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A Comparison of Delay Reduction and Behavior Systems Theories

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Running Head: Cross-Motivational Choice

ABSTRACT

Choice, the simple allocation of responses amongst alternatives, has been extensively studied in the past. Most often, choice has been studied on concurrent variable interval schedules. A variety of quantitative models, including matching, behavioral economics, and momentary maximizing, have had varying degrees of success in accounting for choice behavior. The present study examined predictions of two more recent theories, behavior systems theory and delay reduction theory. Rats were deprived of both food and water and were exposed to a "cross-motivational" choice, in which one alternative produced food, the other water. Periodically, the animal was given the opportunity to change its initial choice. That is, if it had chosen food, it was given the opportunity to immediately obtain water. According to the delay reduction theory, the rat should choose the more immediate reinforcer, even if this involves changing its initial choice. According to the behavior systems theory, the rat will be "locked in" to a particular choice alternative once the initial choice is made. Results showed an average overall switching from initial choice to immediate reinforcement 40.89% of the time. A further breakdown revealed that when the initial choice was food, there was switching 27.4% on the average. When the initial choice was water, the rats switched 92% of the time. These results supported neither the delay reduction nor the behavior systems theories completely.

Choice behavior and its underlying processes have been studied extensively in the past (see Davidson & McCarthy, 1988 for review). Although the term "choice" seems to imply a cognitive process, it has traditionally been viewed as the simple allocation of responses amongst alternatives (Ferster & Skinner, 1957). That is, to the extent that two or more alternatives exist, a behaving organism is said to be "choosing" between alternatives.

Choice on concurrent variable interval schedules

In operant conditioning paradigms, choice has most commonly been studied on concurrent variable interval (conc VI) schedules. Concurrent variable interval schedules present two or more response alternatives to reinforcement each independently associated with a variable interval schedule of reinforcement. Analysis of choice behavior on conc VI schedules has been at the forefront of recent trends toward quantification of behavior. Hernstein (1961) first proposed that choice could be described by Equation 1, the simple matching law:

$$\frac{P_1}{P_1 + P_2} = \frac{R_1}{R_1 + R_2} \qquad (1)$$

where P_1 and P_2 are response rates to the two alternatives, and R_1 and R_2 are reinforcement rates for those alternatives. According to the matching law, an organism will respond with the same relative frequency as the relative frequency of reinforcements that are available. For example, if 30% of reinforcements are acquired from one of two schedules, 30% of responses would therefore be allocated to that alternative.

More recently, the matching law has been revised to account for more variance (Baum, 1974). Studies have shown that Baum's "generalized matching law" is a good description of conc VI schedules (Baum,1978), often accounting for 90% or more of the variance. However, the matching law is not without its problems. Some have criticized the assumptions underlying matching. Timberlake (1982) has identified three assumptions behind the matching law. (1) Responding is directly related to relative obtained reinforcement, (2) The total amount of behavior is constant, and (3) All behavior is reinforced. Timberlake went on to criticize these assumptions because (1) Behaviors that may be intrinsically reinforced on their own schedules are not taken into consideration, (2) It is absurd to say that the total amount of behavior is constant because this implies that across all conditions of reinforcement, deprivation, and schedules the total amount of behavior occurring never changes. (3) The model provides no place for unreinforced responses. In summary, matching provides a good explanation of choice under limited circumstances. The assumptions behind matching are apparently invalid and the inconsistency of these assumptions has led to a search for different models.

In the late 1970s and early 1980s, several authors proposed behavioral economics as an alternative to the matching law (Hursh, 1980; Rachlin et al, 1980). According to behavior economics, a reinforcement experiment may be viewed as an economy influenced by the interrelationship between supply, demand, and prices of commodities. Economic theorists predict that an organism will choose the response strategy that yields the highest total value. One analogy would be to liken an organism to a company in the economic society of today. Efficiency is necessary for survival, whether it be in a natural environment or the marketplace.

Behavior economic models also have problems. For example, most non-human organisms lack the computational skills necessary to calculate the most efficient response strategy. Momentary maximizing theory (Hinson & Staddon, 1983; Shimp, 1966) has been proposed as an alternative to the economic models. According to momentary maximizing, the organism will choose the response which has the highest immediate probability of reinforcement. Momentary maximizing theory requires the organism to calculate only the immediate value a reinforcer, a much simpler calculation than that required by economic theories.

Each of the above theories has flaws, but each also has considerable support. Baum (1978) found support for the matching law and its basis that the relative frequency of responses will be proportionate to the relative frequency of reinforcements. Support also exists, however, for the economic theory that focuses on choice being made with reference to the strategy that yields the highest total reinforcement value (Hursh, 1980; Allison, 1982). Still other studies provide evidence for the momentary maximization theory. Apparently, each theory is partially but not completely correct, and another route of investigation is necessary.

Choice and Foraging behavior

It is possible that the explanation of choice behavior lies in models not explicitly developed for use with the conc VI schedule. Two potentially relevant models are behavior systems theory (Timberlake & Lucas, 1989) and the delay reduction hypothesis (Fantino & Abarca, 1985), both of which were developed in an attempt to explain foraging behavior. Foraging behavior is defined as how an organism procures its food in a natural environment. The natural foraging sequence includes at least five activities: (1) searching for food patches, (2) travelling to the food patch, (3) searching for food within the food patch, (4) procuring the food, and (5) handling/eating the food.

The delay reduction theory is one model recently applied to foraging behavior. According to the delay reduction hypothesis (Fantino, 1969) the strength of a stimulus as a reinforcer is determined by the temporal correlation between the stimulus and food (reinforcement). More specifically, a stimulus that is correlated with a greater reduction in time to reinforcement will be a stronger conditioned reinforcer than one that is correlated with a lesser reduction in time to food. Several recent studies have supported the delay reduction hypothesis (Fantino, 1969b, 1977; Squires & Fantino, 1971; Fantino & Case, 1981).

The delay reduction hypothesis predicts that the effectiveness of a stimulus as a conditioned reinforcer may be predicted most accurately by calculating the reduction in the length of time to primary reinforcement correlated with the onset of the stimulus in question, relative to the length of time to primary reinforcement measured for the onset of the preceding stimulus (Fantino, 1969;1977;1981a; Squires & Fantino, 1971). This prediction is captured by Equation 2:

$$R_A = \frac{f(T-t)}{T}, \qquad (2)$$

where R_A is the reinforcing strength of stimulus A, t is the temporal interval between the onset of stimulus A and primary reinforcement, and T is the total time between reinforcer presentations. According to Equation 2, the greater the improvement (T-t), correlated with the onset of the stimulus, the more effective that stimulus will serve as a conditioned reinforcer (R_A). In behavioral terms, the organism should always choose the alternative with the greatest delay reduction (T-t) because this alternative has the highest reinforcement value (R_A).

The delay reduction hypothesis has recently been expanded to describe foraging behavior, since foraging involves choice. For example, Fantino & Abarca (1985), recently studied pigeons in a foraging simulation. They varied the durations of the time it took to find the food patches (search state), the time it took to reach the food patch (travel time), and the amount of time the organism handled the food before eating it (handling time). They also varied the probability that the patch would provide food (reward percentages), and the rates of accessibility of rewards.

The results from these experiments were qualitatively and quantitatively explained by the delay reduction hypothesis. The more time subjects spent searching for or travelling between potential food sources, the less selective they became. In other words, the more likely they were to accept the less preferred outcome. Increasing the time spent handling food increased selectivity. How often the preferred outcome was available had a greater effect of choice than did how often the less preferred outcome was available. It was also found that subjects maximized reinforcement whether it was the rate, amount, or probability of reinforcement that was varied. Finally, there were no significant differences between subjects performing under different types of deprivation (ie., open versus closed economies; Fantino & Abarca, 1985). These results are consistent with the delay reduction hypothesis.

Behavior systems theory was also developed in an attempt to explain foraging behavior. According to Behavior systems theory, an organism possesses organized systems that are responsible for predicting, supporting, and constraining learning (Timberlake 1983a, 1983b, 1984). Specific instances of learning result from the interaction of system structures and processes with the important stimulus support and contingent organization of the surrounding environment. The behavior systems approach conceptualizes learning in terms of the modification of the functional systems of an organism. This view is significantly different from the "blank slate" position taken by many behaviorists. Learning is defined by changes in existing (ie., instinctive) perceptual/response structures and motivational processes of a functioning organism (Timberlake & Lucas, 1985), emphasizing the ecologically relevant regulation and structures.

According to the behavior systems approach, behaviors that occur are determined by the stimulus sensitivities and response organization of the animal (Timberlake et al., 1982). This approach is said to account for the conditioning of behaviors that range from appetitive components far removed from the terminal event in a system, to aspects of the terminal response itself. The outcome not only depends on the nature and timing of the predictive stimuli, but also the stimulus and motivational support in the environment. The behavior system approach appeals to three general levels of conditioning: (1) a general state related to obtaining and consuming food; (2) local substrates related to particular modes, or strategies, of obtaining food; and (3) specific behaviors oriented to as well as controlled by environmental stimuli (Timberlake, 1986).

A behavior system is a complex control structure that is related to a particular function or need of the organism, such as feeding (Timberlake, 1983b), reproduction (Baerends & Drent, 1982), and defense (Bolles, 1970; Boles & Fanselow, 1980) The behavior system has several critical features including, (1) motivational processes that prime other structures, and (2) perceptual-motor structures (modules) that relate specific stimulus sensitivities to particular response components, which are often sequentially and temporally related, and readily elicited, initiated, controlled, and terminated by stimuli resembling effective stimuli in natural settings (Timberlake & Lucas, 1985).

Insert Fig. 1 about here

A hypothetical behavior system is depicted in Figure 1 (from Timberlake & Lucas, 1989). Within behavior systems there are four hierarchically arranged levels of control: systems, subsystems, modes, and perceptual-motor modules. These levels serve to select/coordinate the expression of individual responses (action patterns). The higher levels deal with global organization and motivation, while the lower levels are primarily concerned with local organization and form of expression. These levels of organization are functional concepts that help to designate characteristic combinations of determinants and classes of outcomes, not (in any way) specific neural locations. The system, the highest level, accounts for the tendency of behavior to be organized around important functions, such as feeding, reproduction, drinking, and /or defense. For example, Figure 1 presents a hypothetical feeding system. Systems can be viewed as general motivational states that in turn prime a set (or sets) of underlying substates and modules related to a particular function. The second level of motivation control, the subsystem, refers to coherent strategies serving the general function of the system. For example, Figure 1 depicts both predation and browsing as subsystems of the feeding behavior system. If the organism is in a predation subsystem, then it will be more likely to attend to moving prey, whereas an organism in a browsing subsystem will be more likely to attend to non-living prey. Activating these subsystems sensitize the organism to particular types of stimuli. The third level of control is the mode. Figure 1 shows six different modes ranging from general search to handling and consuming food.

These are motivational substates related to the sequential and temporal organization of action patterns with respect to terminal stimuli in the system. For example, in the feeding system, modes are based in part on the local probability of finding food.

The lowest level of control consists of perceptual-motor modules in which the organism is predisposed to respond to particular stimuli with associative response components. The examples given in Figure 1 are more specific behaviors characteristic of the particular subsystems such as socializing versus hoarding. For example, an organism will treat a moving stimulus differently than a stationary stimulus depending on what subsystem and mode it occupies. In addition to the above information, it is interesting to note that the same system can produce either constraints or predispositions, depending on the environment. (Timberlake & Lucas, 1985).

A number of studies have supported general predictions of the behavior systems theory. Timberlake (1983) presented a rat with a moving object (a rolling ball bearing) that predicted the delivery of food. According to behavior systems theory, this should increase "predatory" behaviors directed to the bearing, ie retrieving, chewing, carrying, seizing, and digging. Predictions were confirmed: The moving ball bearing elicited "predatory" behaviors not found when bearings did not predict food. Nor were the responses directed to the ball bearing like those directed toward the food. The rats showed a more complex set of responding behaviors to the ball bearings than to food pellets: digging, seizing, carrying, and chewing (gnawing) the bearings never occurred in response to the pellets alone. In accordance, the topography of responding to the bearing by the food rates was compatible with predatory behaviors directed toward insects (Timberlake & Washburne, 1989). This experiment shows that interaction with a bearing predicting reward is complexly determined by many factors including such elements as previous experience, the nature of the commodity restricted, the type of reward, and the nature of the experimental task (Timberlake, 1983). In terms of the behavior systems hierarchy, this shows that rats within the predation system will show predator-like behaviors.

Predictions for the present experiment

Both the delay reduction hypothesis and the behavior systems approach address aspects of choice which the traditional theories have overlooked. It is also important to note that neither of these more recent theories are limited to the use of conc VI schedules. There is wide support for each theory. The behavior systems approach is recent, and is in need of additional empirical support. Pitting the two theories against each other will broaden the scope of knowledge about the differences and/or similarities between the two.

The present experiment will narrow the possibilities about predicting choice behavior.

In the experiment, the delay reduction hypothesis and the behavior systems approach were tested. According to the delay reduction hypothesis, the organism will take the shortest route in time to reinforcement. Regardless of whether or not the choice consists of cross-motivational alternatives, the organism will choose the quickest alternative since that alternative will have the highest reinforcement value. According to the behavior systems approach, the organism possesses a structural set of systems, such as feeding, reproduction, etc. that are triggered by environmental stimuli. The organism will take the shortest path only if the two following conditions are fulfilled: (a) the reinforcer is within a current behavior system, and (b) the stimuli present are evolutionarily appropriate for the reinforcer (for example a moving stimulus will not be as easily associated with a water reinforcement). According to the behavior systems, if the choice is cross-motivational (ie, food versus water), the animal will not always choose the reinforcement closest in time. Instead, it will respond according to the behavior system in which it currently resides. The present experiment examined these different predictions of the two theories.

METHODS

Subjects

The subjects were six male rats of the Long Evans strain, obtained from the breeding colony at Illinois Wesleyan University. Rats were 90 days old at the start of the experiment. Each rat was housed individually.

Apparatus

The apparatus was a standard operant conditioning unit, BRS/LVE model number RTC-028, with dimensions measuring 26cm high, 31 cm long, and 24 cm wide. The floor of the unit consisted of wire bars, the front and back walls stainless steel, and the side walls plexiglass. On the front wall there was one houselight in the chamber 12.5 from either side wall, and one centimeter from the ceiling. The front wall also contained two retractable bars which, when extended, were 2.5 cm from the floor and 9 cm from the closest wall. Above the bar, there were three stimulus lights approximately 2 cm apart and 5.5 cm from the bar. There were two reinforcement cups, one for food and one for water that were approximately

.5 cm apart and 11 cm from the closest wall.

The entire apparatus was enclosed in a sound-attenuating chamber. The system was controlled by MED associates interface and IBM PC clone running MED PC software.

Procedure

Subjects were deprived of food and water until they were approximately 80% of their ad libitum body weight. The water deprivation was on a 23 hour schedule; the rat was given water for a period of one hour at least 60 minutes after each session. Food was also distributed at least 60 minutes after each session as needed, in order to keep the rats at 80% of their normal weight.

Pre-Training Rats were shaped by hand to respond to the left bar to obtain food and the right bar to obtain water. Following shaping, rats received ten sessions of pre-training. At the start of the session, one bar became available, activating the following sequence: (1) during the first 15 seconds of the sequence, no stimuli were present, (2) during the second 15 second period, one white light directly above the bar came on, (3) during the third 15 second period, two lights (white and green) came on and finally, (4) during the fourth 15 second period, all lights (red, green, and white) above the bar came on. During the final three seconds of the interval, all three lights flashed rapidly. Reinforcement was delivered after a total of 60 seconds for the first response after the lights began flashing. The reinforcer was food or water, depending on which bar was initially presented.

After reinforcement was delivered, the bar retracted, the other bar became available, and the previous procedure repeated with the new bar. The bars continued to alternate for the entire 30 minutes. The purpose of the pre-training procedure was to expose the animals to the relationship between bar location (left or right) and the type of reinforcer (food or water), as well as the relationship between the stimuli and reinforcer availability.

Test Condition Phase Following pre-training, ten sessions of a test phase were conducted. Both bars became available to the rat concurrently. After the rat initially pressed one of the two available bars, the remaining bar retracted and remained unavailable for the remainder of the trial. The procedure then continued exactly as in the pretraining sequence with the chosen bar. After reinforcement, both bars retracted, both bars again became available, and a second trial began. The procedure continued for 30 minutes.

Probe Trials After ten sessions of the test condition, probe trials were introduced. Sessions with probe trials were identical to test condition sessions, with the exception that probes occurred on approximately 10% of the trials. The probe trials were identical to standard trials with the following exception: At a random time during the 60 second interval before reinforcement, the alternative bar that was not initially chosen became available, accompanied by three flashing lights above the bar (predicting reinforcement within three seconds for responding on that bar.) According to the delay reduction hypothesis, the rat should immediately switch to the alternative bar as opposed to the bar to which it has initially committed itself. The behavior systems approach predicts that the rat will continue with the bar to which it has initially committed, signifying that the response sequences within the system to which it has committed cannot be interrupted. In other words, the rat will not switch to the bar that signals immediate reinforcement.

Insert fig. 2 about here

RESULTS

On the average, subjects switched from their initial choice on 40.89% of probe trials. Two t-tests for the difference between sample and population means were calculated. The first test compared the obtained switching percentage to the hypothetical percentage predicted by the delay reduction hypothesis (100%). The results of this t-test indicated a significant difference [$t_{(6)}=4.53$; $p<.05$]. The second test compared the obtained switching percentage to the hypothetical percentage predicted by the behavior systems hypothesis (0%). The results of this t-test also indicated a significant difference [$t_{(6)}=3.13$; $p<.05$].

The overall probability of switching masks some interesting effects which are apparent when switching from the food bar and switching from the water bar are considered separately. For instance, when the initial choice was the left bar, which gave a food reinforcer, the subjects only switched to the alternate bar 27.4% of the time on the average. However, when the right bar, which gave a water reinforcer was the initial choice, the subjects switched to the bar that gave them food 92% of the time on the average. A t-test for paired samples confirmed that the probability of switching was significantly higher when the initial choice was water than when the initial choice was food [$t_{(6)}=5.06$; $p<.005$].

DISCUSSION

The most interesting result is the fact that rats are more likely to switch when the initial choice they make is water than when the initial choice is food. This supports neither behavior systems nor delay reduction. According to the delay reduction hypotheses, the animals should have switched to the immediate reinforcer at every opportunity, but the results show a switch only 40.89% of the time. The behavior systems theory would predict a 0% switch from the initial choice, and the results obviously prove otherwise. The present study does not provide direct support for either theory; this further demonstrates the complexity of studying cross-motivational choice. The results suggest several possible explanations.

First, the food pellet may serve as a stronger reinforcer than water. In comparison, the amount or size of the food pellet outweighed the volume of water obtained for the same amount of work.

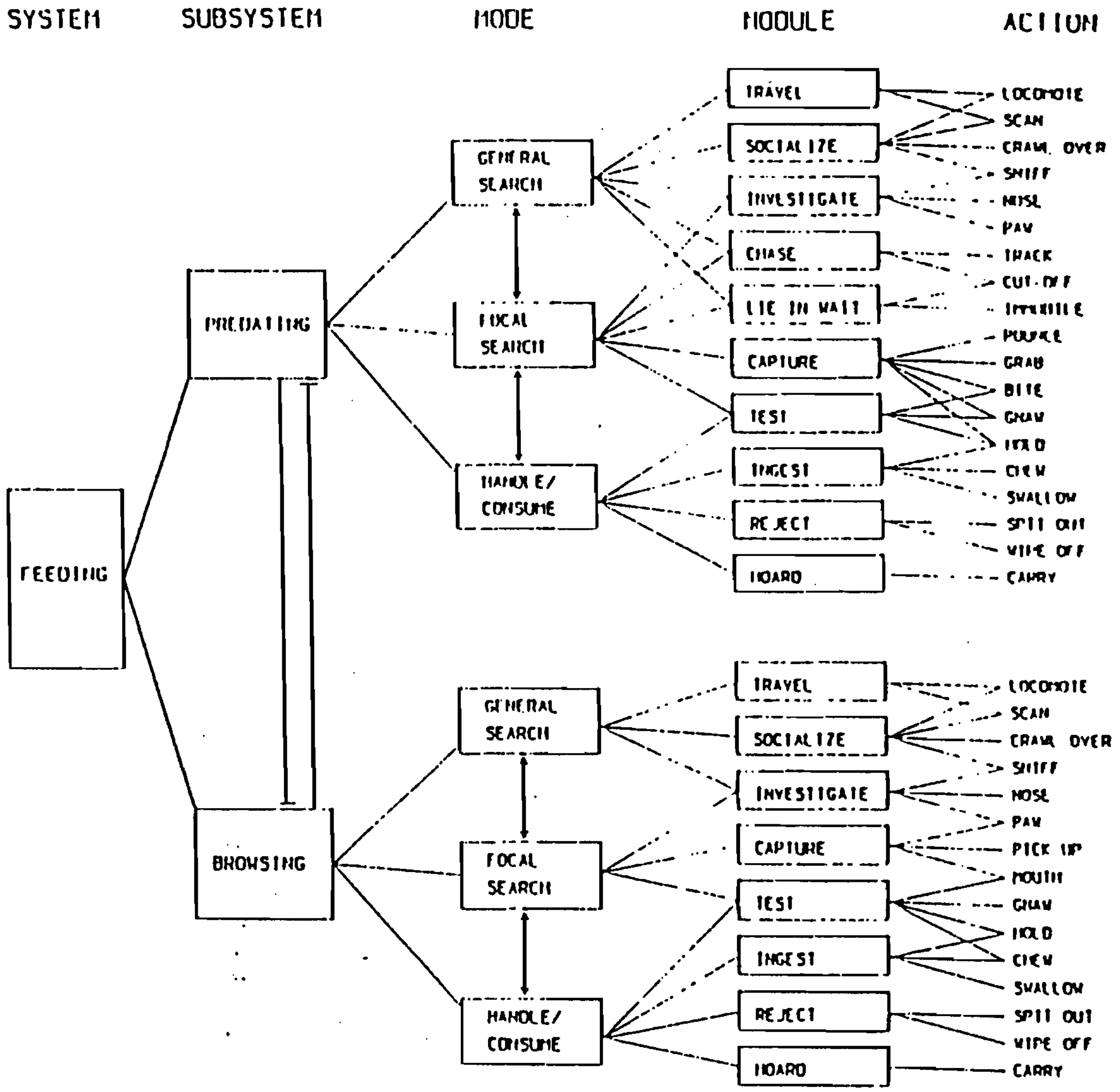
Second, it is possible that the food/water deprivations were unequal. Depriving an animal of food enough to maintain 80% of its body weight may be relatively greater than a 23 hour water deprivation. In other words, depriving an animal of food may affect results to a larger degree than depriving an animal of water for 23 hours. However, initial choice must be taken into consideration. If food and water deprivations were unequal, the animal should have initially chosen the food reinforcement consistently. The fact that they switched from the initial water reinforcement leads to further questioning as to the effects of deprivation. Along these lines, the food reinforcer cannot be viewed as being exclusively reinforcing, as evident by initial water choices. The food may be a better reinforcer in this case, but not an exclusive one as water was chosen as well.

In any case, the above examples illustrate the difficulty of scaling across motivational systems, as suggested by the behavior systems theory. It may indeed be extremely difficult to compare cross-motivationally due to large differences in each system. Within the same organism the systems stimulated during hunger or thirst are quite different. What activates each system may be difficult to compare because what makes an organism physiologically hungry differs greatly from what might make the same organism physiologically thirsty. For example, according to the glucostatic theory of hunger (Petri, 1986), there exist receptors in the hypothalamus that are sensitive to changes in the ratio of blood glucose in the arteries and veins. It is believed that a decrease in blood glucose signalled by glucoreceptors in the lateral hypothalamus triggers an eating response. Conversely, an increase in blood glucose in the ventral medial hypothalamus is thought to inhibit eating.

However, when the same organism is thirsty, the glucoreceptors are not responsible for signalling thirst. According to the osmometric thirst theory, this process begins with a buildup of sodium outside of cells. Any buildup of sodium creates a condition in which water would be pulled from the cells by osmosis to create equilibrium on both sides of the cell membrane. Specialized cells detect a change in their own volume as a result of cellular water loss. These osmoreceptors are responsible for triggering drinking behavior when cell volume decreases in order for cell fluid balance to return to normal (Petri, 1986). Although there is an obvious physiological difference between the two processes, food and water systems have not traditionally been differentiated. The results of the present study further indicate the need for these systems to be viewed separately.

Alternatively, the results may indirectly support the behavior systems theory. The animals more routinely switch to the food reinforcement, which may suggest that the food system is more powerful than the water system. What motivates the animal to get involved in the food system may be physiologically more powerful than their water system. Although the food reinforcer might be stronger than the water, the physiological systems may actually have the most control. The animal may just be "locked in" to the food system more strongly than the water system, assuming the animal was equally hungry and thirsty.

Future experimentation is necessary to further clarify the present findings. First, it may be fruitful to shorten the time interval used in the current design. The 60 second interval used in the present design may have gone beyond some attentional span that could have affected the results. Second, it also may be helpful to increase the size of the water reinforcer to better match the size of the food reinforcer. This change could help alleviate controversy concerning the equality of reinforcement. Finally, changing the deprivation course (eliminating supplemental food and water outside of the session) may also affect the probability of switching.


SYSTEM
SUBSYSTEM
MODE
MODULE
ACTION
FEEDING
PREDATING
BROWSING
GENERAL SEARCH
FOCAL SEARCH
HANDLE/ CONSUME
TRAVEL
SOCIALIZE
INVESTIGATE
CHASE
LIE IN WAIT
CAPTURE
TEST
INGEST
REJECT
HOARD
LOCOMOTE
SCAN
CRAWL OVER
SNIFF
NOSE
PAW
TRACK
CUT-OFF
IMMOBILE
POUNCE
GRAB
BITE
GNAW
HOLD
CHEW
SWALLOW
SPIT OUT
WIPE OFF
CARRY
GENERAL SEARCH
FOCAL SEARCH
HANDLE/ CONSUME
TRAVEL
SOCIALIZE
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INGEST
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HOARD
LOCOMOTE
SCAN
CRAWL OVER
SNIFF
NOSE
PAW
PICK UP
MOUTH
GNAW
HOLD
CHEW
SWALLOW
SPIT OUT
WIPE OFF
CARRY

FIGURE 1

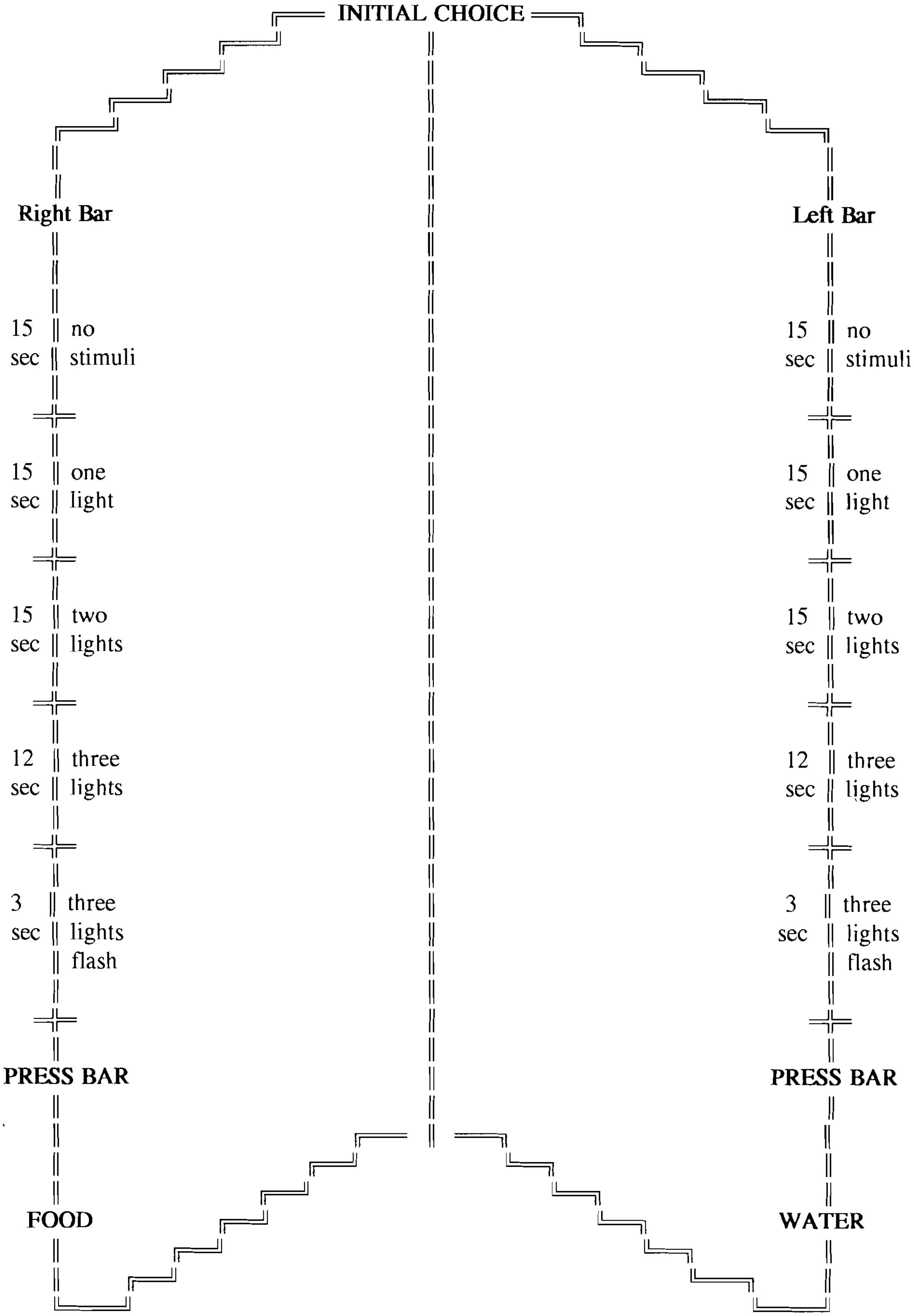
INITIAL CHOICE
Right Bar
15 sec
no stimuli
15 sec
one light
15 sec
two lights
12 sec
three lights
3 sec
three lights flash
PRESS BAR
FOOD
Left Bar
15 sec
no stimuli
15 sec
one light
15 sec
two lights
12 sec
three lights
3 sec
three lights flash
PRESS BAR
WATER

FIGURE 2

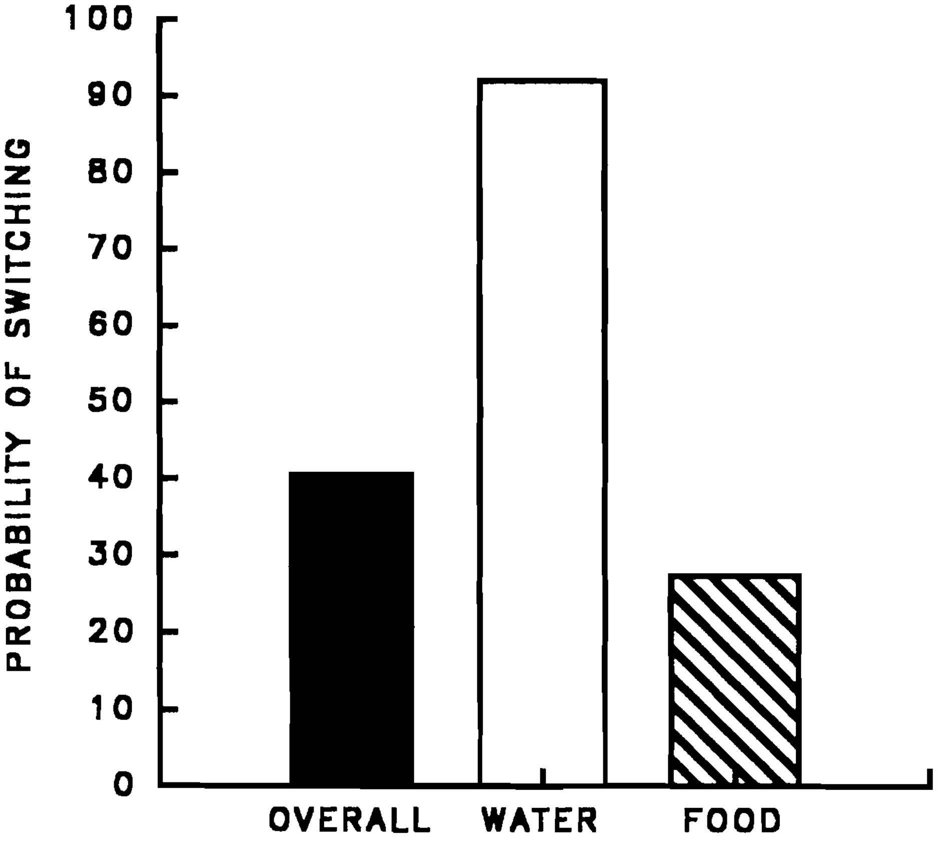
PROBABILITY OF SWITCHING
100
90
80
70
60
50
40
30
20
10
0
OVERALL
WATER
FOOD

FIGURE 3

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