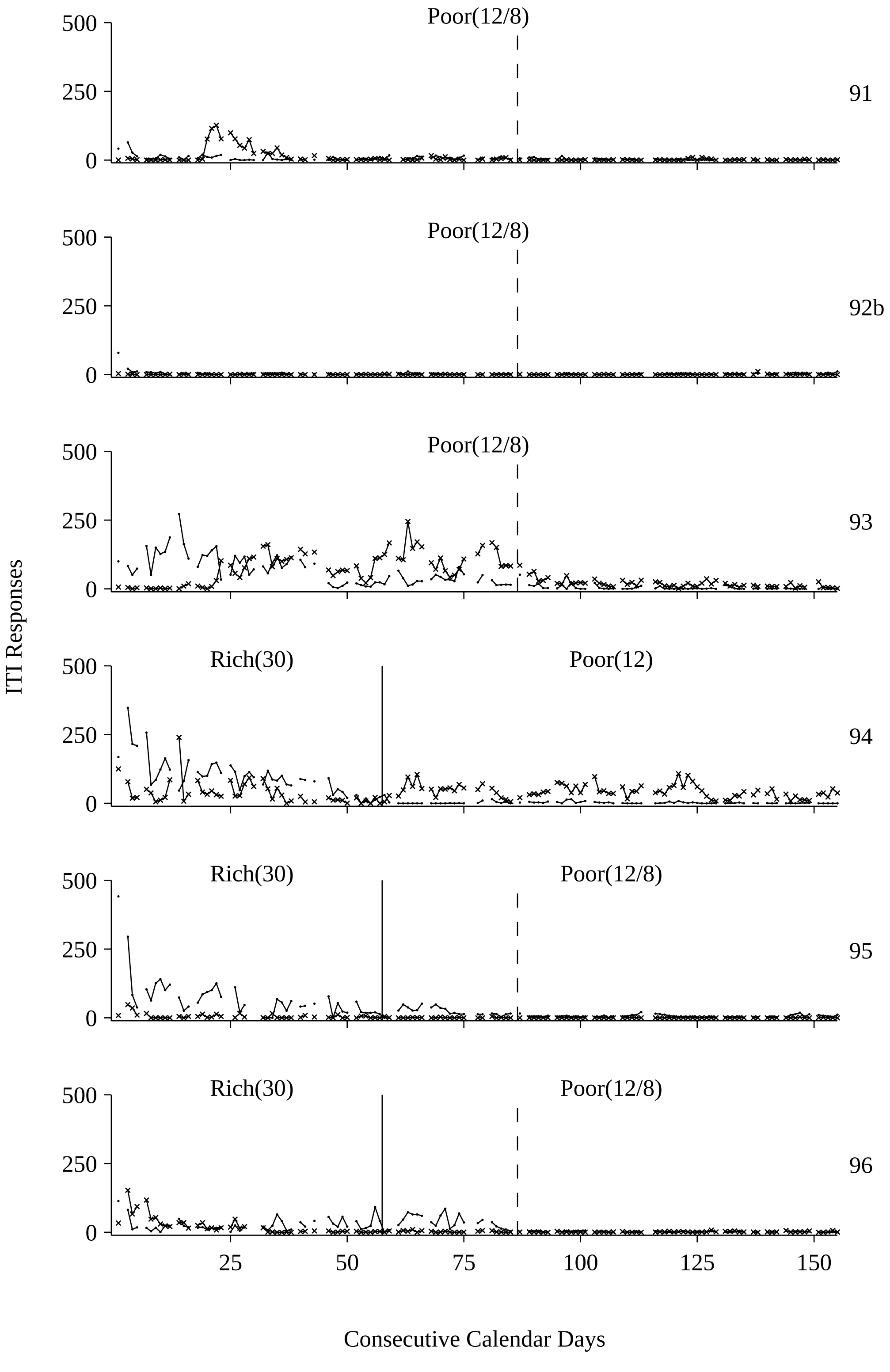

Figure 19. Experiment 3b: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

Table 19
Experiment 3b: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions			
	Plain Wheat		Salted Wheat	
Hen	Poor		Poor	
91	.86*		.92*	
	(18)		(12)	
92b	.54*		U	
	(19)		(0)	
93	.82*		.98*	
	(19)		(14)	
	Rich	Poor	Rich	Poor
94	.96*	.94*	1*	.84*
	(7)	(10)	(6)	(12)
95	.97*	.97*	.85	1
	(6)	(12)	(4)	(2)
96	.59	.60*	U	.99
	(7)	(12)	(1)	(3)

*p<.05

pecks during several sessions early in the Poor Condition. Hen 92b typically responded less than 5 times on either key throughout the Poor Conditions but more often on the plain-wheat key. Hen 93 responded between about 30 and 200 times on both keys in the Poor Condition before the total number of trials was reduced, with more plain-wheat-key responses early in the condition, then reversing to more salted-wheat-key responses towards the end of the condition. For this hen, responding on both keys usually remained below 30 following the reduction of trials. Hen 94 usually responded approximately 100 times on the plain-wheat-key and about 30 times on the salted-wheat key early in the Rich Condition. When Hen 94’s condition changed to Poor, plain-wheat ITI pecks tended to remain below 10 and salted-wheat pecks stabilised between 30 and 100 pecks. Hen 95 responded up to 295 times on the plain-wheat key and responding decreased to around 50 pecks in the Rich Condition. During this condition there were only occasional salted-wheat ITI pecks, usually occurring less than five times. For this bird in the Poor Condition, salted-wheat key responses were rare and plain-wheat key responses remained at or below 50 for several sessions and then declined to 5 or fewer on most subsequent sessions. Hen 96 generally responded similarly to Hen 95, approximately 20 times, on both keys at the beginning of the Rich Condition, but then usually fewer than 5 times on the salted-wheat key at the end of this condition. This tendency continued through the beginning of the Poor Condition and then responding on both keys tended to remain below five responses when the number of trials in the Poor Condition decreased.

Table 20 summarises ITI responses across all conditions and shows the percentage of plain- and salted-wheat ITI responses. In Experiment 3a, data were presented for responding occurring during magazine presentations; for the current and other experiments utilising ITIs, the ITI began timing when an effective response occurred. So, ITI responses and the during-magazine responses were the same kind of responding—any key pecks that were not effective key pecks. Hen 92b and 95's ITI responses occurred mostly on the plain-wheat key with 8% or less occurring on the salted-wheat key while Hens 91, 93, 94, and 96's ITI responses occurred mostly on the salted-wheat key with 35 to 62% or responses occurring on this key. Total ITI responses on the plain-wheat key ranged from 384 for Hen 92b to 4,927 for Hen 93; total ITI responses on the salted-wheat key

Table 20
Experiment 3b: Total ITI Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	669	38	1106	62
92b	384	92	33	8
93	4927	43	6491	57
94	4745	47	5304	53
95	3950	93	283	7
96	2230	65	1175	35

ranged from 33 for Hen 92b to 6,491 for Hen 93.

Table 21 shows pre-session body weight means for the last 20 sessions of each condition and Figure 20 shows hens' pre-session body weights plotted across days. Mean body weights of Hens 94, 95, and 96 tended to be lower in the Poor Condition than in the Rich Condition. All hens' body weights were similar to body weights in corresponding conditions of Experiment 3a except for Hen 94's body weight in the Poor Condition. This hen's body weight was comparable to its body weight in the Rich Conditions of both experiments.

Table 21
Experiment 3b: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions	
Hen	Poor	
91	1567	
92b	1427	
93	1616	
	Rich	Poor
94	2034	1963
95	1831	1515
96	1734	1536

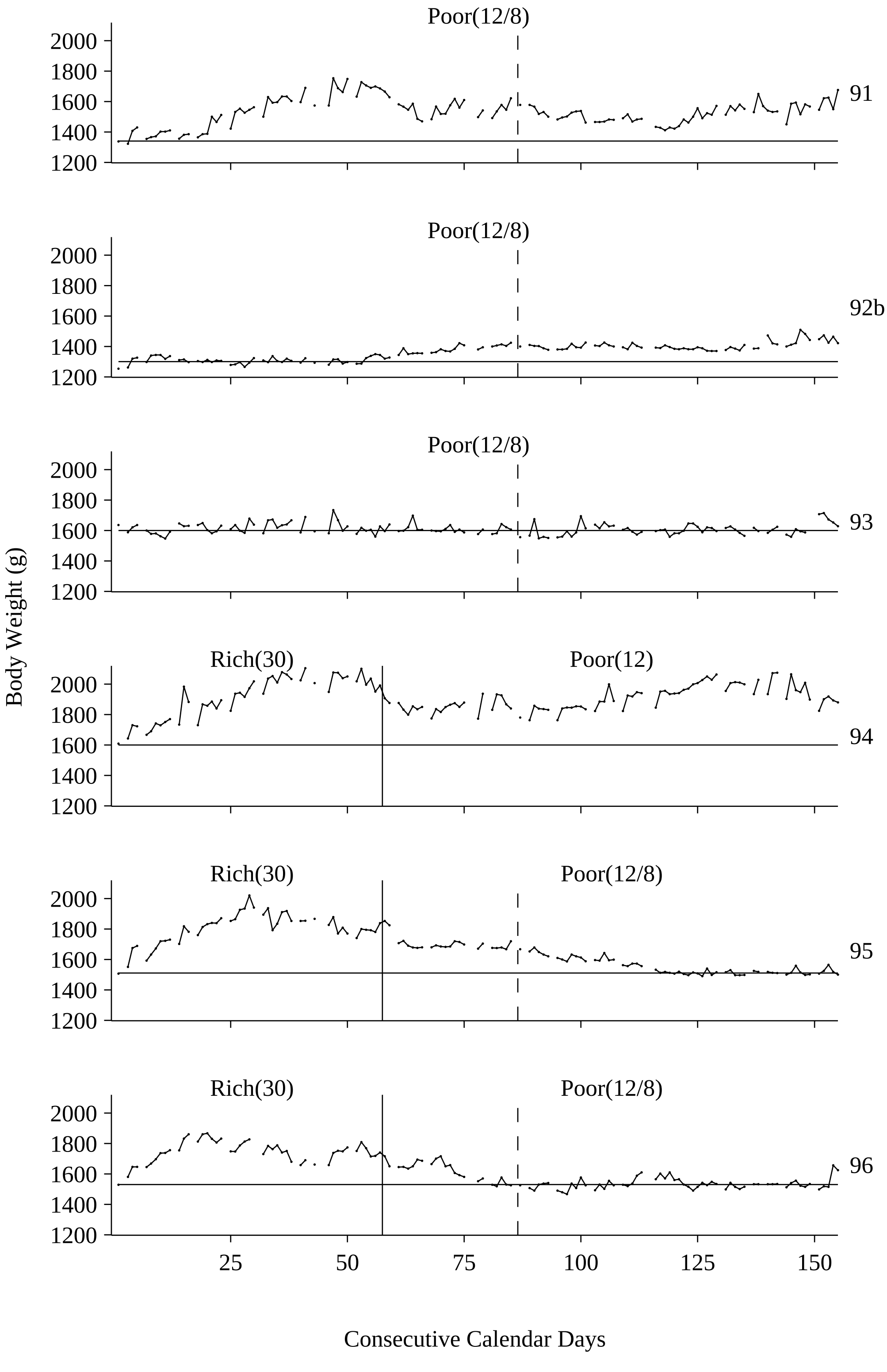

Figure 20. Experiment 3b: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate changes in the programmed number of trials, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the maximum number of trials possible for each condition.

Discussion

The purpose of this experiment was to investigate the effects of a fixed-length ITI when added to the procedure of Experiment 3a. It was hypothesised that the ITI would increase the variability of responding between the two keys, thereby increasing he chances of an inferior- or relative-inferior-good effect occurring. Variability did increase for some hens, but the effects were not found for hens not previously showing the effect (i.e. for all hens except Hen 94). The addition of the 60-s ITI was accompanied by ITI responses that decreased across sessions for most birds, as they did in Experiment 2. The data from Figure 19 should be interpreted with caution because the length of time for ITI responses changed with conditions such that fewer trials result in shorter ITI time overall (60 s for each trial). The variability of effective responses increased for all hens except Hens 94 and 96 when compared with responding in Experiment 3a. Hen 94's behaviour was already variable in Experiment 3a and Hen 94 showed little variability in both experiments.

Hen 94 was the only hen to show the inferior-good effect in the current experiment. The effect also occurred for this hen across all three condition changes in Experiment 3a. The only other hen to show the effect in this previous experiment was Hen 93 in its first condition change. Across the three condition changes for 3 hens in the current experiment, the inferior-good effect only occurred for one change. So, salted-wheat responses did not change opposite to income changes as often as in Experiment 2, Silberberg et al., or Hastjarjo et al. The weaker, relative-inferior-good effect found when both wheats' had positive income elasticities in Experiment 2 was not found in the current experiment because salted-wheat responses were rare for Hens 95 and 96. Hen 95's income elasticities actually showed the opposite effect, with salted-wheat responding being more sensitive to income changes than plain-wheat responding. The results of the current experiment show salted wheat to be an inferior good for 33% of condition changes (one of three, and only for Hen 94) as it was of a lower value, cost than plain wheat, and it involved more responses with decreases in income. Also, the eat-time data shown in Figure 18 along with the large significant correlations shown in Table 19 suggest that effective responses were followed by wheat consumption.

If responding in the first condition of the current experiment is compared with responding in the last condition of Experiment 3a for each of the 6 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the Rich Condition indicating an inferior-good effect only for Hens 91 and 93. For the same comparison, the median number of plain-wheat responses was lower in the Poor Condition than in the Rich Condition for all 6 hens. Overall, if the final non-fixed-ITI condition of Experiment 3a is used for comparison with data from the fixed-ITI conditions of current experiment, then nine condition changes occurred (one change for Hens 91, 92b, and 93 and two changes for Hens 94, 95, and 96). The median number of salted-wheat responses was higher in the Poor Condition than in the Rich Condition indicating an inferior-good effect on three occasions (one occasion for each of Hens 91, 93, and 94). The median number of plain-wheat responses was lower in the Poor Condition than in the Rich Condition on all nine occasions. So, this between-experiment comparison shows salted wheat to be an inferior good for 33% of condition changes. These data should be interpreted with caution because the latter experiment included an ITI while the former did not. It is therefore not possible to separate the effects of the ITI from the effects of the condition change on responding.

The within-session patterns of early intended-inferior-good consumption and late intended-superior-good consumption found in Hastjarjo et al. (1990a), Silberberg et al. (1987), for Hens 73a, 74, and 75 in Experiment 2, and slightly for Hen 94 in Experiment 3a was found only in Hen 94's Poor Condition. The possibility of this pattern being important for the inferior-good effect, then, remains. The addition of ITI responses to within-session responding changed the patterns for Hens 93 and 96 from nearly-exclusive plain wheat responding to responding on both keys throughout the session. This difference in pattern reflects both hens' tendency to respond on the salted-wheat key during the ITI and on the plain-wheat key when responses were effective. If the percentage of effective and ITI responses are compared between Table 17 and Table 20, it can be seen that percentages differed by 10% or less for Hens 92b, 94, and 95, and by 28% or more for Hens 91, 93, and 96. So, for the former hens, effective and ITI responses were more strongly correlated then for the latter hens. Further, the change in pattern with the addition of ITI responses can be seen for 2 of these 3 latter hens, Hens 93 and 96 in Figure 17, suggesting that for at least the last 20 sessions of this hen's Poor Condition effective and ITI responses were not strongly correlated (otherwise, the pattern would not have changed). For all hens except Hen 95, the percentage of salted-wheat responses was higher for ITI responses than for effective responses, showing that these 5 hens responded on both keys but responded on the salted-wheat key proportionally more during the ITI than during trials.

These results challenge the hypothesis that the ITIs in Experiment 2 and in Silberberg et al. (1987) exerted stimulus control over temporally-extended behaviour patterns or suggest that the effect in the current and published total-trials experiments occurs for different reasons. The ITIs in the current experiment were accompanied by at least occasional ITI responses for all birds and clearly did increase variability in sessions for at least 4 of 6 hens: Hens 91, 93, 94, and 95. Hen 95 did not show the effect, but the addition of the ITI in the Rich Condition was accompanied by more salted-wheat responding than in previous conditions.

So, ITIs, fixed or varied, seem to be important for the effect because they at least provide time for behaviour to vary and perhaps increase the chances of hens' behaviour contacting the contingencies involved with both keys. Forced choices, as in Hastjarjo et al. (1990a), may have also had this effect. Whether ITIs and their accompanying houselights also exerted stimulus control over responding is still unknown. However, given that Hastjarjo et al. found the effect without the variable ITI, a parsimonious explanation would account for the inferior-good effect by identifying the common elements of all experiments demonstrating the effect.

One aspect of similarity in Experiment 2, Experiment 3a, Experiment 3b, and the Hastjarjo et al. (1990a) study was that subjects' body weights tended to be higher in the Rich Condition than in the Poor Condition. Additionally, the body weight of one of the monkeys in the Silberberg et al. (1987) study decreased to 74% of its free-feeding weight during the Poor Conditions (body weight data from the other monkey was not presented). So, body weight co-varied with overall reinforcement. It may be the case, then, that changes in overall reinforcement caused changes in body weight that, in turn, caused shifts in responding. That is, overall reinforcement may be non-specific in its effects.

The effects of body weight on behaviour have been examined across species and behaviours. Early studies have shown that organisms generally become more active with weight loss (Bolles, 1967 as cited in Collier, 1969). Collier (1969) found that chickens' response rates increased as body weight decreased; however, when body weights decreased beyond 75% chickens response rate slowed. He also found that wheel running and treadmill running increased with decreases in body weight to at least 80 to 70% of free-feeding weight. Snyderman (1983a) showed that when rats responded under VI schedules at 70% and 90% of their free-feeding weight, rats' asymptotic rate of responding was higher for the lower body weight. McSweeney (1974) found that when pigeons responded under unequal concurrent VI schedules, response rates increased when body weights decreased from 110% of free-feeding weight to 80%. Pigeons at the higher body weights, usually above 100% of their free-feeding weight, had higher coefficients of variation of daily response rates than at lower body weights. Snyderman (1983b) arranged an experiment where pigeons responded to a key lit one of two colours where one colour was associated with three times as much food as the other. The key colour changed as the pigeons waited. Birds responding at 80% of their free-feeding body weight tended to be more impulsive than birds responding at 95%; that is, response ratios tended to approach one for birds at 80% while ratios tended to move towards the key associated with the larger food amount for birds at 95%. Similarly, Herrnstein and Loveland (1974) found that response ratios deviated from reinforcement ratios as body weights decreased from 105% to 80% of pigeons' free-feeding weights when birds responded under unequal concurrent VI schedules. Baum (1974) interpreted Herrnstein and Loveland's findings as evidence that deprivation (as evidenced by % of free-feeding body weight) is one of the variables that affects the sensitivity parameter in the generalised matching law whereby organisms' behaviour is less sensitive to reinforcement as body weight decreases. So, when an organism's body weight decreases, the literature suggests that response rates should increase to a point and then decrease with further decreases in body weight, that more spontaneous activity should occur, and that sensitivity to reinforcement should decrease (thus, creating undermatching in matching experiments). There is also some evidence that when body weights are high enough, variability of response rates increase (McSweeney).

Biological literature relating to body weight is not scarce. Two prominent theories have attempted to account for data in this literature—set-point and settling-point theories. Both theories state that body weight is regulated metabolically and behaviourally such that homeostasis (a steady state of body weight) is achieved. In homeostatic systems, negative feedback signals reverse change while positive signals amplify change (Campbell & Reece, 2002). In terms of body-weight set or settling point, negative feedback signals should cause bodyweight to decrease towards the point and positive feedback signals should cause bodyweight to increase towards the point.

Pinel (2000) describes how set-point might work in humans:

> .when fat deposits are below a person's set point, a person becomes hungrier and eats more, which results in a return of body-fat levels to that person's set point; and conversely...when fat deposits are above a person's set point, a person becomes less hungry and eats less, which results in a return of body fat levels to their set point. (p. 264)

Here, *hunger* may be interpreted as physiological changes that increase or decrease the chances of eating, a positive feedback signal. Settling-point theory is similar in that a body weight is defended metabolically and behaviourally; however, this body weight is defended not in relation to a set body weight, but by limiting body weight changes in the same direction. "The idea is that as body-fat levels increase, changes occur that tend to limit further increases until a balance is achieved between all factors that encourage weight gain and all those that discourage it" (Pinel, 2000, p. 266). These two theories will not be compared or contrasted further, rather, some of the metabolic and behavioural mechanisms that might be related to both theories will be highlighted to show that changes in body weight can affect metabolism and behaviour.

According to Leibel, in the 1940's and 50's, Hetherington and Branson were the first to find that two centres in the hypothalamus part of the brain are involved in weight regulation (Gibbs, 1996). The ventromedial hypothalamic region (VMH) was thought to be responsible for satiety and the lateral hypothalamus, hunger (for a critique see King, 2006). Early rationales were based on experimentation that showed that animals, usually mammals, with lesions at the VMH gained weight. Animals would then *defend* this new body weight both metabolically and behaviourally. Behavioural mechanisms might include behaviour leading up to and involving food consumption. According to a wide body of research, these behavioural mechanisms can be influenced by several metabolic mechanisms that function as satiety signals, usually peptides released into the blood from receptors in the gastrointestinal tract (Leibowitz, 1992 as cited in Pinel, 2000). Leibel (Gibbs, 1996) highlights some of the well-known metabolic mechanisms across a variety of species, again usually mammals, that involve the following humoral factors: insulin, leptin, neuropeptide Y (NPY), glucagon-like peptide 1 (GLP-1), cholecystokinin (CCK), and corticotrophin releasing factor (CRF).

Insulin is a pancreatic peptide hormone and is secreted in an animal's bloodstream in relation to its body fat (adiposity) such that more adiposity results in more insulin, less adiposity, less insulin (Ley et al., 1996, as cited in Pinel, 2000). Biologists refer to this release of insulin as a negative feedback signal because it decreases food intake (Pinel, 2000). Evidence for insulin as a negative feedback signal include the discovery of insulin receptors in the brain (Baura et al., 1993 as cited in Pinel, 2000) and findings that infusions of insulin in the brain are accompanied by less eating and lower body weight (Campfield et al., 1995; Chavez, Sealey, & Woods, 1995 as cited in Pinel, 2000).

Leptin is a protein that is produced by the stomach (Pico', Oliver, Sa'nchez, & Palou, 2003) and by adipose tissue (Y. Zhang et al., 1994) and is also considered a negative feedback signal (Seeley & Schwartz, 1997 as cited in Pinel, 2000). Evidence for leptin as a negative feedback signal is similar to the evidence for insulin. Schwartz et al. (1996a as cited in Pinel, 2000) found that levels of leptin in the blood of animals and humans correlates with levels of adiposity. There are also receptors for leptin in the brain (Schwartz et al., 1996b as cited in Pinel, 2000). Finally, injections of leptin into mice that have genes predisposing them to obesity (ob/ob mice) have been shown to reduce food consumption and adiposity (Campfield et al., 1995 as cited in Pinel, 2000).

NPY and GLP-1 may mediate the effects on leptin and insulin in the central nervous system. When NPY is injected into the cerebral ventricles or the hypothalamus of the brain of rats, food intake increases (M. W. Schwartz, Woods, Porte, Seeley, & Baskin, 2000). NPY levels also increase with decreases in adiposity and with decreases in leptin and insulin in the brain (M. W. Schwartz et al.). GLP-1, an incretin hormone, is secreted into the blood from cells in the gastrointestinal tract when meals containing large amounts of carbohydrates and fats are ingested (Meier, Nauck, Schmidt, & Gallwitz, 2002). The hormone’s main effect is that it stimulates insulin secretion, thereby accompanying a reduction in food intake.

Finally, CCK and CRF are both negative feedback signals. CCK is peptide that is secreted into the blood from cells in the gastrointestinal tract and has specific receptors (M. W. Schwartz et al., 2000). Gibbs, Young, & Smith (1973 as cited in Pinel, 2000) found that rats ate smaller meals following CCK injections. CRF is a neuropeptide that is part of a system involving other peptides and CRF receptors that influence food intake (Richard, Lin, & Timofeeva, 2002). For example, in neonatal chicks injections of CRF were shown to decrease food consumption (R. Zhang et al., 2001).

In a review of temporal control of feeding in fowls, Savory (1999) claimed that over a dozen peptides are released in fowls' digestive tracts. Of these peptides, he highlights CCK and another peptide, bombesin (BBS), as proposed satiety agents (negative feedback signals). When these peptides were injected into fowls, feeding was suppressed in the following 15 to 30 min. However, the injections may have caused abdominal discomfort which then caused the suppression. The evidence for the role of peptides and other chemicals in feeding behaviour of fowls is somewhat sparse. It may be the case that combinations of peptides contribute to satiety (Savory); overall, though, the role of metabolism with respect to body weight is at least partially understood.

So, metabolic changes occurring with weight changes or changes in food consumption have been shown to affect behaviour (namely food procurement and consumption). The function of body weight, with respect to food consumption, then, should be describable in behavioural terms. It has been shown that the net effects of weight loss or gain are an increase or decrease in food consumption, respectively. Body weight, then, may function as an establishing operation (EO) or abolishing operation (AO). According to Michael (1993), an EO is:

> an environmental event, operation, or stimulus condition that affects an organism by momentarily altering (a) the reinforcing effectiveness of other events and (b) the frequency of occurrence of that part of the organism's repertoire relevant to those events as consequences. (p. 191)

Additionally, EOs may increase the effectiveness of S^Ds associated with reinforcers, thereby operating on all three terms of the three-term contingency (Dougher & Hackbert, 2000). Where an EO increases effectiveness of S^Ds and reinforcers as well as increasing behavioural frequencies, an AO decreases effectiveness of S^Ds and reinforcers as well as decreasing behavioural frequencies (Laraway, Snycerski, Michael, & Poling, 2003).

In the published inferior-good studies and in the current series of experiments, body weight was low and the inferior-good tended to be consumed more in Poor Conditions then in Rich Conditions. Across all of these studies, the two goods differed along the dimensions of quality (taste) and quantity, so these two dimensions may have differentially affected responding according to their respective EOs and AOs. According to McSweeney and Murphy (2000) some of the previously-discussed humoral factors such as CCK are satiety factors and they can be behaviourally defined as AOs (Murphy, McSweeney, Smith, & McComas, 2003). In the current series of experiments, the reinforcing effectiveness of the quantity dimension may have changed with these humoral satiety factors such that the quality dimension became more controlling as quantity became abolished (Experiment 1 provided evidence that the quality dimension controlled consumption when quantities were equal). Additionally, McSweeney and Murphy highlighted the role of oral stimulation in satiation, suggesting that repeated food presentations can cause habituation whereby feeding decreases as a result (also an AO, according to Murphy et al.). Repeated presentations of each type of wheat would be expected to abolish their own reinforcing effectiveness due to oral factors and satiety factors, but at different rates given the different quality and quantity of each. For birds at high body weights, then, the quality dimension (the intended superior good) may have had more control due to the decrease in reinforcing effectiveness of the quantity dimension, while for birds with low body weights, the quantity dimension (the intended inferior good) may have had more control. In short, values (as defined by Equation 6) of each reinforcer may have been different at high and low bodyweights. This account fits the data of the published inferior-good studies as well as the studies in the current series, even though each experiment found the inferior-good effect with different procedures.

An interesting finding of Experiment 2 was the immediate change in responding in the first session of the replication of some conditions for Hens 75 and 76a. Figure 2 shows an immediate shift to exclusive responding to the plain-wheat key in the first session of the second Rich Condition for Hen 75 and an immediate shift to responding on both keys in the first session of the second Poor Condition for Hen 76a. For both of these hens, responding in the previous sessions during the previous condition was much different. Such immediate shifts suggest some kind of antecedent control. Although ITIs may have functioned as such, the more-parsimonious argument was that body weight varied with condition changes and that body weight functioned as an EO or AO for the quantity dimension of food as a reinforcer. Body weights in the current series of experiments, then, would have also varied with houselight colours such that high body weights were associated with one colour and ITI length and low body weights with the other colour and ITI length. Through this differential paring with body weights houselights and perhaps ITIs may have become conditioned EOs (CEOs).

CEOs, “are variables that alter the reinforcing effectiveness of other events, but only as a result of the individual organism’s history” (Michael, 1993, p. 198). If houselights and perhaps ITIs were CEOs in Experiment 2, then the short ITIs (blue houselights) increased the reinforcing effectiveness of the 3 s of plain wheat and the long ITIs (amber houselights) increased the reinforcing effectiveness of the 10 s of salted wheat. Houselights and ITIs can be further categorised as surrogate CEOs (Michael) because they were previously-neutral stimuli that were correlated with body weight, the hypothesised EO. The sight of snow is an example of a surrogate CEO (McGill, 1999). Through being correlated with cold weather, the sight of snow may be enough to increase the effectiveness of warm clothing as reinforcers, may increase behaviour associated with the attainment of warm clothing, and may increase the effectiveness of S^Ds associated with behaviours that bring about warm clothes. As such, houselights and perhaps ITIs may have come to function as body weight functioned because of their continued correlation with body weight.

In Experiment 2, both melioration and maximisation were discussed and both could account for the inferior-good effect with the conceptualisation of the ITIs and houselights as S^Ds or conditional stimuli. Melioration required an additional parameter reflecting overall reinforcement in Equation 6 and a perspective of temporally-extended behaviour under stimulus control (or conditional stimulus control). Maximisation was difficult to disprove due to its reliance on unobservable utility functions. If houselights and ITIs are conceptualised as surrogate CEOs or as surrogate conditioned AOs (CAOs) and body weights as EOs or AOs, then can both melioration and maximisation still account for the effect?

Other studies have found changes in responding with changes in overall reinforcement and the problems that these data have presented to the matching equations have been discussed. Elsmore, Fletcher, Conrad, and Sodetz (1980) manipulated income by changing the ITI between trials for monkeys' responding reinforced by heroin and food pellets. When income increased, monkeys responded more often on the heroin key than when income was low. Hursh and Natelson (1981) conducted a similar experiment between electrical brain stimulation (EBS) and food when rats responded under two equal VI schedules. Income increased by decreasing the variable time interval and these increases were accompanied by more responding on the EBS lever than when income was low. In a study examining rats' responding under equal VI schedules where food and a saccharin solution were available, experimenters found that increasing income by decreasing the variable interval time caused more responding on the saccharin lever (Shurtleff et al., 1987). All of these studies, the published inferior-good studies, and some data from the current series of experiments showed shifts in responding when qualitatively-different reinforcers were available and when overall reinforcement changed. As discussed previously, these data imply an additional parameter in Equations 1, 2, and 3 for the matching law to hold. Baum (1979) and Herrnstein (1981) responded to data showing changes in preference for quantitatively different reinforcers with changes in overall reinforcement rate by suggesting that reinforcers sate at different rates. Shurtleff et al. agree, for example, "the failure to observe constant choice ratios may reflect within-session changes in reinforcer value due to change in deprivation or other, unspecified establishing operations, rather than a predictive failure of matching theory" (1987, p. 274). This account preserves melioration but does not suggest that either melioration or maximisation is better at accounting for the inferior-good effect. Conceptualising the stimulus conditions of each condition as CEOs or CAOs and body weights as EOs or AOs does not challenge maximisation because they can be seen as variables that affect utility. With respect to Equation 6, if EOs or AOs differed between Rich and Poor Conditions while the other dimensions remain constant, then each reinforcer's value may have differed between conditions. Responding, then, should have changed across conditions as a result of the changing reinforcer values, and it did.

If the stimulus conditions of condition changes functioned as CEOs or CAOs and if body weights functioned as EOs or AOs, then the absence of the effect in Experiment 3a and parts of Experiment 3b may be body-weight related. If hens' body weights never became low enough to establish quantity as a reinforcer (e.g., if body weights rarely fluctuated under each birds' "body-weight set point", assuming that such a point or something like it exists), then the bird would be expected to consume mostly plain wheat. This tendency was found in Experiment 3a and parts of Experiment 3b. Birds in all experiments thus far received post-session food if their body weights fell below their post-feed threshold (approximately 80% of their free-feeding weight, see Experiment 1). So, it may have been the case that birds' "set points" were below their post-feed threshold, thus they may have never reached their "set points" due to the post-session feedings and therefore the EO for the 10 s of salted wheat may never have been in effect. Ethical requirements precluded decreasing birds' body weights below 80% of their free-feed thresholds, so testing this hypothesis by lowering body weights was not possible. Instead, the next experiment re-evaluated birds' post-feed thresholds to ascertain the possibility of re-running the experiment at lower body weights, should the thresholds be shown to be too high.

Experiment 4: Post-Feed Threshold Re-Assessment (Group 9)

If set-point theory (Gibbs, 1996) is an accurate explanation of how hens maintain body weight, then deviations from this set point should be met with changes in behaviour whereby the net result is a change in body weight towards the set point. In this respect, body weight may serve as a an EO or AO whereby body weights above set point abolish the quantity dimension of wheat as a reinforcer allowing the quality to control responding (with the opposite relation for body weights below set point). If EOs and AOs are viewed as parameters affecting time allocation or responding, then they can be seen as parameters that may affect reinforcer value as in Equation 6.

In Experiment 3a and Experiment 3b, if birds' post-feed thresholds (i.e., their approximate 80% body weights as described in Experiment 1) had been set too high, then they would have been post fed following any sessions where their body weights fell below this weight, thus keeping their body weights above the set point for establishing the quantity dimension of wheat as a reinforcer. If, on the other hand, birds' post-feed thresholds had been set under their set-points, then the lack of the inferior-good effect could not be attributed to the lack of contact with set points. Ethically, birds' body weights were not allowed to fall under their post-feed threshold without them receiving supplemental feed to return their body weights to at or above this threshold. So, if the thresholds were too high, then re-evaluating birds' free-feeding weights and recalculating their post-feed thresholds may have resulted in lower thresholds. The current experiment re-evaluated post-feed thresholds of 6 of the 7 subjects from Experiment 3a and Experiment 3b by allowing birds to free feed and re-calculating their post-feed threshold (as in Experiment 1) for use in a replication of Experiment 3a and Experiment 3b.

Method

Subjects

Subjects were the 6 Group-9 hens of Experiment 3b and were numbered 91, 92b, 93, 94, 95, and 96. The experiment occurred in the hens' home cages located in the same room as described in Experiment 1. Water, standard food pellets, and grit were continuously available. Experimenters weighed each hen approximately every other day and hens were given grit approximately twice weekly and vitamins approximately weekly.

Apparatus

The digital hanging scale and cone from Experiment 3a were used to weigh subjects. Hens consumed food pellets from small plastic feed containers inside of their home cages.

Procedure

Experimenters fed hens daily by topping off each hens' feed container with pellets. As in previous experiments, experimenters weighed each hen approximately daily. The experiment ended when body weights reached visual stability such that no trend was evident for at least 5 sessions.

Results

Figure 21 shows daily body weights of all birds across 47 consecutive days in Experiment 4. All body weights increased for approximately 15 days and then stabilised for the remaining 32 days. Stable body weights were estimated for Hens 91, 92b, 93, 94, 95, and 96 by visually inspecting Figure 21. Stable body weights were 1850 g, 1770 g, 2100 g, 2140 g, 2050 g, and 1930 g, respectively.

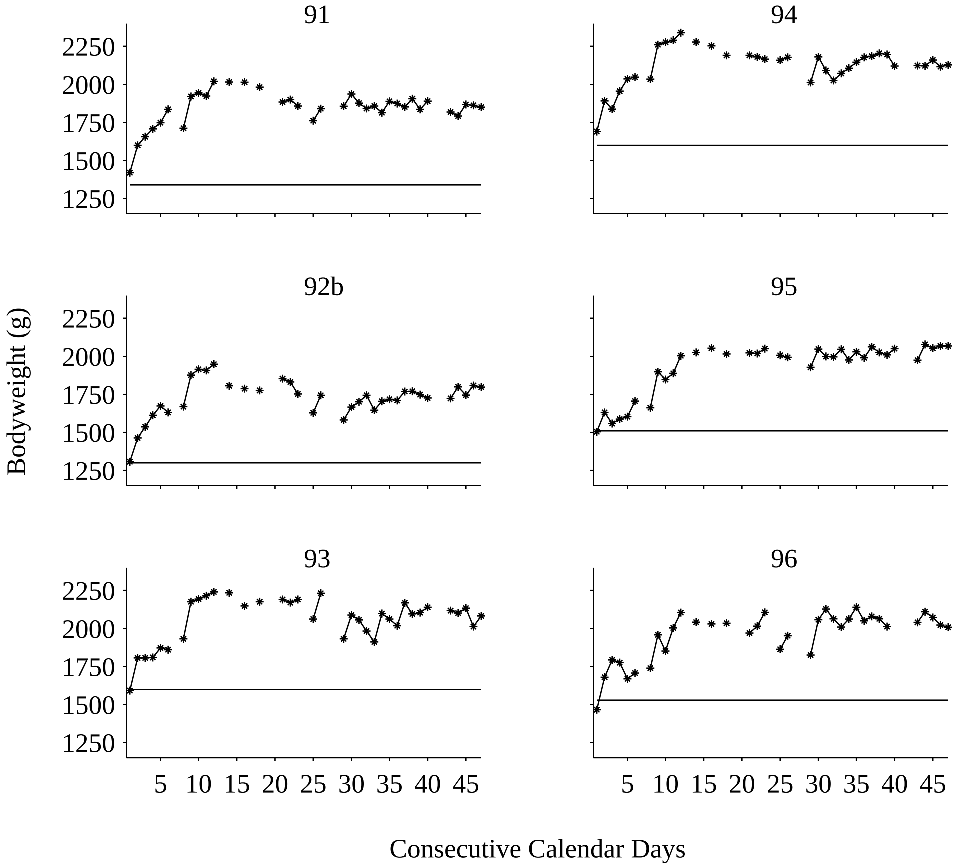

Figure 21. Experiment 4: Body weights across consecutive calendar days. Horizontal lines indicate original post-feed thresholds (approximately 80% of free-feeding body weight) used in Experiments 3a and 3b.

All body weight estimates were multiplied by 0.8 to yield new post-feed thresholds at approximately 80% of birds’ new free-feeding weights. Old and new post-feed thresholds and change in post-feed thresholds are displayed in Table 22. All new thresholds were 10 to 140 g higher than old thresholds.

Table 22
Experiment 4: Old-, New-, and Change-in-Post-feed Thresholds

	Post-Feed Threshold (g)		
Hen	Old	New	Change
91	1340	1480	+140
92b	1300	1420	+120
93	1600	1680	+80
94	1600	1710	+110
95	1510	1640	+130
96	1530	1540	+10

Discussion

Table 22 shows that for all hens, newly-calculated post-feed thresholds were higher than old post-feed thresholds. So, if Experiment 3a and/or Experiment 3b were replicated and if hens were post fed at these new post-feed thresholds, then hens would be post fed more often thereby keeping their body weights at a higher level then in the previous experiments. If hens in these previous experiments did not show the inferior-good effect because they did not reach their set point (if the EO for quantity was not in effect), then using the new post-feed thresholds in replications would not change the results. Because it was not ethically allowable to decrease body weights below 80%, the question of the birds' not reaching their set points (or at least a body weight low enough to establish quantity as a reinforcer) needed to remain unanswered.

There were at least two previously-discussed procedural differences that might account for the inferior-good effect occurring in Hastjarjo et al. (1990a), Silberberg et al. (1987), and Experiment 2, and not occurring (or occurring less convincingly) in Experiment 3a: the ITIs during the sessions and the forced choices at the beginning of sessions. In the former three experiments and in Experiment 3b, the effect occurred and the common variables were ITIs (fixed or varied) and/or forced choices. Previously, the conceptualisation of houselights and ITIs as S^D or conditional stimuli had been dropped in favour of CEOs or AEOs as the latter account was more parsimonious and fit more data. So, what about the ITIs and/or forced choices might be important?

As discussed in Experiment 3b, ITIs and forced choices increased the chances that responding would occur on both keys. ITIs increased session time thereby allowing a larger sample of behaviour to occur in which behaviour was more likely to vary than in a smaller sample. Forced choices necessarily caused responding on both keys. Behaviour needs to come into contact with contingencies in order for it to be controlled by those contingencies. Therefore, in order for the inferior-good effect to occur, behaviour needs to come into contact with the contingencies of both keys and in order for behaviour to contact contingencies of both keys, the procedure needs ITIs, forced choices, or something else that allows responding vary.

The following experiment replicated Experiment 2, but with subjects from Experiments 3a and 3b. Given that the inferior-good effect was found in Experiment 2 and that it emerged for Hen 91 when income elasticity was calculated for the change between the last condition of Experiment 3a and the first condition of Experiment 3b, it was predicted that the effect would occur with this procedure. Occurrence of the effect would provide more evidence that the varied-length ITI (Silberberg et al., 1987), as opposed to the fixed-length ITI (Hastjarjo et al., 1990a), was indeed an important variable and that subsequent experiments might further investigate the varied-length ITI. Non-occurrence of the effect would suggest further scrutiny, but the body-weight set-point issue still remains a possibility or perhaps some carry-over effects from the previous long-running experiments affected responding.

Experiment 5: Long/Short ITI (Group 9)

Experiment 2 and the Silberberg et al. (1987) study with monkeys demonstrated the inferior-good effect by manipulating income through changing the ITI of fixed-length sessions. Experiment 3a was a partial replication of the Hastjarjo et al. (1990a) study with rats and manipulated income through changing the total number of trials occurring in sessions. Although the effect occurred in the Hastjarjo et al. study, the results of Experiment 3a were not comparable—the procedure did not result in the inferior- or relative-inferior-good effect for most hens in most conditions (Hens 93 and 94 were the exceptions, and the inferior-good effect occurred only once for Hen 93). Instead, birds usually responded exclusively or nearly exclusively on the plain-wheat key. When a 60-s ITI was added to the procedure of Experiment 3a in Experiment 3b, responding varied more for all hens except Hen 92b, the inferior-good effect occurred again for Hens 93 and 94, and the effect emerged for Hen 91 (but note that this analysis of the effect involved comparison of responding between the last condition of Experiment 3a, with no fixed-length ITI) and the first condition of Experiment 3b, with fixed-length ITI). Given this increased variability and the emergence of the effect for Hen 91 (especially after over 450 days of nearly-exclusive plain-wheat responding), something about the ITI may have been important for the effect to occur.

In Experiment 2 and Experiment 3b and in Silberberg et al. (1987) and Hastjarjo et al. (1990a) the difference between the ITIs was that they varied between short and long durations across conditions or stayed at 60 s while total number of trials varied across conditions, respectively. There are no data in any of these experiments that suggest a difference in behaviour due to differences in the ITI used in income manipulations. That is, it did not seem to matter if a fixed or varied ITI was used, only if an ITI was used at all. Whether the ITI needed to be a certain duration remains an empirical question.

The current experiment was a replication of Experiment 2 with the 6 subjects from Experiment 3b. If the addition of the 60-s ITI in Experiment 3b was important for the inferior-good effect to emerge for Hen 91 (when income elasticities were calculated for the change between the last condition of Experiment 3a and the first condition of Experiment 3b) a replication of Experiment 2 with these subjects should result in the effect as well. It was expected that the results would be similar to the results of Experiment 2. If not, then carry-over effects from the previous experiments and individual bird differences, such as not reaching body-weight set point, would require closer scrutiny.

Method

Subjects

Subjects were the 6 Group-9 hens used in Experiment 4 numbered 91, 92b, 93, 94, 95, and 96 and were housed, maintained, and post fed in the same way as described in Experiment 2. The newly-calculated post-feed thresholds (from Experiment 4) were used.

Apparatus

The equipment from Experiment 3a was used for this experiment.

Procedure

The procedure was the same as the procedure of Experiment 2, except houselight colours were reversed as in Experiment 3a so that amber houselights were on in the Rich Conditions and blue were on in the Poor Conditions as in Experiment 3a. ITIs were always 40 s in the Rich Condition and 105 s in the Poor Condition resulting in a maximum of 30 and 12 trials, respectively. Hens 91, 92b, and 93 were exposed to a Poor Condition then a Rich Condition and Hens 94, 95, and 96 were exposed to the same conditions in the opposite order. The MED-PC 2© software monitored all session events as in Experiment 2 and data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a.

Results

As in previous experiments, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. Table 23 shows the median number of responses for the last 20 sessions of each condition. For all 6 income changes (1 change per hen) across the 2 conditions for all 6 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the adjacent Rich Condition on 2 occasions. This inferior-good effect occurred for Hens 91 and 94. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Rich Condition on all 6 occasions. Figure 22 shows the number of effective responses that occurred within each income condition. The patterns in these graphs follow the same patterns as described by the medians in Table 23. Additionally, Hens 91, 93, and 94 showed variability in responding across both conditions while Hens 92b, 95, and 96 showed little variability in responding regardless of condition as these hens tended to respond nearly exclusively on the plain-wheat key. Table 24 summarises responses across all conditions and shows the percentage of plain- and salted-wheat responses. For all hens except Hen 94, responses occurred

Table 23
Experiment 5: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions			
	Plain Wheat		Salted Wheat	
Hen	Poor	Rich	Poor	Rich
91	10	29	2	0
92b	12	30	0	0
93	11	24	1	6
	Rich	Poor	Rich	Poor
94	19	0.5	11	11.5
95	30	12	0	0
96	30	12	0	0

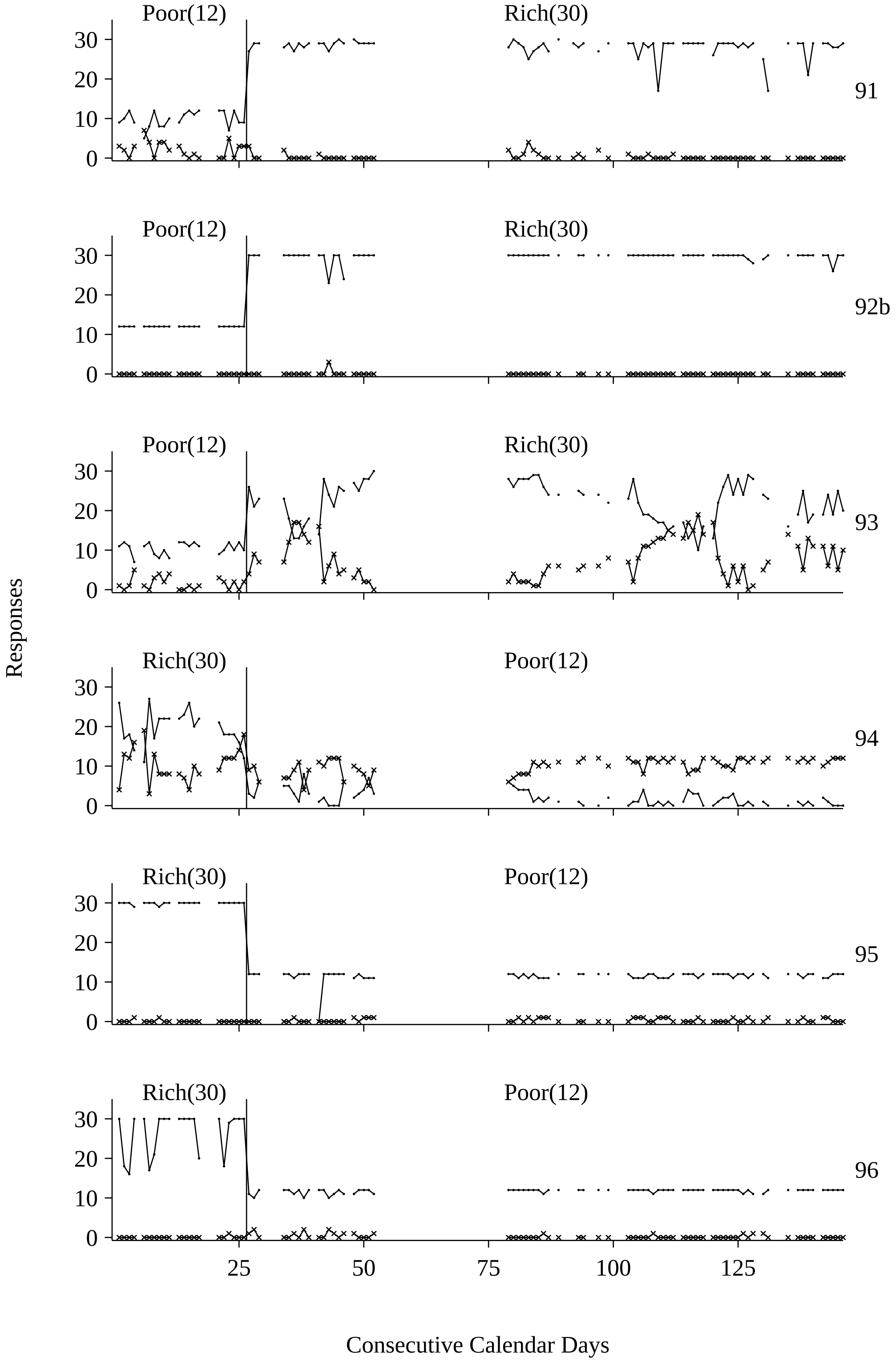

Figure 22. Experiment 5: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

Table 24
Experiment 5: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	2200	97	67	3
92b	2331	100	3	0
93	1770	75	578	25
94	543	37	927	63
95	1433	98	25	2
96	1382	99	18	1

mostly on the plain-wheat key with 0 to 25% occurring on the salted-wheat key for Hen 93 and 0 to 3% for Hens 91, 92b, 95, and 96. Total responses on the plain-wheat key ranged from 543 for Hen 94 to 2,331 for Hen 92b; total responses on the salted-wheat key ranged from 3 for Hen 92b to 927 for Hen 94.

Income elasticities for salted and plain wheat were calculated for each condition change as in previous experiments using Equation 5 and are presented in Table 25 and represented in bar graphs in Figure 23. The table and figure show three different patterns. Hens 91 and 94 had positive plain-wheat and negative salted-wheat elasticities. Hens 92b, 95, and 96 had positive plain-wheat elasticities near one and undefined salted-wheat elasticities.

Table 25
Experiment 5: Income Elasticities for Each Condition Change (U=undefined)

	Consecutive Condition Changes	
	Plain Wheat	Salted Wheat
Hen	Poor/ Rich	Poor/ Rich
91	1.3	-0.7
92b	1.1	U
93	0.8	3.5
	Rich/ Poor	Rich/ Poor
94	1.7	-0.1
95	1	U
96	1	U

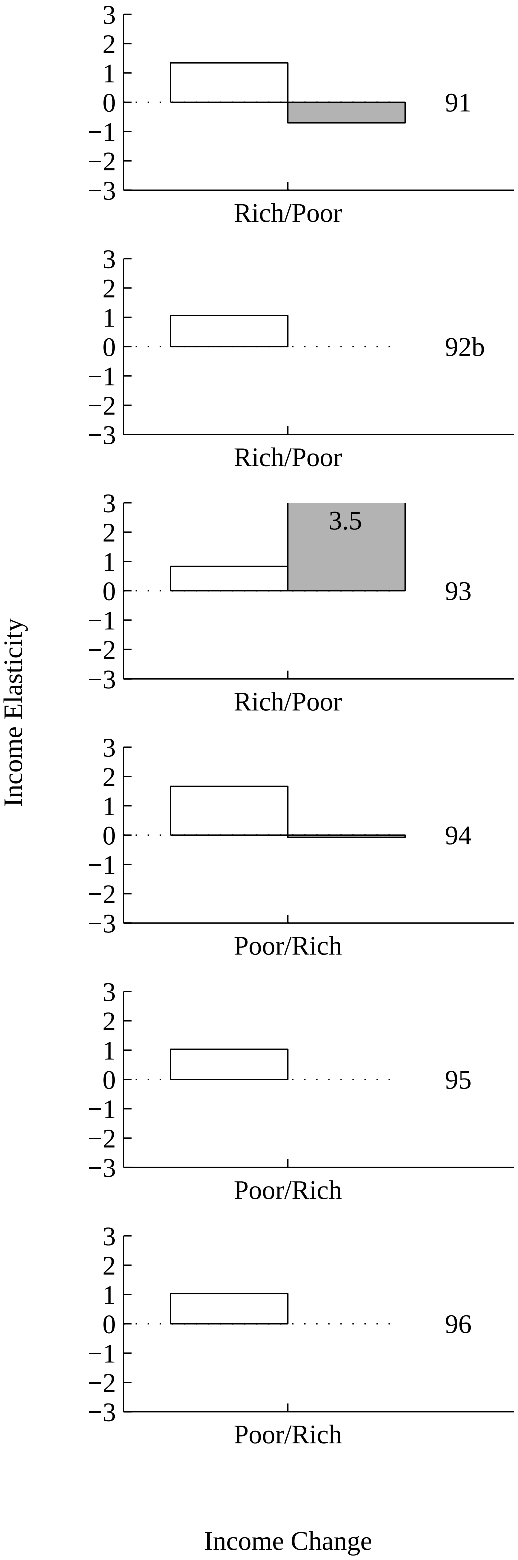

Figure 23. Experiment 5: Income elasticities for each condition change.

Hen 93’s income elasticities were positive for both wheats, with salted-wheat’s elasticity being larger than plain wheat’s. Plain-wheat elasticities ranged from 0.8 to 1.7 while salted wheat elasticities ranged from -0.7 to 3.5 with three undefined values.

Figure 24 shows cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key for the last 20 sessions of each major condition. The graphs do not show similar behaviour across birds. Hens 92b, 95, and 96 tended to respond nearly exclusively on the plain-wheat key, so the graphs show little or no variability in responding. The lack of variability is also apparent in the Rich Condition for Hen 91 and in the Poor Condition for Hen 94 as either plain-wheat or salted-wheat responses, respectively, tended to occur exclusively. During the Poor Condition for Hen 91 and during both conditions for Hen 93, responding on both keys occurred throughout the sessions. Hen 94 was the only hen showing a pattern of early salted-wheat and late plain-wheat responding. This pattern occurred in this bird’s Rich Condition.

When ITI responses were added to cumulative within-session responses, the patterns described above remained the same for most hens as shown in Figure 25. The only pattern that differed was that of Hen 93 in its Poor Condition. The addition of ITI responses increased the slope of this function because the bird responded on both keys during these last 20 sessions, but ITI responses tended to occur on the salted-wheat key while effective responses tended to occur on the plain-wheat key.

Figure 26 presents durations of eat times. As in previous experiments, the patterns resembled response patterns except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. Overall,

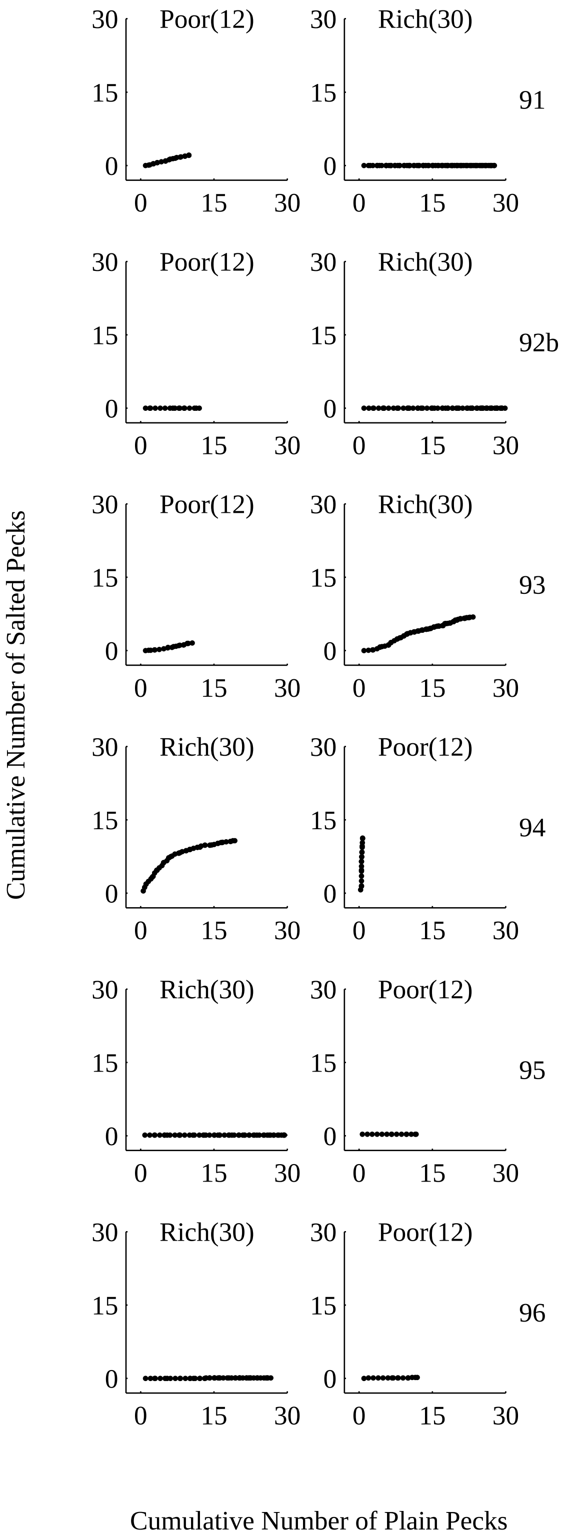

Figure 24. Experiment 5: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

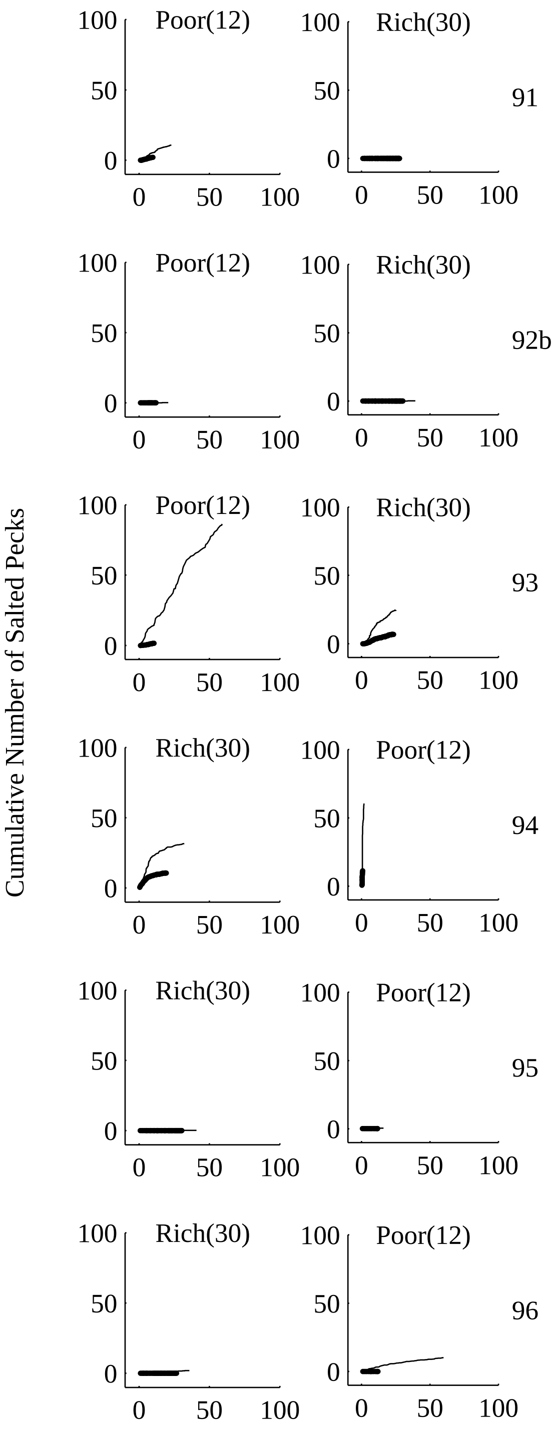

Figure 25. Experiment 5: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

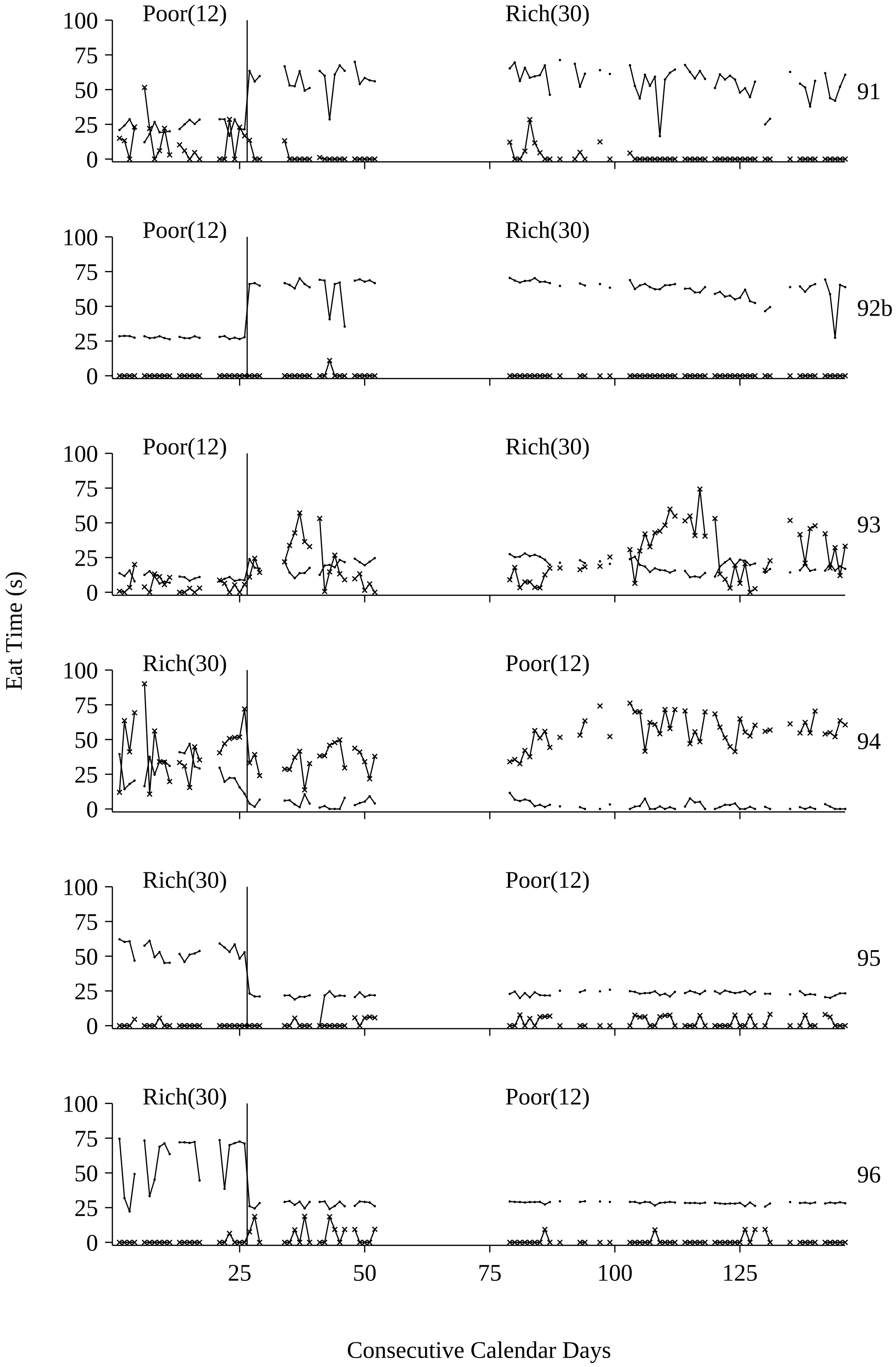

Figure 26. Experiment 5: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

more responding on a key tended to be associated with longer eat times for the type of food associated with that key. Table 26 displays Pearson correlation coefficients for eat times versus wheat weights as well as their sample sizes.

Table 26
Experiment 5: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions			
	Plain Wheat		Salted Wheat	
Hen	Poor	Rich	Poor	Rich
91	.97*	.81*	1*	U
	(4)	(11)	(4)	(2)
92b	-.17	.63*	U	U
	(4)	(11)	(0)	(0)
93	.88	.61*	U	.97*
	(4)	(11)	(1)	(11)
	Rich	Poor	Rich	Poor
94	.98*	.68	.93	.52
	(4)	(8)	(4)	(11)
95	-.6	.04	U	.92
	(4)	(11)	(1)	(3)
96	.96*	.78*	U	1*
	(4)	(11)	(1)	(3)

*p<.05

When eat times and their wheat weights were both zero, they were omitted from analysis to avoid inflating the correlations. When there was no variability in either eat time or wheat weight or when samples had less than two pairs of data, correlation coefficients were undefined as was the case for salted-wheat in Hen 91, 95, and 96's Rich Conditions, both of Hen 92b's conditions, and in Hen 93's Poor Condition. Correlations varied within and between birds as well as the two types of wheat, but no consistent differences were found. An alpha level of .05 was used to test for statistical significance of the coefficients and all significant correlations were large (Cohen, 1988) and positive: 7 out of 12 for plain wheat and 3 out of 12 for salted wheat or 4 out of 12 in the Poor Conditions and 6 out of 12 in the Rich Conditions. Sample sizes ranged from 0 to 11. As there were several significant and non-significant correlations, the significant correlations may have occurred through chance, so should be interpreted with caution.

Figure 27 shows hens' total number of ITI responses across sessions. All hens responded during the ITI for at least some sessions and there were large differences in the number of ITI responses across subjects. ITI responses for Hens 91, 92b, and 95 ranged from 0 to 52 and for Hens 93, 94, and 96 ranged from 0 to 221 across all sessions and conditions. In most sessions across both conditions, Hens 91, 92b, 95, and 96 made more plain-wheat-ITI responses than salted-wheat-ITI responses while the opposite was true for Hens 93 and 94. ITI responses changed across conditions only for Hens 93, 94, and 96. Hen 93's plain-wheat-ITI responses decreased from the Poor to the Rich Condition while its salted-wheat- ITI responses remained about the same. Hen 94's salted-wheat ITI responses increased from the rich to the Poor Condition while its plain-wheat- ITI responses remained similar. The opposite was true for Hen 96. Its plain-wheat ITI responses increased from the rich to the Poor Condition while its plain-wheat-ITI responses remained similar across conditions. Table 27 summarises ITI responses across all conditions and shows the percentage of plain- and salted-wheat responses. For all hens except Hens 93 and 94, ITI responses occurred mostly on the plain-wheat key with 2 to 23% occurring on the salted-wheat key. For Hens 93 and 94 ITI response occurred mostly on the salted-wheat key at 77

Table 27
Experiment 5: Total ITI Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	928	77	279	23
92b	766	98	16	2
93	1575	23	5291	77
94	984	17	4871	83
95	1165	98	26	2
96	3590	87	538	13

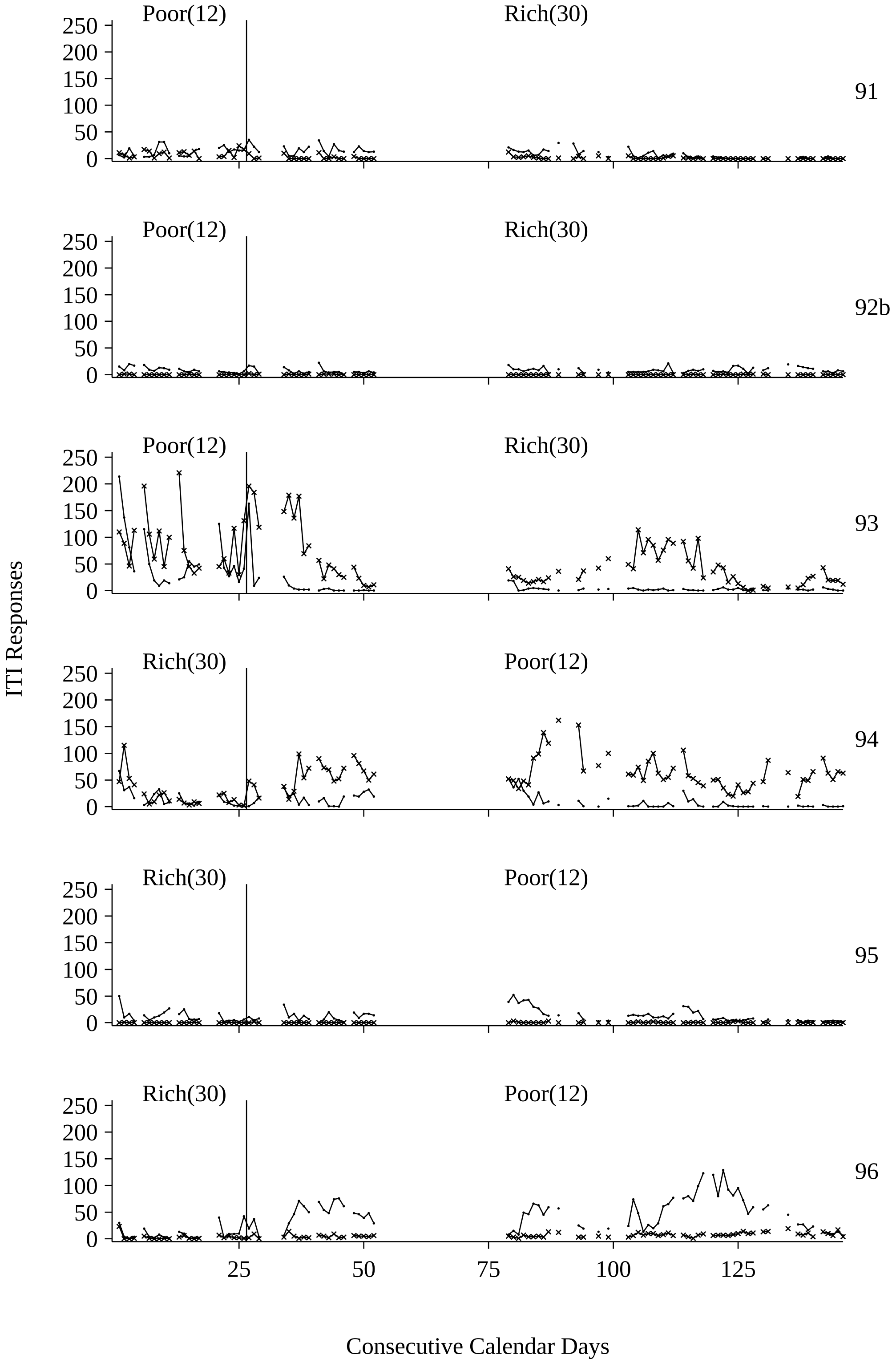

Figure 27. Experiment 5: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the maximum number of trials possible for each condition.

and 83%, respectively. Total responses on the plain-wheat key ranged from 766 for Hen 92b to 3,590 for Hen 96; total responses on the salted-wheat key ranged from 16 for Hen 92b to 5,291 for Hen 93.

Table 28 shows pre-session body weight means for the last 20 sessions of each condition and Figure 28 shows hens' pre-session body weights plotted across days. Body weights of all hens except Hen 94 tended to be lower in the Poor Condition than in the Rich Condition. Hen 94's mean body weights for both conditions were within 1 g of each other.

Table 28
Experiment 5: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions	
Hen	Poor	Rich
91	1552	1766
92a	1425	1596
93a	1676	1979
	Rich	Poor
94	1881	1880
95	1806	1646
96	1631	1547

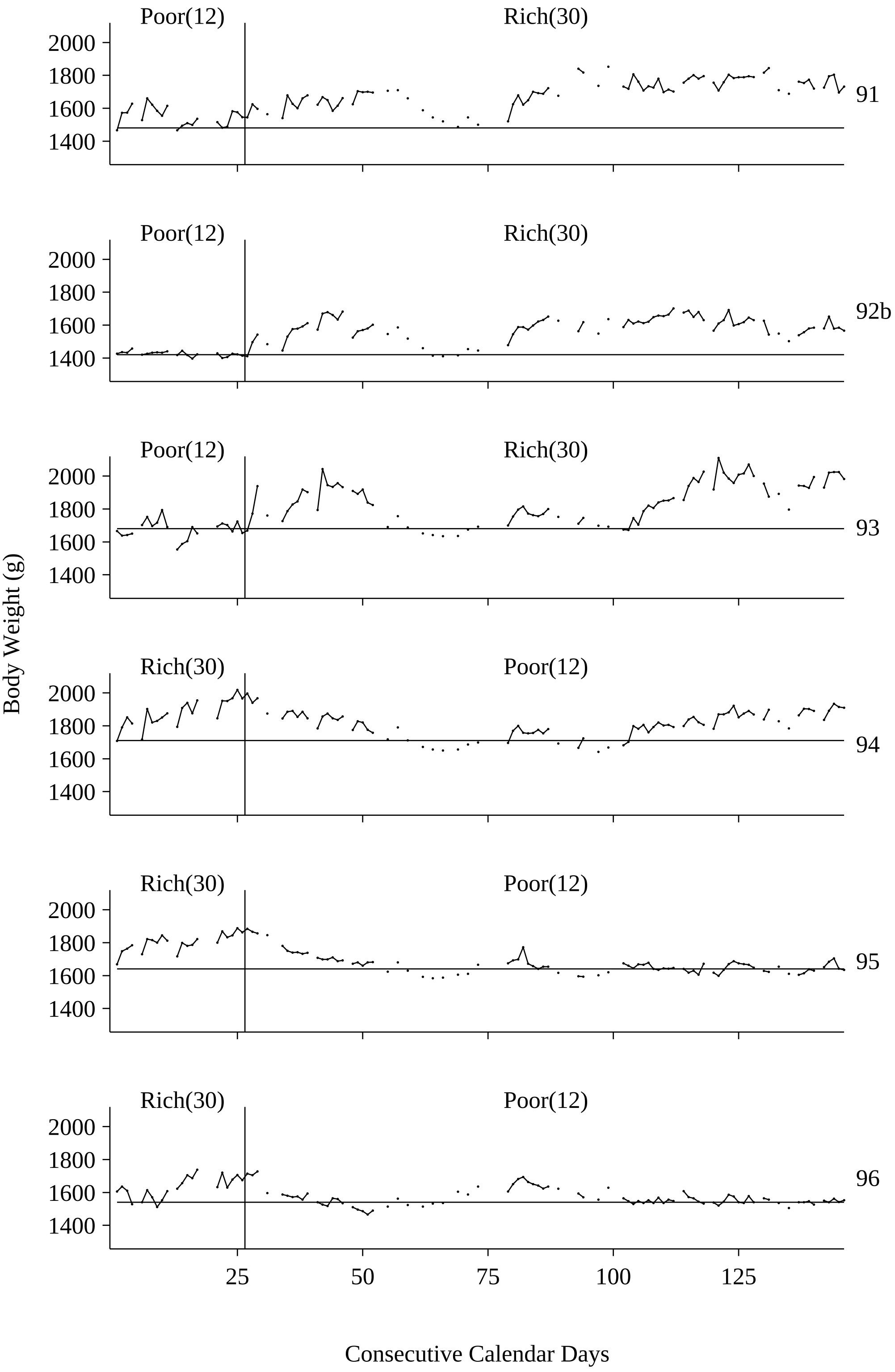

Figure 28. Experiment 5: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate ITI changes, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the maximum number of trials possible for each condition.

Discussion

The purpose of this experiment was to investigate whether or not the procedure from Experiment 2 would result in the inferior- or relative-inferior-good effect for the Group-9 hens, especially for the hens that did not show the effects in Experiments 3a and 3b. The effect occurred for 6 of 18 condition changes (33%) for the Group-7 birds used in Experiment 2, but in only 3 of 18 condition changes (17%) for the Group-9 birds in Experiment 3a, and in only 1 of 3 condition changes (33%) for the Group-9 birds in Experiment 3b. The procedure of this experiment was the same as the procedure of Experiment 2 except for the houselight colours and individual ITI durations but the results did not convincingly show the inferior-good effect as they did in Experiment 2. Across all 6 hens in the current experiment, Hens 91 and 94 were the only hens that responded more on the salted-wheat key in the Poor Condition than in the Rich Condition. Eat-times followed this pattern as well. So, the inferior-good effect occurred for these two hens, while Hens 92b, 95, and 96 responded exclusively or nearly exclusively on the plain-wheat key, and Hen 93 responded on both keys across both conditions. So, the inferior-good effect was observed for 2 of 6 condition changes (33%). No hens showed a relative-inferior-good effect where both wheats' income elasticities were positive with larger elasticities for the plain wheat. It is noteworthy that Hen 94 was the only hen that showed the inferior-good effect across all three of these latter experiments. Given that the eat-time graphs in Figure 26 showed patterns similar to the response graphs in Figure 22 and that there were some significant positive correlations between eat-time and weight consumed, it can be assumed that these hens consumed wheat following effective responses.

Hen 94 was the only hen that showed the expected early intended-inferior-good responding and late intended-superior-good responding found in the published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) and for Hens 73a, 74, and 75 and in Experiment 2. Hen 94 also showed this pattern in one condition in Experiment 3a. The early intended-inferior-good and late intended-superior-good pattern occurred in Rich Conditions in Experiments 2, 3a, and 5 and was more pronounced in the Rich Conditions than in the Poor Conditions in Hastjarjo et al. It is still unknown whether the pattern for this hen and other hens co-varied with unmeasured variables and whether or not they are important for the effect to occur. A comparison of the percentage of effective and ITI responses between Table 24 and Table 27, shows that percentages differed by 20% or less for Hens 91, 92b, 94, 95 and 96, and by 52% for Hen 93. So, for all but Hen 93, effective and ITI responses were strongly correlated suggesting that the addition of ITI responses to effective responses would not change within-session patterns. Figure 17 confirmed that when ITI responses were added, a change in pattern occurred for Hen 93 such that the slope of the function increased. For all hens, the percentage of salted-wheat responses was higher for ITI responses than for effective responses except for Hen 95 where both percentages were 2%. This relation shows that these 5 hens responded on both keys but responded on the salted-wheat key proportionally more during the ITI than during trials.

In Experiment 2, the inferior-good effect occurred for 4 of 6 hens in 6 of 18 condition changes (33%) and the relative-inferior good effect occurred for 5 of 6 hens in 13 of 18 condition changes (72%). Why did the relative-inferior-good effect not occur and why did the inferior-good effect occur for only 2 of 6 hens in 2 of 6 condition changes (33%) this experiment? Because the procedures of these two experiments were virtually identical, the differing results must be due to subjects' individual differences (physiology or behavioural history), to extraneous variables, or due to a combination of these variables. Previously, birds reaching or not reaching body weight set point was introduced as a physiological difference that might underlie the occurrence or non-occurrence inferior-good effect. If set points are normally distributed in the population of hens, then it may be the case that the no-effect birds never reached their set point because their set points were lower than their post-feed thresholds. However, this hypothesis was not testable test because of the earlier-described ethical restrictions relating to body weight reduction and because there is no definitive test for set point. So, the body weight set-point issue may have been the case, but the hypothesis was not testable.

Given that hens in the current experiment were also involved in previous experiments, previous learning may have affected responding. In the Poor and Rich Conditions, respectively, houselight colours were blue and amber in Experiment 3a, aqua and red in Experiment 3b, and blue and amber again in Experiment 5. So, if houselight colour exerted any control over responding (especially as a CEO or AEO), then this control may have extended from Experiment 3a to Experiment 5. The rationale for using houselight colours from Experiment 3a in the current experiment instead of colours from Experiment 3b was because there was no difference in responding between conditions for most hens in Experiment 3a, so it appeared as though houselights did not exert control over behaviour. In Experiment 3b, responding varied between conditions more than in Experiment 3a, so houselights may have exerted some control over behaviour in that experiment. If the inferior-good effect emerged in the current experiment with houselight colours from Experiment 3b, then it would have been difficult to separate the carry-over CEO or AEO effects from the variables that caused the inferior-good effect in Experiment 2. The effect did emerge for Hen 91 and it continued for Hen 94 but it did not occur for other hens. So, it may have been the case that carry-over effects relating to non-occurrence of the effect occurred for some birds. As such, behaviour in the current experiment may have been under the control of the houselights rather than the programmed contingencies for these hens. Additionally, it is possible that extraneous variables may have affected responding, but there are no obvious candidates. The body weight set-point issue still remains as a possible explanation as well. If carry-over effects did occur, then what might the nature of these carry-over effects be?

Experiment 3a occurred over 463 consecutive calendar days with the first condition lasting 56 days; the second, 144; the third, 152; and the fourth, 111. Each bird, then, would have been exposed to each of the two conditions (including each replication) for 208 and 255 days. As the daily responding for most birds rarely varied (expect for Hen 94), this fixed pattern of responding would have occurred for most of the sessions and under the stimulus conditions of all conditions for most birds, except for Hens 91 and 94. The result would have been a long history of this fixed pattern of responding under both stimulus conditions for at least 4 out of the 6 hens. If body weights functioned as EOs and AOs as described in Experiment 3b and if ITIs and houselights gained control as CEOs or CAOs as hypothesised in Experiment 2, then it would be expected that any carry-over effects would be due to CEO or CAO effects because the same houselights (hypothesised CEOs or CAOs) were used. Further, because the continued pairing of stimuli with EOs and AOs is a necessary condition for stimuli to be CEOs and CAOs, it would be expected that any such carry-over effects would be transient.

However, there are no data available to estimate the length of time required for transient effects to disappear.

The current experiment occurred over 145 days with a break of 26 days during the second condition due to lab personnel availability; the first condition lasted for 26 days and the second lasted for 93 days (with the break removed). Experiment 2 lasted for 328 days with the first condition lasting 50 days; the second, 63; the third, 144, and the fourth, 71. All of the birds showing the effect in Experiment 2 did so prior to 75 consecutive days—50 days in the first condition and 25 in the second. If carry-over effects did occur in the current experiment, then one expected effect would be a time where birds behaved as they did in Experiment 3a, due to the CEOs or CAOs in effect, followed by a transition to stable responding as in the results of Experiment 2. As the first condition lasted only 26 days (compared with the shortest condition in Experiment 2 lasting 50 days), this length of time may not have been enough for carry-over effects to disappear and for houselights and ITI to become new CEOs or CAOs for this condition. The length of the second condition, 93 days, was comparable to condition lengths in Experiment 2, but it is not possible to tell if this length of time was enough for carry-over effects to disappear. So, it is possible that the difference between the current experiment and Experiment 2 was due to carry-over effects relating to houselights as CEOs or CAOs. Whether or not longer-running conditions would have made a difference in the effect emerging is unknown.

In Experiment 3a and Experiment 3b, the function of ITIs (variable and fixed) and forced choices were discussed in terms of variability and contacting contingencies. Namely, ITIs provided time for behaviour to vary and increased the chances that behaviour would contact the contingencies of both keys and forced choices directly caused behaviour to contact the contingencies of both keys. For hens not showing the effect in any experiments in the current series, although the addition of ITIs may have increased variability and thereby increased contingency contact on both keys, they may have in fact rarely contacted the contingencies on both keys. Forced choices, however, guarantee contingency contact. The next experiment replicated Experiment 3b with the addition of forced-choice trials at the beginning of the session as in the Hastjarjo et al. (1990a) rat study and included the houselights from Experiment 3a. It was expected that the addition of the forced choices would provide contact with the contingencies and that the inferior-good effect would occur.

Experiment 6: Few/Many Trials with ITI and Forced Choice (Group 9)

Experiment 3a was a partial replication of the Hastjarjo et al. (1990a) study with rats; partial, because it did not include forced-choice trials at the beginning or a fixed-length ITI and because houselight changes accompanied condition changes. It was hypothesised that the inferior-good effect occurred for only 3 of 18 condition changes (17%) in Experiment 3a, and for only Hens 93 and 94, because the sessions did not provide enough time for behaviour to vary, thereby decreasing the chances of behaviour coming into contact with the contingencies of both keys and decreasing the chances of the effect occurring. So, a fixed-length, 60-s ITI was added and houselight colours were changed in Experiment 3b. In this experiment, the effect occurred for only 1 of 3 condition changes (33%) for only Hen 94. But, when responding in the first condition of Experiment 3b (with a fixed, 60-s ITI) was compared with responding in the last condition of Experiment 3a (with no ITI) for all 6 hens, the inferior-good effect was found for Hens 91 and 93 (2 of these 6 additional between-experiment condition changes) as well, resulting in a total of 3 out of 9 condition changes (33%) across 3 hens where the inferior-good effect occurred. These effects are less convincing than the 4 of 6 hens showing the inferior-good effect in 6 of 18 condition changes (33%) or the 5 of 6 hens showing the relative-inferior-good effect in 7 of 18 condition changes (39%) in Experiment 2. If the main function of ITIs was that they increased time for behaviour to vary which, in turn, increased the chances of contacting contingencies on both keys, then perhaps there were occasions where ITI responses occurred on both keys, but birds still did not contact the contingencies of both keys frequently.

Although ITI responses occurred for all hens in Experiments 3b and 5, comparison of Figure 9 with Figure 14 and Figure 22 shows that variability of effective responses did not increase for Hens 92b, 95, and 96 as much as they did for Hens 91, 93, and 94. Behaviour of these former hens that did not show the inferior-good effect, then, may not have contacted the contingencies of both keys enough for the effect to occur. This lack of contact and the long histories of fixed response patterns across several conditions may have contributed to the lack of the effect with these hens.

A way of guaranteeing contact with the contingencies of both keys would be to provide forced-choice trials at the beginning of each session where keys are lit individually and successively for a few trials and responding to each key provides its usual reinforcer. Hastjarjo et al. (1990a) began sessions with 5 forced-choice trials on each lever and their total number of trials was 30 in the Poor Condition and 150 in the Rich Condition. The current experiment tested the effect of forced choices on the inferior-good effect by providing 1 forced choice on each key at the beginning of sessions. The number of forced choices on each key used by Hastjarjo et al. was approximately 3% of the total number of trials in their Rich Condition, so this percentage was used to calculate the number of forced-choice trials used in the current experiment. Because Hastjarjo et al.'s Poor and Rich Conditions differed by a magnitude of five whereas conditions in the current experiment differed by a magnitude of three, the number of forced choices used by Hastjarjo et al. was equal to approximately 17% of the total number of trials in their Poor Condition while the number of forced choices used in the current experiment was equal to approximately 8% of the total number of trials in this experiment's Poor Condition. Sessions then occurred as in Experiment 3b, ending after 12 trials in the Poor Condition under blue houselights and 30 trials in the Rich Condition under amber houselights. It was expected that the forced choices would increase the chances of the inferior-good effect or relative-inferior-good effect occurring through birds' behaviour more regularly contacting the contingencies of both keys and that the effect would occur for hens previously showing the effect and that it would also emerge for hens previously not showing the effect.

Method

Subjects

Subjects were the 6 Group-9 hens used in Experiment 5 numbered 91, 92b, 93, 94, 95, and 96 and were housed, maintained, and post fed as described in Experiment 2.

Apparatus

The equipment from Experiment 3a was used for this experiment.

Procedure

Sessions began with a single forced-choice trial on each key separated by a 60-s ITI. The rest of the procedure was the same as Experiment 3b, except houselight colours from Experiment 3a were used so that amber houselights were on in the Rich Conditions and blue were on in the Poor Conditions and the total number of trials were always 30 and 12 respectively. The order of forced choices was determined randomly by the MED-PC 2© software. Hens 91, 92b, and 93 were subjected to a Poor Condition, then a Rich condition, and then the same two conditions again and Hens 94, 95, and 96 were subjected to the same conditions but in reverse order. The MED-PC 2© software monitored all session events as in Experiment 2 and data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a.

Results

The maximum number of trials that occurred for each subject in each condition was the same as in Experiment 5: 12 trials in the Poor Conditions and 30 trials in the Rich Conditions. As in previous experiments, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. The median numbers of responses for the last 20 sessions of each condition are shown in Table 29. For the 18 income changes (3 changes per hen) across the 4 conditions for all 6 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the adjacent Rich Condition on 5 occasions. This inferior-good effect occurred for Hens 91, 93, and 94. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Rich Condition on all 18 occasions.

Table 29
Experiment 6: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Rich	Poor	Rich	Poor	Rich	Poor	Rich
91	12	30	4	29.5	0	0	8	0
92b	12	30	12	30	0	0	0	0
93	11	29	3	0	1	1	9	28
	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
94	26	0	1	0	1	12	29	12
95	30	12	30	12	0	0	0	0
96	30	12	30	12	0	0	0	0

Figure 29 shows the number of effective responses that occurred within each income condition. The patterns in these graphs generally followed the same patterns as described by the medians shown in Table 29: generally, more salted-wheat responses in some of the Poor Conditions than in the Rich Conditions and more plain-wheat responses in the Rich Conditions than in the Poor Conditions.

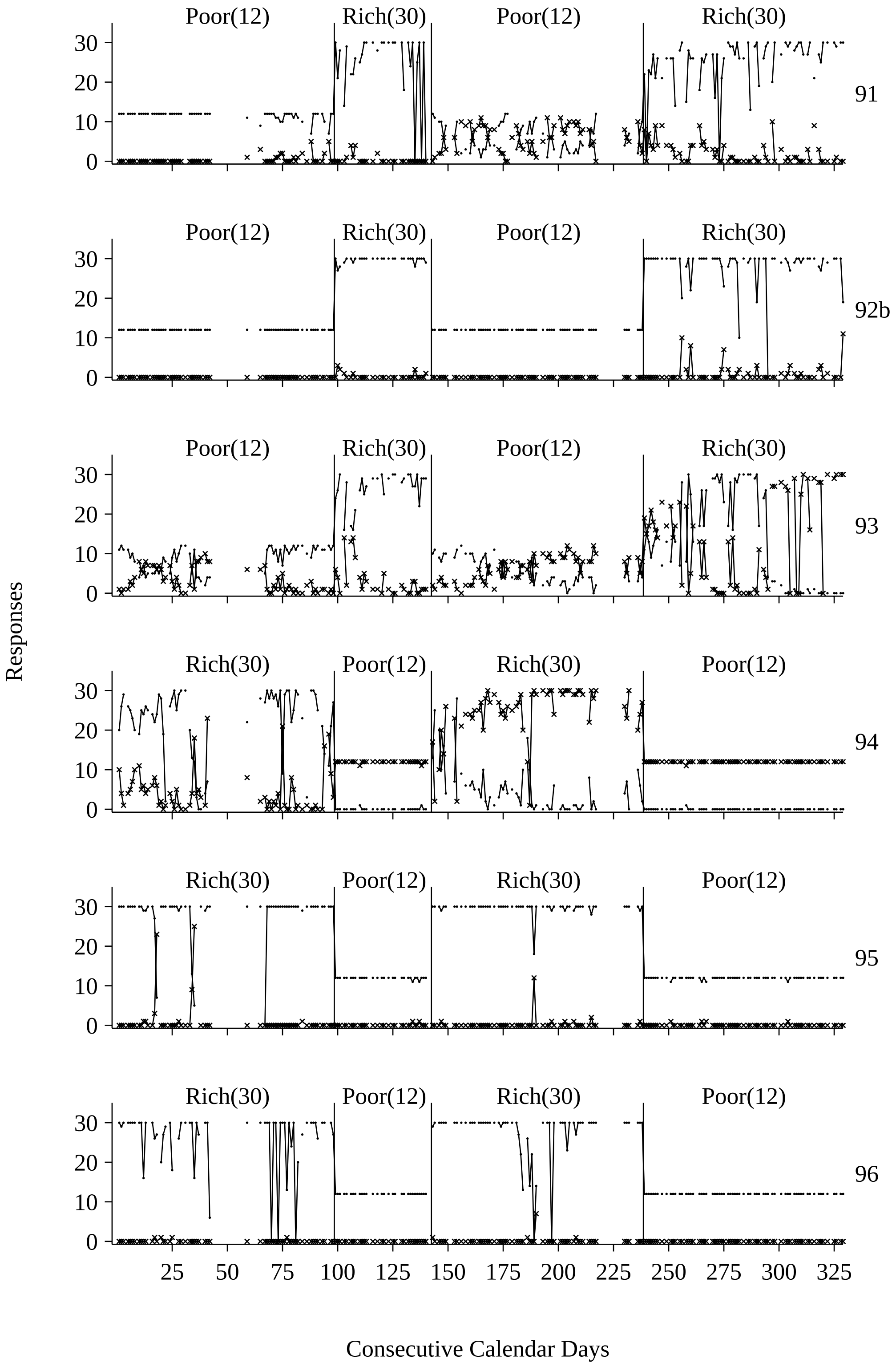

Figure 29. Experiment 6: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

For Hen 91, the pattern occurred for its entire second Poor Condition but for only the second half of its first Poor Condition. For Hen 93, there was a period of nearly-exclusive responding on the salted-wheat key at the end of the second Rich Condition that differed from earlier responding in that condition as well as from responding in the first Rich Condition. The graphs also show that variability in responding differed across hens. Hens 91, 93, and 94 showed variability across both conditions while Hens 92b, 95, and 96 did not. These latter 3 hens tended to respond nearly exclusively on the plain-wheat key regardless of condition. Table 30 summarises responses across all conditions and shows the percentage of plain- and salted-wheat responses. For all hens except Hen 94, responses occurred mostly on the plain-wheat key with 37% occurring on the salted-wheat key for Hen 93 and 0 to 13% for Hens 91, 92b, 95, and 96. Total responses on the plain-wheat key ranged from 1,720 for Hen 94 to 4,642 for Hen 95; total responses on the salted-wheat key ranged from 14 for Hen 96 to 2,880 for Hen 94.

Table 30
Experiment 6: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	3456	87	529	13
92b	4210	98	72	2
93	2596	63	1547	37
94	1720	37	2880	63
95	4642	98	89	2
96	4310	100	14	0

Income elasticities for salted and plain wheat were calculated for each condition change using Equation 5 as in previous experiments. These elasticities are presented in Table 31 and represented in bar graphs in Figure 30. Hens 92b, 95, and 96 had positive plain-wheat elasticities of one and undefined salted-wheat elasticities. Hen 91 also showed this pattern in its first condition change but showed positive plain-wheat and negative salted-wheat elasticities for its second and third condition change. This latter inferior-good-effect pattern also occurred in the second and first condition changes for Hens 93 and 94, respectively. For the second and third condition change for Hen 94, income elasticities were positive for both wheats, with plain-wheat's elasticity being larger than salted wheat's. A similar pattern occurred for Hen 93's first condition change, but with a value of 0 for the salted-wheat income elasticity. Finally, for this hen's last condition change an inferior-good effect occurred, but with plain wheat as the inferior good and salted wheat as the superior good. Across all hens, plain-wheat elasticities ranged from -0.7 to 4.3 while salted wheat elasticities ranged from negative infinity to 1 with 10 undefined values.

Table 31
Experiment 6: Income Elasticities for Each Condition Change (U=undefined)

	Consecutive Condition Changes					
	Plain Wheat			Salted Wheat		
Hen	Poor/ Rich	Rich/ Poor	Poor/ Rich	Poor/ Rich	Rich/ Poor	Poor/ Rich
91	1	1.4	4.3	U	-∞	-0.7
92b	1	1	1	U	U	U
93	1.1	1.5	-0.7	0	-13.3	1.4
	Rich/ Poor	Poor/ Rich	Rich/ Poor	Rich/ Poor	Poor/ Rich	Rich/ Poor
94	1.7	∞	1.7	-18.3	0.9	1
95	1	1	1	U	U	U
96	1	1	1	U	U	U

Figure 31 shows cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key for the last 20 sessions of each major condition. Hens 92b, 95, and 96 tended to respond nearly exclusively on the plain-wheat key regardless of condition, so the graphs show little or no variability in responding. Hen 91 showed this lack of variability in all but its

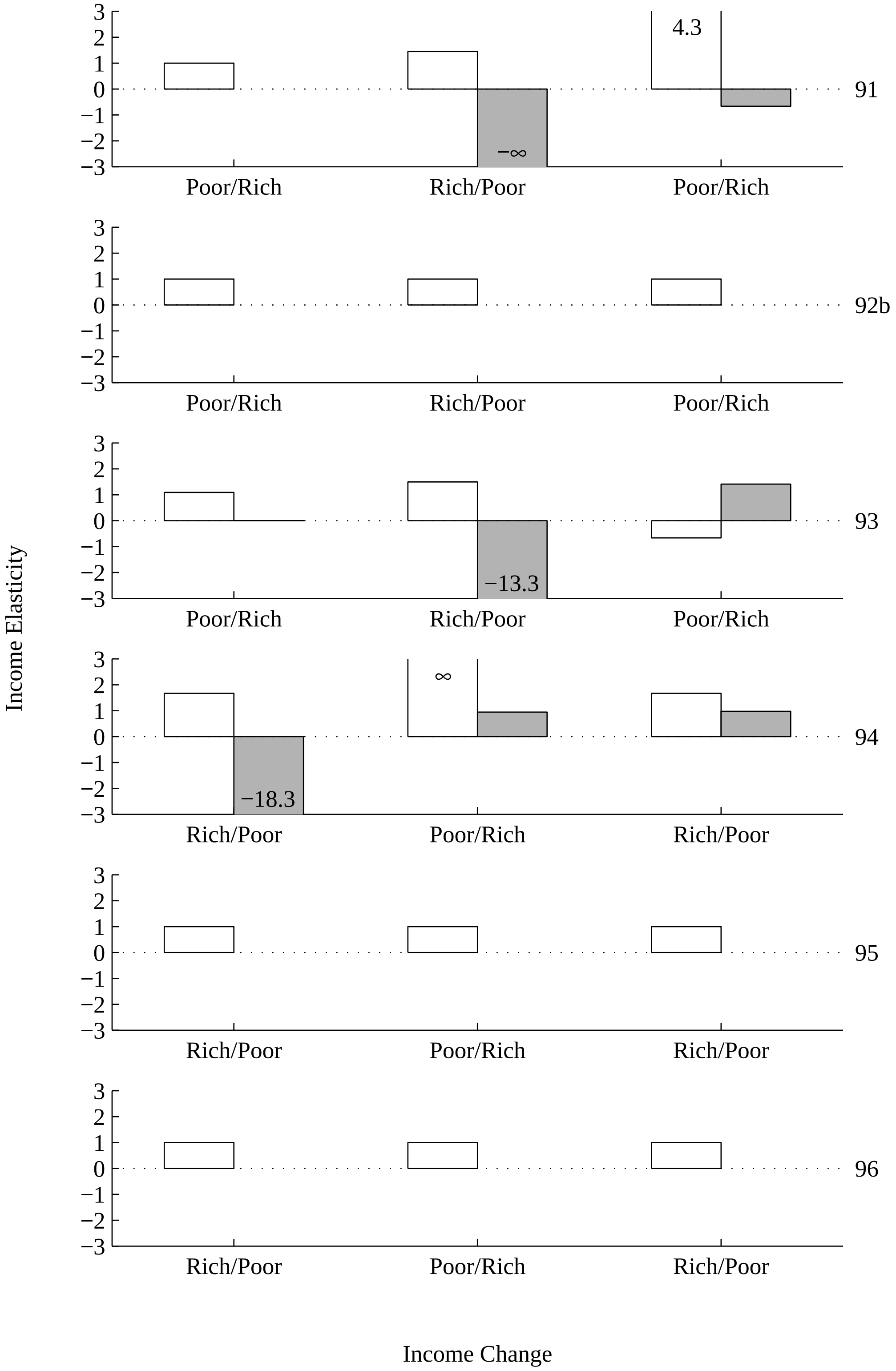

Figure 30. Experiment 6: Income elasticities for each condition change.

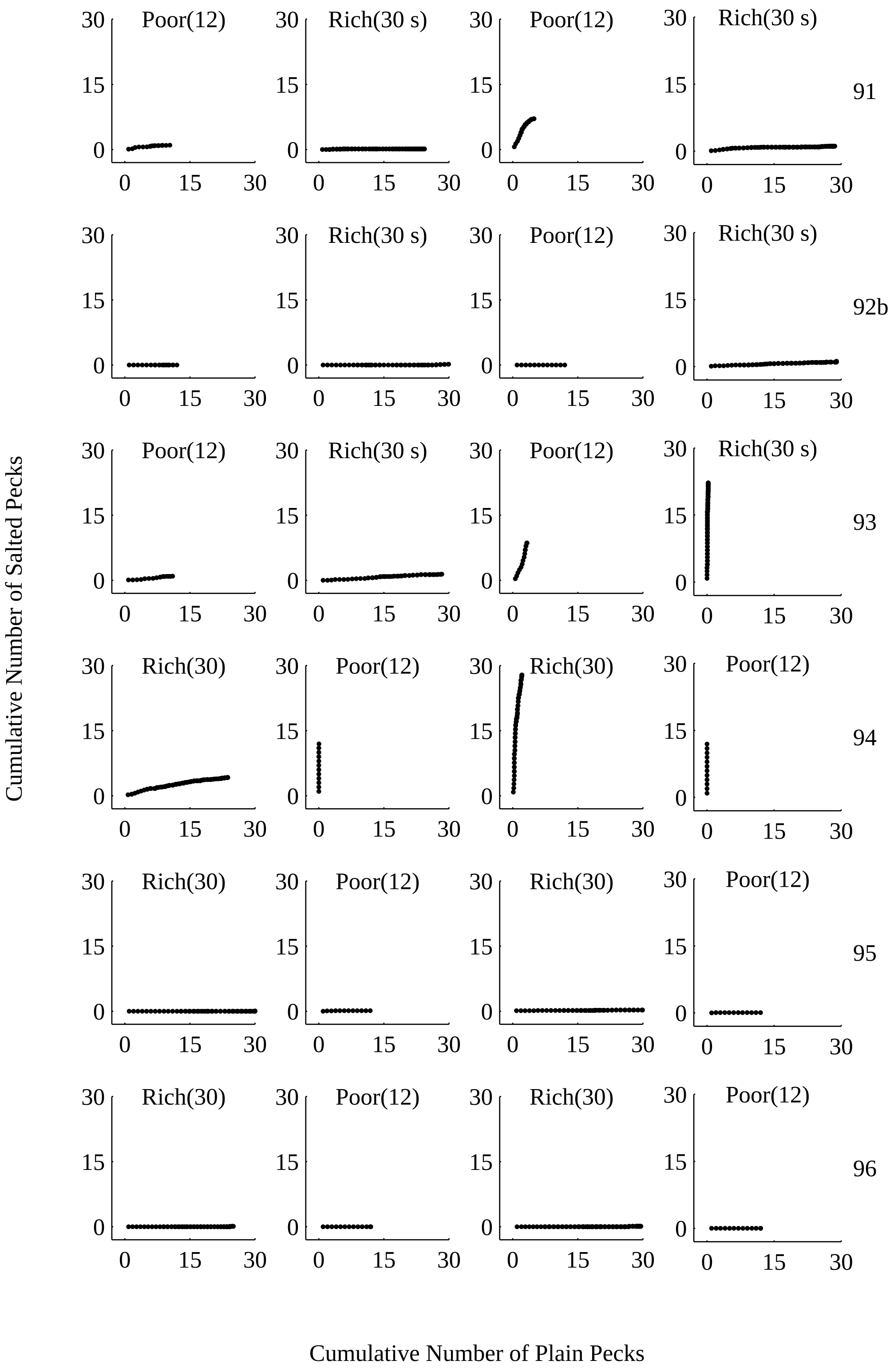

Figure 31. Experiment 6: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses for each successive trial across the last 20 sessions of the condition.

second Poor Condition where the expected early salted-wheat responding and late plain-wheat responding pattern occurred. Hen 93's first Poor and Rich Conditions also showed this lack of variability while its second Poor and Rich Conditions showed responding on both keys and responding on mostly the salted-wheat key, respectively. Finally, Hen 94 tended to respond nearly exclusively on the salted-wheat key in all but its first Rich Condition where it responded on both keys. Adding ITI responses to cumulative within-session responses did not change the patterns for most hens as shown in Figure 32. The only patterns that differed were that of Hen 93 in its first Poor and Rich Conditions and Hen 94 in its first Rich Condition. The addition of ITI responses increased the slope of these functions because the birds responded on both keys during these last 20 sessions, but ITI responses tended to occur on the salted-wheat key while effective responses tended to occur on the plain-wheat key.

Figure 33 presents eat-time durations. The plain-wheat sensor had intermittent faults from Day 24 through Day 91, so these data were omitted from analysis. As in previous experiments, the eat-time patterns resembled response patterns except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. Overall, more responding on a key was associated with longer eat times for the type of food associated with that key. Pearson correlation coefficients for eat times versus wheat weights and sample sizes for each coefficient are displayed in Table 32. When an eat time and its respective wheat weight were both zero, they were omitted from analysis to avoid inflating the correlations. Coefficients were undefined for any samples that had no variability in either eat time or wheat weight. Undefined values were found for plain wheat in both of Hen 94's Poor Conditions and for salted wheat in some

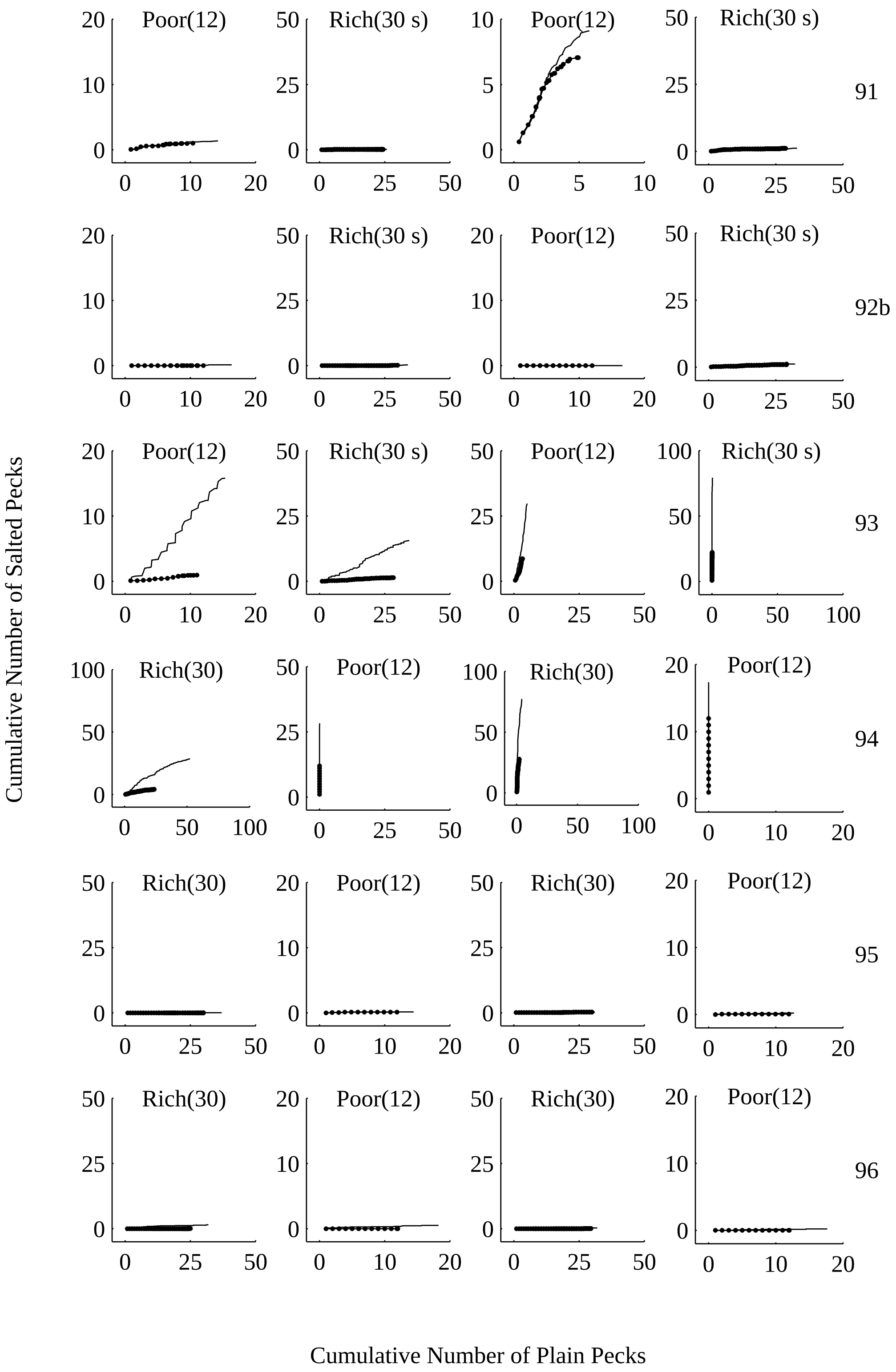

Figure 32. Experiment 6: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

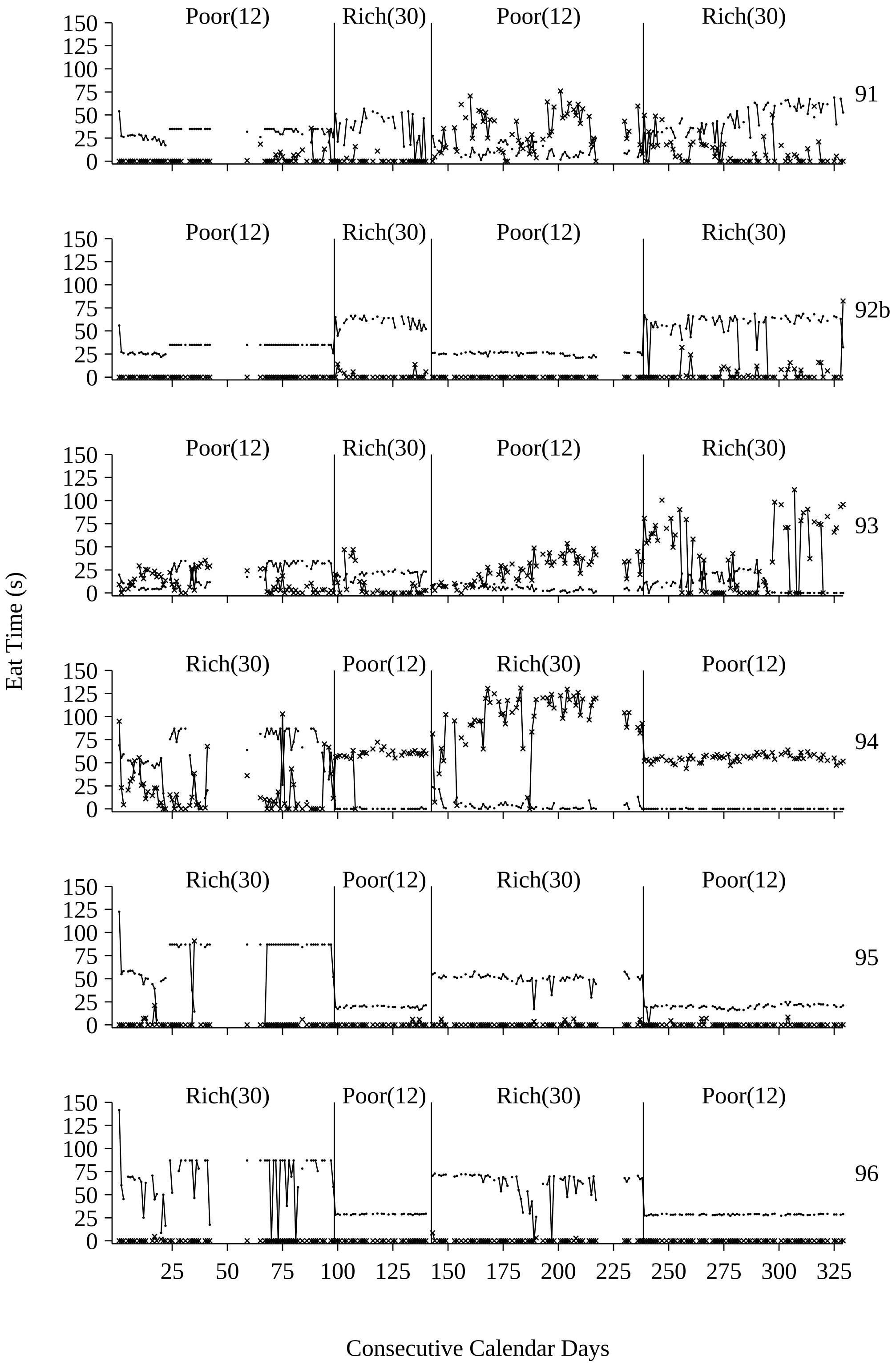

Figure 33. Experiment 6: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

conditions for Hens 92b, 95, and 96. Correlations differed within and between birds as well as within and between the two types of wheat, but there were no consistent differences. An alpha level of .05 was used to test for statistical significance of the coefficients and all statistically-significant correlations were large (Cohen, 1988) and positive: 2 out of 24 for plain wheat and 8 out of 24 for salted wheat or 3 out of 24 for the Poor Conditions and 7 out of 24 for the Rich Conditions. Sample sizes varied and ranged from 2 to 9. There were several significant and non-significant correlations, so significant correlations may have occurred through chance and should be interpreted with caution.

Table 32
Experiment 6: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Rich	Poor	Rich	Poor	Rich	Poor	Rich
91	1	1*	.78	-.04	.94	.85	1*	.91*
	(2)	(3)	(3)	(9)	(4)	(3)	(3)	(8)
92b	-1	-.50	-.83	-.60	U	U	U	.80*
	(2)	(3)	(3)	(9)	(4)	(3)	(3)	(8)
93	1	.96	.96	.95*	.97*	1	1*	.96*
	(2)	(3)	(3)	(9)	(8)	(3)	(3)	(9)
	Rich	Poor	Rich	Poor	Rich	Poor	Rich	Poor
94	1	U	.91	U	.95*	.93	.81	-.10
	(2)	(3)	(3)	(9)	(5)	(3)	(3)	(9)
95	1	-.24	.82	-.39	.99*	.90	U	.46
	(2)	(3)	(3)	(9)	(4)	(3)	(3)	(9)
96	1	.79	.96	.07	-.70	U	U	U
	(2)	(3)	(3)	(9)	(5)	(2)	(3)	(8)

*p<.05

Figure 34 shows hens' ITI responses on both plain- and salted-wheat keys. All hens responded during the ITI for at least some sessions and there were large differences in the number of ITI responses across subjects. Hens 91, 92b, 95, and 96 tended to respond less than 25 times on either key across conditions (except for the first few sessions for Hens 95 and 96 where ITI responding exceeded 25). Hens 93 and 94 responded on both keys across sessions, but the salted-wheat key

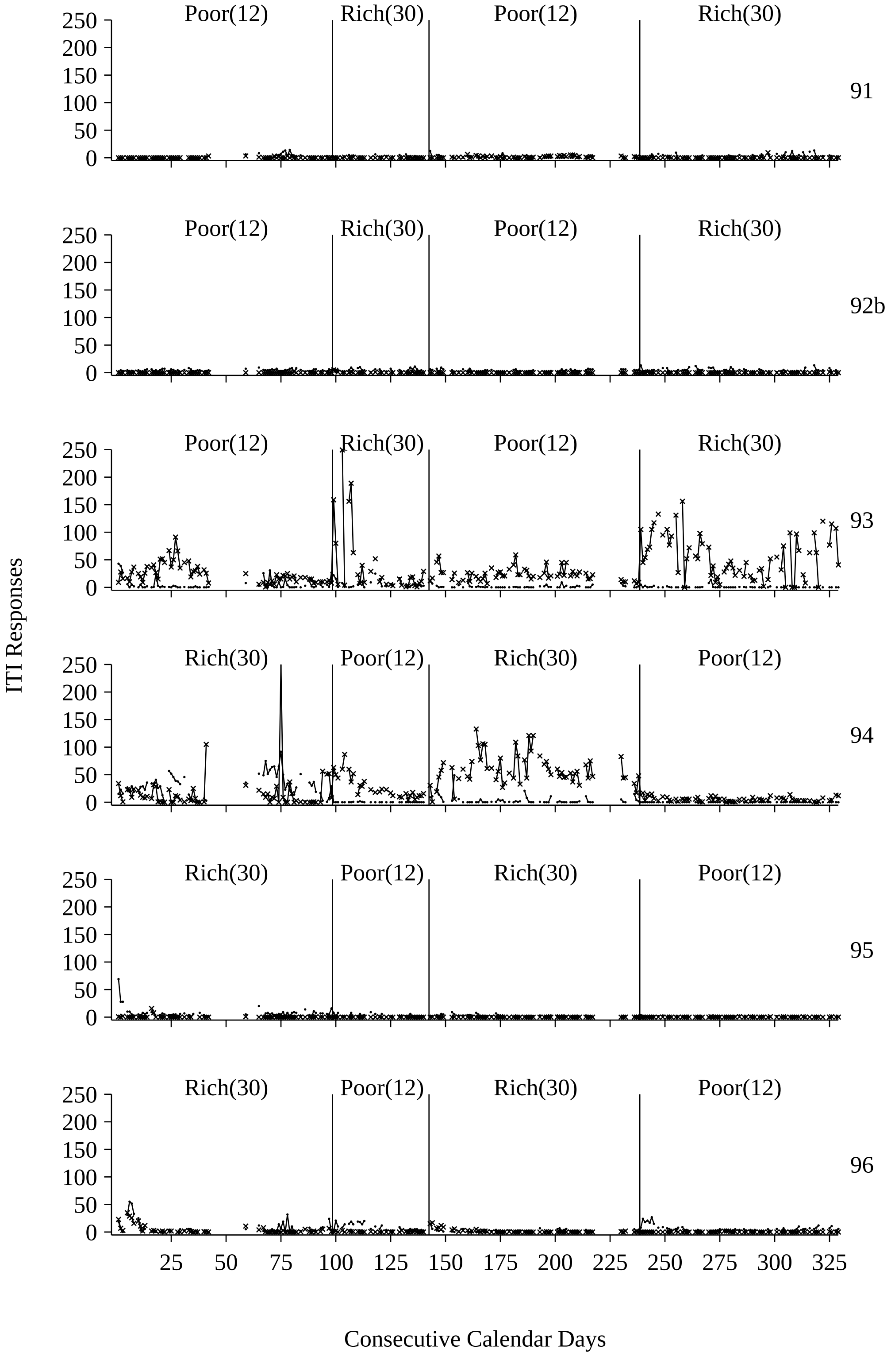

Figure 34. Experiment 6: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate changes in the programmed number of trials. Bracketed values indicate the maximum number of trials possible for each condition.

tended to be pecked more, especially after the first Rich Condition for Hen 94. These birds' salted-wheat ITI responses were usually under 100 per session apart from some sessions in the Rich Conditions where responses were more frequent. Plain-wheat ITI responses for these birds tended to be similar to those of the other birds remaining below 25 on most sessions except for Hen 94's first Rich Condition where they reached beyond 50 on some days. Table 33 summarises ITI responses across all conditions and shows the percentage of plain- and salted-wheat responses. For all hens except Hens 93 and 94, ITI responses occurred mostly on the plain-wheat key with 2 to 25% occurring on the salted-wheat key. For Hens 93 and 94 ITI responses occurred mostly on the salted-wheat key at 73 and 92%, respectively. Total ITI responses on the plain-wheat key ranged from 412 for Hen 91 to 2,117 for Hen 94; total ITI responses on the salted-wheat key ranged from 21 for Hen 92b to 7,780 for Hen 93.

Table 33
Experiment 6: Total ITI Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	412	78	116	22
92b	870	98	21	2
93	668	8	7780	92
94	2117	27	5833	73
95	760	95	39	5
96	1197	75	406	25

Table 34 shows pre-session body weight means for each hen in each condition and Figure 35 presents hens' pre-session body weights plotted across days. Body weight means of the last 20 sessions of each condition for Hens 92b and 93 tended to be lower in the Poor Conditions than in the Rich Conditions with mean body weights in the second Rich condition being higher than in the first. Hen 91 showed a similar pattern to these two hens but the mean body weight in its second Poor Condition was higher than those of all other conditions. Hens 94, 95, and 96 also showed a similar pattern to Hens 92b and 93 except mean body weights in their second Poor Conditions were higher than those of the first Poor and Rich Conditions.

Table 34
Experiment 6: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions			
Hen	Poor	Rich	Poor	Rich
91	1514	1616	1812	1778
92b	1423	1492	1437	1659
93	1699	1772	1730	1855
	Rich	Poor	Rich	Poor
94	1902	1854	2138	2077
95	1759	1708	2088	1784
96	1609	1547	1701	1628

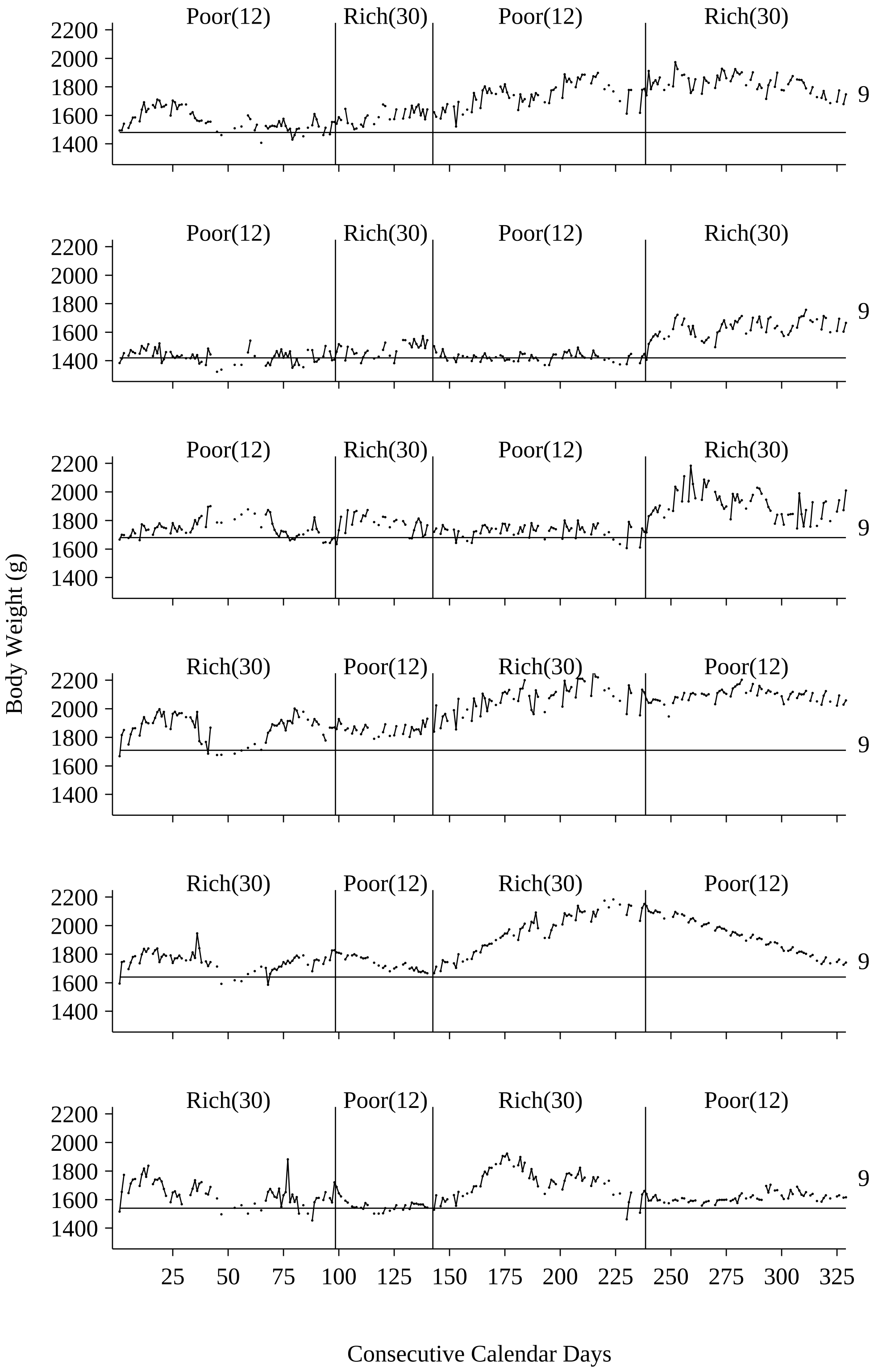

Figure 35. Experiment 6: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate changes in the programmed number of trials, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the maximum number of trials possible for each condition.

Discussion

This experiment investigated the effect of adding forced-choice trials to the procedure of Experiment 3b. It was predicted that these forced-choice trials would guarantee contingency contact thereby increasing the chances that the inferior-good effect would occur for birds previously showing the effect as well as for birds not previously showing the effect. The rationale for using the houselights from Experiment 3a and Experiment 5 in the current experiment was different from the rationale for using the houselights from Experiment 3a in Experiment 5. It was decided to keep the same houselight colours in the current experiment as in Experiments 3a and 5 to minimise the differences between experiments. In retrospect, it would have been better to use the same colour houselights in Experiment 3b as well as it would have decreased the number of changes between experiments, making it easier to identify variables important for the inferior- and relative-inferior-good effects. Across all hens from the current experiment, the inferior-good effect occurred for 3 of 18 condition changes (17%) in Experiment 3a (for Hens 93 and 94), in only 1 of 3 changes (33%) in Experiment 3b (for Hen 94), in 2 of 6 changes (33%) in Experiment 5 (for Hens 91 and 94), and for 5 of 18 changes (28%) in the current experiment (for Hens 91, 93, and 94). No hens showed a relative-inferior-good effect of larger positive income elasticities for plain wheat than for salted wheat in these previous experiments, but in the current experiment, Hen 94 showed this relative effect in its second and third condition change while Hen 91 showed the relative effect in its first condition change. For this first condition change, the elasticity of salted wheat was zero for this hen indicating that salted-wheat responding was insensitive to the income change. So, the addition of forced-choice trials to the procedure of Experiment 3b did result in the effect for Hens 91, 93, and 94 whereas the absence of these trials in Experiment 3b resulted in the effect for only Hen 94. The expected early intended-inferior-good responding and late intended-superior-good responding found in the published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) and for Hens 73a, 74, and 75 in some Rich Conditions of Experiment 2, for Hen 94 in a Rich Condition in Experiments 3a and 5, was found for only Hen 91's second Poor Condition.

The percentage of effective and ITI responses shown in Table 30 and Table 33, shows that percentages differed by 10% or less for Hens 91, 92b, 94, and 95, and by 25% for Hens 93 and 96. So, for Hens 91, 92b, 94, and 95 effective and ITI responses were strongly correlated suggesting that within-session patterns would not change with the addition of ITI responses to effective responses. Figure 32 shows that a slight pattern was found in Hen 94's first Rich Condition when ITI responses were added to effective responses. This occasion was the only occasion across all experiments in the current series where the addition of ITI responses to effective responses changed the pattern to resemble the expected early intended-inferior-good responding and late intended-superior-good responding. Adding ITI responses to effective responses also caused a pattern change for Hen 93's first Poor and Rich Condition with an increased slope of the function, and for Hen 94's first Poor Condition with a slight shift towards the expected early salted-wheat and late plain-wheat responding. Hen 96's pattern did not change even though overall it responded proportionally more on the salted-wheat key during the ITI than during trials. This lack of change in the last 20 sessions of conditions suggests that during these sessions, effective and ITI responses were strongly correlated. For all hens, the percentage of salted-wheat responses was higher for ITI responses than for effective responses except for Hen 92b where both percentages were 2%. This relation shows that these 5 hens responded on both keys but responded on the salted-wheat key proportionally more during the ITI than during trials. Results of this experiment, previous experiments, and the published experiments cited above still do not reveal whether or not the patterns co-varied with unmeasured variables or how they might relate to the inferior-good effect.

Across all four experiments involving this group of hens (not including the income elasticities for the condition change between Experiments 3a and 3b), Hen 94 was the only hen that consistently showed the inferior- or relative-inferior-good effects. For this hen, the effect occurred for six out of eight condition changes across all Experiments while a relative-inferior-good effect occurred for the remaining two condition changes. Hens 91and 93 showed the inferior-good effect for three and two of seven condition changes, respectively, with Hen 93 also showing a relative-inferior-good effect for one condition change. These effects occurred in Experiments 3a and 6 for Hen 93 and in Experiments 5 and 6 for Hen 91. Recall that Hens 91, 92, and 93 were not exposed to a condition change in Experiment 3b, so income elasticities could not be calculated; however, when responding in the first condition of Experiment 3b (with 60-s ITI) was compared with responding in the last condition of Experiment 3a (with no ITI), the inferior-good effect was found for Hens 91 and 93. So across all 7 hens participating in some or all of the four experiments above, Hens 91, 93, and 94 showed the inferior- or relative-inferior good effect across at least two experiments while Hens 92a, 92b, 95, and 96 never showed either effect. This difference suggested an investigation of the commonalities within each group of hens as well as the differences between groups.

A common characteristic of responding for hens showing the effect was that responding varied between the two keys more than for hens not showing the effect. Examination of ITI responses for Experiment 3b in Figure 19, for Experiment 5 in Figure 27, and for the current experiment in Figure 34 show similar patterns across experiments for each hen. That is, ITI responding for each hen was similar from experiment to experiment. Table 35 and Table 36 summarise effective and ITI responses (including the during-magazine responses of Experiment 3a) across Experiments 3a, 3b, 5, and 6 for all hens participating in these experiments except for Hen 92a because this hen only experienced a single condition. The hens not showing the effect (Hens 92b, 95, and 96) tended to respond exclusively or nearly exclusively on the plain-wheat key, so the percentages of effective salted-wheat responses across all experiments were 4% or less. For the hens showing the effect (Hens 91, 93, and 94), these percentages

Table 35
Experiments 3a, 3b, 5, 6: Total Effective Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	14811	92	1210	8
92b	13716	99	180	1
93	11336	78	3159	22
94	9783	62	6047	38
95	14718	96	638	4
96	14691	98	338	2

Table 36
Experiments 3a, 3b, 5, 6: Total ITI Responses

	Plain Wheat		Salted Wheat	
Hen	Total	%	Total	%
91	2209	73	826	27
92b	2925	99	40	1
93	3283	20	13319	80
94	4839	29	11707	71
95	3717	93	263	7
96	6825	87	990	13

were 8, 22, and 38%, respectively. These results might have been expected as the inferior-good effect requires responding on both keys, so this measure of variability should show more variability for the birds exhibiting the inferior-good effect, and it does. Findings were similar for ITI responses. The hens not showing the effect tended to respond exclusively or nearly exclusively on the plain-wheat key during the ITI, so the percentages of salted-wheat ITI responses across all experiments were 13% or less while hens showing the effect had salted-wheat ITI percentages of 27, 80, and 71%, respectively. So, hens that showed the inferior-good effect responded on the salted-wheat key during the ITI proportionally more than hens that did not show the effect.

This finding lends some credence to the discussion of the importance of variability with respect to the inferior-good effect. In Experiment 3a it was hypothesised that because session time was short, the behaviour of some hens (namely, hens not showing the effect) may not have contacted the contingencies of both keys due to the lack of time for behaviour to vary. The addition of a 60-s ITI in Experiment 3b did not result in the effect for birds not previously showing the effect but when the variable-length ITI procedure from Experiment 2 was used in Experiment 5, the effect emerged for Hen 91. In the current experiment when forced choices were added to the procedure of Experiment 3b, the effect occurred for all 3 hens previously showing the effect. So the ITIs in these experiments may have been important for the inferior-good effect because they increased the chances that hens would contact the contingencies of both keys only because they provided time for behaviour to vary between the two keys. It cannot be argued that contingency contact entails the effect because all hens engaged in some effective responses on the salted-wheat key. The data of the current experiment show that a forced choice on both keys at the beginning of the session was not enough to shift responding from exclusive or nearly-exclusive responding on the plain-wheat key for the birds previously not showing the effect. However, it still may be the case that more contingency contact increased the chances of the effect occurring, but that other variables affected responding, such as the body-weight set-point issue discussed in Experiment 4. Also, the possibility of carry-over effects as suggested in Experiment 5 may have played a role and will be discussed later in this section.

One difference between the procedure of the current study and that of Hastjarjo et al. (1990a) was the number of forced-choice trials as well as the number of session trials. Hastjarjo et al. programmed 10 forced-choice trials and either 30 or 150 session trials while the current experiment provided only 2 forced-choice trials and either 12 or 30 session trials. It could have been that more forced-choice trials (more contingency contact) would have shifted responding. Only 2 forced-choice trials were used in the current experiment because there were so few session trials during sessions. The number of forced-choice trials in Hastjarjo et al. was one third of the number of trials in their Poor Condition, so the number of forced-choice trials in the current experiment was intended to be at or below this fraction for at least rough consistency. Four forced-choices were not used in case the number of trials in the Poor Condition required a reduction as in previous experiments. If, for example, the number of trials decreased to eight, then the number of forced-choice trials would be beyond the one third in Hastjarjo et al. Whether or not more forced-choice trials would have made a difference is an empirical question. Given the small number of trials in Poor Conditions, adding more forced-choice trials would not be recommended.

The number of forced-choice trials would quickly approach the number of Poor-Condition-session trials, thereby adding both variability and a relatively large amount of food to the digestive tract making any changes difficult to attribute to a single variable.

In the previous experiment, the possibility that carry-over effects from Experiment 3a affected responding was discussed because that experiment occurred over 145 days while the preceding Experiment 3a occurred over 463 days. The current experiment used the same houselights as these former two experiments, so the same argument might be applied here. There is at least one session for one hen showing evidence of houselights exerting antecedent control that would have to be due to learning in previous experiments. In the 20 Rich-Condition sessions prior to Day 99, Hen 94 responded on the plain-wheat key between 9 and 30 times per session (except for one session where only 3 responses occurred). For this hen, Day 99 was the first session of the first Poor Condition and it responded 0 times on the plain wheat key and exclusively, 12 times, on the salted-wheat key. This responding remained stable for the 30 sessions across the entire Poor Condition except for two sessions where 1 response occurred on the plain-wheat key with the remainder occurring on the salted-wheat key. This immediate shift in responding resembled that of Hens 75 and 76a during some Rich Conditions in Experiment 2; this resemblance and the immediacy of the shift suggest that it is unlikely to be coincidental. The shift would have had to have been due to the change in houselight colours because there were no other programmed events that would provide a discriminable stimulus change in this first session of the condition. This occurrence provided more evidence that the houselights gained antecedent control for at least this hen and the two hens from Experiment 2. In Experiment 2 it was unclear whether the houselights or the ITIs functioned as such because both were correlated; however, houselights would have been more salient than the passage of time and thus more likely to exert control. If this kind of control was a CEO or CAO, then a correlated EO or AO is implied. Body weight is the current hypothesised candidate, as introduced in Experiment 3a.

This experiment occurred over 328 days, a long period of time, suggesting that carry-over effects were not a major contributor to the absence of the inferior-good effect in the current study. As stated in Experiment 5, though, there are no data available to estimate the length of time required for transient effects relating to the houselights as CEOs or CAOs to change as these stimuli supposedly become correlated with body weight. It would be surprising if such antecedent control spanned the entire experiment, especially given the different experimental arrangements and the guaranteed contingency contact. It is more likely that if carry-over effects did occur, they would be transient and behaviour would have come under control of current antecedent stimuli and consequences, at least after some time. It is not possible to tell, though, if hens not showing inferior- or relative-inferior-good effects were behaving in line with carry-over effects or if behaviour was insensitive to the contingencies that result in the effects, or a combination of both.

In Experiments 3a, 3b, 5, and in the current experiment, the inferior-good effect or relative-inferior-good effect did not occur as reliably as it did for the other group of birds serving in Experiment 2. In Experiment 2, hens exhibited at least one of the effects for 13 of 18 condition changes (72%). For the group of hens that served in the current and previous experiments, hens exhibited at least one of the effects for 14 out of 45 condition changes (31%) across all experiments. Further, of the 3 birds exhibiting either inferior- or relative-inferior-good effects, Hens 91 and 94 tended to do so in at least two experiments, with Hen 94 showing the effect across some conditions in all four experiments. The expected early intended-inferior-good and late intended-superior-good responding occurred only three times across these four experiments: in a Rich Condition in Experiments 3a and 5 for Hen 94 and in a Poor Condition in Experiment 6 for Hen 91. The importance of these occasional within-session patterns reported in the published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) and in the current series of experiments is still unknown. Across Group 7 and Group 9 hens showing and not showing inferior- or relative-inferior-good effects, responding on the salted-wheat key during trials and during the ITI tended to be proportionally larger for hens showing the inferior-good effect or relative-inferior-good effect than for hens not showing an effect. That is, responding varied between the two keys more for hens showing the effect. There were also conditional stimulus effects in the current experiment as well as in Experiment 2 as there were immediate changes in responding that accompanied condition changes. These effects have been discussed in terms of CEOs, with the houselight colours possibly gaining control through their association with different body weights and were investigated in the remaining experiments.

It is still unknown why some birds did not show the inferior-good effect or relative-inferior-good effect. Although the effects occurred for 3 of the 6 hens from Group 9 in the current experiment (the effect occurred for only 1 or 2 hens from this group in previous experiments) the difference cannot be attributed to the forced-choice trials because all of these hens had exhibited the effect in at least one previous experiment. The relation between body weight set point and the effects was hypothesised in Experiment 4 and it remains a possibility that these hens' post-feed thresholds were above their set points, thereby not allowing salted wheat to be established as a reinforcer. Due to the long experimental histories of the hens in this group, they were not subjects in further experiments as it was not possible to evaluate how these histories might affect future behaviour.

As body weight was shown to co-vary with income conditions for most birds in most experiments and because of its possible role as an EO, body weight was further investigated to ascertain its role in the inferior- and relative-inferior-good effects. As body weight is a composite of a hen's bones, organs, adipose tissue, digestive-tract contents, and egg, it is possible to ascertain the contribution of some of these components to overall body weight. The next experiment involved the Group 7 hens that served in Experiments 1 and 2. Its purpose was to investigate the dimensions of a particular component of body weight—the weight of food in a hen's crop. In an experiment by DeMarse, Killeen and Baker (1999), pigeons with smaller crops tended to show within-session decreases in responding sooner than pigeons with larger crops. The authors suggested that small-crop birds satiated faster than the other birds, so within-session decreases occurred sooner. A similar process may have occurred for hens showing the inferior- or relative-inferior-good effect. If reinforcers sate at different rates as sessions progress (Baum, 1979; Herrnstein, 1981; Shurtleff et al., 1987), a shift in responding from the salted-wheat key to the plain-wheat key may have occurred due to the satiation effects of salted-wheat. In terms of Equation 6, as the value of the salted-wheat key decreased due to satiation (an AO), responding on the salted-wheat key also decreased and responding on the plain-wheat key increased. If this process were the case, then hens with smaller crops should have been more likely to show the effect because their within-session changes should have occurred sooner. Experiment 7 measured the weight of plain and salted wheat consumed across several sessions for the Group-7 hens from Experiments 1 and 2 to ascertain crop size as described by DeMarse et al. As Hen 71 showed the inferior-good effect once and Hen 72 showed neither effect while all other hens showed either effect for all three condition changes, it was predicted that these two hens would have the smallest crop capacity according to DeMarse et al.'s definition.

Experiment 7: Crop Capacity Assessment (Group 7)

In the previous experiments and in the published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987), body weights tended to be higher in Rich Conditions than in Poor Conditions. As this between-condition difference was never controlled for by, say, only conducting daily sessions for birds that were within a certain body-weight range, it was not possible to separate the effects of body weight from the effects of the programmed changes in these previous experiments. Also, the programmed changes between Rich and Poor Conditions involved changes in both houselight colour and the total number of trials, so there were at least three variables that changed with condition changes. Each of these variables could have affected behaviour individually and/or by interacting with one or more of the others.

The relation between body-weight set point and the inferior- and relative-inferior-good-effects was hypothesised to pivot around metabolic changes (e.g., changes in insulin, leptin, NPY, GLP-1, CCK, and CRF) that changed with food consumption or adiposity. That is, subjects with high adiposity or more food in the gut may have been in a different metabolic state compared with subjects with low adiposity or less food in the gut. These different states may have had different establishing or abolishing effects on inferior and superior goods. But, at least one author found that evidence of the role of gut peptides with respect to feeding was inconclusive (Savory, 1999). However, body weight is determined by several types of tissue and organs in the body besides adipose tissue and also by anything that the organism consumes, such as food, water, and grit. So, it is possible that the establishing and abolishing effects described above may have stemmed from changes in other body tissue components, organs, and/or changes in the amount of food, water, and grit in the body.

Tissue and organs along the alimentary tract (digestive tract) have been shown to play a role in the control of eating across a variety of species (Forbes, 1995). Savory (1999) discussed what can loosely be described as EOs and AOs in birds: short-term hunger and satiety mechanisms (these mechanisms can also be thought of in terms of positive and negative feedback signals, respectively, as discussed in Experiment 3b). However, the idea of a body-weight set point may suggest a stronger relation between it and food consumption than the literature supports. According to Savory,

> Because such mechanisms appear to have only loose control over meal eating, it seems appropriate to think in terms of degrees of hunger and satiety, rather than "set-points," determining probabilities of feeding starting and stopping. Severe nutrient deficit, or an empty intestine, may represent a lower limit at which initiation of feeding is imperative, and a gut full to capacity an upper limit at which feeding would have to stop. Probabilities of feeding starting and stopping increase as these limits are approached, and at some intermediate point there is an equilibrium where hunger and satiety are zero. (p. 341)

This conceptualisation remains in line with body weight or components of body weight as EOs and AOs because EOs and AOs also vary between limits. If the amount of food in the body or changes in the organs holding the food are EOs or AOs (perhaps exclusively or in combination with adiposity or other variables), then physiologically, what might be the nature of this control and can it be isolated to specific organs?

The visual estimates of stable body weights for hens feeding ad libitum in Experiment 4 ranged from 1,770 to 2,140 g. So, food and body fat (adiposity) would have contributed a percentage of this overall body weight, but these data were not collected. A rough estimate of the weight of food consumed daily can be derived from Figure 1. The figure shows the daily change in weight of plain- and salted-wheat dispensers during ad libitum access. As both wheats were often spilled on the floor, the weight consumed can only be estimated. Across all 6 hens, visual inspection of the figure shows that the weight varied around 100 g. The percentage of body weight accounted for by food for hens in Experiment 4 may have then ranged from 4.7 to 5.6%. Further, Brown Shaver hens bred by a company in the Netherlands are reported to consume 114 g of feed per day and to weigh 2000g (Hendrix Genetics, 2006); for these hens, the percentage of body weight accounted for by food would be on average 5.7%. These data are similar to the data and estimates from Experiment 4.

In a study by Deeb and Lamont (2002), several hundred G*allus-domesticus* chicks of various strains were raised with ad libitum access to food and water for 8 weeks. After this time, the full-grown hens were euthanized and body composition measurements were recorded to ascertain each organ's percentage of overall body weight. The range of body weights for F2 Fayoumi hens were the closest to the Brown Shaver hens from Experiment 4. Deeb and Lamont's hens' body weights ranged from 1013 g to 2316 g. Of these body weights, abdominal fat weighed between 8.4 (0.54%) and 96.8 g (6.37%) with an average of 49.77 g (3.25%). It might then be assumed that these percentages might roughly describe the percentage of abdominal body fat in Brown Shaver hens. So, for a hen consuming food ad libitum, an average of 5.7% of its bodyweight may be food in various stages of digestion and 3.25% may be abdominal fat.

The food would be distributed across the hen's digestive tract, shown in Figure 36 (Hendrix Genetics, 2006). According to this figure, the digestive process begins when food enters through the mouth and travels through the oesophagus and into the crop where it is stored and moistened. Moistened food

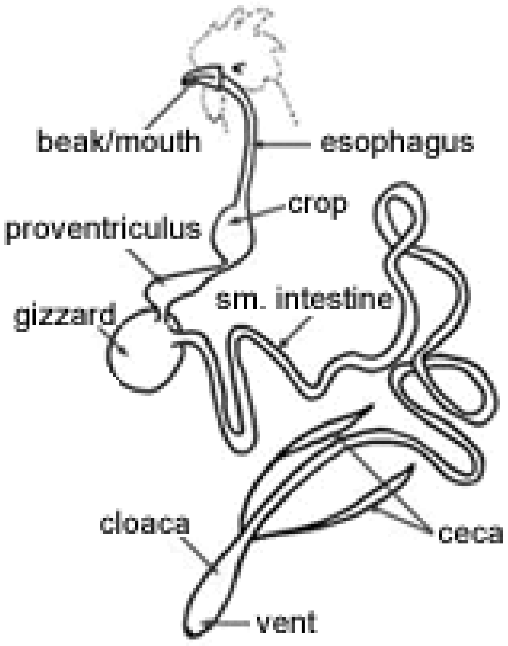

Figure 36. Digestive tract of a hen (University of Toronto, Department of Physics, 2006).

then enters the proventriculus, or glandular stomach, where hydrochloric acid and pepsin, an enzyme, continue the process. The gizzard breaks down the food further as its muscles grind it with grit (previously consumed by the bird). Ground food continues into the intestines where enzymatic digestion and absorption of proteins, carbohydrates, fats, and other products of digestion occurs. The large intestine stores the waste and absorbs water until it is excreted through the vent. So, at any point in time the digestive system could have varying amounts of food in various stages of digestion. According to Savory (1985), the passage of food through the digestive tract is responsible for the initiation and termination of meals in birds. So, it is possible that the components of body weight in certain parts of the digestive tract may establish, when these components are relatively empty, or abolish, when relatively full, the reinforcing effectiveness of the intended inferior good.

There is evidence in the literature of the relation between meal initiation and digestive tract emptying as well as the association between meal termination and digestive tract filling (see Savory (1999) for a review). The crop appears to be the part of the digestive tract that is the most influential on feeding behaviour. When various combinations of mash and nutritive and non-nutritive additives were infused into crops of adolescent cockerels, food intake decreased in the following 3 hr (Shurlock & Forbes, 1981). In an experiment where chickens' crops were inflated with balloons, the amount eaten in 15 min decreased (Richardson, 1970). When crops of Japanese quail and domestic fowls were removed, they ate less, but only if food was limited to short periods of time or if food was diluted with an indigestible filler (Savory, 1985). For birds getting ad-libitum access to food, crop removal only affected 30 to 40% of birds, namely those birds that ate larger, less-frequent meals. The rest of the birds consumed food and gained weight similarly. Richardson found similar effects with chickens. Crop-removal only affected the amount consumed when feeding time was restricted. These data show that crop filling is at least loosely associated with meal termination for some birds. Food consumption by birds that eat less-frequent, large meals, such as hens participating in experimental sessions where most of the birds' daily ration of food is consumed, may be more likely to be affected by crop filling than birds that eat frequent small meals, say in an ad-libitum eating situation.

Additionally, time-of-day has been shown to affect feeding behaviour in birds. In natural light, for birds having unrestricted access to food there tends to be, "a conditioned change to cumulative filling of the crop (and gizzard) with food to be processed in the intestine during the overnight fast," at the end of the day (Savory, 1999, p. 344). For some birds, there may also be an increase in feeding in the morning, dependent on the amount of food stored at the end of the previous day such that more food stored results in less of an increase (Savory, 1980). This research implies that fading daylight somehow causes crop filling.

The effect of crop filling on key pecking by pigeons has been explored. For example, when pigeons responded under a VI schedule with varying reinforcer durations and grain sizes, within-session changes in response rates occurred sooner for longer reinforcers and larger grain sizes (Bizo, Bogdanov, & Killeen, 1998). These changes were greatest for pigeons that ate the least during ad-libitum feeding, so perhaps these pigeons had the smallest crops. In a series of experiments with pigeons, Demarse et al. (1999) found that within-session decreases in response rates under a VI-30-s schedule occurred faster for birds with larger crop capacities than for birds with smaller crop capacities. They also found that when these birds were fed before sessions, within-session decreases occurred sooner and that overall, these decreases were sooner for small-capacity birds than for large-capacity birds. The authors indicate that the weight consumed relative to crop capacity (as measured by weight consumed in a free-feeding situation) is important for predicting within-session changes, not just the weight consumed. These experiments are consistent with the research that shows that crop filling is associated with decreases in feeding behaviour. Overall, research involving bird crops suggest that these decreases of feeding or response rate occur quicker for birds with smaller crops than for birds with larger crops and that these changes are related to the weight consumed relative to crop capacity rather than to just the weight consumed.

The length of time that it takes for food to pass through the digestive tract varies with food type. According to Browne (1922), a meal of oats fed to birds with empty crops passed through the tract in 27 to 28, hr with the crop emptying in the first 18 to 20 hr. When gizzard contents were examined 10 and 20 min following consumption of oats, some oat grains were found indicating that some food passed through the crop in this timeframe. Another experimenter found that 30 g of corn (an weight probably smaller than the meal described above) fed to empty-crop hens passed into the gizzard in about 11 to 13 hr and 50 g passed in approximately 24 hr (Brown, 1904). The results for oats were reported to be similar. Keith, Card, and Mitchell (1927) report an experiment (written in German) where experimenters measured the rate of passage of 30 g of wheat, barley, maize, and oats (C. Schwartz & Teller, 1924). Wheat and barley passed in about 11 hr while maize and oats passed in about 12 hr; however, times ranged from 5 to 15 hr. These experimenters also reported that whilst in the crop, food became heavier due to the moisture it absorbed. Wheat gained 11.43, 32.69, and 36.71% of its weight in 4, 6, and 8 hr, respectively. In a more recent experiment with broiler breeders, experimenters examined the contents of the crop, gizzard, and other parts of the digestive tract at intervals of up to 24 hr following feeding (Jones, Zaczek, MacLeod, & Hocking, 2004). One group of hens consumed 76 g of food in one instalment daily and another group consumed about this much food ad libitum. The wet-weight of food in the crop at 1 hr after feeding the 76-g hens was heavier for these hens than for the ad-libitum hens as evidenced by: approximately 110 g versus approximately 15 g of food in the crop. Crops contained near-zero weights of food at 20 and 24 hr, for the 25-g and ad-libitum hens, respectively. Gizzard contents of the ad-libitum hens reached near-zero weights at 24 hr, but 25-g hens still had approximately 12 g of food in gizzards at this interval (cf. 22 g at 1 hr following feeding). These experimenters also reported an increase in moisture content of crop contents across the 24 hr. Their graphs show increases in water-to-dry-matter ratio comparable to the percentages reported by Schwartz and Teller.

This research suggests that, when given ad-libitum access to food, hens will consume approximately 100 g per day. Hens given ad-libitum access will consume this amount in small, frequent bouts while hens restricted to a single bout will consume this weight in a shorter time. Hens consuming a large amount of food are likely to have empty crops in about 24 hr while hens consuming smaller amounts are likely to have empty crops in about 20 hr or less. Whilst in the crop food gains weight through moisture absorption such that at 8 hr it weighs approximately 36.71% more. Most digested food is excreted within 24 hr or beyond, with small amounts remaining in parts of the digestive tract after the gizzard. However, these results should be interpreted with some caution given the large variability reported by Schwartz and Teller (1924) and given the large changes in commercial hen physiology (e.g., especially the increased growth rates) in the last 60 years (Konarzewski, Gavin, McDevitt, & Wallis, 2000). They do provide a rough guide to the rate at food passes through the digestive tract.

Beyond crop filling, there are other variables that have been shown to affect amount consumed per meal. Savory (1999) highlighted literature supporting nutrient density, ambient temperature, age, sex, and duration of food access as variables and claimed that these variables are also associated with variation in most components of the digestive tract. That is, these variables may be associated with dimensions of parts of the digestive tract which, in turn, may affect amount consumed. He suggested that when meal size changes gradually over time, that these longer-term changes are due to the accompanying changes in capacity of parts of the digestive tract.

So, it is feasible that the digestive system or specific parts of it such as the crop play a role in establishing and abolishing inferior and superior goods as reinforcers. That is, when body weights of subjects in inferior-good experiments were high partly because there was a lot of food in parts of the digestive tract (and perhaps partly due to additional adiposity) due to being exposed to many trials in the Rich Condition, the intended superior good was established as a reinforcer; when body weights were low, the intended inferior good was established. Another previously-discussed possibility is that the effects were related to adipose tissue and yet another possibility may be that these variables interact to result in EOs and AOs. However, according to Savory (1999), there has been little evidence to support any theory of homeostatic control (viz. body weight set point), so the current and subsequent experiments focussed on the role of the digestive tract, especially the crop, with respect to the relative-inferior- and inferior-good effects.

The purpose of the current experiment was to ascertain the crop capacity of the Group-7 hens from Experiment 2, the experiment showing the relative-inferior- and inferior-good effects across the most conditions and the most birds. There is ample evidence showing the importance of crop filling with respect to meal termination. Given this evidence and that within-session changes under VI schedules were greatest for pigeons that consumed the least when food was freely available (Bizo et al., 1998), for pigeons that had larger crop capacities, and for pigeons that were given food before sessions (DeMarse et al., 1999), it was expected that a similar relation might be involved in the relative-inferior- and inferior-good effects where the value of each alternative chages during the session (see Equation 6). Therefore, within-session changes may be manifested as a shift from salted-wheat to plain-wheat responding and this shift may occur sooner or not at all for smaller-cropped birds than for larger-cropped birds. In the current experiment, hens from Experiment 2 consumed plain or salted wheat from magazines during sessions so that a measure of their crop capacity could be used to estimate the percentage of crop filled at the onset of sessions in Experiment 2. If the weight consumed relative to crop capacity was the key variable in the pigeon research above (DeMarse et al.) and if the same relation was important for relative-inferior- and inferior-good effects in the current series of experiments and in the published works, then the hens showing the effect only once or not showing the effects in Experiment 2 (Hens 71 and 72, respectively) may have had smaller crops than the hens showing the effect.

Method

Subjects

Subjects were 5 of the 6 hens used in Experiment 2, numbered 71, 72, 73a, 74, and 75 as well as a new hen, Hen 76b, to replace Hen 76a. Hens were housed and maintained as in Experiment 2.

Apparatus

The experimental chamber was the same chamber used in Experiment 2. The analogue hanging scale and cone from Experiment 1 were used to weigh subjects but the scale was changed to UWE HS-3000 digital hanging scale with a resolution of 2 g and a maximum of 3,000 g on Day 68. Magazines were weighed with a Wedderburn EEW-10K digital table scale with a resolution of 1 g and a maximum of 11,000 g. The computer, software, and equipment from Experiment 2 controlled the experiment but the computer and software were changed to a Windows-based computer operating MED-PC for Windows 3© software on Day 123. Following the data collection of the experiment, daily outdoor maximum and minimum temperatures for the days spanning the entire experiment were provided by the National Institute of Water & Atmospheric Research (NIWA) in New Zealand. These data were collected from the Ruakura Electronic Weather Station 12616 located at Ruakura AgResearch Centre, less than 1 km away from the laboratory where the experiment took place.

Procedure

Hens were weighed approximately daily and their body weights were checked approximately once per week. Experimental sessions occurred for hens that were within +/- 50 g of their post-feed threshold on these checking days. These hens consumed plain wheat or salted wheat during experimental sessions and did not receive any other feed on these days. Hens that were not within this margin were fed 50 cc of standard pellets plus more cc if their body weight was below the threshold, as described in Experiment 2. Sessions began without the houselights or key lights illuminated. There were no programmed consequences for pecks on either key and water was always available. Depending on the condition, either plain wheat was available in the left magazine or salted wheat was available in the right magazine. The magazine operated continuously from the onset of the session for 3-sec durations with 0.5 sec intervals between presentations. Hens 71, 72, and 73a began with salted wheat while Hens 74, 75, and 76b began with plain wheat. Sessions ended after 40 min. Each hen consumed plain or salted wheat in the above manner until the weight consumed was visually stable across all hens. The MED-PC 2© software monitored the duration of eat-time bouts where time accrued in 0.1-s intervals so long as the hens head was in the magazine. Data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a. Additionally, 10 samples of 100 cc of plain wheat, salted wheat, and food pellets were weighed to calculate food densities.

Results

This experiment operated concurrently with Experiment 3a. In that experiment, Hen 92a died following its first condition change from Poor to Rich because it consumed a large amount of salted wheat during its first Rich-Condition session. As a result, the procedure of the current experiment was immediately changed to decrease the chances of salt poisoning. Hens 71, 72, and 73a were switched to the plain-wheat condition and Hens 74, 75, and 76b were never exposed to the salted-wheat condition. Also, data sheets containing the weights of wheat consumed from Day 315 to Day 363 were lost, so these data were not available for analysis. The missing data were from 5 sessions for Hen 71 and from 7 sessions for Hens 73a and 74. This experiment terminated based on visual stability of weight consumed across all hens and analysis was not done on only the last several sessions (as in previous experiments where the last 20 sessions were used) because behaviour at the end of the experiment did not appear more stable than behaviour at the beginning of the experiment. Rather, behaviour appeared as though it would continue to vary (but not trend), so the experiment was terminated and data from the entire experiment was used for analysis.

The weights of plain and salted wheat consumed during each session are displayed in Figure 37. The figure shows that across all hens, the weight of salted wheat consumed ranged from 38 to 130 g while the weight of plain wheat consumed ranged from 65 to 201 g. Weight means and standard deviations are presented in Table 37. Means for plain wheat ranged from 110 to 142 g with standard deviations ranging from 23 to 28 g. Means and standard deviations for salted wheat ranged from 74 to 85 g and from 26 to 38 g, respectively. A comparison of plain- and salted-wheat means for Hens 71, 72, and 73a shows that

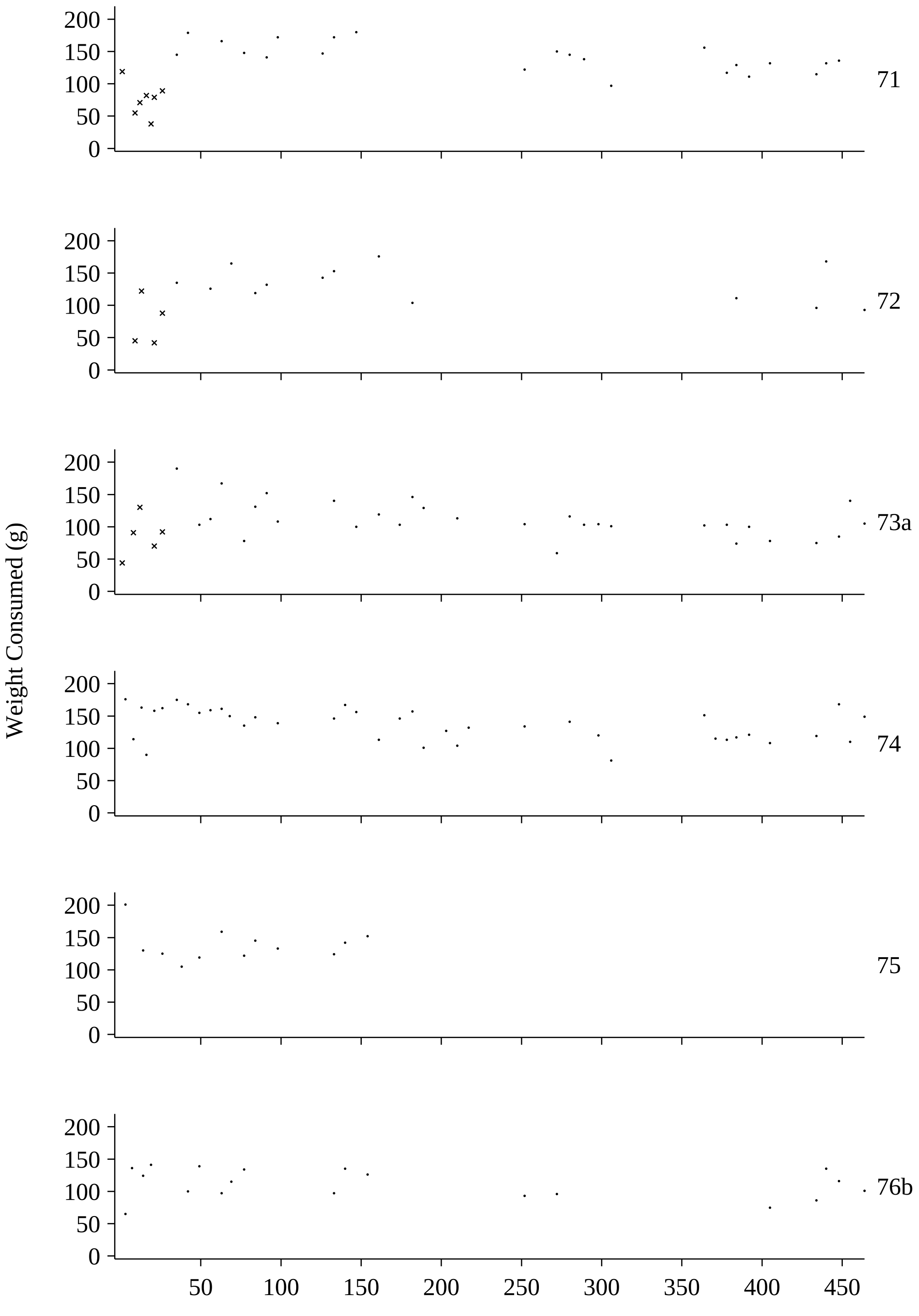

Figure 37. Experiment 7: Weights of plain-wheat (•) and salted-wheat (×) consumed across consecutive calendar days.

plain wheat means were higher than salted wheat means. For these hens, salted-wheat means were 53, 56, and 77% of plain wheat means, respectively. A comparison of plain- and salted-wheat standard deviations for these hens shows that standard deviations were similar for each type of wheat. Hen 72 had a slightly higher standard deviation for salted wheat at 38 g compared to its plain-wheat standard deviation of 28 g. So, hens tended to consume more plain wheat than salted wheat by weight and showed similar variability, in terms of weight consumed, in consumption for each type of wheat.

Table 37
Experiment 7: Means with Standard Deviations (in Brackets) of Weights Consumed, Eat Times, and Eat Rates and Eat-Time versus Wheat-Weight Correlations with Sample Sizes (in Brackets)

Hen	Weights (g)		Eat Time (s)		Eat Rate (g/s)		Correlation (*r*)	
	Plain Wheat	Salted Wheat	Plain Wheat	Salted Wheat	Plain Wheat	Salted Wheat	Plain Wheat	Salted Wheat
71	142	76	792.5	718.1	0.18	0.11	.64*	.89*
	(23)	(26)	(174.5)	(198.4)	(0.13)	(0.13)	(20)	(7)
72	132	74	1006.3	678.6	0.13	0.11	.63*	.42
	(28)	(38)	(252.8)	(264.5)	(0.11)	(0.14)	(11)	(4)
73a	110	85	530.6	639.5	0.21	0.13	.66*	.99*
	(28)	(32)	(188.3)	(254.4)	(0.15)	(0.13)	(26)	(5)
74	137		605.4		0.23		.38*	
	(24)	.	(174.0)	.	(0.14)	.	(34)	.
75	138		675.2		0.20		.13	
	(25)	.	(220.0)	.	(0.11)	.	(12)	.
76b	111		457.5		0.24		.61*	
	(23)	.	(120.3)	.	(0.19)	.	(16)	.

*p<.05

Figure 38 displays plain- and salted-wheat eat-time durations for each session. Across hens, the eat times for salted wheat ranged from 265.4 to 994.6 g while eat times for plain wheat ranged from 174.6 to 1,418.9 s. Table 37 shows eat-time means and standard deviations. Means for plain wheat ranged from 457.5 to 1,006.3 s with standard deviations ranging from 120.3 to 252.8 s. Means and standard deviations for salted wheat ranged from 639.5 to 718.2 s and from 198.4 to 264.5 s, respectively. For Hens 71, plain- and salted-wheat means were similar, for Hen 72, the plain-wheat mean was higher, and for Hen 73a, the salted-

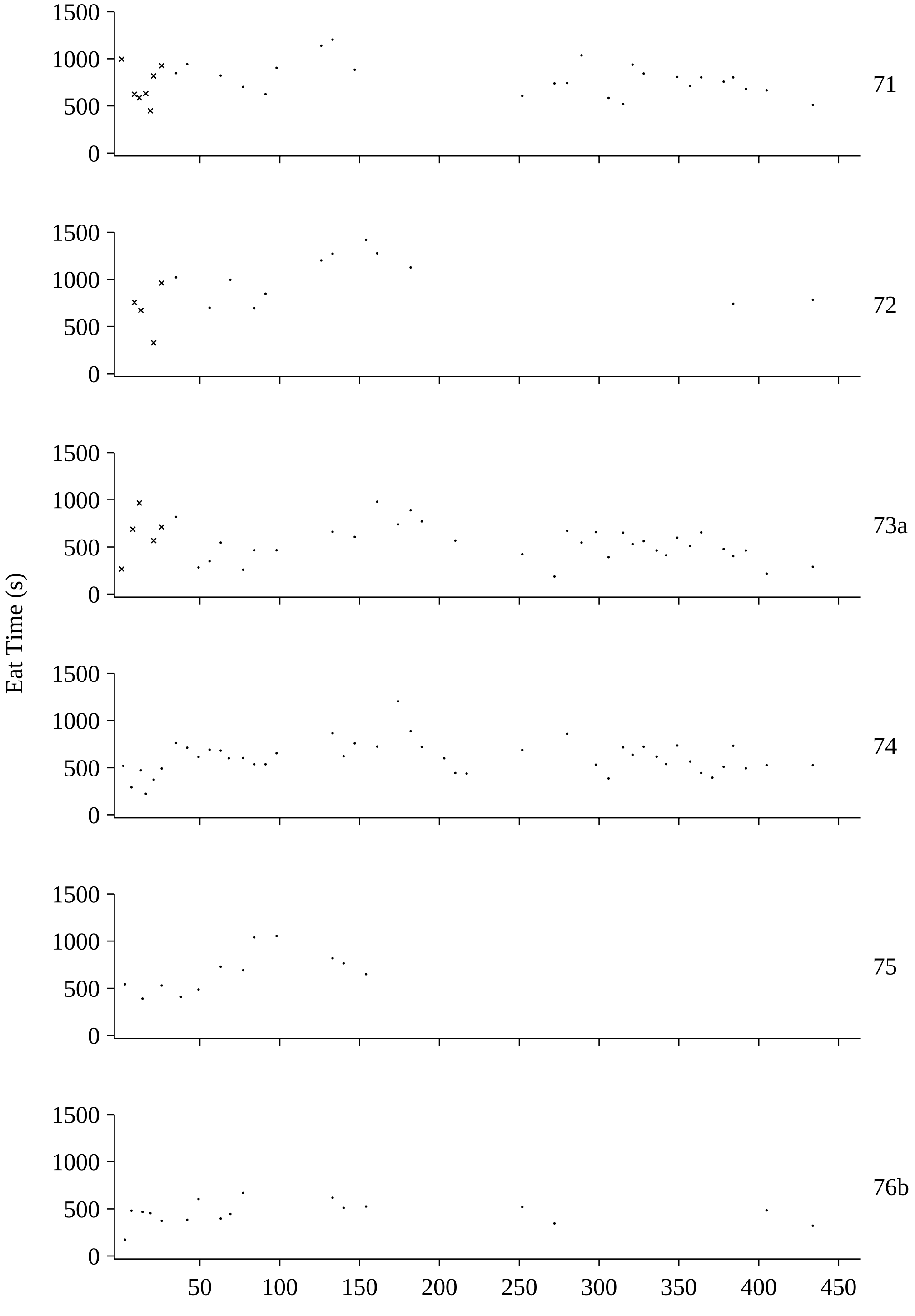

Figure 38. Experiment 7: Durations of eat times for plain-wheat (•) and salted-wheat (×) across consecutive calendar days.

wheat mean was higher. For these hens, salted-wheat means were 91, 67, and 121% of plain wheat means, respectively. Plain- and salted-wheat standard deviations were similar for each type of wheat. Hen 73a had a slightly higher standard deviation for salted wheat at 254.4 s compared to its plain-wheat standard deviation of 188.3 s. These eat-time data differ from the weight data in that there were no large differences in eat times found between the two types of wheat. Hens consumed plain wheat and salted wheat for similar durations of time and with similar variability.

Mean weights consumed were divided by mean eat times to yield mean eat rates so that weights of wheat consumed could be estimated for sessions in Experiment 2 by multiplying these eat rates by each session's eat time. The same operation was done to yield eat-rate standard deviations. These mean eat rates and their standard deviations are presented in. Mean plain-wheat eat rates ranged from 0.13 to 0.24 g/s and standard deviations ranged from 0.11 to 0.19 g/s; mean salted-wheat eat rates were either 0.11 or 0.13 and standard deviations ranged were either 0.13 to 0.14 g/s. Plain-wheat eat rates were comparable between Hens 73a, 74, 75, and 76, ranging from 0.20 to 0.24 g/s, and between Hens 71 and 72, at 0.18 and 0.13 g/s. For the 3 hens consuming both types of wheat, the mean eat rates for salted wheat were slower while standard deviations were similar.

Pearson correlation coefficients for eat times versus wheat weights are displayed with each correlation's sample size in Table 37. When an eat time and its wheat weight were zero, they pair were omitted from analysis to avoid inflating the correlations. Coefficients varied across hens (but were similar for plain wheat for Hens 71, 72, 73a, and 76) and between types of wheat for the 3 hens that consumed both wheats. Using Cohen's (1988) classification described in

Experiment 3a and an alpha level of .05, plain-wheat correlations were large and statistically significant for Hens 71, 72, 73a and 76b; medium and statistically significant for Hen 74; and small for Hen 75. Salted-wheat correlations were strong and statistically significant for Hens 71 and 73a and medium for Hen 72. Sample sizes ranged from 11 to 34 for plain wheat and from 4 to 7 for salted wheat.

Hens' pre-session body weights and body weights on non-session days are shown in Figure 39. Overall, body weights fluctuated around each hen's post-feed threshold. Following days where sessions occurred, body weights were much higher as the amount of food consumed on these days was larger than on non-session days. Body weights gradually reduced towards each hen's post-feed threshold following days when sessions occurred. There was a span of time from approximately Day 150 to 400 where body weights for Hens 71, 72, 75 and 76b tended to remain high and often outside of the +/-50 g of the post-feed threshold, resulting in less sessions during this time.

The weights of the 10 samples of 100 cc of plain wheat, salted wheat, and pellets were processed into means and standard deviations. For plain wheat the mean and standard deviations were 78.0 and 0.94 g; for salted wheat, 63.6 and 1.35 g; and for pellets, 62.3 and 1.70 g. Each mean weight was then converted to a density by dividing it by 100 cc to yield a measure in g/cc which would have the same value as the standard measure of kg/m^3. Densities were 0.78 g/cc for plain wheat, 0.64 g/cc for salted wheat, and 0.62 g/cc for pellets. So, densities of salted wheat and pellets were comparable while the density of plain wheat was 22% higher than that of salted wheat or pellets.

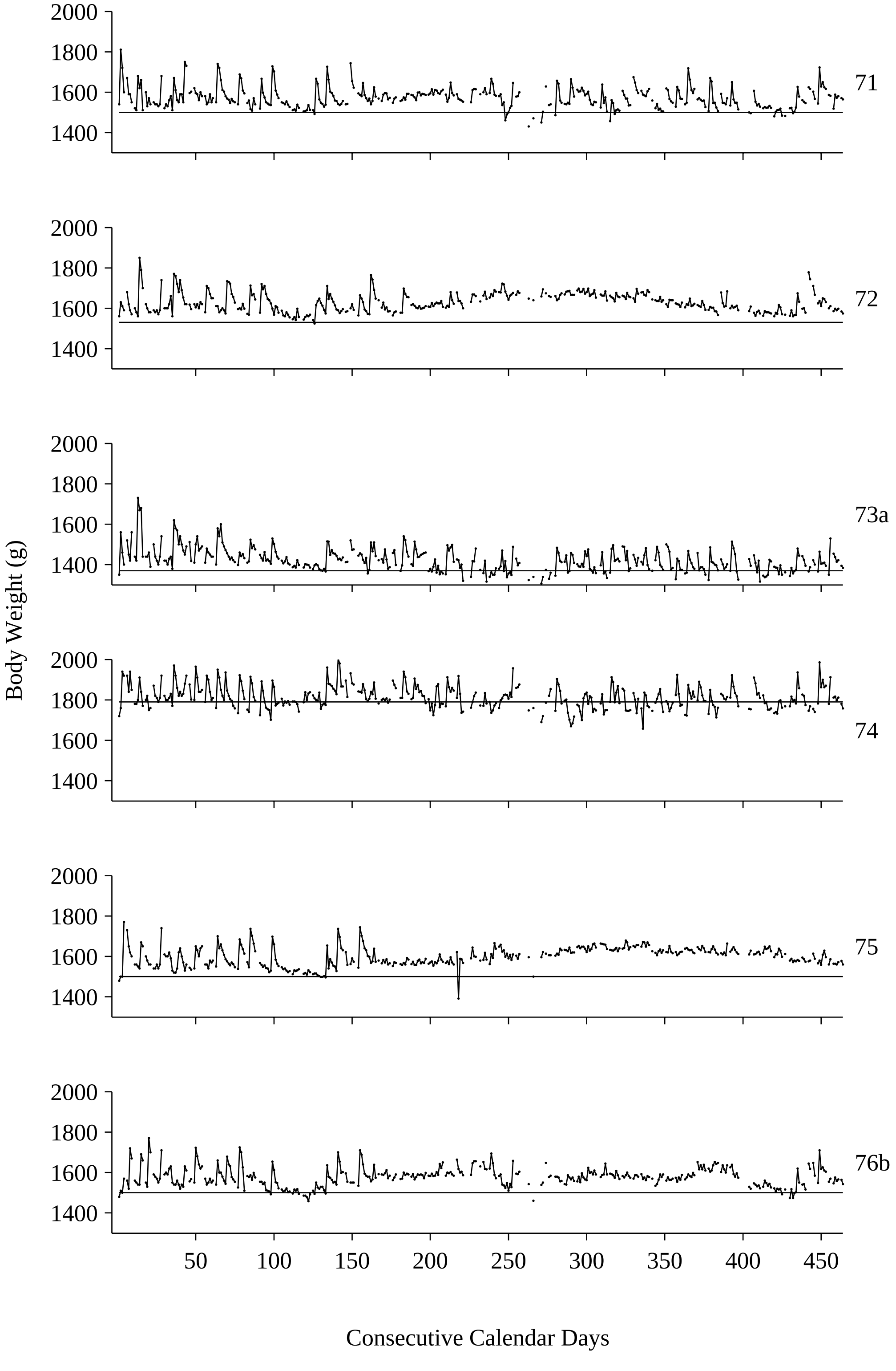

Figure 39. Experiment 7: Pre-session body weights and body weights on non-session days across consecutive calendar days. Horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight).

Discussion

The current experiment was intended to measure the crop capacity of the remaining Group-7 hens from Experiment 2 to investigate the relation between the inferior- and relative-inferior-good effects and crop capacity. It was predicted that smaller-cropped birds would be less-likely to show the effects than larger-cropped birds due to within-session changes of shifting from salted wheat to plain wheat occurring faster or not at all for birds with smaller crops. That is, in reference to Equation 6, smaller-cropped birds were expected to show quicker decreases in the value of salted wheat (as evidenced by less responding to, or less time allocated on the salted-wheat key) than larger-cropped birds. In Experiment 2, salted wheat was an inferior good or relative inferior good for all three condition changes for Hens 73a, 74, 75, and 76a and was an inferior good for one of three condition changes for Hen 71. Hen 72 never showed either effect. If the effect was more likely to occur for larger-cropped birds, then Hens 71 and 72 should have had the smallest crops (i.e., should have consumed the least plain wheat ad libitum).

Table 37 shows that this relation was not the case. Hen 71 showed the inferior-good effect for one of three condition changes and consumed the most plain wheat (142 g) and Hen 72 never showed either effect but consumed a weight comparable to Hens 74 and 75 (132 g). These two hens showed the inferior-good effect once and the relative-inferior-good effect twice for three condition changes. Hen 73a consumed the least plain wheat, but still showed the relative-inferior-good effect for three of three condition changes. Hen 76a showed the inferior-good effect for all three condition changes, but this hen deceased prior to the current experiment, hence a crop-size estimate was never obtained. So, for these birds, crop capacity as measured by the weight of plain wheat consumed ad libitum was unrelated to the inferior- and relative-inferior-good effects. Birds with smaller crops were not more likely to show the effect than birds with larger crops. However, the number of possible trials in each condition in Experiment 2 differed across birds (see Table 2). If the percentage of crop filled is a better predictor of within-session changes than crop capacity (DeMarse et al., 1999), then birds with similar-capacity crops may have had different percentages of their crop filled due to the differences in the numbers of possible trials. So an alternative explanation is that the percentage of crop filled mattered, but that the differences in total possible trials across birds for each condition resulted in different percentages of crop filling which resulted in the presence and absence of the inferior- and relative-inferior-good effects for birds with similar-capacity crops.

This explanation would be supported if Hens 71 (one inferior-good effect) and 72 (no inferior- or relative-inferior-good effects) experienced a larger number of trials in conditions when compared to birds with similar capacity crops. This larger number of trials would have resulted in a greater percentage of crop filling, all other variables being the same. Hen 71’s crop capacity was 142 g so it was comparable to Hen 74, at 137 g, and Hen 75, at 138 g; all 3 hens had similar standard deviations. The highest total possible number of trials in Rich and Poor Conditions were as follows: 38 and 13 for Hen 71, 46 and 16 for Hen 74, and 29 and 10 for Hen 75, respectively. So for both conditions, Hen 71 had the second highest number of trials of these 3 hens with similar crop capacities. Hen 72’s crop capacity was 132 g, so the closest capacities were also Hen 74 and 75’s. The total possible number of trials in Rich and Poor Conditions for Hen 72 was 29 and 12. So for Rich Conditions, Hen 72’s total possible number of trials tied the lowest number of trials of these 3 similar-capacity hens and for Poor Conditions it had the second highest. These data suggest that Hens 71 and 72 did not have a larger percentage of their crops filled in sessions than the hens with similar-sized crops that showed inferior- or relative-inferior-good effects.

The conclusion above, though, rests on the assumption that the birds eat at the same rate. That is, that each response on a key results in the same weight of wheat consumed across birds. Data from published research suggest that this assumption is flawed as the weight of food consumed per minute varies between birds, genetic lines, times of day, environments; within meals; and according to the presence or absence of other birds (social facilitation) (Savory, 1999). Similarly, when eat rates were calculated for hens in the current experiment by dividing mean plain weight consumed by mean eat time (see Table 37), different rates were found for each hen and their standard deviations were at least half of the size of the means, indicating large variability. Finally, the correlations between eat time and weight consumed in previous experiments of the current series differed across hens and conditions as did the correlations calculated for the current experiment (see Table 37), again suggesting differences in the weight of food consumed per minute. Building on the problematic conclusion above, if Hens 71 and 72 ate faster than the other hens of a similar crop size, then in Experiment 2 they may have had a larger percentage of their crops filled and resultantly may not have showed inferior- or relative-inferior-good effects. The calculated eat rates of the current experiment do not support this conclusion as both birds had the slowest eat rates. This lack of support should be interpreted in the light of the large variability discussed above. Also, these rates were calculated during ad-libitum access which might be different to eat rates during 3- or 10-s magazine operations.

Without a direct measure of the amounts consumed per response in Experiment 2, the within- and between-subject variabilities of feeding efficiency (weight eaten per time interval) make these data difficult to interpret in terms of percentage of crop filled. The crop-capacity estimation procedure was based on Demarse et al. (1999) who found that allowing pigeons at 80% body weight to eat ad libitum for 1 hr for 3 sessions resulted in no significant difference across the 3 sessions. The mean weight consumed across all birds was 38.13 g and error bars on their Figure 1 suggests a mean standard deviation of approximately 3 g. The data of the current experiment were more variable than these data with standard deviations ranging from 23 to 28 g for plain wheat, and, as a result, the experiment took much longer before weights consumed were judged visually stable. There was also a difference between crop capacity as measured by ad libitum consumption of plain wheat and by consumption of salted wheat. As the densities of plain and salted wheat differed, when considering both kinds of wheat, crop fill may be better discussed in terms of volume by dividing the mean weights of plain and salted wheat consumed by their respective densities. For example, if 100 g of each of these wheats was consumed, then dividing this weight by the wheat's density would result in 128 cc of plain wheat or 156 cc of salted wheat. The estimates of mean volumes consumed during this experiment and their standard deviations for each hen are shown in Table 38. The difference in both crop capacity measures is still apparent following this conversion. Crops measured by ad libitum consumption of plain wheat would be estimated to be larger than crops measured by ad libitum consumption of salted wheat. Also, variabilities of weights and volumes of salted wheat consumed were higher than

Table 38
Experiment 7: Estimates of Means with Standard Deviations (in Brackets) of Volumes Consumed

Hen	Volumes (cc)	
	Plain Wheat	Salted Wheat
71	182 (29)	119 (41)
72	169 (36)	116 (59)
73a	141 (36)	133 (50)
74	176 (31)	
75	177 (32)	
76b	169 (29)	

those of plain wheat. It is unknown why this difference in variability occurred, especially considering that there were fewer salted-wheat sessions than plain-wheat sessions. The opposite difference in sample sizes would be expected if the larger variability was purely due to the greater chances of including extreme values due to the larger sample size. Given that Hen 92a deceased following the consumption of a large amount of salted wheat in Experiment 3a (the autopsy showed swelling and redness in early parts of the digestive tract) and that all birds consumed more plain wheat than salted wheat when given ad-libitum access in this experiment and in Experiment 1, the smaller weights or volumes of salted wheat consumed and their larger variabilities may be related to the aversiveness of salt in the digestive tract.

This difference in crop capacity as measured by ad-libitum access to each kind of wheat suggests that *crop capacity* is a misnomer. As such, the term will be replaced in favour of a more accurate description: simply, *weight of plain-* or *salted-wheat consumed ad libitum*. In Demarse et al. (1999), the reinforcer used during VI responding was the same mixed grain used in their crop-capacity assessment, so their measure of the weight consumed relative to crop size (as a predictor of within-session decreases) would not have been compromised by measuring crop capacity with one reinforcer and using a another reinforcer during VI sessions. In the current experiment, because of the difference in the weight of plain- or salted-wheat consumed ad libitum (i.e., two different estimates of crop capacity), calculations of the weight consumed relative to crop size in Experiment 2 (percent of crop capacity, to use Demarse et al.'s words) would be dubious. Further, even if, say, the weight of plain-wheat consumed ad libitum was used as a crop-capacity estimate, in that experiment hens consumed plain and salted wheat in differing amounts across sessions, so the resulting estimate of the weight consumed relative to crop size would be equally dubious. Therefore, the intent to estimate the percentage of crop filled during sessions in Experiment 2 will be dismissed.

The finding that body weights for Hens 71, 72, 75 and 76b tended to remain high from Day 150 through approximately Day 400, often higher than body weight required to run the experiment (the post-feed threshold +/- 50 g), prompted scrutiny of environmental variables that may have affected all of these hens. The only variable that was thought to affect these hens as such was ambient temperature; Savory (1999) listed this variable, amongst others, as a variable that could affect amount consumed per meal. In a study with mature single comb white leghorn roosters, Taher, Gleaves, and Mather (1985) found that when these animals were shifted from an ambient temperature of 22.2 °C to either 13.3 or 30.0 °C, the colder-temperature roosters consumed more food and the warmer-temperature roosters consumed less food. Another study compared domestic fowls' feeding patterns at 8, 20, and 32 °C (Savory, 1986). In the coldest temperature, birds ate larger meals at a faster rate with more time between meals than at the warmer temperatures. Similarly, reductions in ambient temperature from 32 °C to 6, 1, or .6 °C caused increases in meal size for pigeons (Henderson, Fort, Rashotte, & Henderson, 1992). The high body weights for Hens 71, 72, 75 and 76b from Day 150 through approximately Day 400 may be accounted for by temperature.

The NIWA provided retrospective outdoor temperature maximums and minimums from an electronic weather station less than 1 km from the laboratory. Assuming that there is a reasonable correlation between outdoor temperature and indoor temperature (there was no heater or air conditioning where the experiments took place or where the hens were housed), these data may show a relation between temperature and bodyweight. Based on the data from the published research, the temperatures for Days 150 through approximately 400 should have been higher than the temperatures on other days, thereby reducing the need for food to maintain body weight. This relation might be quantified by calculating correlation between temperature and weight consumed. A correlation between temperature and bodyweight would be meaningless because the amount of food consumed was not constant across days. Even if days following sessions were removed (where bodyweights were highest, presumably due to the food in the digestive system), subsequent days usually showed high, but decreasing bodyweights and on non-session days birds may have been fed different amounts to maintain body weights. So, a few variables may have varied along with temperature resulting in body weight changes thereby making correlations between temperature and bodyweight uninformative.

Figure 40 is a re-plot of Figure 39 with bars representing maximum outdoor temperature plotted in the background of the body weights. The figure

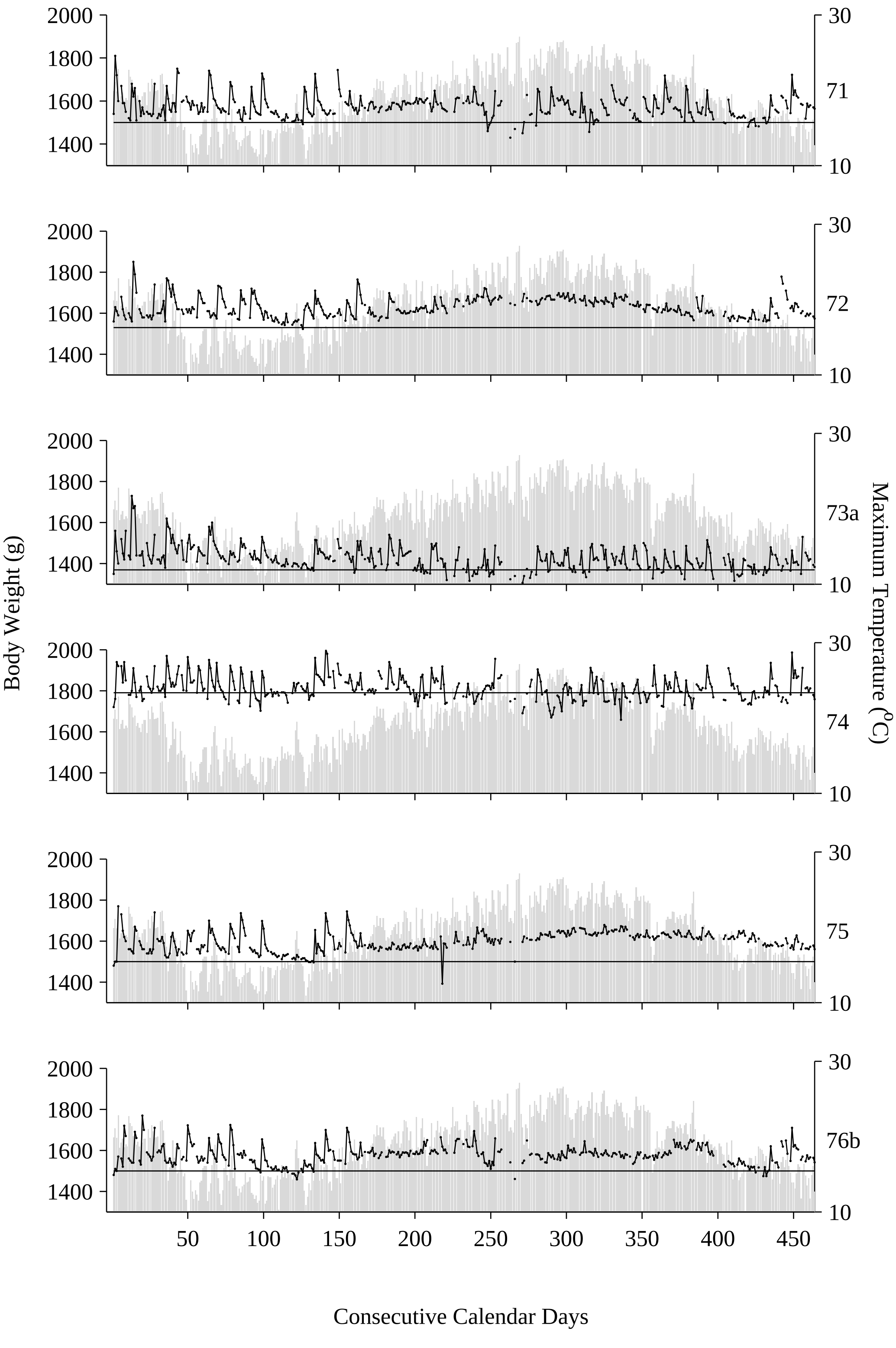

Figure 40. Experiment 7: Pre-session body weights and body weights on non-session days across consecutive calendar days. Horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Background bars represent daily maximum outdoor temperatures.

shows that the warmest days occurred from approximately Day 150 to Day 400, suggesting that high temperatures co-varied with high body weights which resulted in Hens 72, 75, and 76b not meeting the body weight criteria for participating in sessions during this time (cf. Figure 37). Table 39 presents correlations between the previous day's maximum and minimum outdoor temperature and the weight of plain wheat consumed. Correlations for maximum temperatures ranged from -.24 to -.39 for Hens 71, 72, 73a, and 74 and were .48 and -.01 for Hens 75 and 76b, respectively, and correlations for minimum temperatures ranged from -.32 to -.04 for the first 4 hens and were .23 and .34 for Hens 75 and 76b, respectively. A test of statistical significance with an alpha level of .05 revealed only one significant result—Hen 74's maximum-temperature correlation coefficient—so, these results should be interpreted with caution as the correlations could have occurred through chance. The small-to-medium (Cohen, 1988), negative correlations for the first 4 hens suggest that as the maximum and minimum temperatures rose, the weight of plain wheat consumed tended to decreased. The small-to-medium, positive correlation found for Hens 75 and 76b

Table 39
Experiment 7: Maximum and Minimum Temperature versus Plain-Wheat-Weight Correlations and Sample Sizes (in Brackets)

	Correlation (*r*)	
Hen	Max	Min
71	-.25	-.12
	(22)	(22)
72	-.39	-.32
	(12)	(12)
73a	-.24	-.14
	(28)	(28)
74	-.35*	-.04
	(36)	(36)
75	.48	.23
	(12)	(12)
76b	-.01	.34
	(18)	(18)

*p<.05

may be reflective of the fact that the sampled data involved similar weights and similar maximum temperatures. The correlation may have been different if it included weights consumed across a wider range of temperatures. The same argument might be made for Hen 74 and 76b's lack of correlation for minimum and maximum temperatures, respectively. The most samples (22 to 36) were taken for Hens 71, 73a, and 74 and these samples included the widest range of temperatures, so these correlations are probably the best indicators of the relation between temperature and the weight of plain wheat consumed, but, as stated earlier, most are not statistically significant and may have resulted by chance. This relation, though, is supported in the literature (Henderson et al., 1992; Savory, 1986, 1999; Taher et al., 1985).

The data in Figure 40 (compare the temperature bars in Figure 40 with the weights consumed in Figure 37) and Table 39 show that outdoor temperature fluctuations outside of the laboratory may have affected the weight of plain wheat consumed during ad-libitum access at +/- 50 g of hens' post-feed thresholds (i.e., approximately 80% body weight). In terms of the role of the digestive tract with the inferior- and relative-inferior-good effects, birds in colder temperatures would have had a faster rate of food passage through the digestive tract than birds in the warmer temperatures. If the amount of food in the digestive tract (especially the crop) is indeed important for the effects, then all else being the same, birds in colder temperatures would have had less food in their digestive tract than birds in warmer temperatures and this difference may have resulted in the effect on some days (or some conditions) but not in others.

The rate of a hen's food passage is related to its basal metabolic rate (BMR), defined as, "the rate at which the quiet, resting, fasting body breaks down foods (and therefore releases heat)," (Tortora & Anagnostakos, 1990, p. 814). It can be determined by measuring an organism's rate of heat loss, the amount of oxygen consumed, the amount of carbon dioxide produced, and the rate of food consumption as all of these variables change with changes in BMR (Campbell & Reece, 2002). BMRs vary within and across species. For organisms of the same species BMRs can vary due to age, sex, size, body and environmental temperatures, quality and quantity of food, activity level, oxygen available, hormonal balance, and time of day (Campbell & Reece). Across organisms, larger organisms tend to have higher BMRs than smaller organisms, but when divided by body weight to yield BMR per unit of bodyweight, smaller organisms tend to have higher BMRs per unit of body weight than larger organisms (Campbell & Reece, 2002, p. 845).

In young chickens, resting metabolic rate (a metabolic-rate measure under less-stringent conditions than BMR) increased with lean body weight (Konarzewski et al., 2000). Also, across 248 avian species McKechnie and Wolf (2004) found a similar relation between BMR and bodyweight. According to Winchester (1940) the BMR of *Gallus domesticus* with a body weight of 2,710 g is 6.005 watts (W, a measure of energy expenditure per second) (as cited in McKechnie & Wolf, 2004); a 2,000 g hen is about 4.8 W (University of Toronto, Department of Physics, 2006). Human BMRs are approximately 75 W (Campbell & Reece, 2002, p. 845); a woman at 60 kg has a BMR of about 68 W, and a man at 70 kg, 87 W (University of Toronto, Department of Physics). Body weights and BMRs for other species are as follows: rats, 1.45 W at 260 g; pigeons, 1.55 W at 300 g; male dogs at 16 kg, 20 W; sheep at 45 kg, 50 W; and cows at 400 kg, 266 W (University of Toronto, Department of Physics). For a two-to-three-year-old female Japanese macaque, the same species used in Silberberg et al. (1987), its BMR ranged between 19.92 and 27.09 W, depending on the season, when converted from kilocalories per day (Iwamoto, 1974). Monkeys of this age weigh approximately 5 kg (Takahashi et al., 2006). It can be assumed, then, that rats in the Hastjarjo et al.(1990a) study had a BMR of approximately 1.45 W; hens in the current series of experiments, about 6.005 W; and monkeys in the Silberberg, et al. study, approximately 19.92 to 27.09 W.

The fact that BMRs increase with body size suggests that two hens of different body weights would require two different amounts of food to maintain body weight. Incidentally, the crop sizes of pigeons were unrelated to the amount of food required to maintain body weights (nor were they related to body size) (DeMarse et al., 1999), so this lack of relation may be the case with hens as well. If the amount of food in the digestive tract played a role in inferior- and relative-inferior-good effects than if all variables remain the same, larger hens should have less food in their digestive tracts than smaller hens due to their faster BMRs. Larger hens, then, should show within session changes slower than smaller hens and therefore shift to plain wheat later than smaller hens. Unfortunately, as described earlier, each hen had different numbers of total possible trials making a comparison of body weights with effects difficult. Hens 71 and 72, had post-feed thresholds (approximately 80% of free-feeding body weight) of 1500 and 1580 g, respectively. These thresholds were the same as Hens 75 and 76, respectively, and the latter 2 hens showed the effects while the former 2 hens did not, save one occurrence of the inferior-good effect for Hen 71. Also the hens with the highest threshold (Hen 74 at 1790 g) and the lowest threshold (Hen 73a at 1370 g) both showed the effects. So there are no clear patterns with respect to free-feeding body weight (or post-feed thresholds) and the inferior- and relative-inferior-good effects, but this relation was not well investigated by controlling the suspected variables involved.

If the digestive system does play the hypothesised role in inferior- and relative-inferior-good effects in terms of EOs and AOs, then establishing and abolishing effects in experiments of the current series and in the published experiments may have varied with respect to each organism's BMR. Further, as BMR has been shown to vary with age, sex, size, body and environmental temperatures, quality and quantity of food, activity level, oxygen available, hormonal balance, and time of day, any one or more of these variables may have influenced the BMR which would have affected the rate of food passage which would have resulted in EO and AO changes. At a point in time following eating, organisms with fast BMRs should have less food in their digestive tracts than organisms with slow BMRs, with all other variables being equal. In inferior-good experiments, these fast-BMR organisms may therefore be more likely to consume the inferior good if this emptying of the digestive tract establishes the quantity aspect of the inferior good as a reinforcer. This prediction includes the percentage of crop filled as a possibly-important part of the digestive tract with respect to the effects. The reported early intended-inferior-good responding and late intended-superior-good responding within-session patterns of previous inferior-good experiments fit with this prediction as well. A relatively empty digestive system may establish the quantity dimension of the intended inferior good as a reinforcer until a percentage is filled. Responding may then shift when the quality dimension gains control as the quantity dimension becomes abolished. The conditional-stimulus effects found in the second Rich Condition for Hen 75 and in the second Poor Condition for Hen 76a in Experiment 2 as well as in the first Poor Condition for Hen 94 in Experiment 6 are also explainable by reference to food in the digestive tract. Houselights were previously described as CEOs and their control was hypothesised to have occurred through their differential association with high and low body weights (because body weights tended to change with conditions). It may be the case that food in the digestive tract (or parts of the digestive tract such as the crop) was the important component of body weight for the CEO effect. So, houselights may have gained their control through their differential pairing with relatively empty crops (in the Poor Conditions) and relatively full crops (in the Rich Conditions) so that Poor-Condition houselights established salted-wheat as a reinforcer and Rich-Condition houselights established plain-wheat as a reinforcer for the birds affected. Houselights would still be classified as surrogate CEOs (Michael, 1993) as discussed in Experiment 3b because they were previously-neutral stimuli that were correlated with relatively empty or relatively full crops.

Although the relation between adiposity and food in the digestive tract (including the percentage of crop filled) and the inferior-and relative-inferior-good effects has not been unravelled, there is enough evidence to suggest that one or both of these variables is important for the effect. Also, there is a lack of parsimonious explanations for the effect. The effect of replicating Experiment 2 with hens at high and low body weights was not examined due to the long time that this would have taken as Experiment 2 took almost a year and birds in Experiment 4 took a long time to return to their post-feed thresholds (low body weights). So, the final two experiments involved manipulating the amount of food in the digestive tract to observe the effects on the inferior-and relative-inferior-good effects.

Experiment 8: Short ITI /Short ITI with Pre Feed (Group 7)

Adiposity (Gibbs, 1996) and food in the digestive tract (Campbell & Reece, 2002; DeMarse et al., 1999; Savory, 1999) have been shown to affect the amount of food consumed during ad-libitum feeding. Metabolic changes occurring with these changes have been considered positive or negative feedback signals with respect to eating (Gibbs, 1996; Pinel, 2000), in the bodies of various species. Behaviourally, these signals may be interpreted as EOs and AOs, respectively. So, if adiposity is low (body weight is below set point), then food would be established as a reinforcer but if it is high (body weight is above set point) then food would be abolished as a reinforcer. If these relations are related to the inferior- and relative-inferior-good effects, then the quantity dimension of food may be established as a reinforcer below body-weight set points and abolished at above body-weight set points while the quality dimension may remain established at any body weight, but maybe not as strong as the reinforcing effectiveness of quantity at certain low body weights. As the quality dimension of the wheat had been changed by adding salt (changing taste), the AO for quality would have been related to the amount of exposure to each kind of wheat, that is, to habituation to the tastes of wheat. In inferior-good experiments, the intended inferior goods were always larger but less-preferred, so if this explanation is applied to the inferior- and relative-inferior-good effects subjects at low body weights (low adiposity) should consume the intended inferior good while subjects at high body weights should consume the intended superior good. This finding occurred, but not all of the time, across the current series of experiments as well as in the published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987), but the role of adiposity has never been examined directly, by, say, doing the same experiments at low and high body weights.

The finding could also be explained through reference to food in the digestive tract, rather than to the bird's body-weight set point. Food in the digestive tract or in specific parts of the digestive tract (such as the crop in birds, see Figure 36) may have served as AOs whereby no food or a little food in the crop established the quantity dimension of food as a reinforcer while more food in the crop abolished the quantity dimension and allowed the quality dimension more control. Savory's (1999) review of the role of the crop in feeding supports this view, although he makes no mention of EOs or AOs his discussion of satiety and hunger factors fits the definition of these terms. Savory also indicated that there is more evidence for the digestive tract's role in feeding than the role of mechanisms relating to set points and that the control by the digestive tract is due to variation in dimensions of parts of the tract. He highlighted CCK and BBS, as 2 of over 12 peptides that are released as food moves through a bird's digestive tract. Both have been shown to cause decreases in feeding (so might be considered negative feedback signals or AOs), but the research on the effects of these peptides on birds' feeding is sparse. Also, changes in feeding may have been due to abdominal discomfort instead of the effects of the peptides (Savory, 1987). In an experiment that tested the effects of transfused blood of fed and fasted domestic fowls on other fed and fasted domestic fowls, all transfused fowls' feeding decreased compared to control infusions (Savory & Smith, 1987). Birds transfused with fed-fowl blood ate less than birds transfused with fasted-fowl blood, but the differences were not statistically significant. When fed and fasted fowls were injected with reconstituted plasma from fasted fowls, the fed fowls' feeding reduced while the fasted fowls' feeding did not when compared with feeding following injections of saline. These results did not indicate a hunger factor (EO) but did provide some evidence of a satiety (AO) factor in the blood.

Overall, adiposity and food in the digestive tract both have been shown to cause changes in humoral factors in the bodies of various species. A literature search did not reveal work directly relating to feeding and levels of adiposity in birds. In hens it has been suggested that the filling of the digestive tract, especially the crop, is responsible for meal cessation and that the release of several peptides (a kind of humoral factor) as food moves through the tract may contribute to meal cessation as well (Savory, 1999). Both of these events might be considered AOs for food as a reinforcer, or perhaps the quantity dimension of food as a reinforcer. More research is required on these factors to better understand how they relate to adiposity, food in the digestive tract, and feeding onset and cessation in domestic hens. If the inferior and relative-inferior good effects are related to any one or more of these variables, then providing extra food to subjects in inferior-good experiments should change the effects. More specifically, subjects given extra feed should behave as small-cropped birds were hypothesised to behave in Experiment 2 (as discussed in Experiment 7)—they should show faster within-session shifts from intended-inferior-good responding to intended-superior-good responding or they should show no shift at all and exhibit exclusive intended-superior-good responding. This result would support crop filling as an AO for the quantity dimension of food.

The final two experiments of the current series tested the effect of extra feed on responding in Poor Conditions to further investigate the AO effects of food in the digestive tract or crop. Experiments 8 and 9 replicated the Poor

Conditions of Experiment 2 with the addition of conditions involving pre-feeding and post-feeding, respectively, for some of the subjects from Experiment 2. To avoid habituation to either reinforcer (McSweeney & Murphy, 2000; Murphy et al., 2003), pellets were used for the extra feed. It was expected that within-subject body weights would be similar between these extra-feed conditions. If so, then pre-fed birds would have had more food in the crop and early part of the digestive tract than post-fed birds, but both would have had similar body weights, controlling for possible adiposity related effects due to differences in body weights. This method would allow for a direct comparison of the effects of relatively-full crops (or filled early parts of the digestive tract) with the effects of relatively-empty crops (or filled late parts of the digestive tract) at similar body weights.

Given the research showing changes in within-session responding and decreases in feeding following crop filling, it was predicted that in Experiment 8, hens fed immediately prior to Poor Conditions would respond as they responded in the latter part of the Rich-Condition sessions in Experiment 2. That is, that these hens would respond on the plain-wheat key due to being in a similar state (with respect to crop filling) to their state part of the way through Rich-Condition sessions. Within-session patterns were predicted to show nearly-exclusive plain-wheat responding as this pattern tended to occur at least part of the way through most Rich Conditions. Behaviourally, the pre-session feedings were expected to abolish the quantity dimension of wheat as a reinforcer, shifting control to the quality dimension. However, the evidence of conditional-stimulus control by houselights (immediate shifts in responding following some condition changes) for Hens 75 and 76a in Experiment 2 and for Hen 94 in Experiment 6 suggested that responding may have also resembled Poor-Condition responding, at least occasionally and perhaps only for Hens 75 and 76a.

Method

Subjects

Subjects were the 6 hens used in Experiment 7 numbered 71, 72, 73a, 74, 75, and 76b. Hens were housed and maintained as in Experiment 2.

Apparatus

The experimental chamber was the same chamber used in Experiment 2 except an additional magazine was located in the centre of the chamber wall, opposite to the keys and other magazines. The dimensions of the magazine were the same as the other magazines as described in Experiment 2. This magazine contained commercial laying pellets and had an infrared sensor like the other magazines. The digital hanging scale from Experiment 7 and cone from Experiment 1 were used to weigh subjects. Magazines were weighed with a Wedderburn EEW-10K digital table scale with a resolution of 1 g and a maximum of 11,000 g. Due to a malfunction, this scale was changed to an ATRAX BH3000 table scale with a resolution of 0.1 g and a max of 3,000 g on Day 396. The computer, software, and equipment from Experiment 2 controlled the experiment. Daily outdoor maximum and minimum temperatures were provided by the NIWA as described in Experiment 7.

Procedure

The procedure was the same as the procedure for Experiment 2 except Pre-Feed Conditions replaced Rich Conditions, the experiment involved a total of six conditions with all hens beginning in the Poor Condition and alternating between Poor and Pre-Feed Conditions, and all magazines were weighed before and after sessions approximately once weekly to ascertain the weight of food consumed. ITIs for each bird were the same as the ITI used for each hen’s final Poor

Condition in Experiment 2 (see Table 2). Hen 72's ITI was increased in this Condition, but the increase had no effect so its initial ITI duration was used. As 76a did not participate in Experiment 2, its ITI was somewhat arbitrarily assigned a value comparable to other hens' ITIs (particularly Hen 71 as it had the same body weight). These ITIs were as follows: 95 s for Hen 71, 105 s for Hen 72, 150 s for Hen 73a, 75 s for Hen 74, 130 s for Hen 75, and 95 s for Hen 76b. The maximum number of trials possible for each subject for all conditions was 13, 12, 8, 16, 10, and 13, respectively. For sessions in Pre-Feeding Conditions, hens first consumed commercial laying pellets from a third magazine in the chamber wall opposite to the wall containing the plain- and salted-wheat keys and magazines. Sessions then immediately began as they did in Poor Conditions. This third magazine operated continuously in 3-s bouts with 0.5 s between bouts so that food was available ad libitum for a duration of time prior. This pre-feeding occurred with the houselights and key lights off and sessions began then ended as they did in Experiment 2, with the amber houselights on, immediately following pre-feeding. Conditions changed when responding on both keys and body weights were judged visually stable. The pre-feeding durations were based on visual inspection of cumulative records of eat time from the last five sessions of Experiment 7. The approximate halfway point of the linear portion of each set of cumulative records was chosen as the pre-feeding duration for each hen. Durations were 420 s for Hen 71, 540 s for Hen 72, 240 s for Hen 73a, 300 s for Hen 74, 420 s for Hen 75, and 180 s for Hen 76b. It was thought that this duration would provide some food in the crop, but that it would not fill the crop and completely abolish food as a reinforcer. Data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a.

Results

Hen 73a deceased during its first Pre-Feed Condition for reasons unrelated to the experiment and was replaced by Hen 73b shortly thereafter and Hen 72 also deceased for reasons unrelated to the experiment, but in its third Pre-Feed Condition. For Hens 71, 74, and 75, some pre-feed durations were changed because either responding decreased markedly on both keys or because responding did not change at all. These changes are rationalised below.

For comparability with previous experiments, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. The median numbers of plain- and salted-wheat responses for the last 20 sessions of each condition are shown in Table 40. For the 29 condition changes (5 changes per hen except for Hens 73a and 73b having 1 and 3 changes, respectively) across the 6 conditions for all 7 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the adjacent Pre-Feed Condition on 17 occasions. This difference occurred for all 5 changes for Hens 71 and 75, for 3 changes for Hens 74 and 76b, for its only change for Hen 73a, and for no changes for Hens 72 and 73b. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Pre-Feed

Table 40
Experiment 8: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions											
	Plain Wheat						Salted Wheat					
Hen	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre
71	0	10	2	4	1	4	13	0	12	8	13	8
72	12	12	12	10	12	4	0	0	0	0	0	0
73a	0	6	.	.	.	.	8	1	.	.	.	.
73b	.	.	0	0	0	0	.	.	8	8	8	8
74	0	6	0	0	0	1	16	9	16	16	15	10
75	0	4	0	0	0	2	10	4	10	9	10	8
76b	1	3	0	0	0	4	12	10	13	13	13	6

Condition on 15 of 29 occasions, occurring for the same numbers of changes for each hen as described above, except for Hen 75 showing this pattern for 3 instead of 5 changes.

Figure 41 displays the number of effective responses for sessions within each income condition which follow the same patterns as the medians in Table 40. Except for Hens 72 and 73b, birds tended to respond more on the salted-wheat key in the Poor Condition than in the Pre-Feed Condition. Hen 72 tended to respond on the plain-wheat key and Hen 73b, the salted wheat key regardless of condition. The only between-condition difference found for Hen 72 was a decrease in the total number of plain-wheat responses in some sessions in the Pre-Feed Conditions. Hen 71's pre-feed duration was changed from 420 to 210 s in its first Pre-Feed Condition because responding on both keys decreased to near-zero frequencies. This duration was used for is second Pre-Feed Condition, but was changed back to 420 s in its third Pre-Feed Condition because salted-wheat responding in the second Pre-Feed Condition remained almost as frequent as in the Poor Conditions and it was thought that the increased pre-feed duration might shift responding towards the plain-wheat key. However, it was reduced to 210 s again in this third Pre-Feed Condition because responding ceased on both keys. Hens 74 and 75 also showed decreases in responding on both keys during their first Pre-Feed Condition, so their durations were decreased from 300 to 150 s and from 420 to 210 s, respectively. Like Hen 71, Hens 74 and 75's salted-wheat responding in the second Pre-Feed Condition remained almost as frequent as in the Poor Conditions, so the original, longer pre-feed durations were used in these hens' third Pre-Feed Conditions.

Different variabilities in responding across hens can be seen in Figure 41.

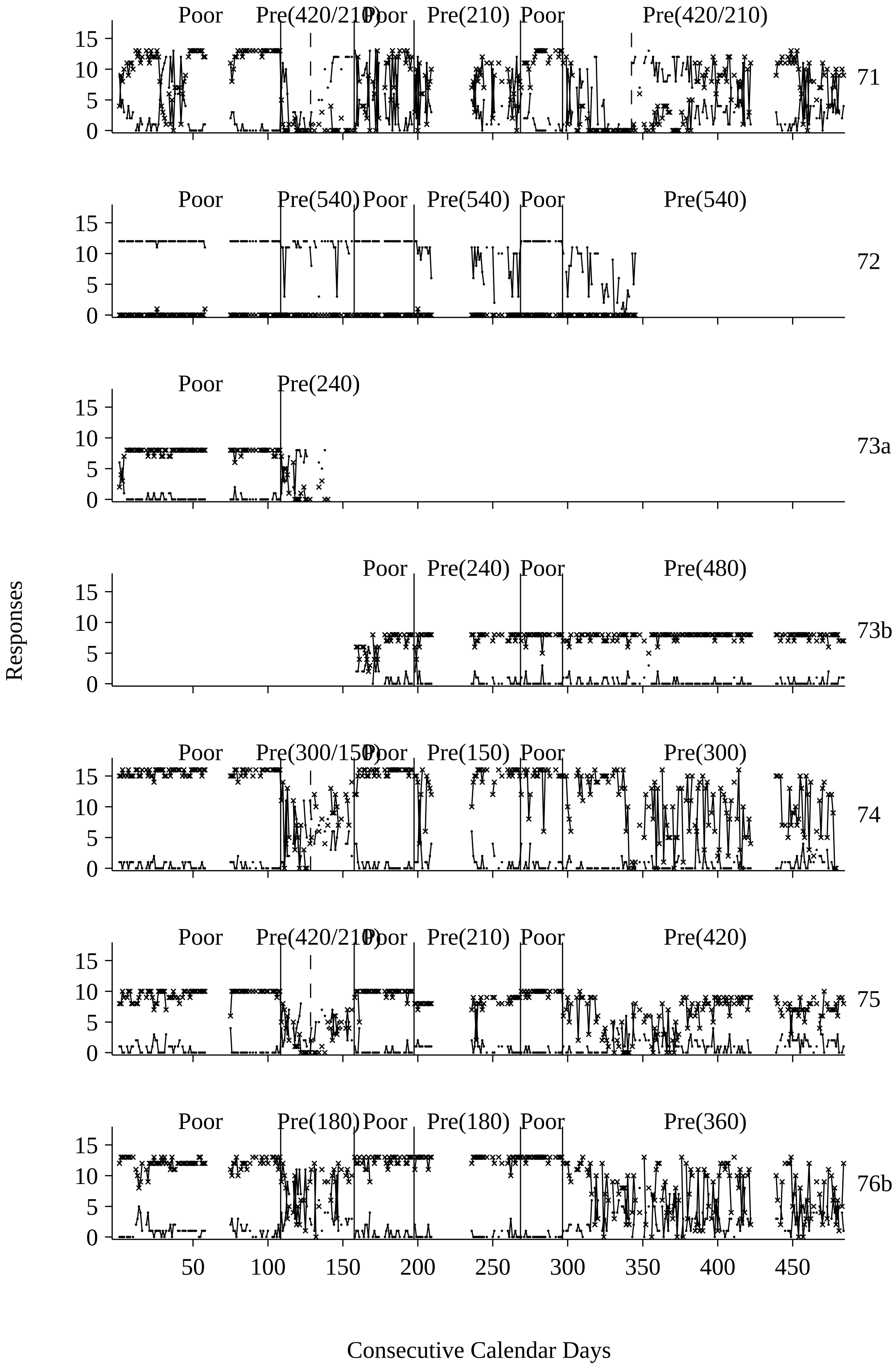

Figure 41. Experiment 8: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition.

Hen 71's responding was consistent for most of its first Poor Condition, with responding usually exclusive to the salted-wheat key. For the remainder of conditions, responding varied more. Hen 72's responding varied only in terms of the total number of plain-wheat response. Responding was usually exclusive to the plain-wheat key across all conditions and the total number of responses was sometimes less than the total possible number of trials in the Pre-Feed Conditions. Hen 73a showed more variability in its Pre-Feed Condition than in its Poor Condition, responding almost exclusively on the salted-wheat key in the Poor Condition and on both keys in its Pre-Feed Condition. Hen 73b showed little variability across all conditions as it tended to respond on the salted-wheat key (except for its first few sessions where responding occurred on both keys). Hens 74, 75, and 76a all showed similar patterns of variability across conditions. Poor Conditions tended to involve less variability that Pre-Feed Conditions except for the second Pre-Feed Condition in which variability resembled that of the Poor Conditions. In Poor Conditions, these hens tended to respond on the Plain-Wheat key and in Pre-Feed Conditions, these hens responded on both keys.

Cumulative within-session responses on the plain-wheat key are plotted against responses on the salted-wheat key for the last 20 sessions of each major condition in Figure 42. Hens 72 and 73b responded nearly exclusively on the plain-wheat key and salted-wheat key, respectively, regardless of condition, so the graphs show little or no variability in responding. This lack of variability occurred for the first and third Poor Conditions for Hen 71 and for all Poor Conditions for Hens 74, 75, and 76b as these hens responded nearly exclusively on the salted-wheat key during these sessions. Within-session responding in the Pre-Feed Conditions for all hens except Hen 73b (and except for the first Pre-Feed

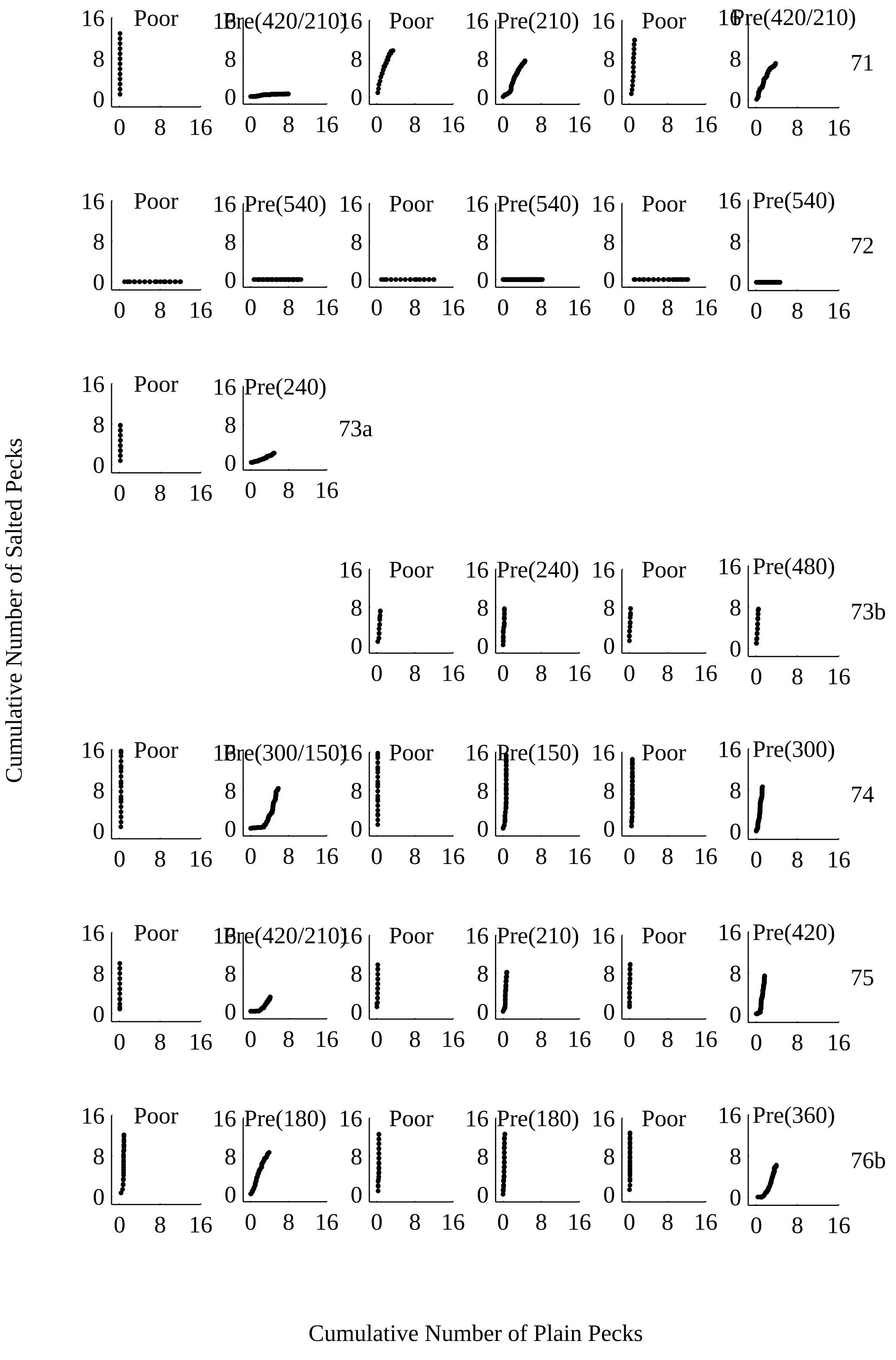

Figure 42. Experiment 8: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

Condition for Hen 71), showed either nearly-exclusive salted-wheat responding, responding on both keys throughout the session, or the opposite of the expected within-session pattern with early responding on the salted-wheat key and late responding on the plain-wheat key. These within-session patterns were not the same across Pre-Feed Conditions within subjects. Hen 71's first pattern showed nearly-exclusive plain-wheat responding while its other two patterns showed responding on both keys throughout the session as did Hen 73a's only Pre-Feed within-session pattern, Hen 74's third pattern, and Hen 76b's first pattern. The early plain-wheat and late salted-wheat responding occurred for Hen 74 and 75's first Pre-Feed Condition and for Hen 75 and 76's third Pre-Feed Condition. The within-session patterns for Hens 74, 75, and 76b all showed nearly-exclusive responding on the salted-wheat key.

The addition of ITI responses to cumulative within-session responses changed the patterns for some hens. Figure 43 shows that Hen 71's effective responses occurred on both keys while its ITI responses tended to occur on the plain-wheat key throughout the session. Hen 72's effective responses occurred nearly exclusively on the plain-wheat key while its ITI responses tended to occur on the salted-wheat key. Hen 73a's ITI responses in its Pre-Feed Condition occurred on both keys, but more often on the salted wheat key when compared with its effective responses.

Eat-time durations are displayed in Figure 44 and, as in previous experiments, the eat-time patterns resembled response patterns except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. Table 41 shows Pearson correlation coefficients for eat times versus wheat weights along with sample sizes as magazines were

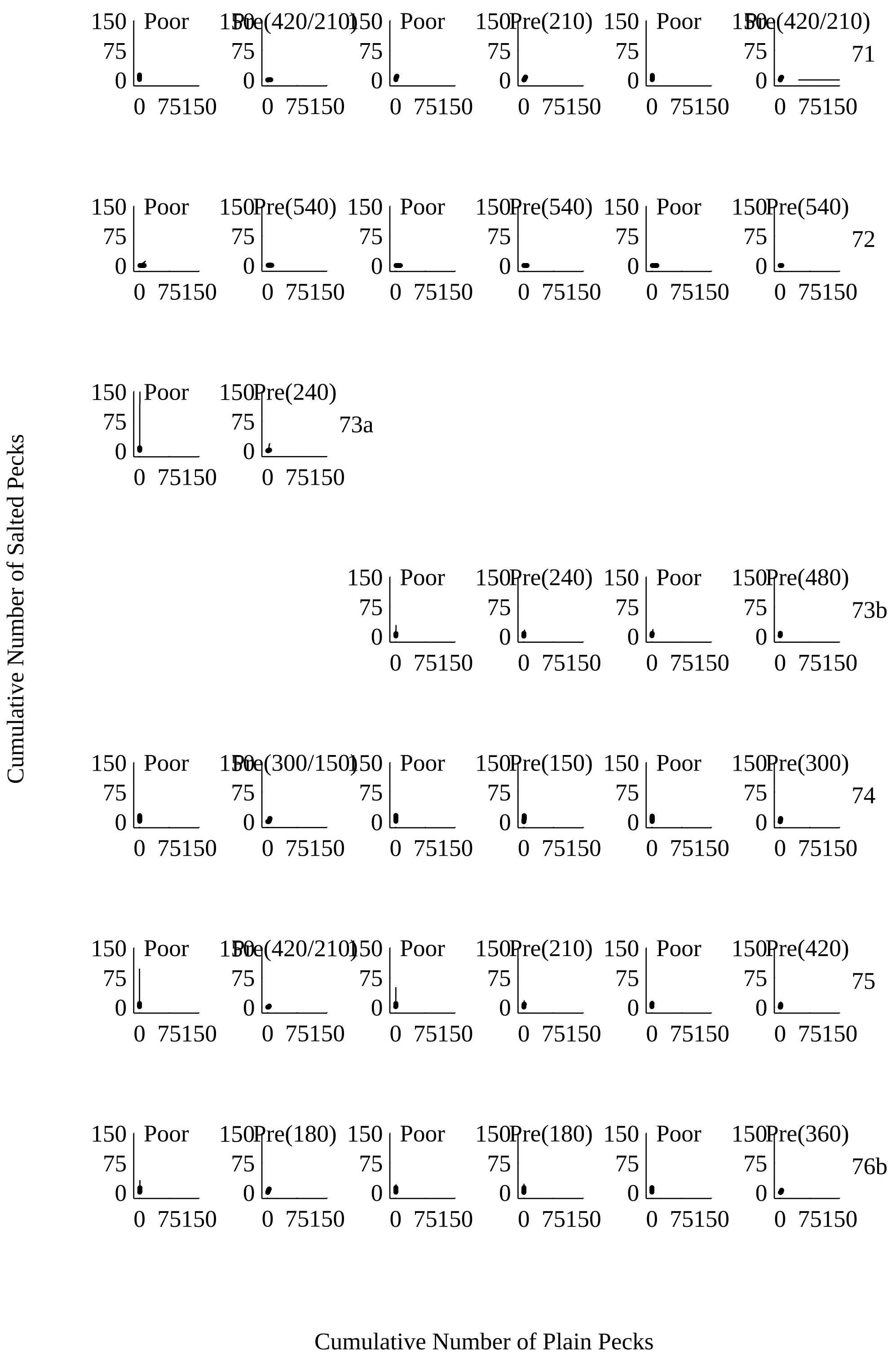

Figure 43. Experiment 8: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

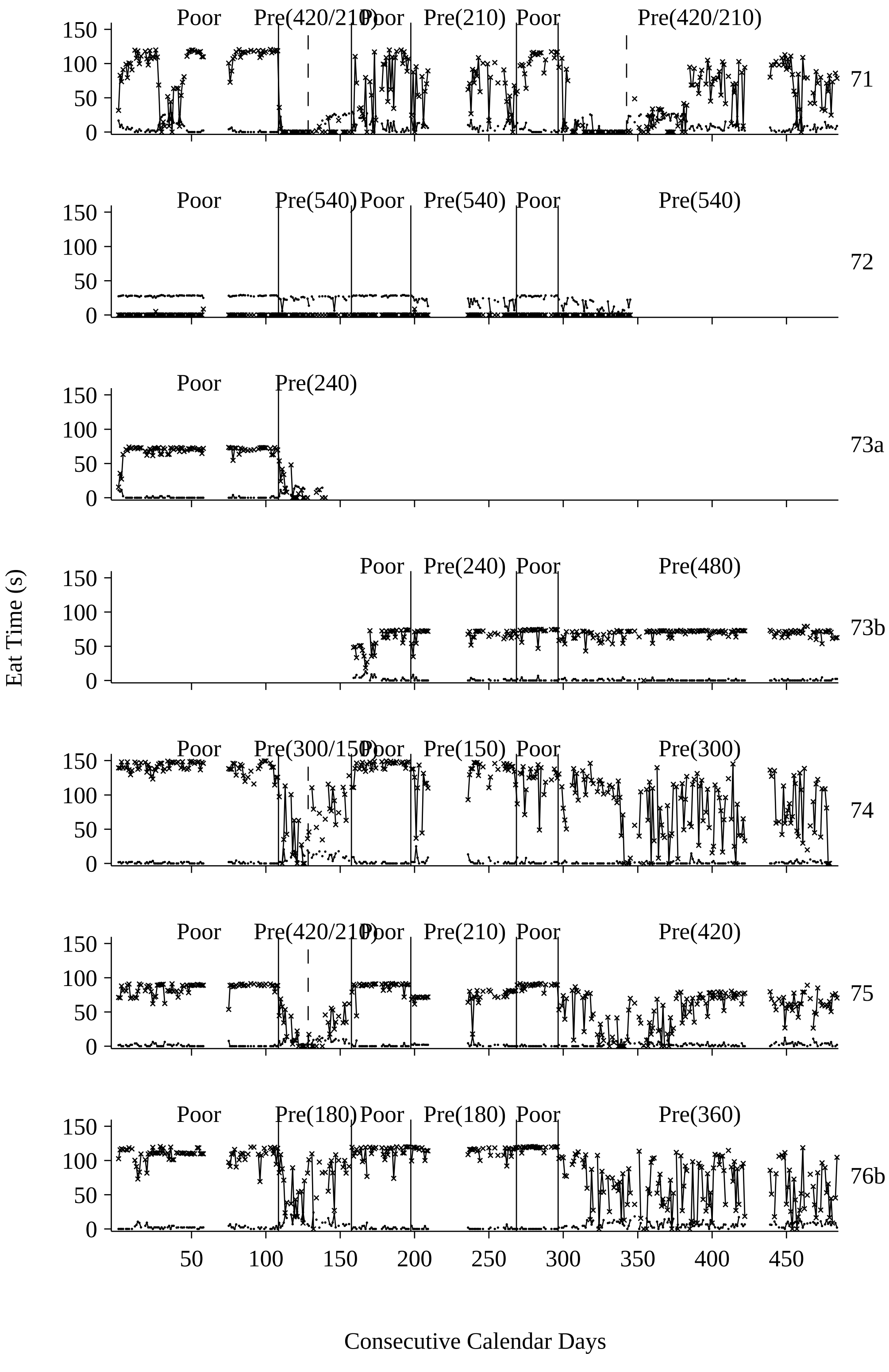

Figure 44. Experiment 8: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition.

weighed only approximately once weekly. When an eat time and its respective wheat weight were both zero, they were omitted from analysis to avoid inflating the correlations. Coefficients were undefined for any samples that had no variability in either eat time or wheat weight and for samples that had less than two pairs of data. This lack of variability or small sample size resulted in undefined values for plain wheat in some conditions for Hens 73b, 74, 75, and 76b and for salted wheat in all conditions for Hen 72 and in the first Pre-Feed Condition for Hen 71. Correlations differed within and between birds as well as within and between the two types of wheat, but no consistent differences were found. An alpha level of .05 was used to test for statistical significance of the coefficients and all but one significant correlation was large (Cohen, 1988) and positive: 6 out of 36 for plain wheat and 13 out of 36 for salted wheat or 7 out of 18 in the Poor Conditions and 12 out of 18 in the Pre-Feed Conditions. Hen 74's plain-wheat coefficient in its first Poor Condition was -.97 and statistically significant. When the five pairs of data were examined, it was found that three

Table 41
Experiment 8: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions											
	Plain Wheat						Salted Wheat					
Hen	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre	Poor	Pre
71	.94*	.80	.84	.96*	1	.35	.34	U	.71	.95*	.83	.94*
	(6)	(5)	(5)	(4)	(2)	(13)	(11)	(1)	(6)	(5)	(4)	(12)
72	-.14	-.23	.39	.79	.81	.58	U	U	U	U	U	U
	(11)	(7)	(6)	(5)	(4)	(7)	(0)	(0)	(0)	(0)	(0)	(0)
73a	1	.95	.	.	.	.	.69*	1*	.	.	.	.
	(2)	(4)					(11)	(3)				
73b	.	.	.93*	1	U	.56	.	.	.77	.33	.65	.25
			(5)	(2)	(0)	(6)			(6)	(5)	(4)	(19)
74	-.97*	-.09	.97*	.98	U	-.37	.70*	.89*	.25	.89*	.43	.83*
	(5)	(7)	(4)	(3)	(0)	(5)	(11)	(6)	(6)	(5)	(4)	(18)
75	.48	.02	U	U	U	.18	.70*	.71	-.42	.75	.38	.79*
	(5)	(7)	(0)	(3)	(0)	(12)	(11)	(4)	(6)	(5)	(4)	(18)
76b	-.45	.94*	.74	U	U	.73*	.82*	.94*	-.17	.38	-.45	.90*
	(6)	(7)	(4)	(1)	(0)	(17)	(10)	(7)	(6)	(5)	(4)	(19)

*p<.05

wheat weights of 0 g were recorded for eat times of approximately 2 s, one wheat weight of 1 g was recorded for 2 s, and one wheat weight of 3 g was recorded for 0 s. Sample sizes also varied and ranged from 0 to 19. There was a mix of several significant and non-significant correlations, so the significant correlations should be interpreted with caution as they may have occurred through chance.

Figure 45 shows ITI responses on both keys across conditions. Hens 71, 72, and 74 rarely responded on either key during ITIs. Hens 73b and 76b also followed this pattern, but following a decreasing trend of ITI responses in each hen's first Poor Condition. These initial ITI responses occurred on both keys for Hen 73b and mostly on the salted-wheat key for Hen 76b. Hen 73a responded during the ITI the most often across all birds with approximately 500 ITI responses occurring on the salted-wheat key with occasional responding on the plain-wheat key during its Rich Condition. ITI responses decreased to near-zero frequencies on some days during its Pre-Feed Condition. Hen 75's ITI responses usually occurred on the salted-wheat key and tended to occur more often int he first two Poor Conditions then in the other conditions, with about 50 of these responses occurring during most Poor-Condition sessions and only occasional responses during the other conditions.

Figure 46 shows pre-session body weights for each hen across days and Table 42 shows means for each hen in each condition. Overall, body weights tended to be higher in the Pre-Feed Condition than in Poor Condition, but not always consistently so as suggested by the means. Hens 73a, 75, and 76b followed this pattern except Hen 75's second Poor Condition had a mean body weight comparable to its Pre-Feed Conditions and Hen 76b's first Pre-Feed Condition had a mean body weight comparable to its Poor Conditions. Hen 71's

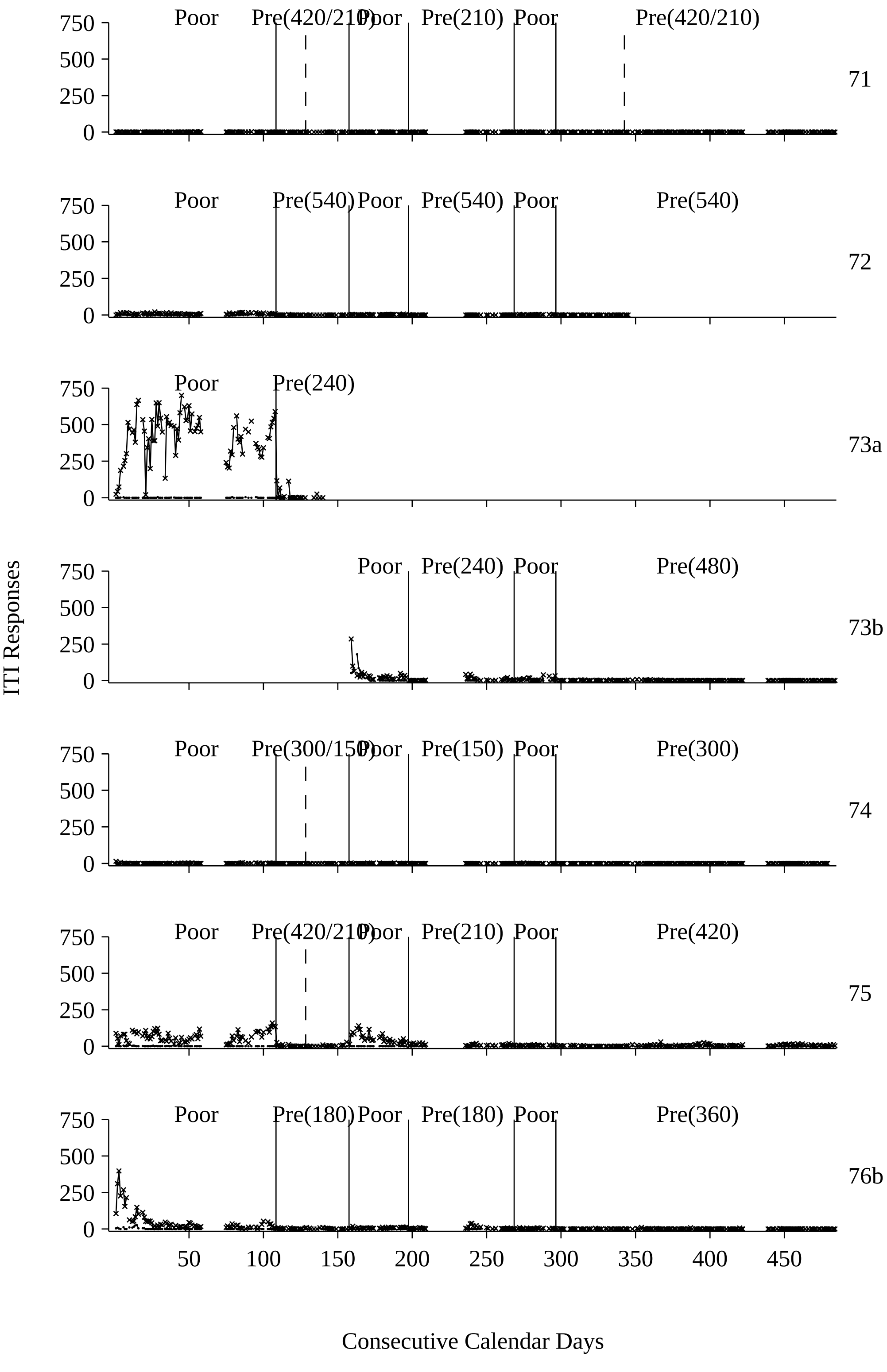

Figure 45. Experiment 8: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition.

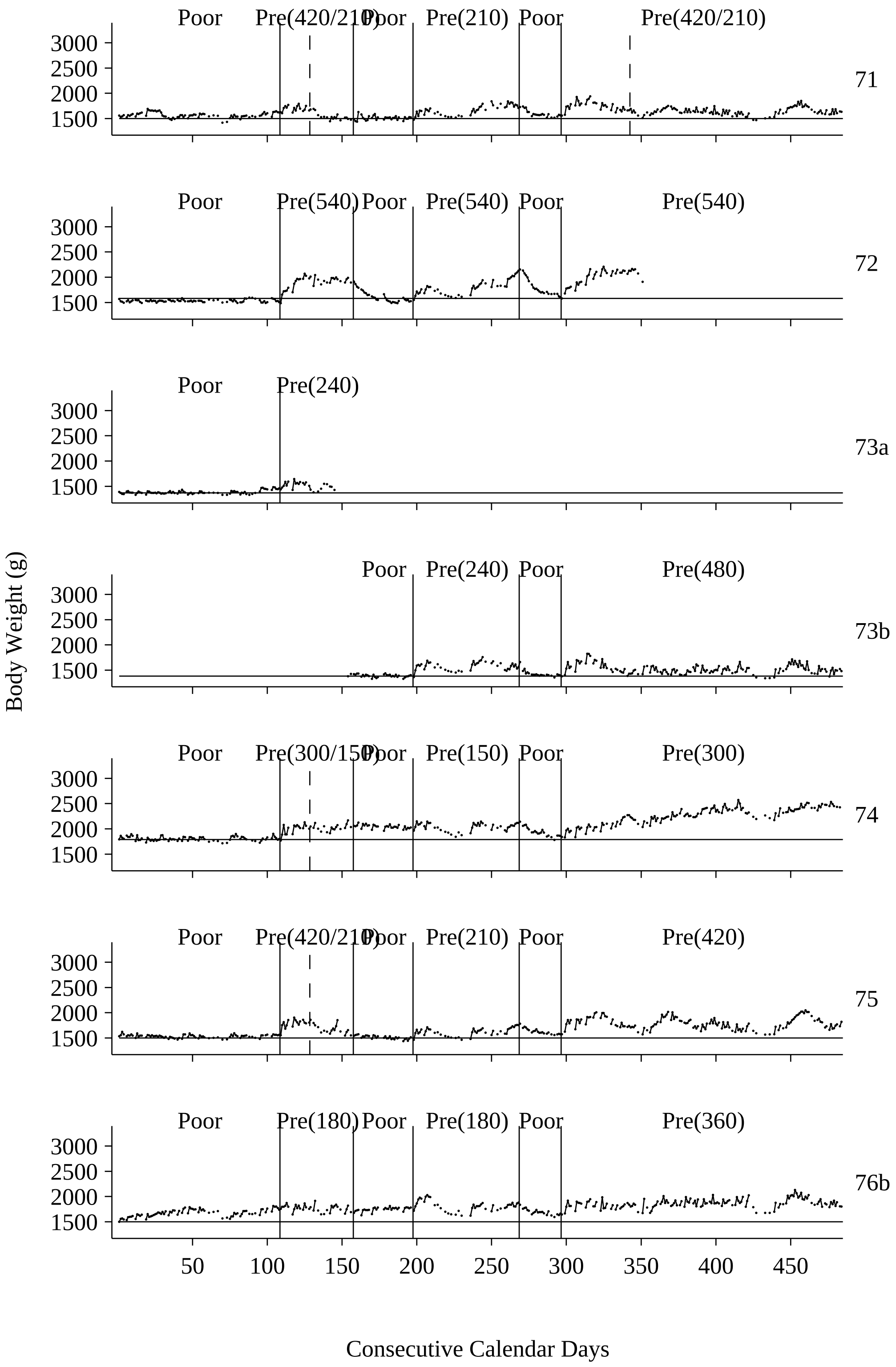

Figure 46. Experiment 8: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate ITI changes, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the programmed duration of session pre-feeding time for each condition.

mean body weight was higher in the second and third Pre-Feed Condition while its mean body weight was comparable across the other conditions. The mean body weight for Hen 72 was higher in all Pre-Feed Conditions with its weight being comparable across the first two Poor Conditions, but higher in the third Poor Condition. Hen 73a's highest mean body weight was in its final Pre-Feed Condition, its lowest was in its first Poor Condition, and its mean body weights in other conditions were comparable. Hen 74's highest mean body weight was in its third Pre-Feed Condition, its lowest was in its first Poor Condition, and its mean body weights in other conditions were comparable. The final Pre-Feed Condition involved the highest mean body weights across all conditions for Hens 72, 74, 75, and 76.

Table 42
Experiment 8: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

Hen	Poor	Pre	Poor	Pre	Poor	Pre
71	1576	1558	1510	1756	1595	1652
72	1540	1948	1543	1923	1794	2110
73a	1415	1529	.	.	.	.
73b	.	.	1383	1612	1418	1496
74	1808	2027	2033	2066	1936	2454
75	1541	1688	1497	1662	1627	1827
76b	1713	1755	1767	1812	1691	1880

Discussion

The purpose of this experiment was to investigate the effects of pre-feeding on Poor-Condition responding. It was hypothesised that food in the early parts of the digestive tract (such as the crop) would abolish the reinforcing effectiveness of the quantity dimension of food, affecting behaviour during the course of sessions as hypothesised in the Rich Conditions of Experiment 2 and in perhaps the published inferior-good studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) as well. So, it was predicted that before-session feeding would cause responding to resemble responding in the latter part of these Rich-Condition sessions—responding on the intended-superior-good operandum—because the quantity dimension of the inferior good would have become abolished as a reinforcer. The possibility of conditional stimulus control by houselights for Hens 75 and 76a and perhaps other birds was also suggested. If this control occurred, it was expected that Pre-Feed-Condition responding would resemble Poor-Condition responding. However, it would not be possible to tell if the similarity in behaviour would be due to the houselights or to other aspects of the environment that were also present during Experiment 2 (such as the ITI length).

Generally, Figure 41 shows that birds' responding in the first and third Pre-Feed Conditions differed from responding in the Poor Conditions in the same way that responding differed between Rich and Poor Conditions in Experiment 2 (cf. Figure 2). Plain-wheat responding tended to increase and salted-wheat responding tended to decrease when conditions changed from Poor to Rich or from Poor to Pre-Feed and the opposites shifts occurred when conditions changed back to Poor Conditions. For the 5 hens that were subjects in Experiment 2 (Hens 71, 72, 73a, 74, and 75), Poor-Condition responding was usually comparable between the two experiments. Pre-Feed responding (i.e., responding during trials in the Pre-Feed Condition) in the first and third Pre-Feed Conditions was similar to Rich responding in Experiment 2 for Hens 73a and 75. Hens 71 and 74's Rich responding differed between their Rich Conditions in Experiment 2; each bird had one Rich Condition where responding varied and one where responding tended to occur on the plain-wheat key. Their Pre-Feed responding resembled the more-variable Rich Conditions. Hen 72 responded nearly-exclusively on the plain-wheat key regardless of conditions in both experiments. For this hen, the only difference in responding in either experiment was during the Pre-Feed Conditions; in these conditions the hen tended to stop responding before the end of some sessions, resulting in fewer responses on the plain-wheat key. This decrease in wheat consumption for Hen 72 is consistent with the published work showing that crop filling affects food-consumption termination (Bizo et al., 1998; DeMarse et al., 1999; Richardson, 1970; Savory, 1985; Savory & Mann, 1999; Shurlock & Forbes, 1981). Inspection of the correlation coefficients in Table 41 and the eat-time data in Figure 44 suggests that birds did consume food following responses, except for times where the pre-feed duration was longer for Hens 71, 74, and 75 (hence, the reason for shortening pre-feed durations). Again, however, these correlations were calculated with small samples and several were non-significant.

So overall, responding in the Pre-Feed Condition resembled responding in the Rich Conditions in that responding on the intended-inferior-good key decreased while responding on the intended-superior-good increased compared to responding in Poor Conditions. This similarity occurred for the first and third Pre-Feed Conditions for Hens 71, 74, 75, and 76b and for Hen 73a's only Pre-Feed Condition (recall Hen 72 always responded on the plain-wheat key, regardless of condition). Further, these 5 hens also exhibited the inferior- or relative-inferior-good effect or both in Experiment 2. For these hens, within-session responding across all Poor Conditions in both experiments was similar: nearly-exclusive responding on the salted-wheat key throughout the sessions. Across Rich and Pre-Feed Conditions, patterns differed. The early-salted-late-plain pattern that occurred in Rich Conditions did not occur in Pre-Feed Conditions. An unpredicted opposite pattern occurred in one Pre-Feed Condition for Hens 74, 75, and 76 and the rest of the Pre-Feed Conditions showed responding on both keys throughout sessions or nearly-exclusive salted-wheat consumption. The only other occurrence of the opposite, early-plain-late-salted pattern was for Hen 94 in its first Rich Condition in Experiment 5.

Given the findings that outdoor temperature may have affected BMR in Experiment 7 (as evidenced by higher body weights and less amounts consumed in warmer temperatures), following data collection it was hypothesised that the temperature was lower in the second Pre-Feed Condition than in the first and third. If food digests faster in cold weather (Henderson et al., 1992; Savory, 1986; Savory & Mann, 1999; Taher et al., 1985) due to increased BMR (Campbell & Reece, 2002), then birds in this second Pre-Feed Condition would have begun sessions with less food in their digestive tract, including crop. The quantity dimension of food may then have remained established as a reinforcer as there may not have been enough food in the tract or crop to abolish quantity as a reinforcer. Figure 47 confirms that the coldest maximum temperatures occurred during the latter half of the second Pre-Feed Condition, suggesting that AO effects on the quantity dimension of food may have been less in this condition than in the other Pre-Feed Conditions.

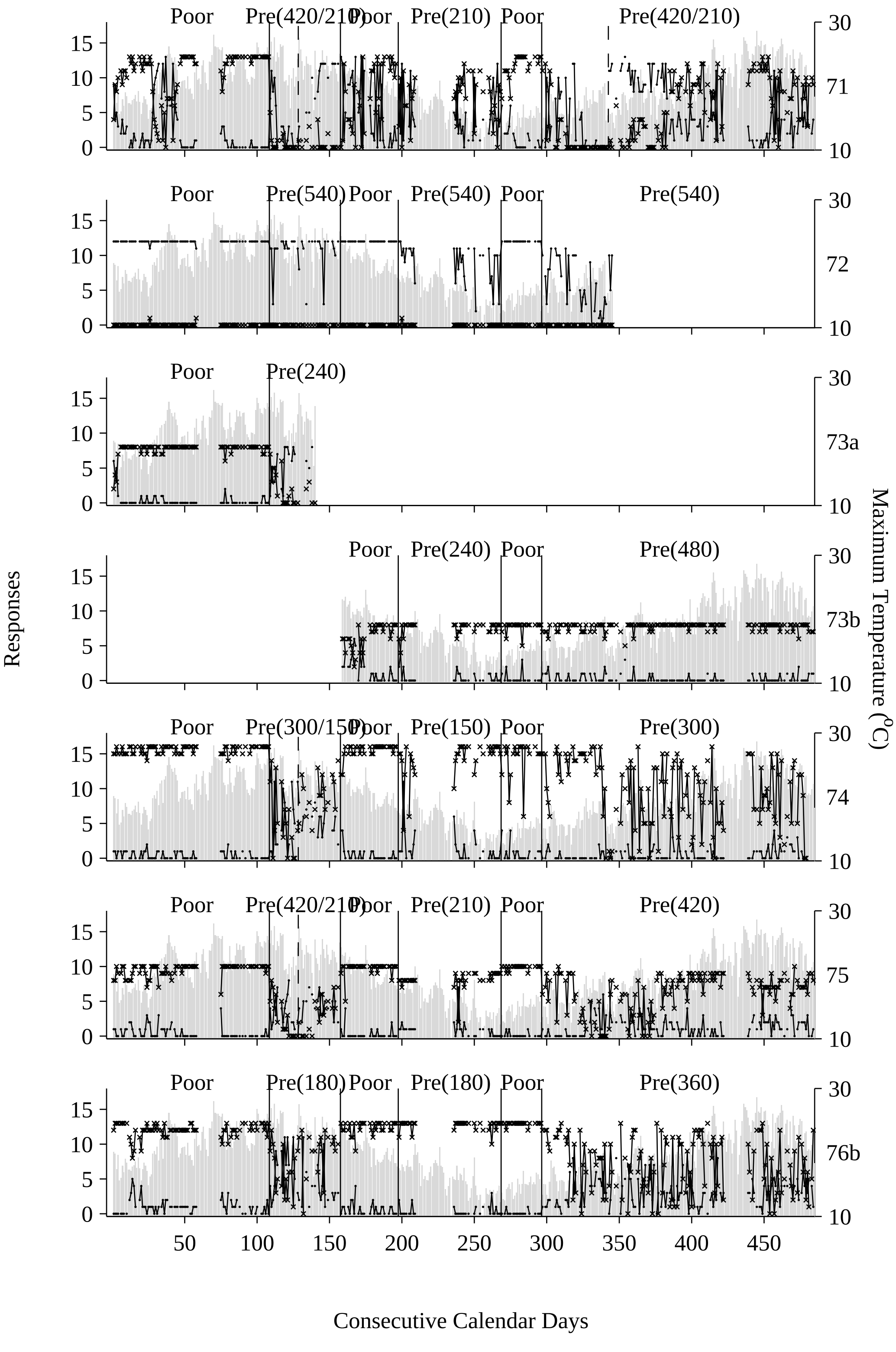

Figure 47. Experiment 8: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition. Background bars represent daily maximum outdoor temperatures.

The early-plain-late-salted patterns found for some hens are more difficult to explain as they have not been documented in the published literature. Perhaps early responding was under the control of plain-wheat as a reinforcer as birds may have begun sessions with the quantity dimension of food abolished as a reinforcer due to the pre-session feeding. Late responding may then have been under the control of something different, perhaps related to the houselights, as maybe both quantity and quality dimensions of food became abolished as reinforcers through both satiation and habituation. If houselights were CEOs or CAOs (depending on the reinforcer) that gained their control through differential pairing with relatively-full or relatively-empty crops, then perhaps their evocative effect (Michael, 1993) prevailed as quality and quantity became abolished as reinforcers. It is unknown if these hens consumed wheat throughout the session or if their consumption slowed. If hens responded without consuming food, then the behaviour may have been similar to behaviour described as *contrafreeloading*—the finding that that organisms can continue to respond when free food is available or after having consumed food (for a review, see Osborne, 1977). Osborne suggested that contrafreeloading provided extra reinforcement beyond that of the reinforcement provided by free food (e.g., stimulus changes, sensory feedback, etc.). The paper reviewed several other conceptualisations as well, but this conceptualisation was said to account for the most data. Without further experiments, it is not possible to determine the nature of these patterns and whether the late responding was evoked by the houselights as CEOs (Michael, 1993), whether it occurred for the same reasons as contrafreeloading has been said to occur (Osborne, 1977), or whether they occurred for another reason.

Data from the current experiment showed that Pre-Feed responding was similar to Rich responding in that more plain-wheat and less salted-wheat responses occurred in these conditions than in Poor Conditions. Colder temperatures seemed to increase salted-wheat and decrease plain-wheat responding in the second Pre-Feed Condition, suggesting that BMR increased for some birds, reducing the amount of food in the crop and establishing the quantity dimension of salted-wheat as a reinforcer. The early-plain-late-salted responding was an unexpected finding with only conjecture explaining the late-salted part of the pattern as occurring due to evocative effects or due to a contrafreeloading conceptualisation (Osborne, 1977). Collectively, these results and the published literature support food in the crop, and perhaps food in other early parts of the digestive tract, as abolishing the effectiveness of the quantity dimension of food as a reinforcer and therefore being important for the inferior- and relative-inferior-good effects. If food-in-the-crop is an AO for the intended-inferior-good, then the effects may not be due to income condition at all, but rather to the effect of the income condition on the amount of food in the crop. The next experiment was intended to test the effect of similar-duration feedings on responding in Poor Conditions, but for feedings occurring after sessions, thereby reducing the amount of food in the crop and early parts of the digestive tract prior to sessions. This feeding was thought to more closely mimic the metabolic state of hens at the beginning of Rich Conditions in Experiment 2 than pre-session feeding.

Experiment 9: Short ITI/Short ITI with Post Feed (Group 7)

Food-in-the-crop or other early parts of the digestive system have been hypothesised to be an AO for the quantity dimension of food as a reinforcer, affecting the occurrence or non-occurrence of inferior- or relative-inferior-good effect if food in the crop varies. One way of testing this hypothesis would be by comparing responding from the Pre-Feeding Conditions in Experiment 8 with responding in conditions where there is less food in the crop, keeping other variables constant. If food in the crop abolishes the quantity dimension of food as a reinforcer, then less food in the crop should have a weaker effect. If the hens from Experiment 8 were fed for the same durations as they were fed in Pre-Feed Conditions, but after sessions instead of before, then hens would begin the next day's session with less food in their crops while their body weights would be similar between the extra-feed conditions across these two experiments. Hens' metabolic states at the onset of these Post-Feed sessions would probably be more similar to their metabolic states at the onset of Rich-Condition sessions than their metabolic states at the beginning of Pre-Feed-Condition sessions. In Rich Conditions, they may have had some food in the crop from the session on the previous day, as research has shown food in birds' crops 24 hours following feeding (Brown, 1904; Jones et al., 2004), but probably not as much as the amounts consumed during Pre-Feed Conditions.

The current experiment was intended to provide data to compare with Rich-Condition responding in Experiment 2 and with Pre-Feed-Condition responding in Experiment 8 by providing approximately the same amount of extra feed after sessions as was provided before sessions in the previous experiment. Across-session patterns for Rich and Post-Feed Conditions were expected to look similar with more responding on the plain wheat key and less on the salted-wheat key when compared to responding in Poor Conditions. With respect to within-session patterns, hens were expected to respond as they responded during the beginnings of Rich Conditions in Experiment 2, with early-salted-late-plain responding or exclusive plain-wheat responding (depending on the hen's behaviour in Experiment 2) because hens would be beginning these sessions with only some food in the crop (the quantity-dimension would not yet be abolished). Also, as suggested in Experiment 8, the previous evidence of conditional-stimulus control by houselights for Hens 75 and 76a in Experiment 2 and for Hen 94 in Experiment 6 suggested that responding could also resemble Poor-Condition responding, at least for Hens 75 and 76a.

Method

Subjects

Subjects were 5 of the 6 hens used in Experiment 8 numbered 71, 73b, 74, 75, and 76. Hens were housed and maintained as in Experiment 2.

Apparatus

The experimental chamber was the same chamber used in Experiment 8. The digital hanging scale from Experiment 7 and cone from Experiment 1 were used to weigh subjects. Magazines were weighed with an ATRAX BH3000 table scale with a resolution of 0.1 g and a max of 3,000 g on Day 396. The computer, software, and equipment from Experiment 2 controlled the experiment. Daily outdoor maximum and minimum temperatures were provided by the NIWA as described in Experiment 7.

Procedure

The procedure was the same as the procedure for Experiment 8 except Post-Feed Conditions replaced Pre-Feed Conditions and the experiment involved a total of four conditions. ITIs and maximum possible numbers of trials for each bird were the same as in Experiment 8 and each bird began in the Poor Condition. For sessions in Post-Feeding Conditions, hens consumed commercial laying pellets from the third magazine, as described in Experiment 8, immediately following the 20 min of discrete trials. Conditions changed when responding on both keys and body weights were judged visually stable. The post-feed durations were the same as the pre-feed durations for each hen’s final Pre-Feed Condition in Experiment 7: 210 s for Hen 71, 480 s for Hen 73b, 300 s for Hen 74, 420 s for Hen 75, and 360 s for Hen 76b. Data from the water infrared sensor were not used due to the sensor problems that occurred in Experiments 2 and 3a.

Results

Again, the last 20 sessions of each condition were considered to be representative of the stable segment of behaviour in each condition. Table 43 provides the median numbers of plain- and salted-wheat responses for the last 20 sessions of each condition. For the 15 condition changes (3 changes per hen) across the 4 conditions for all 5 hens, the median number of salted-wheat responses was higher in the Poor Condition than in the adjacent Post-Feed Condition 10 times. This difference occurred for all 3 changes for Hens 71 and 75, for 2 changes for Hen 73b, for 1 change for Hens 74 and 76. The median number of plain-wheat responses was lower in the Poor Condition than in the adjacent Post-Feed Condition on 9 of 15 occasions, occurring for the same numbers of changes for each hen as described above, except for Hen 73b showing this pattern for only 1 change instead of 2.

Table 43
Experiment 9: Median Effective Responses of the last 20 Sessions of Each Condition

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Post	Poor	Post	Poor	Post	Poor	Post
71	1	4	0	9	12	9	13	4
73b	1	2	4	4	8	6	5	4
74	0	0	0	2	16	16	16	6
75	0	1	0	4	10	9	10	6
76a	1	2	2	2	12	11	11	11

Figure 48 shows the number of effective responses for sessions within each income condition and reiterates the same patterns as described by the medians in Table 43. The figure shows similar variabilities in responding across hens. For Hens 71, 74, 75, and 76b, responding was more variable in the Post-Feed Condition than in the Poor Condition and responding in Hen 74’s second Post-Feed Condition was more variable than in its first. Hen 73b showed a

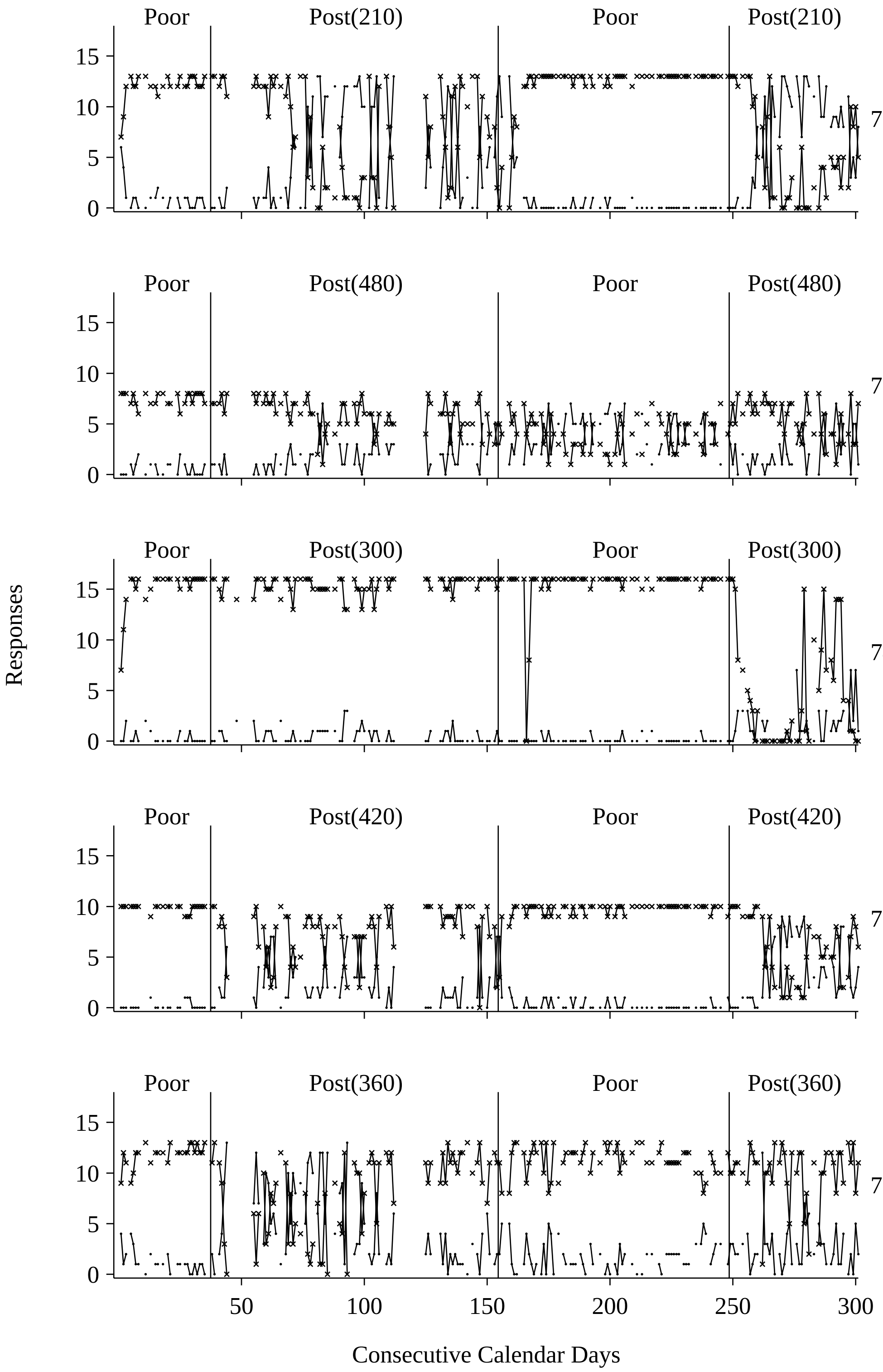

Figure 48. Experiment 9: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session post-feeding time for each condition.

similar pattern of variability, except variability in its second Poor Condition was more similar to variability in its Post-Feed Conditions than in its first Poor Condition.

Figure 49 shows cumulative within-session responses on the plain-wheat key plotted against responses on the salted-wheat key for the last 20 sessions of each major condition. Hens 71, 74, 75, and 76 showed nearly-exclusive salted-wheat responding in the Poor Conditions and responding on both keys throughout the sessions in Post-Feed Conditions, except for Hen 74's first Post-Feed Condition and Hen 76b's second Poor Condition where, Hen 74 responded nearly-exclusively on the salted-wheat key and Hen 76b responded on both keys throughout the sessions. Hen 73b showed a similar pattern across all conditions with early plain-wheat responding and late salted-wheat responding. When ITI responses were added to cumulative within-session responses, patterns did not change as shown in Figure 50.

Eat-time durations are displayed in Figure 51. As found in previous experiments, eat-time patterns resembled response patterns except for the relative changes due to the 10-s availability of salted wheat versus the 3-s availability of plain wheat. of wheat, but no consistent differences were found. An alpha level of .05 was used to test for statistical significance of the coefficients. All significant

Table 44
Experiment 9: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Post	Poor	Post	Poor	Post	Poor	Post
71	-1	.57	U	.39	.87	.69	.86*	1*
	(2)	(6)	(1)	(4)	(3)	(6)	(7)	(4)
73b	U	.74	.93*	.66	-.61	.90*	.97*	.71
	(1)	(6)	(7)	(4)	(3)	(6)	(7)	(4)
74	U	-1	-1	-1	1*	.46	.54	.44
	(2)	(2)	(2)	(2)	(3)	(6)	(6)	(4)
75	U	1*	.85	.66	-.21	.80	.50	.80
	(1)	(3)	(4)	(4)	(3)	(6)	(7)	(4)
76b	U	1*	.77	.26	.93	.99*	.80*	-.09
	(2)	(5)	(5)	(4)	(3)	(6)	(7)	(4)

*p<.05

correlations were large (Cohen, 1988) and positive: 3 out of 20 for plain wheat and 7 out of 20 for salted wheat or 5 out of 20 in the Poor Conditions and 5 out of 20 in the Post-Feed Conditions. Sample sizes also varied and ranged from 1 to 7. Correlations should be interpreted with caution as there was a mix of both significant and non-significant correlations.

shows Pearson correlation coefficients for eat times versus wheat weights as well as each sample size. Eat times and respective wheat weights that were both zero were omitted from analysis to avoid inflating the correlations. When samples had no variability in either eat time or wheat weight or when samples had less than two pairs of data, correlation coefficients were undefined. Undefined values occurred for plain wheat in the first Poor Condition for Hens 73b, 74, 75, and 76b and in the second Poor Condition for Hen 71. There were differences in correlations within and between birds and the two types

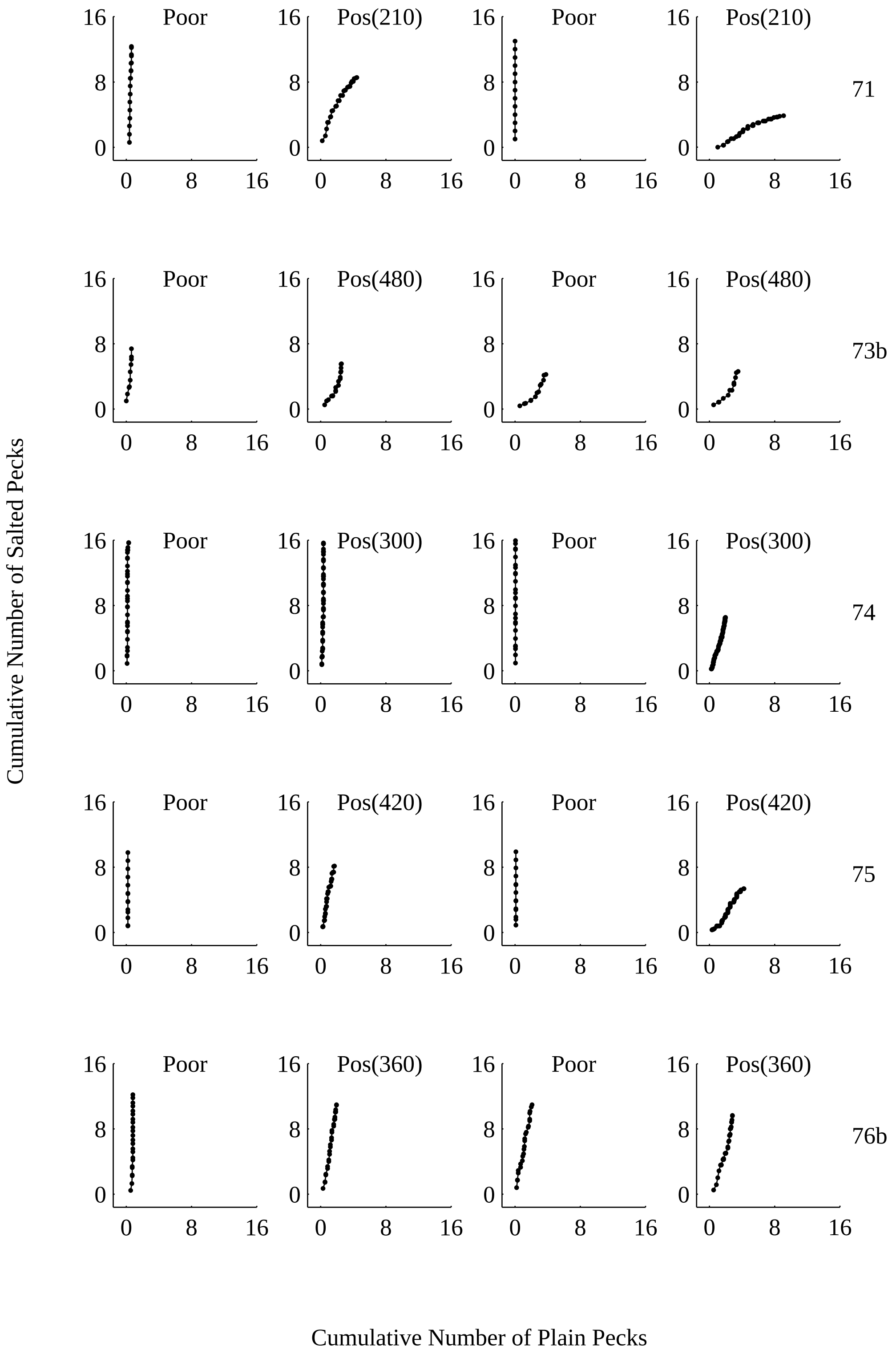

Figure 49. Experiment 9: Cumulative effective responses on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

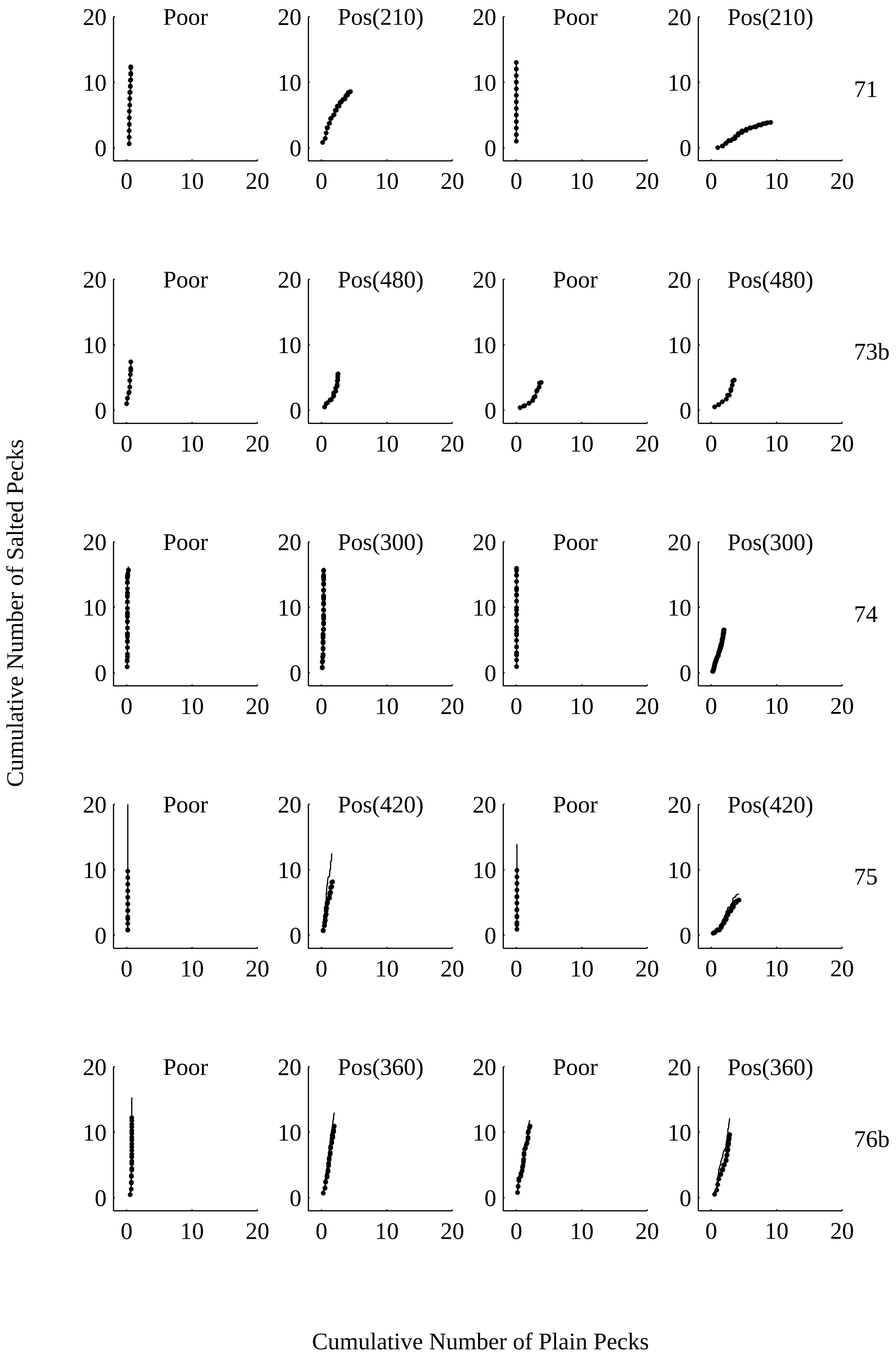

Figure 50. Experiment 9: Cumulative effective responses (heavy line) and effective plus ITI responses (light line) on the plain-wheat key plotted against responses on the salted-wheat key. Each data point represents the mean number of responses across the last 20 sessions of the condition in successive 2-min intervals.

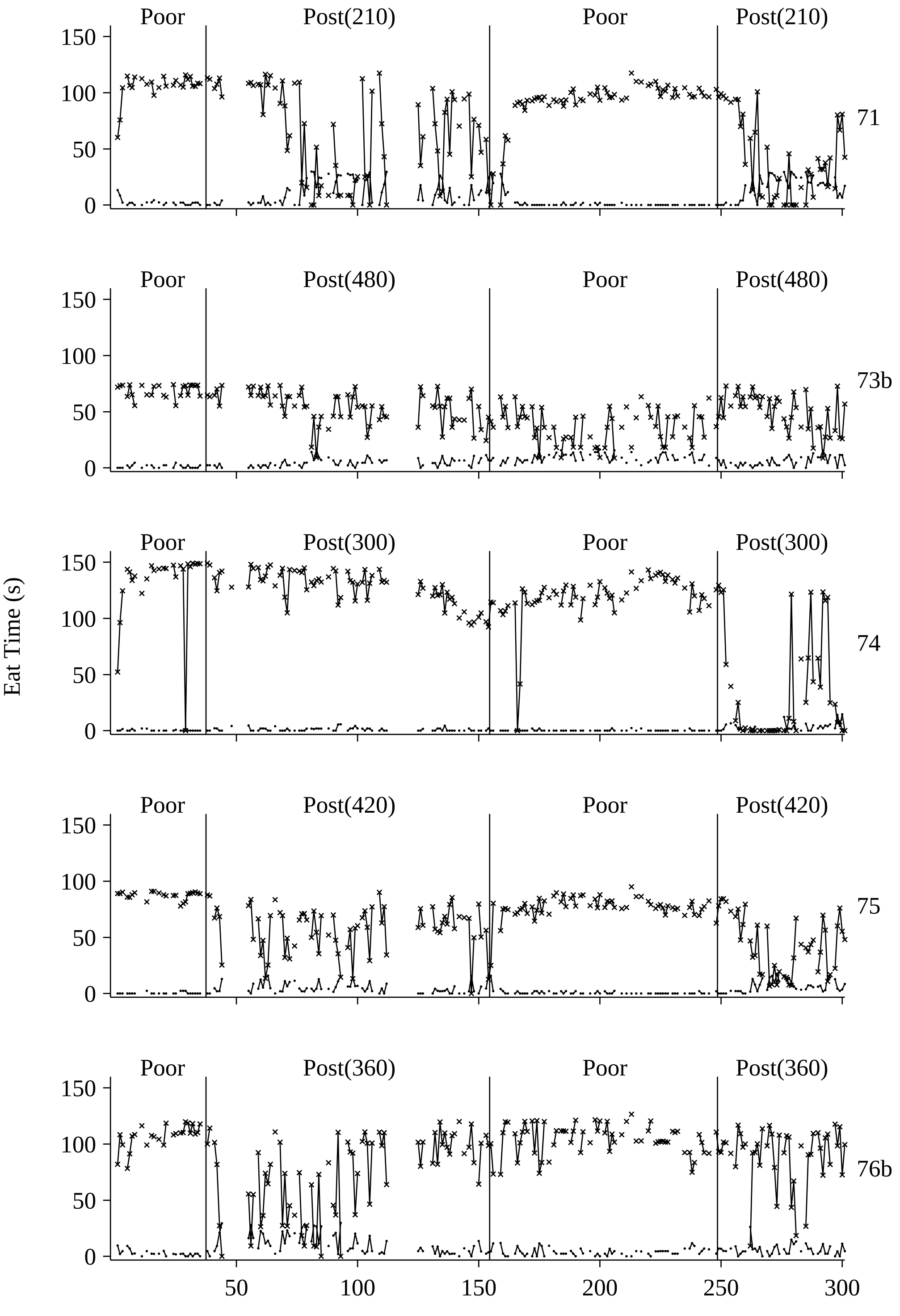

Figure 51. Experiment 9: Durations of eat times for the plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session post-feeding time for each condition.

of wheat, but no consistent differences were found. An alpha level of .05 was used to test for statistical significance of the coefficients. All significant correlations were large (Cohen, 1988) and positive: 3 out of 20 for plain wheat and 7 out of 20 for salted wheat or 5 out of 20 in the Poor Conditions and 5 out of 20 in the Post-Feed Conditions. Sample sizes also varied and ranged from 1 to 7. Correlations should be interpreted with caution as there was a mix of both significant and non-significant correlations.

Table 44
Experiment 9: Eat-Time versus Wheat-Weight Correlations

	Successive Conditions							
	Plain Wheat				Salted Wheat			
Hen	Poor	Post	Poor	Post	Poor	Post	Poor	Post
71	-1	.57	U	.39	.87	.69	.86*	1*
	(2)	(6)	(1)	(4)	(3)	(6)	(7)	(4)
73b	U	.74	.93*	.66	-.61	.90*	.97*	.71
	(1)	(6)	(7)	(4)	(3)	(6)	(7)	(4)
74	U	-1	-1	-1	1*	.46	.54	.44
	(2)	(2)	(2)	(2)	(3)	(6)	(6)	(4)
75	U	1*	.85	.66	-.21	.80	.50	.80
	(1)	(3)	(4)	(4)	(3)	(6)	(7)	(4)
76b	U	1*	.77	.26	.93	.99*	.80*	-.09
	(2)	(5)	(5)	(4)	(3)	(6)	(7)	(4)

*p<.05

ITI responses on both keys are plotted across conditions in Figure 52. Hens 71, 73b, and 74 rarely responded on either key during ITIs, but when responses did occur, they tended to be on the salted-wheat key. Hens 75 and 76b also tended to respond on the salted-wheat key during the ITI, but more often that the other hens. Hen 76b's ITI responses remained under 10 for most of the experiment and Hen 75's started at approximately 20 in its first Poor Condition and decreased throughout the experiment to near-zero by the end of its last Post-Feed Condition.

Figure 53 displays each hen's pre-session body weights plotted across days and Table 45 shows mean body weights for each hen in each condition.

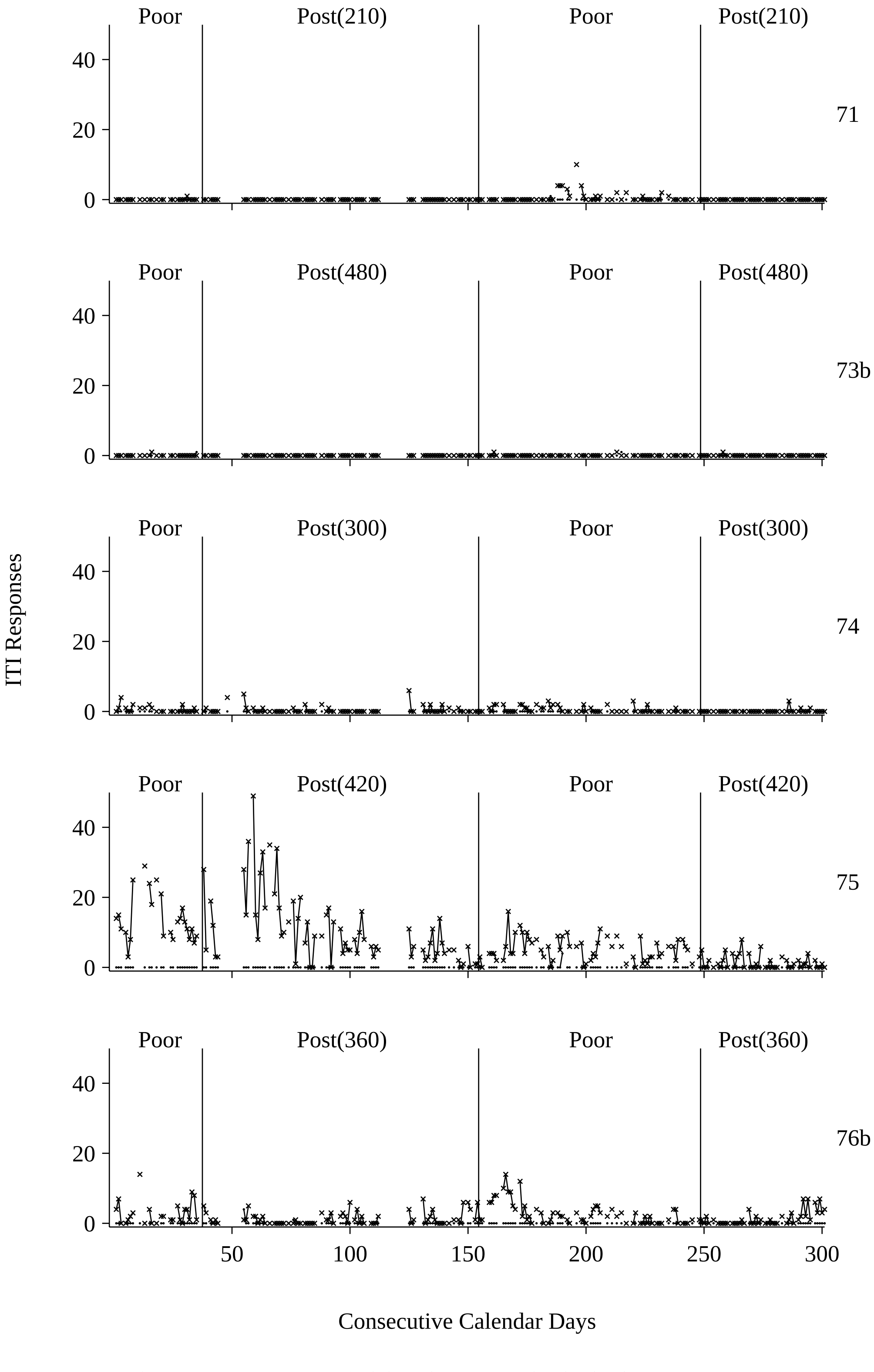

Figure 52. Experiment 9: Frequency of plain-wheat (•) and salted-wheat (×) ITI responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session post-feeding time for each condition.

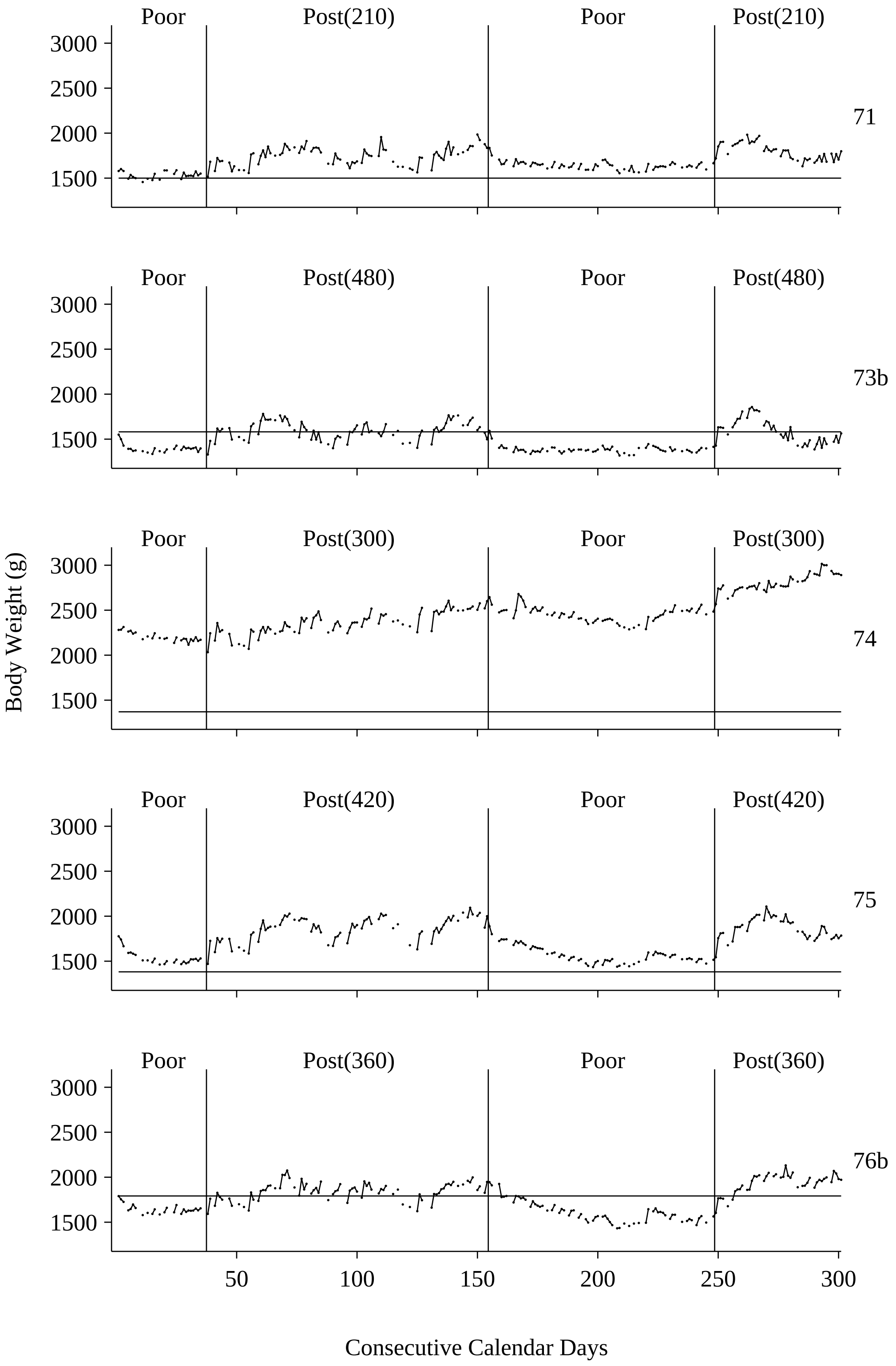

Figure 53. Experiment 9: Pre-session body weights across consecutive calendar days. Solid vertical lines indicate major condition changes, dashed vertical lines indicate ITI changes, and horizontal lines indicate post-feed thresholds (approximately 80% of free-feeding body weight). Bracketed values indicate the programmed duration of session post-feeding time for each condition.

Overall, mean body weights were always higher in the Post-Feed Conditions than in Poor Conditions. Hens' bodyweights tended to be similar in their respective condition replications except for Hen 74. This hen's bodyweight was stable during its first Poor Condition, increased during its first Post-Feed Condition, stabilised again during its second Poor Condition, and increased again in its second Post-Feed Condition.

Table 45
Experiment 9: Mean Body Weights (g) for the Last 20 Sessions of Each Condition

	Successive Conditions			
Hen	Poor	Post	Poor	Post
71	1529	1803	1633	1724
73b	1383	1640	1389	1480
74	2185	2506	2465	2887
75	1511	1934	1546	1824
76b	1629	1877	1561	1978

Discussion

This experiment investigated the effects of post-session feeding on Poor-Condition responding for comparison with responding in Rich Conditions of Experiment 2 and Pre-Feed Conditions in Experiment 8. Food in the early parts of the digestive tract, including the crop, may have affected behaviour during these Rich Conditions and Pre-Feed Conditions by abolishing the quantity dimension of food as a reinforcer. It was predicted that overall responding in Post-Feed Conditions would be similar to overall responding in Rich and Pre-Feed Conditions, but that within-session responding in Post-Feed Conditions would be more similar to within-session responding in Rich Conditions than in Pre-Feed Conditions. That is, Post-Feed-Condition within-session responding was expected to show the early-salted-late-plain pattern or the exclusive plain-wheat pattern. This prediction was based on the amount of food in birds' crops at the beginning of sessions in each condition because in Rich Conditions, birds may have begun sessions with some food in their crops, but probably not as much as after the before-session feeding in Pre-Feed Conditions. The state of the crop or early part of the digestive tract at the beginning of Post-Feed Conditions would have been similar to the state at the onset of Rich Conditions because in both cases, crops emptied for approximately 24 hr between sessions.

The overall response patterns for this experiment shown in Figure 48 are similar to the patterns found in Experiments 2 and 8: more plain-wheat responses and less salted-wheat responses in the Rich, Pre-Feed, and Post-Feed Conditions than in Poor Conditions (cf. Figure 2 and Figure 41). Responding in the Post-Feed Conditions of the current experiment was similar to responding in the Pre-Feed and Rich Conditions of Experiments 2 and 8 with a tendency to respond more on the plain-wheat key and less on the salted wheat key compared to responding in Poor Conditions, as predicted. The pattern is the same as the pattern of the inferior-or relative-inferior-good effect without the income change, but with additional feeding instead of an increase in income. As in previous experiments, the correlation coefficients in Table 44 and the eat-time data in Figure 51 suggest that birds did consume food following most responses. In some Post-Feed Conditions, eat-times may have decreased (e.g., Hens 71, 74, and 75), suggesting that food may have not been consumed following occasional responses. As in previous experiments, the small sample size and mix of significant and non-significant correlations raises the possibility that these correlations occurred by chance.

Within-condition responding in Post-Feed Conditions involved the predicted early-salted-late-plain pattern for only 1 hen. Responding on both keys occurred throughout sessions for 3 hens and the unexpected early-plain-late-salted pattern occurred for 1 hen. No hen responded exclusively on the plain-wheat key. For the hens responding on both keys throughout the session, perhaps if more trials occurred, the pattern would have developed into the previously found early-salted-late-plain pattern due to additional plain-wheat responses during the latter trials. For all hens, within-session responding in all but one Poor Condition was similar to within-session responding in most of the Poor Conditions in Experiments 2 and 8, with nearly-exclusive responding on the salted-wheat key throughout the sessions. The early-salted-late-plain responding that occurred in previous Rich Conditions for Hens 74 and 75 (and the deceased Hen 73a) occurred for both of Hen 71's Post-Feed Conditions but not for any other hen. In Experiment 8, this unexpected pattern was suggested to be the result of two sources of control and the same may have happened for Hen 73b here. Early responding may have been under the control of plain-wheat as a reinforcer while late responding may have been under the control the houselights as in the evocative effect of EOs (Michael, 1993). Alternatively, this behaviour may have been similar to contrafreeloading behaviour (Osborne, 1977).

Three of the hens, Hens 71, 74, and 75, were subjects in Experiment 2 and all 3 showed the inferior- or relative-inferior-good effects. Hen 73b began part-way through Experiment 8 and did not show this overall pattern; it was also the only hen that showed the early-plain-late-salted pattern in this experiment. It may have been the case that experience with inferior- or relative-inferior-good effects was necessary for the overall pattern found in the current experiment. However, Hen 76b showed the general pattern in Experiment 8 and was not a subject in Experiment 2, suggesting that prior experience was not necessary for the overall pattern to occur. In retrospect, it would have been interesting for Hen 76b to be a subject for the procedure of Experiment 2 because in the Pre-Feed and Post-Feed Conditions its overall pattern resembled the pattern of more-plain-wheat responses and less-salted-wheat responses in the Rich Condition found for hens showing the inferior- and relative-inferior-good effects. This hen would be predicted to demonstrate the effects in an inferior-good experiment if food in the crop or digestive tract functions as hypothesised.

In Experiments 7 and 8, outdoor temperature was hypothesised to have affected BMR such that colder temperatures resulted in faster BMRs and faster digestion rates, reducing the amount of food in the crop and digestive tract and establishing the quantity dimension of food as a reinforcer. If so, then the coldest temperatures during this experiment should have been during the first Post-Feed

Condition, when Hen 74's behaviour was similar to its behaviour in the adjacent Poor Conditions. Figure 54 shows that the coldest temperatures during the experiment occurred during the latter third of the first Post-Feed Condition, perhaps explaining the difference in Hen 74's behaviour between the two Post-Feed Conditions. Also, Hens 75 and 76's responding suggests that they may have consumed more plain wheat and less salted wheat in the earlier, warmer days of the first Post-Feed Condition.

This experiment showed that overall patterns of Post-Feed-Condition responding were similar to Rich-Condition and Pre-Feed-Condition responding as more plain-wheat and less salted-wheat responses occurred in these conditions compared to Poor Conditions—an effect similar to the inferior-good effect, without the income change. Within-session responding, though, varied within and between hens in Rich, Pre-Feed, and Post-Feed Conditions across Experiments 2, 8, and 9, respectively. It may be the case that these patterns varied with the amount of food in the crop which could have been different between sessions and experiments due to temperature differences, yesterday's session consumption, etc. For example, in Experiments 8 and 9, the pre- and post-feed was pellets, so crops with pellets may have been different from crops with wheat. These data also fit the hypothesis that factors that affect BMR, such as temperature, can affect the inferior- or relative-inferior-good effect as evidenced by the colder temperatures and higher salted-wheat responding in the first Post-Feed Condition than in the second Post-Feed Condition.

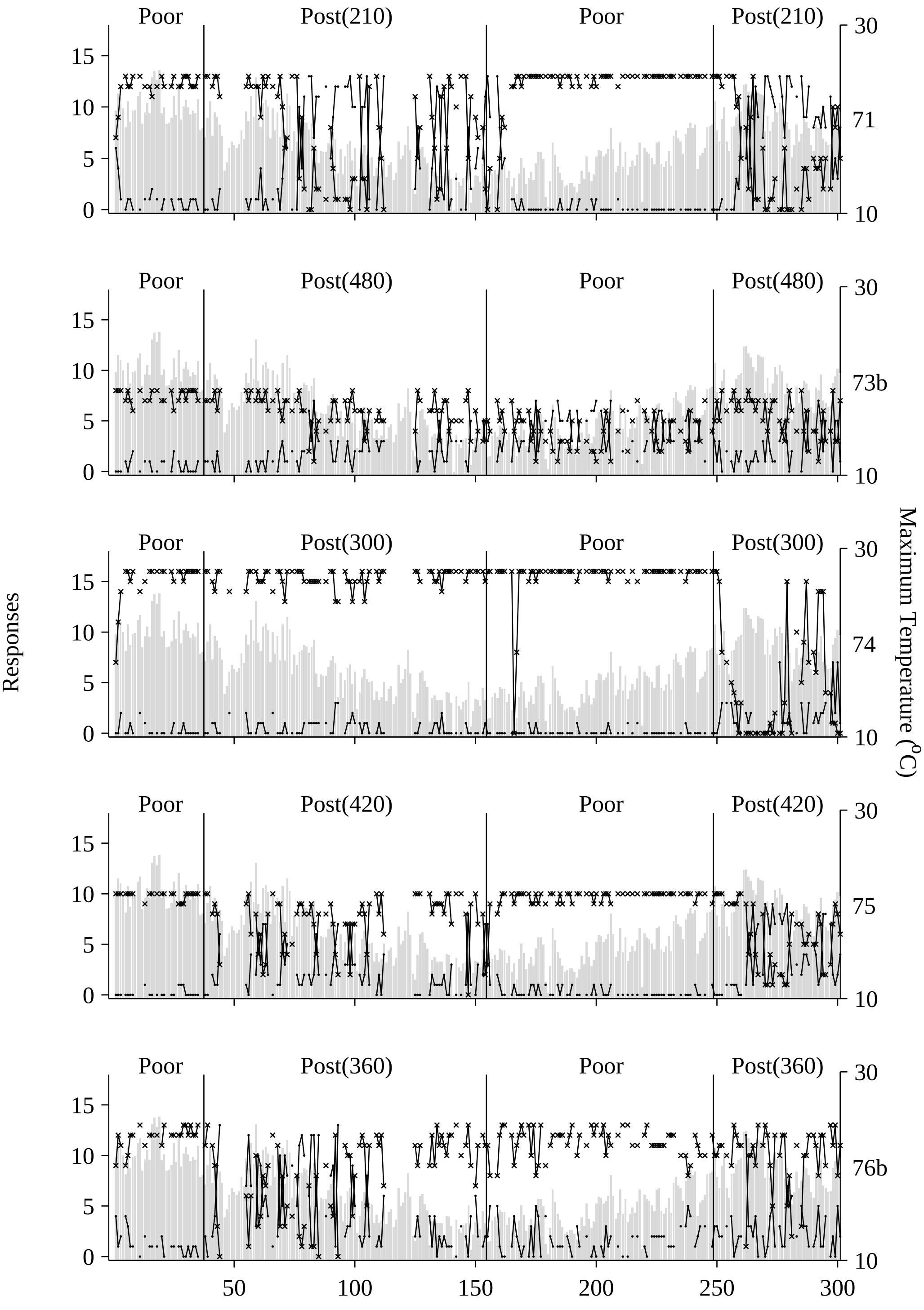

Figure 54. Experiment 9: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition. Background bars represent daily maximum outdoor temperatures.

General Discussion

This series of experiments investigated the inferior-good effect to identify some of the variables controlling it so that an adequate explanation of the effect could be formulated and the empirical validity and usefulness of inferior-, normal-, and superior-good concepts could be evaluated. Table 46 and Table 47 summarise effects across all experiments by indicating inferior- and relative-inferior-good effects for each condition change, rough depictions of within-session patterns, as well as post-feed thresholds and amounts of wheat consumed in Experiments 1 and 7. Partial replications of the published procedures showing the inferior-good effect by manipulating the ITI as an income analogue (Silberberg et al., 1987) and the total number of trials as an analogue (Hastjarjo et al., 1990a) demonstrated the inferior-good effects for some hens. The effect was less convincing for hens in the current series as it did not occur for all hens in all conditions. However, the weaker, relative-inferior-good effect (whereby income changes resulted in increases in consumption of both wheats, but proportionally more for plain wheat) did occur for some hens showing the inferior-good effect as well as for some hens not showing the inferior-good effect. These experiments were the only experiments of their kind where hens served as subjects, providing some generality of the findings of the effects of income found for other species (rats, monkeys, pigeons, and humans).

The inferior- and relative-inferior-good effects occurred for the most income changes and for the most hens in Experiment 2 which utilised the ITI income analogue for Group-7 hens. The inferior- and relative-inferior good effects occurred less convincingly when the total-trials income analogue was used in Experiment 3a, when a fixed ITI was added in Experiment 3b, and when

Table 46
Summary of Effects for Experiments 1, 2, 5, 7, 8, and 9

Hen	Post Thresh. (g)	Experiment 1		Experiment 7		Experiment 2 (Group 7) or 5 (Group 9)							Experiments 8 and 9									
		Free Plain (g)	Free Salt (g)	Crop Plain (g)	Crop Salt (g)	ΔInc. 1	ΔInc. 2	ΔInc. 3	Rich 1	Rich 2	Poor 1	Poor 2	Poor 3	Poor 4	Poor 5	Poor 6	Poor 7	Pre 1	Pre 2	Pre 3	Post 1	Post 2
71	1500	571	77	142	76	-	-	×	│	—	/	│	│	/	│	│	│	—	/	/	(	(
72	1580	1051	35	132	74	-	-	-	—	—	—	—	—	—	—	.	.	—	—	—	.	.
73a	1370	1381	400	111	85	✓	✓	✓	(	(	│	│	│	.	.	.	.	/	.	.	.	.
73b	1380	.	.	.	.	.	.	.	.	.	.	.	.	│	│	│	)	.	│	│	)	)
74	1790	1119	254	137	.	×	✓	✓	—	(	│	│	│	│	│	│	│	)	│	│	│	/
75	1500	572	392	138	.	×	✓	✓	—	(	│	│	│	│	│	│	│	)	│	│	/	/
76a	1580	564	429	.	.	×	×	×	—	—	/	/	.	.	.	.	.	.	.	.	.	.
76b	1500	.	.	111	.	.	.	.	.	.	.	.	│	│	│	│	/	/	│	)	/	/
91	1480	.	.	.	.	×	-	-	—	.	/	.	.	.	.	.	.	.	.	.	.	.
92b	1420	.	.	.	.	-	-	-	—	.	—	.	.	.	.	.	.	.	.	.	.	.
93	1680	.	.	.	.	-	-	-	/	.	/	.	.	.	.	.	.	.	.	.	.	.
94	1710	.	.	.	.	×	-	-	(	.	│	.	.	.	.	.	.	.	.	.	.	.
95	1640	.	.	.	.	-	-	-	—	.	—	.	.	.	.	.	.	.	.	.	.	.
96	1540	.	.	.	.	-	-	-	—	.	—	.	.	.	.	.	.	.	.	.	.	.

Effect: ΔInc. n =Income-Change Number n - = No Effect ✓ = Relative-inferior-good effect × = Inferior-Good Effect

Pattern: │ = Nearly Exclusive Salted — = Nearly Exclusive Plain / = Plain & Salted (= Early Salted/Late Plain) =Early Plain/Late Salted

Table 47

Summary of Effects for Experiments 3a, 3b, 5, and 6

Hen	Post Thresh (g)	Experiment 3a							Experiment 3b			Experiment 5			Experiment 6						
		ΔInc. 1	ΔInc. 2	ΔInc. 3	Rich 1	Rich 2	Poor 1	Poor 2	ΔInc. 1	Rich 1	Poor 1	ΔInc. 1	Rich 1	Poor 1	ΔInc. 1	ΔInc. 2	ΔInc. 3	Rich 1	Rich 2	Poor 1	Poor 2
91	1480	-	-	-	—	—	—	—	.	.	)	×	—	/	-	×	×	—	—	—	(
92a	1600	.	.	.	.	.	│	.	.	.	.	.	.	.	.	.	.	.	.	.	.
92b	1420	.	-	-	—	—	.	—	.	.	—	-	—	—	-	-	-	—	—	—	—
93	1680	×	-	-	—	—	│	—	.	.	/	-	/	/	✓	×	-	—	│	—	/
94	1710	×	×	×	—	(	/	—	×	/	│	×	(	│	×	✓	✓	/	│	│	│
95	1640	-	-	-	—	—	—	—	-	/	—	-	—	—	-	-	-	—	—	—	—
96	1540	-	-	-	—	—	—	—	-	—	—	-	—	—	-	-	-	—	—	—	—

Effect: ΔInc. n =Income-Change Number n - = No Effect ✓ = Relative-inferior-good effect × = Inferior-Good Effect

Pattern: │ = Nearly Exclusive Salted — = Nearly Exclusive Plain / = Plain & Salted (= Early Salted/Late Plain) =Early Plain/Late Salted forced-choices were added in Experiment 6 as the effects only occurred for some hens and did not always replicate with conditions replications. Across all experiments occasional early-plain-late-salted within-session patterns occurred, as reported in the two published studies, usually in Rich Conditions, but other patterns occurred as well, casting doubt on the importance of this pattern with respect to the inferior- and relative-inferior good effects. Body weights tended to be higher in Rich Conditions than in Poor Conditions across experiments and there were occasions where responding shifted immediately following a condition change, suggesting that houselight-colour changes accompanying income changes affected responding.

When Group-7 hens were fed before or after Poor-Condition Sessions in Experiments 8 and 9, respectively, overall patterns of responding resembled the inferior- or relative-inferior-good-effect responding found in Experiment 2 where hens responded on the salted-wheat key more in Poor Conditions than in Rich or extra-feed conditions and on the plain-wheat key more in Rich and extra-feed conditions than in Poor Conditions. Within-session patterns varied within and across subjects in these extra-feed conditions, without convincing resemblance to the patterns in the Rich Conditions. The series of experiments provided some insight into the variables controlling the effect and some of these variables are discussed below.

Variables Controlling the Inferior- and Relative-Inferior-Good Effects

Silberberg et al. (1987) provided guidelines on selecting a commodity pair to serve as inferior and superior goods where the pair were substitutable, differed in taste, and differed in price such that the less-valued good was less expensive than the more-valued good. Several pieces of research in the area of behavioural economics have demonstrated reinforcer substitutability of reinforcers varying in several dimensions (e.g., Bauman et al., 1996; Belke et al., 2006; Hursh, 1980, 1984) as well as the use of schedules of reinforcement as price analogues (e.g., Bauman, 1991; Bauman et al., 1996; Boice, 1984; Collier et al., 1992; Foster et al., 1997; Hursh & Natelson, 1981; Lea & Roper, 1977; Mathis et al., 1996; Roper, 1975; Sumpter et al., 1999; Tustin, 1995). This body of research clearly shows that price (response requirement) and reinforcer substitutability (quality) are both variables that affect responding. Additionally, several studies (e.g., Belke et al., 2006; Carroll & Rodefer, 1993; Collier, 1981; DeGrandpre et al., 1993; J. K. Green & Green, 1982; Hastjarjo & Silberberg, 1992; Hastjarjo et al., 1990b; Shurtleff & Silberberg, 1990; Shurtleff et al., 1987; Tsunematsu, 2001; Wakita et al., 1994) have shown that changing overall reinforcement, an analogue of income, also affects responding. When the right combination of prices (response requirements), substitutable commodities (reinforcers similar along a dimension such as caloric value but different along another dimension such as taste), and incomes (overall amount of reinforcement available) are set, inferior-, normal-, superior-, and Giffen goods can be demonstrated (e.g., Battalio et al., 1991; Hastjarjo et al., 1990a; Silberberg et al., 1987). The current series of experiments fits with this body of literature as these variables were manipulated and the inferior- and relative-inferior-good effects were demonstrated, albeit, less convincingly than the published studies.

Another variable was suspected to affect responding in the current series. In Rich Conditions, hens were usually heavier than in Poor Conditions, suggesting that changes in responding could have been due to between-condition differences in body weights instead of the income manipulations themselves. The specific components of body weight that may have affected responding as such were identified as adiposity and the amount of food in the early part of the digestive tract. Levels of adiposity have been shown to cause metabolic changes which affect feeding, in a variety of species but usually mammals (e.g., Gibbs, 1996), but research on these metabolic changes in birds is somewhat sparse. Metabolic changes occurring during eating have been similarly cited, but criticised, and food in the digestive tract (especially the crop) put forth as more important in the control of feeding behaviour (Savory, 1999). Research has shown that food in the crop and digestive system can affect responding (DeMarse et al., 1999; Richardson, 1970; Savory, 1985, 1999). These effects of food consumption on further eating have been termed satiety signals or factors (e.g., McSweeney & Murphy, 2000), negative feedback signals (e.g., Campbell & Reece, 2002), and AOs (Murphy et al., 2003); all of these terms refer to the decrementing effect of food in the digestive tract on food consumption.

If food in the digestive tract abolishes food as a reinforcer, it may act more on the quantity dimension of food while the taste (quality) dimension may remain unaffected so long as habituation to reinforcer taste did not occur. With respect to inferior-and relative-inferior-good effects in the current series of experiments, the intended inferior good would have been abolished as a reinforcer as the digestive tract filled and the better-quality, smaller intended-superior good would have gained more control due to its still-established taste as a reinforcer. Silberberg et al. (1987) briefly argue against this point, based on Herrnstein (1981) suggestion that reinforcers sate at different rates, by suggesting that their use of nutritionally-identical foods (monkey chow and monkey chow adulterated with a bitter herb) bypassed this argument. However, they did not consider that quality and quantity might be subject to different AOs. The responding of hens in Pre- and Post-Feed Conditions in Experiments 8 and 9 provide some evidence for this AO-hypothesis as overall responding in these extra-feed conditions resembled responding in Rich Conditions for several hens. Further, when overall responding in Experiments 8 and 9 was re-analysed with maximum temperatures overlaid, the coldest maximum outdoor temperatures were found during blocks of sessions that failed to show expected high levels of plain-wheat responding. These data, temperature data from Experiment 7 showing that maximum temperature and body weight co-varied and that maximum temperature and amount consumed may have varied in the opposite direction, and published literature (Henderson et al., 1992; Savory, 1986, 1999; Taher et al., 1985) all show the relatedness between temperature and amount consumed. If temperature affects BMR which affects the rate of food digestion (Campbell & Reece, 2002), then hens in cold temperatures would be expected to have less food in their crop than in warm temperatures. In Experiments 8 and 9, hens in cold extra-feed conditions would be expected to respond on the salted-wheat key more often than in warm extra-feed conditions because in cold conditions, the quantity dimension of food would have been established as a reinforcer due to hens having less food in the crop than in warm conditions. This difference in responding was observed thereby providing more evidence that food in the crop or other parts of the digestive tract may play a role in the inferior- and relative-inferior-good effects.

Five of 6 hens showed the inferior- and/or relative-inferior-good effects in Experiment 2, but not across all conditions. If temperature played a role in the non-occurrence of the effect in this experiment, then the coldest temperatures should have been in Rich Conditions for hens that did not show the greater-plain-responding and less-or-equal-salted-wheat responding in these conditions when compared to Poor Conditions. Hen 71 was the only hen not showing the effect for all three condition changes due to mostly salted-wheat responding in its first Rich Condition. It was expected that the maximum outdoor temperatures in the second half of Hen 71's first Rich Condition would be colder than those of its second Rich Condition. Figure 55 shows that this difference in temperature was the case: plain-wheat responding occurred when temperatures were warmer, earlier in the first Rich Condition, but then shifted to nearly-exclusive salted-wheat responding for the rest of the condition. Responding during sessions in the second Rich Condition began with nearly-exclusive salted-wheat responding but shifted to nearly-exclusive plain wheat responding, providing more evidence of the possible relation between food in the digestive tract (as affected by temperature) and the inferior- and relative inferior-good effects.

So, the effect of income on consumption in this series of experiments, and perhaps in other income experiments, may be non-specific in that high or low income may have simply resulted in much or little food in the digestive tract prior to each session. Given that body weight would have co-varied as well, it still may be the case that another aspect of bodyweight, such as adiposity, was responsible or partly responsible. A way to tease apart these variables would be to use the procedure of Experiment 2, but to conduct the experiment at high and low body weights and fasting (or minimally feeding) birds for a day between each session to decrease the amount of food in birds' digestive tracts before sessions. This procedure would allow assessment of the effects of only body weight on responding in Rich and Poor Conditions. If food in the digestive tract is important while other components of body weight are not, than mostly salted-wheat

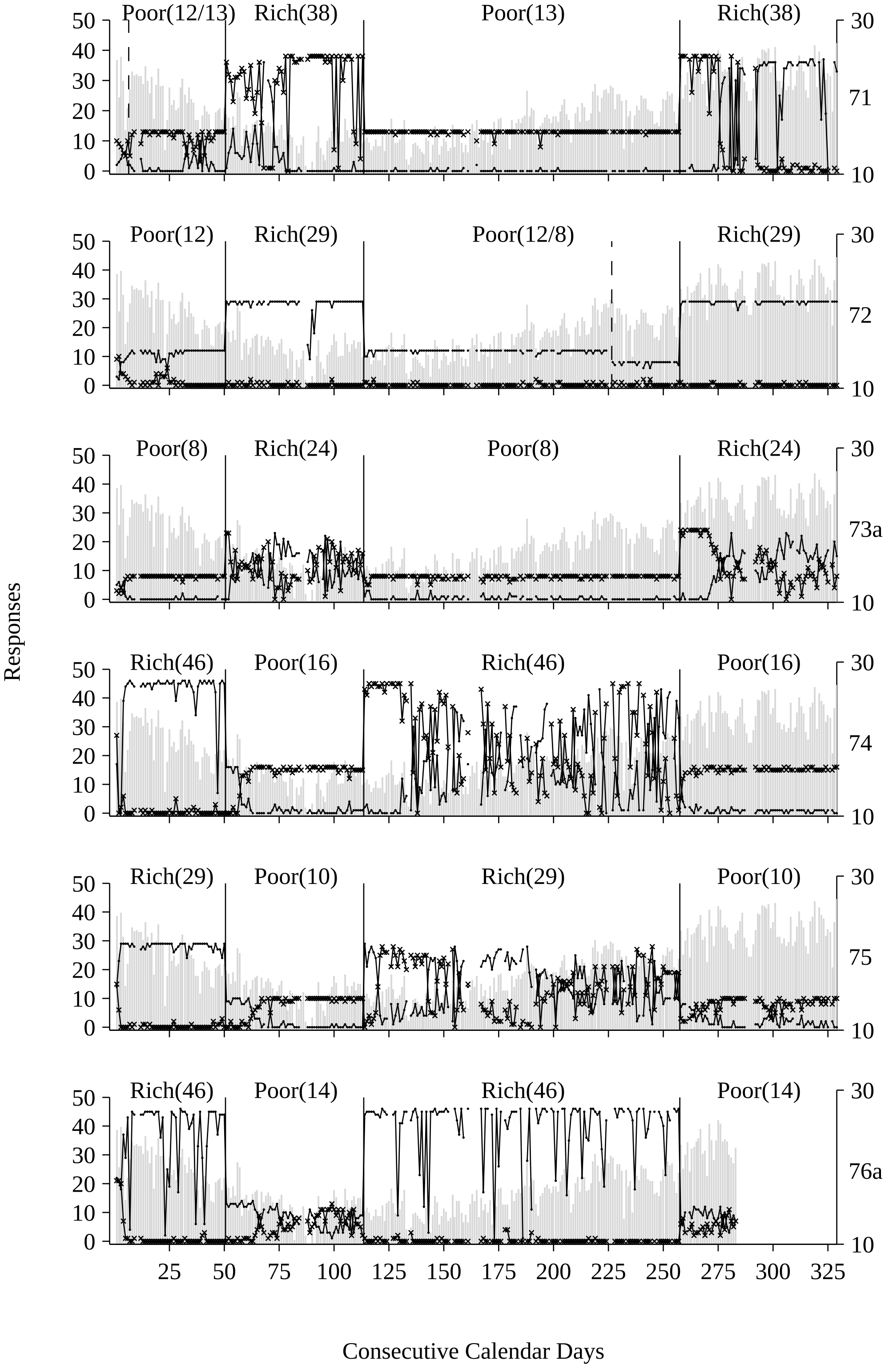

Figure 55. Experiment 2: Frequency of plain-wheat (•) and salted-wheat (×) responses across consecutive calendar days. Solid vertical lines indicate major condition changes and dashed vertical lines indicate ITI changes. Bracketed values indicate the programmed duration of session pre-feeding time for each condition. Background bars represent daily maximum outdoor temperatures.

responding would be expected in these experiments as the digestive tract would be relatively empty at session onset regardless of condition. If a similar experiment occurred but if hens were instead allowed to feed ad-libitum the day between sessions, mostly plain-wheat responding would be expected due to food in the digestive tract (if, again it is the only important part of body weight). If body weight and food in the digestive tract interact, then the least salted-wheat responding would be expected for the high-body-weight-ad-libitum birds and the most for the low-body-weight-skipped birds, and the others would be somewhere in between.

For any future experiments investigating inferior- and relative-inferior good effects, temperature should be controlled (or at least monitored) as it has been shown to affect the amount of food in the digestive tract. The same income manipulations (i.e., programmed number of trials) should be used across hens so that effects of differences in these manipulations are not masked. Hens of similar 80% body weights should perhaps be used, again to avoid masking the possible effects of differing 80% body weights and birds of a similar “crop capacity” (DeMarse et al., 1999) might be used, again to avoid masking effects of “crop capacity” as it has been shown to affect within-session responding. Additionally, future experiments could compare the effects of different temperatures, income manipulations (numbers of trials), 80% body weights, and “crop capacities” on the inferior- and relative-inferior good effects by varying these variables systematically whilst re-conducting the procedure of Experiment 2.

An aspect of the procedure, not necessarily a specific variable, which may have affected the occurrence or non-occurrence of the inferior- and relative-inferior-good effects was the opportunity for behaviour to vary. Although not explicitly tested, procedures in the current series of experiments that provided time for behaviour to vary by providing ITIs (fixed or varied) or by incorporating forced choices seemed to result in more variability of responding between the two keys. This variability may have been important in that it increased the chances of contacting the contingencies on both keys (or guaranteed contingency contact as in the use of forced-choice trials), increasing the chances of the effects occurring.

Although the early-intended-inferior-late-intended-superior-good responding reported in the literature (Hastjarjo et al., 1990a; Silberberg et al., 1987) occurred occasionally in the current series of experiments, it did not occur consistently and did not seem to be related to the occurrence or non-occurrence of the inferior- or relative-inferior-good effects. For example, Hen 73a was the only hen to show the inferior-good effect for all 3 condition changes in Experiment 2, but it never showed this within-session pattern. It may be the case that the patterns varied with another variable such as the amount of food in the crop at the beginning of sessions. If Experiment 2 could occur with accurate measurements of the amount consumed daily, then the correlation between these amounts and within-session patterns could be examined.

The immediate shift in responding found for Hens 75 and 76a in Experiment 2 and for Hen 94 in Experiment 6 suggest that the houselights played a role in this shift because houselight changes were the only immediately-salient programmed changes that occured with income changes . The published studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) did not utilise houselights or other conditional changes, but the inferior-good effect was still found. These results suggest that the houselights are not important for the inferior-good effect, but that in the current series, the houselights may have gained control by being paired with an EO—food in the digestive tract or body weight. As such, the houselights fit the definition of a CEO (Michael, 1993). This conceptualisation of the control of houselights as a CEO, body weight or food in the digestive tract as an AO, and the quantity and quality dimensions of the two foods as being subject to different AOs seemed more parsimonious than conceptualisations involving temporal or total-trials discriminations and complicated within-session patterns. The use of houselights makes it difficult to determine the controlling variables following condition changes as control may have been due to houselights, other variables (such as the income change itself or the amount of food in the digestive tract), a combination, or a shift in control from, say, houselights to another variable. It is therefore suggested that houselights are not used in future experiments for comparability with published experiments and to avoid the difficulty in determining the variables responsible for shifts in responding.

Finally, differences between hens showing and not showing the inferior- or relative-inferior-good effects might be speculated given the findings in the currents series of experiments. If the effects are related to body weight and food in the digestive tract, then birds not showing the effect may have had slower BMRs (or perhaps other physiological differences), thereby keeping body weight relatively high and perhaps keeping more food in the digestive tract. Also, between hens, hens received different amounts of food daily, had different numbers of trials, may have received more or less post-feed after sessions (thereby creating a more-open economy), had different 80% body weights, had different eat rates, and laid eggs at different times. As suggested earlier, these variables would be better understood if they were controlled in future experiments.

Explanations for the Inferior- and Relative-Inferior-Good Effects

Matching and its underlying behavioural process, melioration, have been well researched in behaviour analysis. Findings of these studies indicate that the ratio of organisms' response rates or time allocated to two alternatives equals the ratio of obtained reinforcement rates on those two alternatives (see Davison & McCarthy, 1988). This relation can be seen in Equations 1, 2, or 3. The term *value* has been quantified in these latter two equations to capture parameters of reinforcement that affect response and time ratios. In Equation 3, it can be seen that value captures reinforcer rate, amount, and immediacy as well as other reinforcer parameters. Although the matching law can be seen as tautological (Rachlin, 1971), it provides a framework for finding those parameters of reinforcement that affect response and time ratios, making it a useful tool for predicting behaviour. The law itself does not explain behaviour, but its assumed underlying behavioural process, melioration, touches on explanation. Herrnstein and Vaughan's (1980) definition of melioration refers to the ability of organisms to detect differences in local reinforcement rates and their ability to reallocate behaviour to the higher rate. Presumably this detection ability would also span other reinforcer parameters such as amount (e.g., Catania, 1963; Neuringer, 1967) and immediacy (e.g., Chung & Herrnstein, 1967).

If Equation 3 can be adapted to suit the choice situation in the published and current series of inferior-good experiments, then Equation 6 might suit as it states that time allocation ratios should be equal to the ratios of amounts times a ratio of quality-scaling factors (as in H. L. Miller, 1976). However, as other income studies have shown, behaviour in the current series of experiments changed with changes in income, suggesting that Equations 1, 2, 3, and 6 are inadequate in these contexts. Melioration, then, may not be part of a sufficient explanation for behaviour affected by income changes as it is assumed based on the matching law.

The explanations of the inferior-good effect by Silberberg et al. (1987) and Hastjarjo et al. (1990a) did not span beyond labelling the phenomenon with economic terms. Both studies highlight that models of choice based on matching are insufficient because they do not predict that changes in income (overall reinforcement) will affect behaviour; there are no income-related parameters in Equations 1, 2, or 3. As such, both authors conclude that economic concepts are useful in behaviour analysis because they account for behaviour such as behaviour affected by income (income elasticity, see Equation 5) and behaviour in the presence of qualitatively different reinforcers (reinforcers of differing demand elasticities, see Equation 4) whereas matching-based accounts do not (for a review, see Hursh, 1980, 1984; Madden, 2000).

Although economic concepts may describe the relations found in behavioural-economic experiments and may provide guidance in predictions, they probably do not provide an explanation of the phenomena that they label. For example, economists have recourse to the concept of utility and behaviour is said to maximise utility towards a bliss point (Kagel et al., 1985) given a set of economic (experimental) constraints (Herrnstein et al., 1997; cf. with Rachlin et al., 1981). However, utility is invisible and assumed (Vaughan & Herrnstein, 1997), making it difficult to disprove assertions about utility maximisation—the answer to “Why did the organism behave in a certain way?” is always, “because it maximised utility.” Unless utility can be empirically validated, it is probably not a helpful concept in explaining behaviour.

Given the data in the current series of experiments that showed that body weights changed with condition changes, food in the digestive tract or other aspects of body weight were hypothesised to be the proximal variables that caused shifts in responding with income changes. If this was the case, then Equation 6 might be re-considered in the light of EOs and AOs relating to bodyweight changes, or more specifically, changes in the amount of food in the digestive tract. If food in the digestive tract was an AO, then this AO may have affected the quantity dimension of food as a reinforcer, especially in Rich Conditions when there may have been more food in the digestive tract than in Poor Conditions, but not the quality dimension. Values of each alternative would have changed throughout the session, thereby resulting in the predicted early-salted-late-plain responding found for some hens (similar to those patterns reported in the published studies) and the overall changes in responding found with condition changes. This explanation is more favourable than an explanation couched in economic concepts and immeasurable constructs such as utility as it more clearly identifies the variables that might be important for the phenomenon, fits with a large body of research (matching research), fits with a different level of analysis (the physiology of the organism), is parsimonious, and does not rely on concepts not already established in behaviour analysis.

A previously-unmentioned view in economics that may also fit with the above conceptualisation is the minimum-needs hypothesis. Stated simply, organisms behave such that minimum survival needs are met first (Kagel et al., 1985). Kagel et al. found that the behaviour of rats' responding reinforced by pellets and sodium saccharin solution fit this hypothesis in that when rats were in low-income conditions (when there were relatively few programmed discrete-trials) pellets were mostly consumed, but in high-income conditions, both reinforcers were consumed. Shurtleff et al. (1987) found similar results with rats and these reinforcers in a procedure closer to procedures typical of matching procedures using concurrent VI schedules. If hens in the current experiment were responding similarly, then the quantity dimension of food would be seen as a minimum need while the quality would be seen as a controlling variable once minimum needs were met. In terms of EOs and AOs and Equation 6, the minimum-needs hypothesis does not change their hypothesised effects on value and provides somewhat of an explanation regarding the underlying biological process. If there can be an ability of organisms to detect differences in local reinforcement rates and reallocate behaviour to the higher rate accordingly (Herrnstein & Vaughan, 1980), then it is not a far stretch to assume that organisms might have abilities to behave as to meet minimum survival requirements prior to behaving in ways controlled by less-needed reinforcers.

Given the large body of research supporting melioration and matching, the lack of explanatory power of economic concepts relating to the inferior-good effect, the evidence of the effects of body weight (especially food in the digestive tract) on responding, and the behavioural concepts of AOs and EOs, the most parsimonious explanation of the inferior- and relative-inferior-good effects in the current experiment seems to be that changes in one ore more components of body weight (especially food in the digestive tract) occurred with changes in income and these bodyweight-component changes shifted responding. With respect to Equation 6, values of each alternative may have changed depending on the AO effects of food in the digestive tract such that the intended-inferior-good was relatively-abolished as a reinforcer in Rich Conditions and relatively-established in Poor Conditions. The early-intended-inferior-good-late-intended-superior-good pattern found occasionally in the current series of experiments and in the published inferior-good studies (Hastjarjo et al., 1990a; Silberberg et al., 1987) fit this conceptualisation. These within-session patterns resemble the early-pellet-late-saccharin-responding found for rats in the minimum-needs studies (Kagel et al., 1985; Shurtleff et al., 1987) suggesting that hens may have been meeting their minimum survival requirements first. Thus, the inferior- and relative-inferior-good effects, at least in the current series of experiments, seem to be non-specific with respect to income changes. This finding calls into question the usefulness of the concept of inferior goods, as well as the other good-concepts relating to income elasticity.

Usefulness of Inferior-, Normal-, and Superior-Good Concepts

If the inferior- and relative-inferior good effects are indeed the result of body-weight-component changes and not income manipulations themselves in these experiments, then the concepts of inferior-, normal-, and superior-goods, and income elasticity as a concept itself (see Equation 5) would appear to be less useful than concepts involving Equation 6, AOs and EOs, and the minimum-needs hypothesis. Further, if non-specific effects of income were the case, then use of these economic concepts may mask the already-established behavioural concepts that might shed better light on the phenomena.

However, income elasticity and the concepts of inferior-, normal-, and superior-goods have been well-used to predict behaviour in human economies (Samuelson & Nordhaus, 2005), so are at least useful insofar as they can be used to predict human behaviour. They still only label a relation, namely between income and consumption, but they do not explain behaviour. It may be the case that the non-human behaviour in the published income studies and in the current series of experiments merely resembled the inferior-good effect and that the causes of this seemingly-similar behaviour for humans and non-humans differs. Behaviour of humans, after all, can be verbally-controlled and the use of budgets, for example, relies on verbal control. So given that the concepts have proven useful in predicting behaviour in human contexts and that they have been used to predict behaviour in non-human experiments, the terms should not be abandoned, but studied further.

As *inferior-, normal-,* and *superior-goods* are labels for different ranges of income elasticities (see p. 20), it is probably better to consider the usefulness of income elasticity as a concept rather than its descriptive labels. The non-human literature on income elasticity is small. On 22 October 2006, the PsychINFO database was searched for *income elasticity* or *income elasticities* anywhere in the database and 35 articles were returned. Inspection of titles and abstracts suggested that of the 35 articles, 2 involved non-humans and other articles in the group of 35 cited these 2 articles: Cooper and Mason (2001), and Kirkden, Edwards, and Broom (2003). Cooper and Mason was a conference presentation titled, *Income Elasticity as an Indicator af Behavioural Priorities in Mink (Mustela Vison)* and Kirkden et al. was a theoretical article titled, *A Theoretical Comparison of the Consumer Surplus and the Elasticities of Demand as Measures of Motivational Strength.* Also, searches of databases for biology-related literature (BasicBIOSIS and AGRICOLA) did not reveal any non-human research beyond the two mentioned above. Hence, non-human literature on income elasticity is seemingly sparse.

The Battalio et al. (1991) article was not found with the above searches as it was located in an economic journal and found via a reference list in another article. Of the inferior-good studies, this article was the only one that presented income elasticities; however, it was published in *The American Economic Review*, an audience probably different from non-human-behaviour audiences. It appears as though income elasticity is not a concept widely used in the study of non-human behaviour. Its usefulness in the prediction, control, and explanation of non-human behaviour rests on its empirical validity in the lab setting and its usefulness when compared with established behavioural processes, as suggested by Hursh (1984). Although the concept appears valid due to the findings that income differentially affected consumption of different reinforcers in the current series of experiments and in published experiments, the explanation of the non-specific effects of income with respect to established behavioural concepts (Equation 6, EOs, and AOs) challenges its usefulness. Further research on the validity of the concept would help determine its place amongst established behavioural concepts, but at the moment its place is challenged.

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