

# How Do Monkeys (*Macaca mulatta*) Represent Items in Serial Memory

Patricia A. Wilson & Herbert S. Terrace, Ph.D.  
Columbia University Psychology Dept. & NYSPI

## INTRODUCTION

Serial learning has been highly studied in pigeons, rats, monkeys, and humans of all ages. Recent studies have been attempted to determine how non-verbal animals may be able to accomplish such a task. Orlov et. al (2002) found evidence of a categorical strategy rather than an associative chaining process in monkeys. Monkeys also seem to get better and better showing expertise which may imply an increase in organization of their representational model for serial learning (Terrace et. al., 2003). Interactions have been found between spatial and number information (Hubbard et. al., 2005). In fact, there seems to be a neurological homunculus for number. Traditional transitive inference studies imply a linear representational model with distance effects, i.e. items further apart result in quicker and more accurate responses (D'Amato & Colombo, 1988). We therefore hypothesize that perhaps order may also interact with spatial information and have designed a series of experiments to examine this hypothesis. This is the first of such experiments to determine if spatial information naturally assists in learning a serial list.

## METHOD

Monkeys have previous training with a simultaneous chaining task were used for this task. On the original simultaneous chaining paradigm an array of photographs were displayed simultaneously on a touch-sensitive video monitor. The correct order of responses is learned through trial and error. Subjects received a primary reward if and only if they touched the pictures in the correct order. The position of the list items varied randomly from trial to trial to ensure that the subjects could not learn the required sequence as a motor action. In the current paradigm we used the same procedure with a few modifications. A simultaneous chain was displayed in one of four different configurations: linear (vertical [top to bottom] and horizontal [left to right] where the spatial position matches the list order), probe linear (horizontal or vertical but spatial position does not match order position), and simchain (random spatial position), see *Figure 1*. For example, a four-item list, where A was the first item and D the last item, in a horizontal configuration would appear on the screen ABCD whereas a horizontal probe configuration may appear on the screen as CADB.

Subjects were assigned a dominant linear configuration, either horizontal (Benedict) or vertical (Ebbinghaus and Spike). All subjects see four types of configurations: horizontal, vertical, probe of the dominant linear configuration, and simchain. These varying list configurations were presented randomly throughout the session in a 3:3:3:1 ratio. The designation of dominant versus non-dominant affects the number of each type of linear configuration trials they see as well as which linear configuration the probe mimics. In a 60 trial session with a single list 18 dominant linear configuration trials, 18 simchain trials, 18 probe trials, and 6 non-dominant linear configuration trials would be presented.

Errors terminated the trial with a 2-s blackout. All correct presses produced brief auditory and visual feedback. Subjects were given a reward (a 190 mg BioServ banana pellet) only if they responded to all of the list items in the correct order.

FIGURE 1. Trial Types



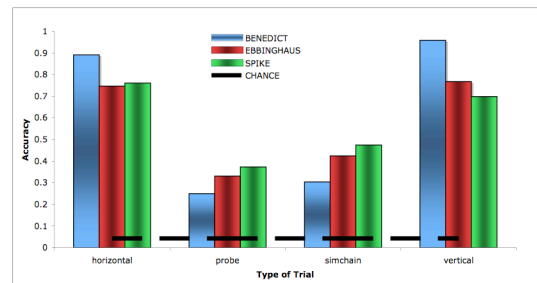
Initially all subjects started with a re-familiarization of basic 3-item list simultaneous chaining paradigm. New lists would be assigned if a criterion accuracy of 40% was met. Once subjects reached criterion for five consecutive days with new three-item lists they were placed on the Linear Configuration paradigm which followed the previously described procedure involving all configuration types. The same criterion was held and new lists were given accordingly. Again once criterion was reached for five consecutive days subjects were given a four-item list. Subjects that achieved criterion on four-item lists for five consecutive days subjects were given two four-item lists per day and sessions changed from 60 trials per day to 100 trials per day. Lists were presented in a blocked array with 50 trials per list still with all configurations randomized within the list block. The ratio of the configuration trials remained the same.

## RESULTS

All of the following results are based on four-item list data. No significant differences were seen between four and three-item list data. Chance on a four-item list is 6%. Benedict and Ebbinghaus are both seeing two four-item lists per day. Spike, however, has yet to reach the necessary accuracy level to be switched to two four-item lists per day so he only sees one four-item list in a 60 trial session.

Figure 2 shows accuracy level on each type of configuration trial by subject. All subjects had higher accuracy levels on linear configuration trials compared to simchain or probe trials. However, probe and simchain trials were still significantly above chance.

FIGURE 2. Accuracy by Trial Type



Error patterns can be useful in determining representational models. *Figure 4* illustrates the error proportions of all subjects combined based on the item that was correct and the type of trial presented. The lines in *Figure 4* indicate the frequency of errors by item correct and type of trial presented. The error patterns found are similar to those typical of the simultaneous chaining paradigm. No differences in error patterns were found as a function of the type of trial shown.

Finally, how do the subjects perform on the probe trials. If subjects were using a simple motor response, probe trials would suffer dramatically. To examine this we looked at the proportion of probe trials in which the subjects chose the first position (left-most if a horizontal probe, top-most if a vertical probe), see *Figure 5*. However, there are times when the first position may be correct. All subjects selected the first position on approximately a third of the probe trials. Approximately 2/3 of the time that was the correct response.

FIGURE 3. Error Patterns

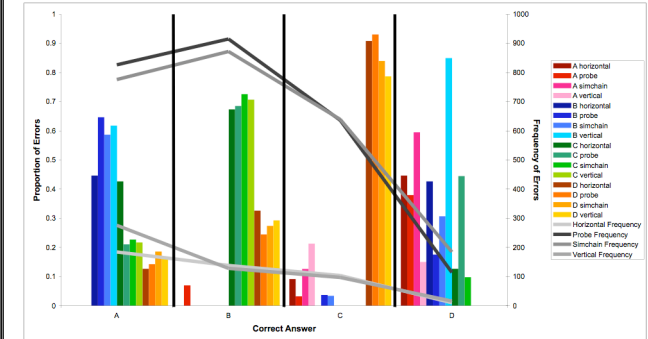
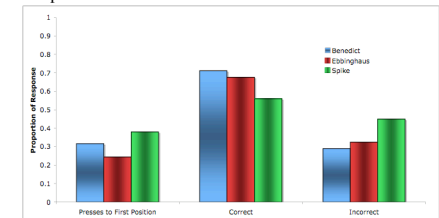


FIGURE 4. Responses on Probe Trials



## CONCLUSIONS

Accuracy was significantly greater on linear spatial configurations than on probe or simchain trials. This increase in accuracy may indicate that the linear spatial organization assisted the subjects in their acquisition of lists. Probe and simchain trials kept the subjects from learning a simple motor response on the linear trials. Evidence that this methodology worked is found in the accuracy level of both probe and simchain trials. These levels are significantly above chance indicating that even on probe trials the subjects were not simply pressing in the linear order but looking for the first item in the list. Error patterns indicate that while subjects' accuracies differed significantly based on trial configuration, the errors they made did not. Error patterns are often taken as evidence of representation models. Since the error patterns were similar it is reasonable to conclude that the same representation model was used regardless of the trial configuration. Finally, their responses on probe trials further indicates that they are not simply responding in a fixed spatial order.

While this study alone does not prove the use of a spatial representation model for serial learning in monkeys, it is the first in a series of experiments that may provide evidence toward that theory.

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Monkeys:  
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•Ebbinghaus  
•Spike