

## List Linking as a Tool to Test Transitive Inference in Rats

Leah Jordan

University of North Carolina Wilmington

Faculty Mentors:

Katherine Bruce, PhD &amp; Mark Galizio, PhD

Department of Psychology

University of North Carolina Wilmington

*Abstract*

*Transitive inference, along with other abstract concepts, has been considered a characteristic unique to humans. Transitive inference is demonstrated when one learns that A is related to B and B is related to C, and then infers that A is related to C. Rats have been shown to demonstrate transitive inference after being trained on four overlapping simple odor discriminations; when trained only on odor pairs A>B, B>C, C>D, and D>E, they spontaneously show transitive inference (e.g., A>C and B>D; Davis 1992; Dusek & Eichenbaum 1997). In the present study, we extend these findings to a novel apparatus and add a list-linking procedure similar to that studied by Treichler et al. (1996) in monkeys. Rats are trained on two separate lists of odor pairs (A-E and F-J) and then the lists are linked through training on EF. Using two lists allows testing for transitive inference using many novel combinations of pairs across and within lists (for example B-H and G-I). Three rats have responded with transitive inference consistently (over 90% of the time) when tested with novel combinations of pairs within lists and two rats have completed the final test after list linking, performing above 75% on between list novel combinations and 70% or above on within list combinations. Transitive inference has been seen across several species and may be evidence of an adaptive process used in establishing social hierarchies among non-humans.*

What cognitive abilities do non-humans possess? In what ways are human and non-human cognition similar and different? These questions are central to our understanding of the basic processes of learning and higher order thinking. Based on a comprehensive review of the research, Lewis and Smith (1993) proposed the following definition: “higher order thinking occurs when [one] takes new information and information stored in memory and interrelates and/or rearranges and extends this information to achieve a purpose or find possible answers in perplexing situations” (p. 136). Concept learning is a type of higher-order learning because it requires subjects to integrate the rule they have learned with the information being presented to solve the task (Lewis & Smith, 1993). A concept may be defined as a cognitive process of classifying elements into categories (Lazareva & Wasserman, 2008). For example, identity is a

concept in which the elements are classified based on their similarity in physical or functional features. A concept becomes abstract when the subject is able to apply the rules learned in training to novel objects or tasks.

One abstract concept is transitive inference. Transitive inference (TI) is exhibited by using previous training of relationships between stimuli to determine a relationship between stimuli that have not been presented together. This task is considered an abstract concept because the inferences that are made can only be deduced from the relations learned previously and applied to the novel situation. TI, according to some (Dusek & Eichenbaum, 1997; Lazareva & Wasserman, 2006; Ayalon & Even, 2008), requires deductive reasoning because it requires the subject to deduce or determine a relationship between stimuli that is not explicitly presented. TI tasks require the subject to accept the premises given and complete the task at hand given those premises.

### *Research on Transitive Inference*

Researchers initially believed that TI tasks could only be solved by humans. It was argued that TI requires verbal feedback from subjects to determine if they indeed can solve the task (Vasconcelos, 2008). However, Bryant and Trabasso (1971) showed that children below age seven were actually capable of the TI task. The stimuli used in Bryant and Trabasso's (1971) study were five sticks of different colors and sizes, labeled A-E. Stimuli are trained in four overlapping pairs: for example, AB+, BC+, CD+, and DE+. The plus sign indicates the reinforced choice. Five items are used because in order for the test to be truly transitive all other explanations for a choice must be eliminated. If only three items are used, the only transitive test would involve the stimuli on the end of the list which have absolute reinforcement histories (either 0% or 100%). With five items, there is one pair within the list (B-D) that is both novel and the choice cannot be made based on absolute reinforcement histories since both have been reinforced 50% of the time.

Bryant and Trabasso (1971) presented two sticks of different colors, stuck out from a box at equal heights, and the child was asked which one was taller. After the choice was made the child was shown the actual sizes of the two sticks. This feedback process allowed the child to order the stimuli along a physical dimension but still required the child to identify the transitive relationships from the memory of the hierarchy at the test instead of comparing sizes. Once the child showed proficient performance at picking the longest stick for each pair during training, a

probe (or test) was given to test for transitive inference. The child was shown the stimuli labeled B and D and asked which stick was longer. Children ages 4 and above were capable of solving the transitive test. The children's inability to solve TI problems previously (as in Piaget, 1928) was in part due to forgetting the relationships between the elements (Bryant & Trabasso, 1971; Vasconcelos 2008). When measures were taken to ensure that the children could recall the premises prior to training, the children below age 7 could perform the transitive task.

This finding led researchers to investigate whether non-human animals were capable of TI. The first study of TI in a non-human subject was that performed by McGonigle and Chalmers (1977). Their study with squirrel monkeys was fashioned after the study of Bryant and Trabasso (1971) with children. Monkeys were trained on four overlapping simple discriminations that created a 5-item hierarchy (A-E) using cylindrical tin containers that were either 'heavy' or 'light' and varied in color. Once the monkeys had shown proficient learning of the premises, they were tested on the BD pair. McGonigle and Chalmers (1977) found that the seven out of eight monkeys were able to infer transitive relationships (the eighth subject failed to complete training and did not get to testing of TI). A number of species have revealed TI abilities: macaque monkeys (Treichler & Tilburg, 1996), pigeons (Steirn, Weaver & Zentall, 1995; von Fersen, Wynne, Delius & Staddon, 1991), fish (Grosenick, Clement, & Fernald, 2007), hooded crows (Lazareva, Smirnova, Bagozkaja, Zorina, Rayevsky, & Wasserman, 2004), and rats (Davis, 1992, Dusek & Eichenbaum, 1997). One question that arises is why should non-humans show TI?

One reason may relate to living in social groups. Rats living in social groups set up dominance hierarchies (Calhoun, 1963). These hierarchies are set up by interactions with other individuals in the group. When a new rat joins a colony it may not interact with every individual in a group but rather with a few. If it were to interact with every individual, that would be energetically costly and could result in death. Instead the new rat may observe those rats' interactions with other individuals in the group that the new rat has not been associated. From these observations, the new rat could then determine his own social position within the colony if he were capable of using TI. In other words, TI could be one way of determining a social hierarchy in a rat colony. Many other species that establish dominances are capable of TI, such as monkeys (Treichler & Tilburg, 1996) and pigeons (Lazareva & Wasserman, 2006).

One way of studying TI in the lab is with preference conditioning (Russell, McCormick, Robinson, & Lillis, 1996). Preference conditioning involves training a subject to prefer or choose one stimulus over another, through reinforcement, thus creating a hierarchy of stimuli. These tasks are also referred to as associative tasks because they require the subject to find a relationship between stimuli (such as reinforcement) that is not apparent on physical dimensions (for example, logical tasks used frequently with humans). Ordered lists for associative tasks are formed via trial and error, when the subject determines in what cases a stimuli is correct or incorrect.

Dusek and Eichenbaum (1997) trained a hierarchy of five scents in rats through a series of overlapping single discriminations. Olfactory stimuli are often used in rat studies and there is much evidence to show that rats can perform many cognitive tasks better when using olfactory rather than visual cues (Slotnick, 2001). In Dusek and Eichenbaum's (1997) study five scents were randomly ordered into a hierarchy (labeled A-E), with the one scent at the top of the hierarchy reinforced 100% of the time and the one at the bottom never reinforced. The stimuli were in no way orderable along a physical dimension such as size. This list was trained by pairing stimuli together that are adjacent to each other in the list making four training, or baseline, pairs (AB, BC, CD, DE). The list was trained by overlapping simple discriminations composed of the elements in the list. The first element of each pair was reinforced and the pairs were presented in increasingly randomized order (i.e., A+B-, B+C-, C+D-, D+E-; where + indicates reinforcement and - indicates no reinforcement for a choice). Each element was presented equally in each session, referred to as intermixed training (Vasconcelos, 2008).

After increasingly randomized phases of baseline pairs to create the list, Dusek and Eichenbaum (1997) tested the rats on the classic B vs. D transitive probe test. The pair BD has been used with many species across many studies involving a 5-item ordered array. This pair is tested because B and D are the only stimuli that have not been paired together in training and have the same reinforcement history. Both B and D have been reinforced 50% of the time, compared to A and E which have 100% and 0% reinforcement histories, respectively. A and E are referred to as end-anchors because they are on the end of the lists and any pairs containing A or E (e.g. CE or AC) could be solved with reinforcement histories instead of learning a hierarchical list. Solving tests containing A or E are still transitive tests but could be solved with reinforcement histories instead of their sole relationship with other elements, as in the BD

example. The elements B and D's relationship can only be deduced if the subject has integrated the elements of the list into a hierarchy. If the rats were not able to form a hierarchy or infer transitive relationships, then they would be expected to perform at chance on the BD task. If they are able to infer a transitive relation, then the rats would perform above chance on the BD task, that is chose B over D since B is "higher up" in the hierarchy (based on the associations with the differentially reinforced end-anchors). Dusek and Eichenbaum found evidence that rats are capable of TI by performing above chance on the BD comparison.

#### *Extending TI Studies: List Linking*

These studies, however, are limited in their ability to test for TI. While more than one pair in a five-item list would qualify as a transitivity task (e.g., AC, BE, etc.), only one, BD, can be used to truly test transitivity. The BD task is the only transitive task that can not be solved using reinforcement histories. In essence, there is only a single trial that can reveal to a researcher if the subject is capable of solving transitivity tasks. This limitation led other researchers to design experiments that extended the list to include more stimuli and thus, more pairs to test transitivity. Many researchers simply added stimuli to the five-item list to make longer lists, such as that by Roberts and Phelps (1994) who extended the training to six items (A-F).

A novel approach was used by Treichler and Tilburg (1996) who designed a study for macaque monkeys that linked two five-item lists together. This procedure attempted to solve two problems. The first was the problem mentioned above, that five-item lists only provide one single trial test of transitivity. Linking two lists together essentially gave researchers a ten-item list and thus, many more tests of transitivity. With a ten-item list there are more than two stimuli that have both been reinforced 50% of the time and have not been trained with the end anchors, thus not allowing reinforcement histories to be a way to solve the task. Treichler et al. (2007), extended list inking to three lists of 5-items, studying macaque monkeys with visual stimuli. This extended the testing pairs to those combining 15 items (A-O). Three different 5-item lists were linked by combining training of all the pairs in one session.

The second goal with linking the lists together was to allow an attempt to test the value transfer theory. Value transfer theory was proposed by von Fersen et al. (1991) to account for TI of the BD pair by reinforcement history. The idea was that each stimulus in the list received a certain value and that value was the product of its pairing with another reinforced stimulus as

well as its direct reinforcement. Thus, values increase or decrease down a list. With two different 5-item lists, the values of stimuli in the same position across lists are theoretically identical since stimuli in the same position in each list have been reinforced in the same manner and are paired with stimuli in the same way. If value transfer were indeed in effect, then the subjects would perform at chance for stimuli that are in the same position across the lists because the stimuli would have the same value (e.g. B and G).

Treichler and Tilburg (1996) trained monkeys on two 5-item lists separately by training each pair individually and tested for transitivity on both lists. He then linked the five-item lists together by using the last stimulus of the first list (E) and the first stimulus of the second list (F). Following the transitive test on the individual lists, the subjects were trained on a single pair composed of the first and last stimuli from the lists, E and F, and thus changing their reinforcement histories to 50% rather than 100% or 0%. Following proficiency on the linking pair, subjects reviewed the first list along with the linking pair to ensure that the rats could still perform accurately on the pairs prior to testing. He found that macaque monkeys were capable of linking the two lists together and did above chance on transitive tasks on the ten-item list. The test of transitivity included all possible combinations of the ten-item list including stimuli that had not been presented together within and between lists. Interestingly, he discovered that pairs that contained stimuli that had more stimuli in between them on the hierarchy (e.g., BI, CH), yielded fewer errors than those pairs containing adjacent stimuli (e.g., AB, FG).

### *The Current Study*

The current study used Sprague-Dawley rats in a systematic replication of Dusek and Eichenbaum (1997) and Treichler and Tilburg's (1996) work. Rats were trained on two separate five-item lists and then trained on a linking pair to link the two lists together to form a ten-item list (similar to Dusek and Eichenbaum, 1997). After one list was trained to criterion, the subject was tested for transitivity on that list and then trained on the second list and tested again for transitivity. The subject was then trained on the linking pair that contained the last stimulus of the first list and the first stimulus of the second list. Following linking pair training, the subject went through review of the past lists to ensure good baseline performance on the first list. Rats were then tested for TI using stimuli between lists.

List linking was done in this study for two reasons, similar to the rationale of Treichler and Tilburg (1996). The first reason was to extend the five-item list to include more possibilities

to test transitivity. The ability of rats to infer transitive relations among stimuli on a five-item list has been widely studied (Dusek & Eichenbaum, 1997; Davis, 1992; Roberts & Phelps, 1994). With more combinations of stimuli to test transitivity, it could be determined whether the subject is learning a few simple discriminations or if the stimuli have been organized into an ordered array by the subject. Further, using list-linking allows for some tests of value transfer theory.

During the final test of list-linking, the focus was on the pairs that contained stimuli from both lists, or between list pairs (e.g., BH, DI), and pairs that contained stimuli from only one list, or within list pairs (e.g., AC, FH). If rats are capable of list linking, percent correct on between list pairs on the final test of list linking should be equal to or above that for within list pairs (Dusek & Eichenbaum, 1997; Davis, 1992). If the rats are not capable of list linking, then percent correct on between list pairs should be at chance or below that of within list pairs.

### Method

#### *Subjects*

Three naïve male Sprague-Dawley rats were received at 60 days of age and initial training began at about 75 days of age. Rats were kept at 85-90% of their free-feeding body weight at the start of training and had free access to water. Subjects were fed between 10-15 g of Purina® Rat Chow daily about 30 minutes after completion of the daily sessions. Rats were housed individually and kept on a 12 hour reverse light/dark cycle with testing done during the dark cycle.

#### *Apparatus*

The apparatus (see Figure 1) was a modified operant chamber. The front wall had a gap, approximately 5.08 cm. high, which was large enough for a Plexiglas tray to slide through. The stimuli were placed in a Plexiglas tray with two holes cut out 1 cm apart. The holes were 5 cm in diameter, large enough for a 2 oz. condiment cup to fit. Two screws on both sides of each hole acted as a ledge for the Plexiglas lids to slide through and cover the cups in the holes. Play sand was placed in clear plastic cups to about 1-1.5 cm below the lip of the cup. Lids, Plexiglas sheets 2 mm thick, were cut into rectangles 7 x 6 cm.



*Figure 1. (left) Photograph of the apparatus, or modified operant chamber, used for the procedure. (right) Photograph of a subject making a response inside the apparatus.*

To scent the lids, they were placed in Tupperware containers holding powdered spice (2 slides for each spice) for at least 24 hours between sessions. The containers held various powdered scents in full concentration in a thin layer covering the bottom with the lids positioned above but not touching the powder directly. Spices used in this study were: dill, clove, nutmeg, cumin, turmeric, ginger, beet, fennel, tomato, worchestershire, carob, bay, coriander, savory, garlic, cinnamon, thyme, raspberry, paprika, onion, sage, anise, lime, allspice, mustard, celery, marjoram, and caraway. Reinforcers were sucrose pellets weighing .45 mg.

### *Procedure*

Each rat was eventually introduced to ten scents that were labeled stimuli A-J to make up a hierarchy. Each rat had his own scent list, so no two rats received the same scents in the same order. The procedure used was a combination of the procedures from Dusek and Eichenbaum (1997) and Treichler and Tilburg (1996). Each stimulus was paired with the stimulus before it in the hierarchy and after it to make up four training pairs or baseline pairs (BL). For example, stimulus B was paired with A, then in the next set of trials with C. Each phase consisted of six trials of each of the pairs that made up the lists. All pairs were represented equally in each session and they appeared in order for Phases 1-3 and randomly in Phase 4. For example in Phase 1, the first set of trials was AB, the next set was BC, followed by CD, then DE. Training was completed for first five stimuli before introducing the second five stimuli. The second stimulus in each pair was reinforced making the list of ten stimuli a hierarchy, with J being reinforced 100% of the time, therefore the “highest” in the rank order.

### *Shaping*

Rats were trained to first dig in the sand in the plastic comparison cups for a sugar pellet buried below the surface of the sand. They were then trained to push the Plexiglas lids back in order to expose the sand to dig for the pellet.

### *Acquiring the First Five-scent List: List 1*

Phase 1 consisted of six trials of each pair of odor stimuli starting with A and ending with E for a total of 24 trials (Refer to Table 1 for an outline of all the phases). There were six trials of AB+, where B was reinforced with a sugar pellet, followed by six trials of BC+, etc. The position of each stimulus in a pair during a trial was randomly placed in right and left sides with the constraint that the reinforced stimulus was never on the same side more than 2 trials in a row. Identical trials could not occur more than twice in a row.

Sand cups were placed in the holes in the comparison tray and a sugar pellet was buried in the correct comparison about .5-.8 cm below the surface of the sand. The appropriate scented lid was then slid over the top of the cup of sand between the two sets of screws. To begin the trial, the experimenter placed the edge of the tray only 1 in. inside the chamber and held for 3 sec. After 3 sec, the tray was then pushed completely inside the chamber. Once the tray was placed in the chamber the rat was allowed to make a choice. A choice was defined as the rat using either the nose or front paws to move the lid past the first set of screws.

A non-correction procedure was used throughout the entire procedure. If the rat chose the correct scent, the rat was allowed to dig for the pellet. However, if the rat chose the incorrect scent, the tray was immediately removed from the chamber, minimizing the ability of the rat to dig in the sand, and not allowing the rat to move the other lid at all. If a rat did not make a choice within two minutes *timed out*, the trial was terminated and the rat moved onto the next trial. If the rat *timed out* three times in a row, the session was terminated. The intertrial interval was about 15 seconds. The initial choice was recorded on a data sheet. Two sets of lids and sand cups were alternated between trials. After each session the percent correct was calculated for each pair. For Phase 1, the criterion for a rat to move onto Phase 2 was to reach 80% or better on each of the four training pairs on two consecutive days.

Phase 2 was similar to Phase 1, except only blocks of three trials of each pair were given in sequenced blocks, then those twelve trials were repeated. For example, the first three trials were AB then trials 13-15 were also AB. The same randomization procedures used in Phase 1

*Table 1. Summary of the Procedural Steps to Complete the Training and Testing of the 10-Item List.*

Phase	Criterion	Trials (in order)
1	≥80%; 2 consecutive days	6 AB+, 6 BC+, 6 CD+, 6 DE+
2	≥80%; 2 consecutive days	3 AB+, 3 BC+, 3 CD+, 3 DE+ (repeat x1)
3	≥80%; 2 consecutive days	1AB+, 1BC+, 1CD+, 1DE+ (counterbalanced, repeat x6)
4	≥80%; 2 consecutive days	6 of each pair; randomly mixed
Probe	1. ≥80%; 2 consecutive days 2. none	1. 2 of each pair; random -continue session with phase 4 if does not reach criterion (24 trials total) 2. 2 of each: BD+, AE+, AC+, AD+, BE+, CE+, XY+ & 1 of each BL
5	2 days	2 of each baseline & 2 trials of each of AC+, AD+, AE+, BE+, CE+ (random) & 3 trials of BD+, XY+
2 <sup>nd</sup> list	Repeat Phases 1-5 with items F-J	
List-	1. ≥80%; 2 consecutive days	1. 24 EF+
Linking	2. Variation: 4/5 on all pairs 2/3; 2 consecutive days or 2/3 & 1 1/3; 3 consecutive days	2. Variation of combination training: 5 trials of each pair of 1 <sup>st</sup> list trained on plus EF+ (random) 3 trials of all baseline pairs of both lists plus EF+ (random)
Test	3 days	3 x 26 trials: every possible combination of items* *3 trials of BI, CH, DG, QR every session

were used in Phase 2 throughout the entire 24 trials. The criterion for Phase 2 was 80% or better for two consecutive days.

Phase 3 used the same pairs as in Phase 1 and 2, but pairs were presented in blocks of four. The block of four consisted of each type of pair in order. For example, trials 1-4 might be: 1)AB, 2)BC, 3)DC, 4)DE, and then trials 5-8 might be: 5)DE, 6)CD, 7)BC, 8)BA. The blocks were counterbalanced over six blocks (24 trials/six presentations of each pair). Identical blocks could not appear more than twice in a row. The same criterion was used: 80% or better on two consecutive days.

Phase 4 consisted of six trials of each pair randomly mixed with no two identical trials appearing more than twice in a row. Reinforced side was also randomized with left or right not being reinforced more than twice in a row. Trials of the same pair could not occur more than twice in a row either. The criterion for Phase 4 was 80% or better on each training pair for two consecutive days. Once this criterion was reached, the rat moved on to the test of the five-scent list (probe session).

In the probe session, the rat first had to demonstrate reliable performance on the reinforced trials. Eight trials of baseline pairs were presented; each pair was represented equally and the second stimulus in the series continued to be reinforced. That is, the stimuli that had been reinforced up till this point continued to be reinforced. The rat had to get at least 7/8 correct to move on to the test of transitivity. If the rat did not reach criterion, the rest of the session consisted of Phase 4 trials, for a total of 24 trials with each training pair being represented equally. The next session began with the test of reliable performance again. If the rat met criterion in the first 8 trials, then the subject moved onto probe trials. The probe trials consisted of two of every new possible combination of the five-item list, an unfamiliar pair of scents to control for learning, and one of each baseline pair. To maintain the hierarchy, reinforcement histories were maintained. All trials during the probe were double-baited, but the noncorrectional procedure remained in place. Altogether with the 8 baseline trials and then the probe trials, there were 26 trials. The test for TI on the 5-item list occurred over one session. The choice made on the first novel presentation of BD+ was recorded. The number of correct trials for BD+ as well as all probes was calculated.

Further training (Phase 5) of the first scent list was introduced the day after the probe test and was done for only two days. This training consisted of 24 trials: two trials of each baseline

training pair and three trials of BD+ and XY+, and two trials each of AC+, AD+, AE+, BE+, and CE+. All comparisons were randomly mixed with no same trial appearing more than twice in a row. A non-correction procedure was used. Once the further training was completed, the rat moved on to acquire the second list of five scents to complete the ten stimuli list.

#### *Acquiring the Second Five-scent List: List 2*

The acquisition of the second set of five scents was done in exactly the same manner as the first, with no exceptions. Once the rat completed the two days of further training, he moved on to linking the two lists.

#### *List Linking*

Once criterion on List 2 was met, we trained the EF+ comparison that would link the lists. Twenty-four trials of EF+ comparison were given to a criterion of 80% or better for two consecutive days. A noncorrectional procedure was used. Once that task was completed, the rat moved on to one of two types of EF+ combination sessions.

*Variation 1.* The combination sessions combined the EF+ pair with all other eight baseline pairs trained previously. A session included three trials of each pair (nine pairs in total) to make a 27 trial session. A noncorrectional procedure was used and criterion was 2 out of 3 on every pair, except one pair may be 1 out of 3, for three consecutive days. However, if this condition was not met and the subject completed 55 sessions, then the subject moved on to the final test.

*Variation 2.* During Variation 1 combination training, we realized that the training was actually training a 10-item list instead of maintaining the two lists as two separate lists. So, Variation 2 was designed to keep the two lists separate by just reviewing one list and not training all nine pairs at once. The combination sessions combined the EF+ pair with the first list that the rat learned. For example, if the rat began with the A-E list, then the rat would add the fifth training pair of EF+ to the A-E list baseline pairs. Five trials of each pair were randomly mixed together with no two identical trials appearing more than twice in a row. The initial choice was recorded and the non-correction procedure was used. Criterion was four out of five on each pair for two consecutive days or until 20 sessions had been completed. Once criterion was reached, the rat moved on to the test of list linking.

### *Test of List Linking*

This test consisted of forty-five trials of every possible combination of the elements randomly mixed (e.g., AJ+, DG+, CH+, etc.). The forty-five trials contained old training pairs as well as novel comparisons. The final test stretched over three consecutive days with 26 trials in each session. Three comparisons of particular interest were presented three times in each session: CH+, BI+, and DG+. A novel comparison was also done three times in a session to control for learning of novel combinations. All other possible combinations were only represented once throughout the three day test. Prior reinforcement histories were maintained and the noncorrectional procedure was used. The initial choice was recorded. The test was then repeated once with a new random order for all pairs, but still keeping the same distribution of pairs.

### *Simple Discrimination*

Once the subject had completed the 6 days of final testing, the subject was trained on a simple discrimination task to compare EF+ training performance to a simple discrimination task with unfamiliar scents.

### *Timing-Out*

For each trial, the rat had 2 minutes to make a choice. If the rat did not respond within 2 minutes, or “timed out”, the trial was terminated and the rat moved onto the next trial. If the rat timed out on three consecutive trials, the session was terminated. The following session began with those trials that were not given at all from the timed out session (trials after the 3 timed-out trials) and then continued with the day’s normal session all in one day. When this occurred, the percent correct for each pair and the total session were calculated with only the trials that were presented that day. Timed-out trials were counted as incorrect. Such instances are marked in the Appendix next to the session in which time-outs occurred.

### *Control Procedures*

Double-bait days were done at least twice every week. A double-bait day consisted of 2 trials in the session that had both comparison cups baited to detect if the rat was tracking the pellet to make the choice. The noncorrectional procedure was still used on these trials. A dependent samples *t*-test was conducted to see if trials with double-bait were significantly different from the performance on regular or non-baited trials.

### Reliability

Inter-rater reliability was done to ensure reliable scoring between experimenters. Inter-rater reliability was performed on List 1 and List 2 probes, 1 random session from either list training, the session prior to List 1 and List 2 probe session, and one of the 3 days of the final test by video taken during the sessions. Since S16 did not complete List 2 training, inter-rater reliability was done for List 1 probe, the day before List 1 probe, and 4 other days during List 1 training. This was a total of 6 sessions for each rat. Observed performances were compared to the recorded video performances for percentage of agreement.

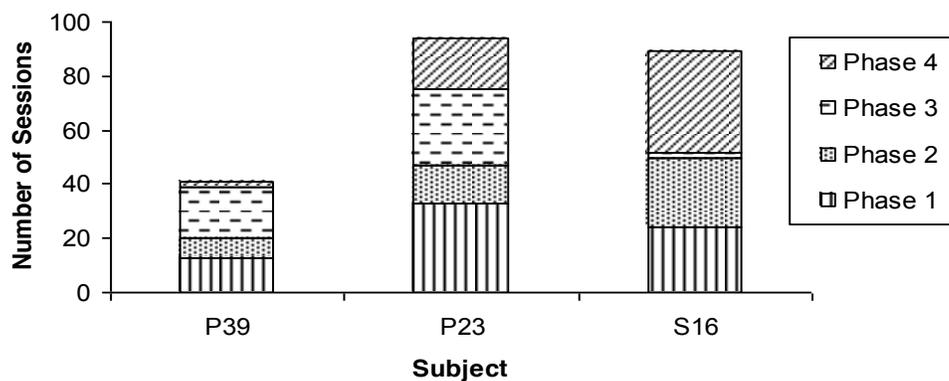
### Data Analysis

Percent correct values were averaged across phases for each training pair and each subject. Binomials were completed to test for significance on probe trials and an alpha level of  $p < .05$  was used, however, all  $p$  values are identified within the results.

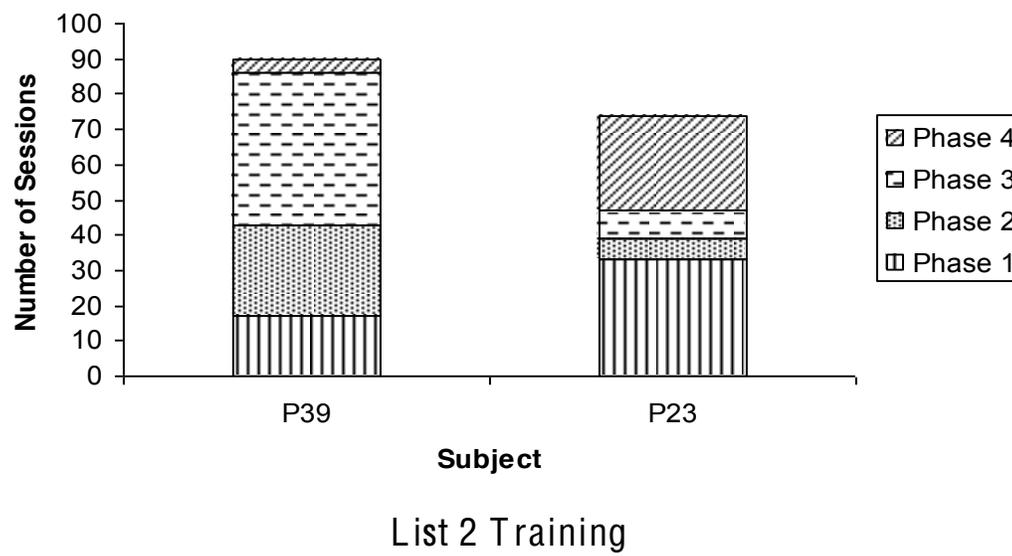
### Results

#### Baseline pair training

Three subjects completed training of List 1. Figure 2 (top) shows the number of sessions to reach criterion on each phase for List 1 training. The average number of sessions to criterion for List 1 was 74.67 sessions (1776 trials). Individual subject data are also presented in Figure 2 (bottom).



List 1 Training



*Figure 2.* Number of sessions to reach criterion for each subject on each phase for List 1 training (top) and List 2 training (bottom). Data from subjects who went through therapy phases are all grouped with the corresponding phase.

Only two subjects completed the training of the List 2. Again, the raw data for each subject are located in Appendices B-D. Figure 2 (bottom) shows the number of sessions to reach criterion on each phase for List 2 training. The average number of sessions to criterion for List 2 was 82 sessions (1968 trials). Individual subject data are presented in Figure 2.

### *5-item List Probe Testing*

The 3 subjects that completed the List 1 training received probe testing on all possible combinations within the 5-item list. Table 2 shows the number correct out of the number of presentations of each pair for each subject for the List 1 probe test. The total percent correct is out of 22 trials, which includes the 8 trials prior to the probe trials that established strong baseline performance (excludes the 2 presentations of the unfamiliar pair). All subjects achieved above 90% correct on the entire probe session. A binomial test for P39's performance on the novel transitive probes for List 1 including BD was significantly above chance (12/12,  $p = .0002$ ). A binomial test for P23 on novel transitive pairs of List 1 including BD revealed significance above chance (11/12,  $p = .0032$ ). S16's performance on the novel transitive pairs of the first list and BD revealed performance significantly above chance (12/12,  $p = .0002$ ).

Table 3 shows the number correct out of the number of presentations on the probe for List 2 of each pair for P23 and P39. The only pairs that were missed were baseline pairs. Binomial tests for performance on the novel transitive probes for List 2 including GI revealed performance significantly above chance (12/12,  $p = .0002$  for both P23 and P39).

Rats performed better on the transitive tests than on the unfamiliar scents used to control for learning of the transitive pairs. For the List 1 transitive test, as seen in Table 2, subjects got 4/6 unfamiliar pairs correct, which is not significantly different from chance ( $p = .3438$ ), and 35/36 of the transitive pairs correct, which is significantly higher than chance ( $p < .0001$ ). For the List 2 transitive test, as seen in Table 3, subjects correctly responded to 2/4 (not significantly different from chance,  $p = .6875$ ) unfamiliar pairs and 24/24 transitive pairs (significantly higher than chance,  $p < .0001$ ).

*Table 2.* Results from the List 1 probe test for each subject.

Subject	BD+	AD+	AC+	BE+	AE+	CE+	BL <sup>a</sup>	All novel transitive pairs	XY (unfamiliar)	Total
P39	2/2	2/2	2/2	2/2	2/2	2/2	3/4	12/12**	2/2	90.91%
P23	2/2	2/2	2/2	2/2	2/2	1/2	4/4	11/12**	1/2	90.91%
S16	2/2	2/2	2/2	2/2	2/2	2/2	4/4	12/12**	1/2	100.00%

*Note.* Table does not display the first 8 baseline trials, but values are included in the total percentage. + = hypothesized outcome if subject is solving the task transitively.

<sup>a</sup>BL=Baseline/Training pairs

\*\* $p < .01$

*Table 3.* Results from List 2 probe test for each subject on each pair.

Subject	GI+	FJ+	FH+	FI+	HJ+	GJ+	BL <sup>a</sup>	All novel transitive pairs	WZ (unfamiliar)	Total
P39	2/2	2/2	2/2	2/2	2/2	2/2	3/4	12/12**	1/2	90.91%
P23	2/2	2/2	2/2	2/2	2/2	2/2	4/4	12/12**	1/2	100%

*Note.* Table does not display the first 8 baseline trials, but values are included in the total percentage. + = hypothesized outcome if subject is solving the task transitively.

<sup>a</sup>BL=Baseline/Training pairs.

\*\* $p < .01$

*List Linking.*

Subject P39 met criterion on EF+ training in 5 sessions and P23 met criterion in 4 sessions. P39, who went through the first variation that reviewed all training pairs (essentially creating a 10-item list) prior to the final list-linking test, never reached criterion prior to the 55 session cutoff. P39 did achieve 2 out of 3 correct at least once on each pair, but never all in one session. The average percent correct for P39 on the list review was 68.62% correct. During the review training, overall performance on pairs AB (157/165), CD (102/165), FG (115/165), GH (123/165), HI (119/165), and IJ (140/165) was significantly above chance ( $p < .0001$ , for all pairs except CD,  $p = .0015$ ). Overall performance on the EF+ linking pair was also above chance, 97/165,  $p = .0145$ . Overall performance on BC and DE were not significantly above chance,  $p = .4382$  for BC (81/165) and,  $p = .2668$  for DE (87/165).

P23 went through the second variation of the list review and he also did not reach criterion prior to the cutoff of 20 sessions. P23 also performed at criterion on each pair at least once throughout the review, but never all in one session. P23's average performance on the review was 67.31% correct. A binomial test for the overall performance on AB, CD, and EF revealed significantly above chance performances (AB, 100/100,  $p < .0001$ ; CD, 67/100,  $p = .0004$ ; EF, 88/100,  $p < .0001$ ). The pair BC also had performance different from chance (32/100,  $p = .0020$ ). Binomials conducted for DE revealed performance not significantly above chance (50/100,  $p = .5398$ ).

*Final list-linking test*

P39 and P23 made it to the final test of all possible combinations of the 10-item list. The results of the 3-day test are displayed in Table 4. Neither rat correctly responded to the DG pair on the first presentation but did to the CH and BI pairs (Table 4). P39 performed higher on the between list transitive pairs, for example BH or EG (81.82%), than the within list pairs (e.g., AE or FI), which includes the baseline pairs (70.00%). For P39, performance on the within list transitive pairs only, was significantly above chance (10/12,  $p = .0193$ ). The between list performance for P39 was significantly above chance with a binomial test (18/22,  $p = .0022$ ). Subjects did not perform different from chance on the unfamiliar pairs on the final list-linking test (1/2,  $p = .7500$ ) but did perform different from chance on all transitive (within and between) pairs (55/66,  $p < .0001$ ).

*Table 4.* Results from the final test of list linking and transitivity for each subject.

Subject	CH+	DG+	BI+	Within list transitive pairs	Within List %	Between list pairs	Between List %	QR+ (unfamiliar)
P39	1/1	0/1	1/1	10/12*	70.00%	18/22**	81.82%	0/1
P23	1/1	0/1	1/1	10/12*	85.00%	17/22**	77.27%	1/1

*Note.* Number correct for CH, DG, and BI are based on the first presentation during the test EF pair considered a between list pair. + = hypothesized outcome if subject is solving the task transitively. Within list percentages based on baseline/training pair and within list transitive pair results on final list-linking test.

\*\* $p < .01$

\* $p < .05$

Further evaluation of the different parts of the final test was done to evaluate the performance of P39 on each list (Table 5). Performance on within List 1 pairs (baseline and transitive) was not significantly above chance (7/10,  $p = .1719$ ) and neither were the transitive pairs alone (5/6;  $p = .1094$ ). Performance on List 2 pairs was not significantly above chance (7/10,  $p = .1719$ ) and neither were the transitive pairs alone (5/6,  $p = .1719$ ).

*Table 5.* Results for within list transitive pairs and training pairs during the final list linking test for each subject.

Subject	Within List 1- Transitive Pairs	Training Pairs- List 1	Within List 2- Transitive Pairs	Training Pairs-List 2
P39	5/6	2/4	5/6	2/4
P23	6/6*	3/4	4/6	3/4

\* $p < .05$

P23 performed lower on the between list pairs (77.27%) than the within list pairs (85%). A binomial test on within list transitive pairs for P23 revealed significantly above chance performance (10/12,  $p = .0193$ ). Performance on between list pairs for P23 with a binomial test showed that performance was also significantly above chance (17/22,  $p = .0085$ ).

Table 5 shows that performance for P23 on within List 1 pairs was significantly above chance (10/10,  $p = .0010$ ) as were the within List 1 transitive pairs alone (6/6,  $p = .0156$ ).

Performance on within List 2 pairs (baseline and transitive) was not significantly above chance (7/10,  $p=.1719$ ) and neither were the transitive pairs alone (4/6,  $p=.3438$ ).

A record was kept of every response made on every pair during the final test. Binomials calculated for the BI and CH pairs for all presentations revealed performance significantly above chance (8/9,  $p=.0195$ , for both). P39's performance on the DG pair was not significantly above chance (7/9,  $p=.0898$ ). P23's performance on the BI pair was significantly above chance (9/9,  $p=.0020$ ). Performance of P23 on the DG pair was lower than chance (0/9,  $p=.0020$ ). Performance on CH was not significantly above chance (7/9,  $p=.0898$ ).

The post-study simple discrimination test using unfamiliar scents revealed that it took P39 one session to reach 80% and P23 two sessions to reach 80% correct. The EF training, in comparison, took P39 five sessions to meet criterion and P23 four sessions to meet criterion. A  $t$ -test analysis of dependent samples of the double-bait trials versus non-double baited trials revealed no significant difference between performances on either type of trial over 55 samples/sessions,  $t(88) = -0.31$ ,  $p=.3786$  (one-tailed).

Inter-rater reliability with a sample of 6 sessions each for P39, P23, and S16 revealed 100% agreement with video of the sessions.

### Discussion

The results for TI on 5-item lists obtained in the current study are similar to those of previous studies performed with rats (Dusek & Eichenbaum, 1997; Davis, 1992). Transitivity was observed in all three subjects for each individual list during the probe sessions (see Tables 2 & 3). The choice of D over B was seen in all the subjects for List 1 and the choice of I over G was seen in all subjects for List 2. Both P39 and P23 performed significantly above chance on both the between transitive pairs and the within list pairs on the final list-linking test. This is true regardless of the fact that P23 went through Variation 2 of the list review, which only reviewed the first list. These results suggest that the hypothesis that rats are capable of list linking should be accepted. The fact that the unfamiliar pairs were not different from chance and the transitive pairs were suggests that the subjects were not learning the novel transitive pairs.

The number of sessions to criterion for the current study proved to be much higher than what has been observed in previous studies. Specifically, Dusek and Eichenbaum (1997) showed around 400 trials (or about 100 sessions) on average for the control subjects to reach criterion to be tested for transitivity on a 5-item list. Subjects in the current study on average took over 1000

trials to reach criterion to be tested on either of the 5-item lists. In Dusek and Eichenbaum's study, there were more trials per session (40 trials/session) than in the current study (24 trials/session) which could have afforded more practice for subjects in the Dusek and Eichenbaum study.

Results of the list linking final test revealed that both P39 and P23 were capable of inferring transitive relationships across lists (see Table 4). However, the results for the probe of list linking and transitivity on the 10-item list did not yield quite as high percentages as those of Treichler and Tilburg (1996).

For example, only P23 achieved significance on the within list pairs during the final list-linking test. When the within list category of the final list-linking test was broken down into the two individual lists, calculations revealed that P23 performed significantly above chance only on pairs that were contained in List 1 (see Table 5). This outcome could be due to the recent review of only List 1 prior to the final test. In contrast, P39 reviewed every baseline pair before the final list-linking test. P39's performance was not significant on either of the lists during the final test. While both P39 and P23's percent correct for the list linking review phase of training was comparable (68.62% and 67.31%, respectively), P23 only had to review and master four pairs. Subject P39 had to review and master nine pairs which may have exceeded memory capacity. P23's poor performance on the within list TI pairs for List 2 could be attributed to the lack of review prior to the final test. Even though the review of List 1 prior to the test was brief (to ensure that the second list was not forgotten) List 1 was more recent. So, the lack of significant performance by P23 on the within list transitive pairs for List 2 could be due to a more recent presentation of List 1 stimuli (proactive interference).

### *Serial Position and Symbolic Distance Effects*

Vasconcelos (2008) presented two phenomena of TI tasks: the serial position effect (SPE) and the symbolic distance effect (SDE). These two effects are found across many studies and seem to be characteristics of any TI task. Beyond the classic evaluation of transitive inference itself, researchers have begun to look into the meaning behind why these outcomes occur. Given the results of my study, I chose to re-examine the data in light of the serial position effect and the symbolic distance effect.

Instead of all baseline pairs having similar average percent correct across the study, there is a general "flat U" shape: Some pairs were mastered better than others. This is the serial

position effect (Vasconcelos, 2008). Specifically, the pairs containing end-anchors (elements on the end of the list that are either always or never reinforced) have higher percent correct values than those pairs that lie within the list (see Figures 3 & 4). As seen in Figures 3 and 4, the serial position effect was observed for this study.

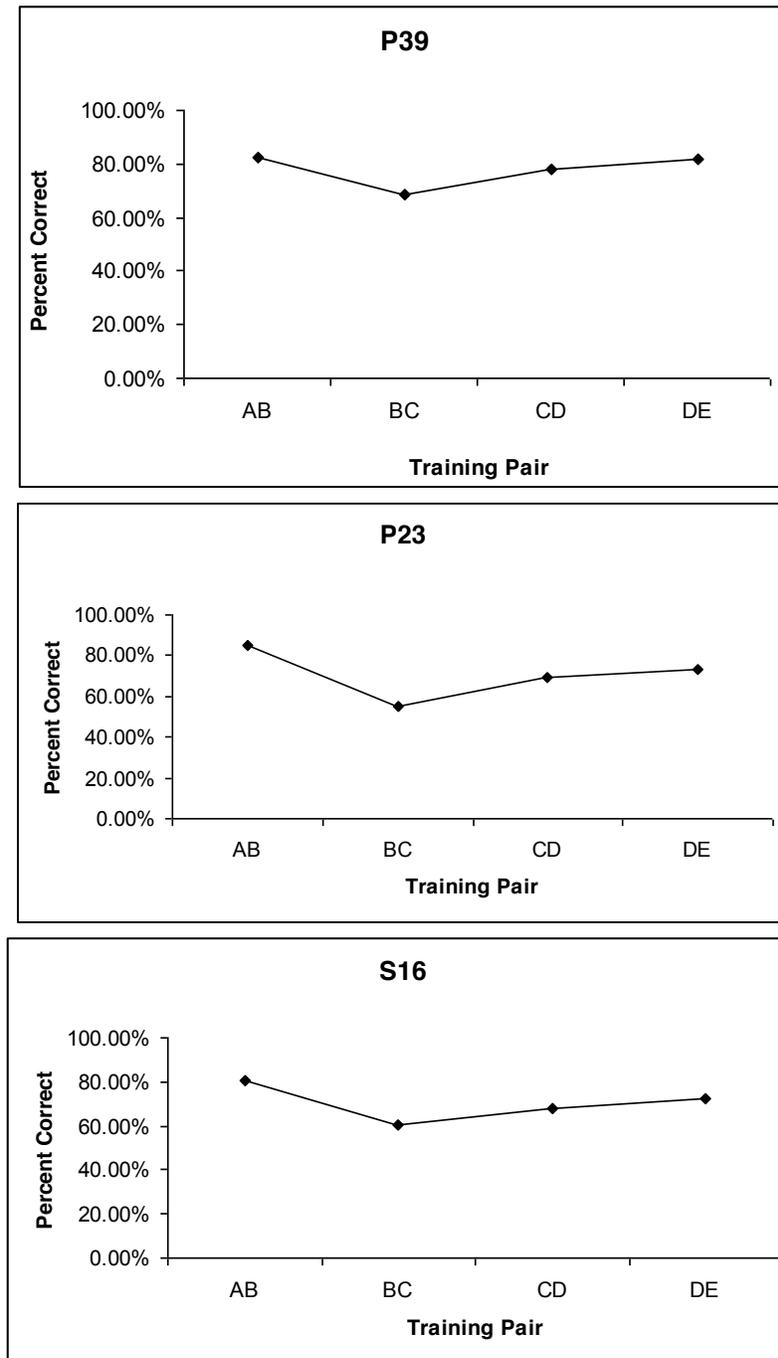
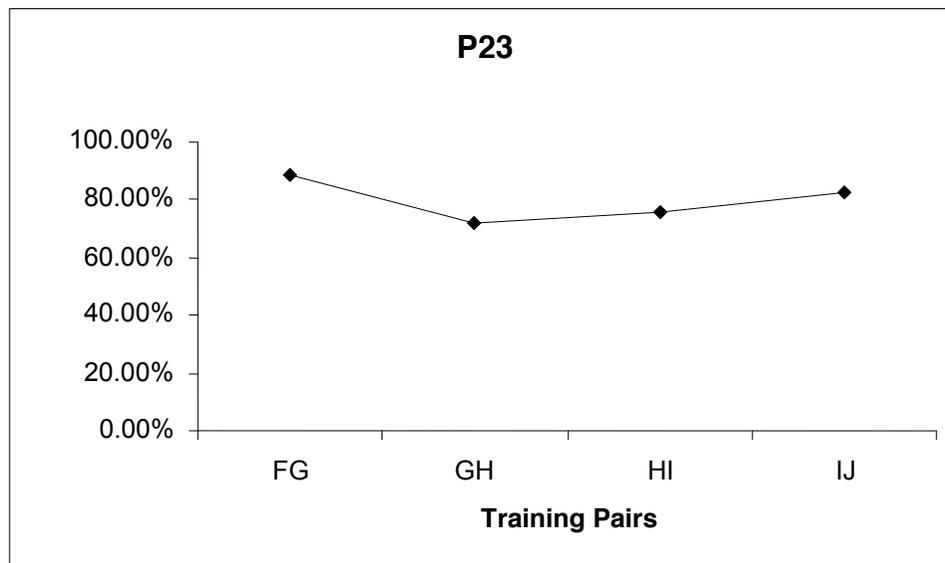
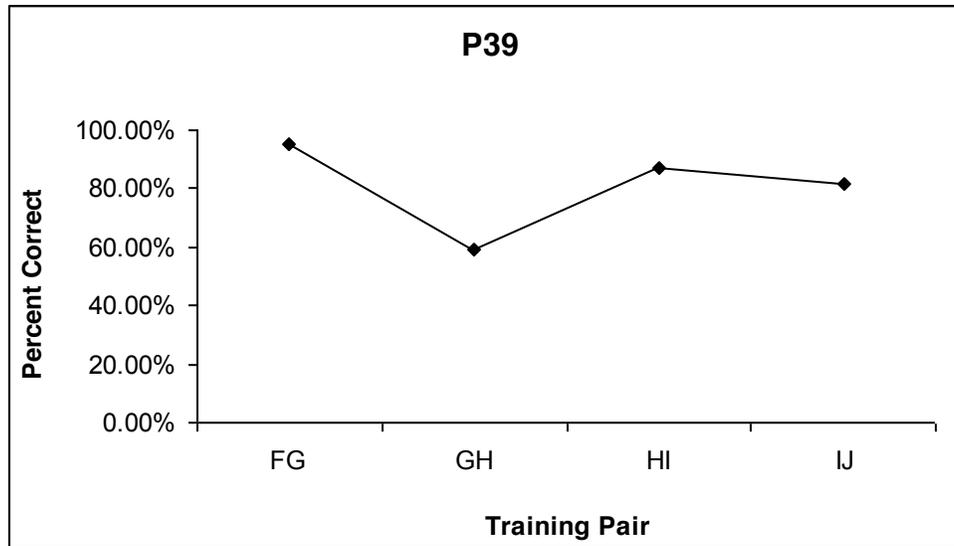


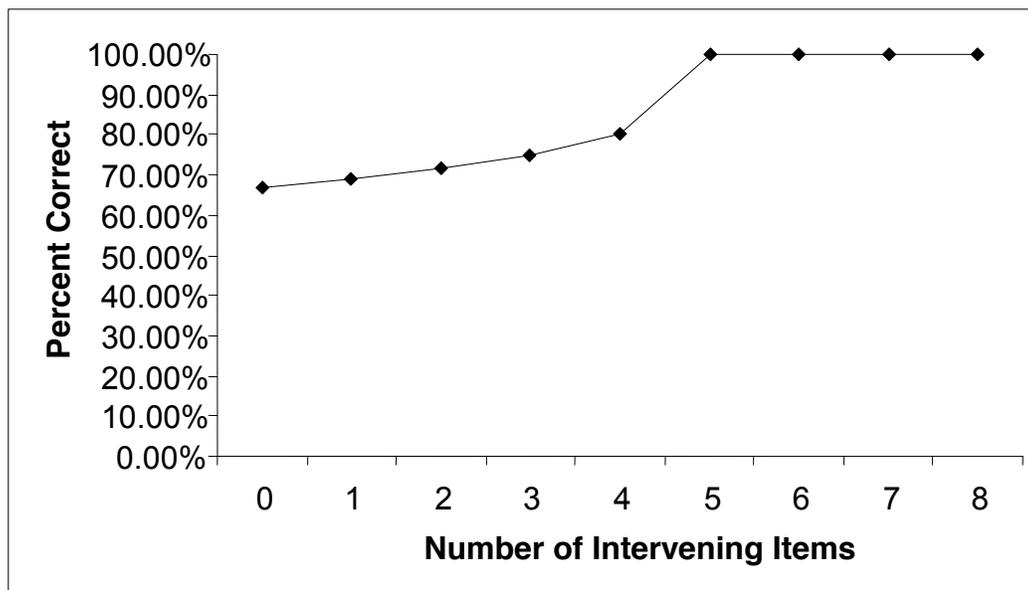
Figure 3. Percent correct on List 1 training for each baseline/training pair averaged across all the phases for each subject, demonstrating evidence of the serial position effect.



*Figure 4.* Percent correct on List 2 training for each baseline/training pair averaged across all the phases for each subject.

The second phenomenon Vasconcelos (2008) discusses is the symbolic distance effect. The symbolic distance effect is the observation that novel transitive pairs given to the subject during testing that have more intervening items between them, have higher percent correct than those with only a couple of intervening items. For example, the novel transitive pair given during testing might be B and I. This pair has 6 intervening items between them: C, D, E, F, G, and H. The pair DG, however, only has 2 intervening items: E and F. The hypothesis, based on review

of past literature, would be that pairs with more items in between them would yield higher percent correct during the probe (Treichler & Tilburg, 1996; Vasconcelos, 2008). In the current study, I found these same results (see Figure 5). First, in the test of transitivity for each list, the novel transitive pairs had higher percent correct than the baseline pairs (see Tables 2 & 3). Second, on evaluation of the final test, percent correct for pairs that contained fewer than 4 items had somewhat variable, yet low, percent correct values (see Figure 5). Pairs that had 4 or more intervening items yielded better percent correct values. In fact, at the point at which there were 4 intervening variables and above, both P39 and P23 had equal percent correct values. With 5 intervening items percent correct reached 100% correct. It is interesting note that subjects performed poorly on the presentations of the training pairs during the final test of list-linking compared to the other test pairs.



*Figure 5.* Percent correct for increasing number of intervening items between stimuli averaged for P39 and P23 on the final test of transitivity of the 10-item list.

P23 and P39 both responded incorrectly to the first presentation of the DG pair during the final list-linking test (see Table 4). This could also be due to the symbolic distance effect. Performance on the BI pair, or the pair with the most intervening items, was above 85% correct and performance on the CH pair, while not significant for P23, was still between 75% and 89%. This shows a gradual decline in performance on the specially selected pairs as the number of intervening objects decreased. However, P23's poor performance on the DG pair was

significantly different from chance . That is, the chance of a subject missing every presentation of that pair by chance alone is very low. Possible third variables that would cause this significance could be aversion to the G scent or the more recent review of List 1 containing the D stimulus.

Many have argued why the symbolic distance effect and serial position effect occur. To argue why they occur begs the question how animals integrate these baseline pairs into accessible memory. Multiple theories exist; these have roots in either cognitive or non-cognitive approaches, such as reinforcement based theories. Cognitive accounts of TI include the organization of the items into a mental spatial array (Vasconcelos, 2008). Supporters of this theory (Roberts and Phelps, 1994) argue that subjects mentally arrange the items into a spatial “line” that can be accessed at any point. Critics of this theory (Vasconcelos, 2008), however, claim that if a mental representation of the lists were available, it would be continuously accessible and the subjects would perform near perfection. The symbolic distance effect could account for the lack of perfection on the transitive tests because items that are close together may be more complicated to decipher, even if there is a mental model. Objects further apart in a spatial array are easier to tell apart than those sitting next to each other.

Both P39 and P23 performed significantly above chance on the between list transitive pairs (see Table 4). These results could be due to the fact that the pairs contain stimuli that are further apart from each other in the hierarchy and have more stimuli between them. The within list transitive pairs had lower performance, with P23 being the only subject to perform significantly above chance on List 1 within list transitive pairs (see Table 5). These pairs have fewer stimuli between them than most of the between list pairs. Thus, the symbolic distance effect could be the reason for the significant performance on the between list pairs and not on most of the within list transitive pairs.

#### *Application to Value Transfer Theory*

Non-cognitive theories are numerous and some involve reinforcement theories while others involve values of each item. The value transfer theory, which was briefly discussed earlier, predicts that the animal solves the TI task by assessing the value of the items being presented (von Fersen et al., 1991). These values are acquired through training of the baseline pairs and are a combination of the direct reinforcement history of the item and the positive value of the item with which it is paired. The positive value of an item is transferred to the other item

with which it is being presented (Cohen et al., 2001). For example, in a hierarchical list in which A is always reinforced, A would have the highest value. The stimulus B is essentially neutral until it is presented with A. When presented with A, some of the positive value of A is “rubbed off” onto B but the value of B is still less than the value of A. This continues on down the hierarchy with a little positive value being transferred to each stimulus until the fifth element has the lowest value of all the elements (von Fersen et al., 1991; Vasconcelos, 2008). This model does not require a mental model of spatial arrangements. While it might seem that the value transfer theory is an organization of values across a hierarchy, much like the spatial model, instead the subject has learned a specific value for each element. When the subject is presented with a novel comparison, it references the specific value for each individual element, independent of the other elements of the list not present. With this model, the subject ends up following a logical rule instead of using relations or associations as with spatial models (von Fersen et al., 1991; Lazareva et al., 2004; Vasconcelos, 2008).

The results of this study do not show overwhelming evidence for value-transfer theory. The items across lists that are in the same position in the list were evaluated based on their first presentation: AF, BG, CH, DI, and EJ. If value-transfer theory were at work, then these pairs would be at chance levels because they have the same value and the subject would be unable to decipher which was greater. Both subjects P39 and P23 got 4/5 of the value-transfer pairs, incorrectly responding to the BG pair. While there are not enough samples of value-transfer pairs to test significance statistically, it is evident by percent correct that both subjects performed well on these pairs, showing that they were able to make a choice and not confused about the similar values of the items. The choices made were in the direction hypothesized by this study.

Secondly, value-transfer implies the animal is capable of cardinality. Cardinality is thought to be the second requirement for counting (Lazareva & Wasserman, 2008; Davis, 1992). Cardinality assumes that the animal assigns each stimulus with a value. The stimulus gets its own value, independent of the other stimuli. Cardinality comes into play because value-transfer assumes that stimuli in the same position across lists will acquire the same value. For example, B and G should acquire the same value when the lists are trained separately because they are both second in the lists. So, regardless of what the stimulus is or what it is labeled, any stimulus in that position should acquire the same value. Performing above chance on the pairs that, according to the value-transfer theory, should have equal values does not mean that they are not

assigning values to stimuli. Perhaps with the review of lists, the values became altered from their original value during the training of the list that aided their choice making in the final test.

Initially, I hoped with the current study to find a possible way to test the value-transfer hypothesis. However, some changes in the current procedure would be necessary. Each stimulus in the list was not reinforced equally during training due to a non-correctional procedure. The results obtained could be due to uneven reinforcement histories across stimuli. In the present study, noncorrectional procedures were used throughout. Although measures were taken to ensure that each pair was represented equally throughout the study, the noncorrection procedure prevented each element from being reinforced equally. So, for example, some of the rats had difficulty learning the second pair, BC or GH, in List 1 and List 2. Since these pairs had higher errors than the other pairs, C or H would have been reinforced less than, say, the always reinforced J stimulus (see Figures 3 & 4). Thus, a theory based solely on reinforcement histories instead of value-transfer theory could not be ruled out.

Another change that would be useful to test value-transfer theory was procedural: the review of the entire list with P39. The review of the 10-item list could have created new values based on the 10-item list instead of two separate 5-item lists. Values for stimuli in a 10-item list would decrease as the 10 stimuli decreased in the hierarchy. In two separate 5-item lists, however, the value of stimuli in the same location across lists would have the same value. So the procedure was changed for P23 to only review List 1.

At first glance, it may seem as though two stimuli in the same location in a list in this study would have the same value. However, it is possible that the linking of the two lists via the EF pair could have altered the values of the stimuli adjacent to the stimuli E and F. In training the List 2, the stimulus F had a value equal to that of A, which was the lowest of the stimuli because it was reinforced 0% of the time. The stimulus E had the highest value in List 1, equal to stimulus J, because it was reinforced 100% of the time. When these two stimuli were linked and the lists were reviewed in combination training, E and F were reinforced 50% of the time instead of 100% and 0%, respectively. The lists are linked to create a relation between the stimuli in the same position. If the lists were not linked, chance performance would be expected because there is no relation between the two testing stimuli for the rat to assess. Thus in this study, value-transfer could be assessed since there was some relation between elements; expecting chance performance for stimuli with in the same position across lists. When tested, though, P39 and P23

did not perform at chance levels. In fact, P39 and P23 together performed correctly on 8 out of 10 value-transfer pairs ( $p = .0547$ ). However, value-transfer can not be ruled out completely because, as stated above, the values for E and F could have been altered with the linking procedure. Stimulus E's value may have decreased and F's value increased since the value of an item is directly affected by its reinforcement history, making, for example, F and A no longer equal. With unequal values, value-transfer can not truly be tested with the current procedure.

### *Limitations and Future Studies*

There are many adjustments that could be made to this design to improve its quality. One modification that could be made would be to use correctional procedure in order for all of the stimuli to be reinforced with the same frequency. In order to speed up the training process, more trials per session might show quicker performance as was observed by Dusek and Eichenbaum (1997). More trials in a session would give the subject more practice with the training pairs. To keep List 1 and List 2 separate lists and prevent them from becoming a 10-item list, I would suggest keeping Variation 2 of the procedure in which only the first list was reviewed with the linking pair prior to the final list-linking test. One other element that would improve the quality of this study would be to have more subjects. More subjects would increase power and provide more opportunities to replicate the results. This study did not have enough power in some cases to detect an effect. For example, on the first presentations of the value-transfer pairs or the three pairs singled out during the final list-linking test, there simply were not enough trials or subjects to detect any effect. The apparatus also posed some problems at times during training. Sometimes the lids would get stuck as the rat was trying to make a choice and would disrupt the session. An apparatus that was more automated (such as the olfactometer) or didn't require the subject to move a lid might be more suitable for smooth procedures.

Finally, there were two pairs that had very low percent corrects during training and then during the final list-linking test for P23, yet, were significantly different from chance: BC and DG, respectively. These results suggest that a third variable is at work and further investigation into these differences would be needed. Possibly, the location of the stimulus in the hierarchy is difficult for the subject to learn or the specific scents are aversive to the subject.

While this study is not the perfect evaluation of the value-transfer theory for TI, it is a good pilot study for list linking abilities in rats. The results from the current study do show

evidence for TI across lists which imply a linking of two separate lists. Subjects were able to infer transitive relations between lists at significant values.

Phylogenetic trees once implied intelligence scales to cognitive scholars and that animals higher up on the tree were more intelligent and had more cognitive abilities (Healy et al., 2009). While some might argue that rats are not “high enough” on the tree, this study is additional evidence that rats are indeed capable of a task referred to as higher order learning and once thought to only be a human ability. The fact that rats are capable of solving TI tasks could imply a strong evolutionary basis for TI since it has been found across so many species, many that are not evolutionarily related to the rat (primates, Treichler & Tilburg, 1996; pigeons, Lazareva & Wasserman, 2006). The fact that these animals tend to be social creatures could imply a need for TI abilities in order to adapt in a new social situation, however, it might be interesting to investigate whether animals that do not set up dominance hierarchies are capable of inferring transitive relations. In the field, in animal societies that do set up hierarchies, there may not be large differences in size in individuals in which to determine the social hierarchy. The current study reveals that rats are still able to transitively infer without the aid of a physical dimensional difference but instead using relations, or associative methods. Currently there are no known studies that test whether rats are capable of using physical dimensions or a logical method to infer transitively, but further studies on this might indicate that rats are indeed capable of the logical processes so attributed to humans.

The processes used by rats, or any species, may be as intricate as value-transfer theory but they could also be less complex, as with a cognitive spatial array. It is important to point out that not all animals solve TI tasks in the same way (Premack, 2007; Batsell, 1993) and that this adds to the amazing diversity of cognitive strategies of the animal kingdom.

## References

- Ayalon, M. & Even, R. (2008). Deductive reasoning: in the eye of the beholder. *Educ Stud Math*, *69*, 235-247.
- Batsell, W.R., Jr. (1993). A classroom simulation of transitivity problems in animals. *Teaching of Psychology*, *20*, 228-230.
- Bryant, P.E. & Trabasso, T. (1971). Transitive inferences and memory in young children. *Nature*, *232*, 456-458.
- Calhoun, J.B. (1963). *The Ecology and Sociobiology of the Norway Rat*. Bethesda, Maryland: US Department of Health, Education, & Welfare.
- Cohen, J.S., Drummond, C. & Terrelonge, N. (2001). Value transfer in simultaneous object discriminations by rats. *Animal Learning & Behavior*, *29*, 326-335.
- Davis, H. (1992). Transitive Inference in Rats (*Rattus norvegicus*). *Journal of Comparative Psychology*, *106*, 342-349.
- Dusek, J.A. & Eichenbaum, H. (1997). The hippocampus and memory for orderly stimulus relations. *Proc. Natl. Acad.*, *94*, 7109-7114.
- Grosenick, L., Clement, T.S. & Fernald, R.D. (2007). Fish can infer social rank by observation alone. *Nature*, *445*, 429-432.
- Healy, S.D., Bacon, L.E., Haggis, O., Harris, A.P., & Kelley, L.A. (2009). Explanations for variation in cognitive ability: Behavioural ecology meets comparative cognition. *Behavioural Processes*, *80*, 288-294.
- Lazareva, O.F., Smirnova, A.A., Bagozkaja, M.S. Zorina, Z.A., Rayevsky, V.V., & Wasserman, E.A. (2004). Transitive responding in hooded crows requires linearly ordered stimuli. *Journal of the Experimental Analysis of Behavior*, *82*, 1-19.
- Lazareva, O.F. & Wasserman, E.A. (2006). Effect of stimulus orderability and reinforcement history on transitive responding in pigeons. *Behavioural Processes*, *72*, 161-172.
- Lazareva, O.F. & Wasserman, E.A. (2008). Categories and concepts in animals. *Learning and Memory: A Comprehensive Reference*, *1*, 197-226.
- Lewis, A. & Smith, D. (1993). Defining higher order thinking. *Theory into Practice*, *32*, 132-137.
- McGonigle, B.O. & Chalmers, M. (1977). Are monkeys logical? *Nature*, *267*, 694-696.

- Piaget, J. (1928). *Judgment and Reasoning in the Child*. New York: Harcourt, Brace and Company.
- Premack, D. (2007). Human and animal cognition: Continuity and discontinuity. *PNS*, *104*, 13861-13867.
- Roberts, W.A. & Phelps, M.T. (1994). Transitive inference in rats: A test of the spatial coding hypothesis. *Psychological Science*, *5*, 368-374.
- Russell, J., McCormack, T., Robinson, J., & Lillis, G. (1996). Logical (versus associative) performance on transitive reasoning tasks by children: implications for the status of animals' performance. *The Quarterly Journal of Experimental Psychology*, *49B*, 231-244.
- Slotnick, B. (2001). Animal cognition and the rat olfactory system. *TRENDS in Cognitive Sciences*, *5*, 216-222.
- Steirn, J., Weaver, A., & Zentall, T. (1995). Transitive inference in pigeons: Simplified procedures and a test of value transfer theory. *Animal Learning & Behavior*, *23*, 76-82.
- Treichler, F.R., Raghanti, M.A. & Van Tilburg, D.N. (2007). Serial list linking by macaque monkeys (*Macaca mulatto*): List property limitations. *Journal of Comparative Psychology*, *121*, 250-259.
- Treichler, F.R. & Van Tilburg, D. (1996). Concurrent conditional discrimination tests of transitive inference by macaque monkeys: list linking. *Journal of Experimental Psychology*, *22*, 105-117.
- Vasconcelos, M. (2008). Transitive inference in non-human animals: An empirical and theoretical analysis. *Behavioural Processes*, *78*, 313-334.
- Von Fersen, L., Wynne, C.D.L., Delius, J.D., & Staddon, J.E.R. (1991). Transitive inference formation in pigeons. *Journal of Experimental Psychology*, *17*, 334-341.