

HAPTIC MATCHING-TO-SAMPLE IN RHESUS MONKEYS

by

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In 1890 James postulated the existence of two memory processes, primary and secondary memory. Primary memory, now commonly called short-term memory (STM), is defined as a limited capacity system which stores material for a brief period of time. Secondary, or long-term memory (LTM), is essentially a permanent storage system. Shortly after this dual process was proposed, there was considerable interest in the question of whether animals could only experience sensory stimuli or whether, in addition, they could store internal representations of these sensory stimuli for a short period of time.

Hunter (1913) conducted a series of experiments which he believed demonstrated that animals could indeed form internal representations of sensory stimuli and, in some species, maintain these representations for a brief duration. Hunter used a delayed response (DR) task in which animals observed the illumination of one of three doors, but they were not allowed to choose from among the doors until a few seconds after the illumination had terminated. Responses to the previously lit door were reinforced, while responses to the other doors were not reinforced. Although the maximum intratrial delay (or retention interval) at which performance was above chance varied widely among the species studied, all animals were capable of responding above chance in the absence of the stimulus light. Hunter concluded that the stimulus light established an intraorganic cue and that, in the absence of the stimulus, this cue diminished over time. Thus, Hunter's results are consistent with the definition of primary memory as first proposed by James.

During the following years a variety of DR tasks were used to study STM in different species (Medin, 1969; Nissen, Riesen, & Nowlis, 1938; Yerkes & Yerkes, 1929). One of the major concerns which originated from Hunter's experiments was the observation that some animals oriented themselves toward the correct stimulus during the retention interval and, hence, may

have used orientation as a cue for correct responding. Subsequently, a number of procedures were devised which apparently precluded the use of positional orientation as cues. Rats (Ladieu, 1944), dogs (Lawicka, 1959), cats (Meyers & McQuiston, 1962), and non-human primates (Gleitman, Wilson, Herman, & Rescorla, 1963; Tinklepaugh, 1928; Yerkes & Yerkes, 1928), were able to successfully perform DR without adopting orientational cues. In addition, maintaining a particular body orientation during the retention interval appeared to be a nonpreferred strategy (Harlow, Uehling, & Maslow, 1932) and one that was not adopted spontaneously (Nissen, Carpenter, & Cowles, 1936). However, since other research suggests that solution of spatial DR sometimes depends on body orientation (French, 1959; Miles, 1957), it is difficult to be certain that orientation is not occasionally used as a cue to bridge the retention interval.

Delayed alternation (DA) has also been used to study STM in animals. This task has the same basic characteristics as DR, except that animals are required to alternate responses between one location and another (e.g., French, 1965). As with the DR task, the animal may use body orientation to bridge the retention interval. At the present time, the extent to which animals use body orientation as a cue in DR and DA is still not resolved.

More recently, delayed matching-to-sample (DMS) has become a widely used procedure to investigate STM in animals. In the most common DMS task, presentation of a visual sample stimulus is followed by a response to that sample and its subsequent removal. At the end of a brief retention interval, the same stimulus reappears in a different position, accompanied by one or more comparison stimuli in the same modality. A response to the comparison stimulus which is identical to the sample is reinforced.

The DMS procedure provides two advantages over DR and DA. First, since the sample and comparison stimuli appear in random locations across trials, it is unlikely that positional cues are used to bridge the retention interval. Therefore, some type of centrally stored representation of the sample stimulus appears to be necessary for above-chance performance in DMS. Second, requiring the animal to respond to the sample stimulus insures that the animal has observed that stimulus. This has been shown to be a critical variable in primate performance of visual discrimination tasks (Stollnitz, 1965).

Primarily on the basis of results obtained with the DMS task, a number of models have been proposed to account for the increasing number of errors which occur as a function of the length of the retention interval. Several of the most prominent hypotheses attribute short-term forgetting to trace decay, proactive interference, retroactive interference, or temporal discrimination deficits. In the following discussion, evidence for these models is based on visual DMS, unless otherwise stated. However, these models are generally not limited to the DMS task but are also applicable to other tasks.

Trace Decay

Decay of a stimulus trace has traditionally been thought to account for the increasing number of errors which occur as a function of the retention interval. The decay model is based on two assumptions. The first assumption is that, in the absence of the sample stimulus, the strength of a memory trace decreases with the passage of time. The majority of studies, in fact, show that animals make fewer matching errors at short retention intervals compared to longer intervals. However, the rate of decrease across retention intervals differs among species. Pigeons with little DMS experience usually respond at chance levels after intervals of 10 sec or less (Berryman, Cumming, & Nevin, 1963), while highly practiced pigeons are capable of above-

chance matching with intervals of 60 sec (Grant, 1976). Well trained non-human primates (D'Amato, 1973; Mello, 1971) and dolphins using auditory cues (Herman & Gordon, 1974) can maintain above-chance performance up to or beyond 2 min.

The second assumption is that the strength of the memory trace increases with longer exposure to the to-be-remembered cues. In pigeons, monkeys, and dolphins, the percentage of correct matches increases when the sample duration is increased but only one response is required (Devine, Jones, Neville, & Sakai, 1977; Grant, 1976; Herman & Gordon, 1974; Herzog, Grant, & Roberts, 1977; Roberts & Grant, 1974), and when sample duration is increased by having the animal respond more than once to the sample (Jarrard & Moise, 1971; Roberts, 1972). The number of errors made by monkeys appears to be independent of sample presentation duration when these presentations are very brief (D'Amato & Worsham, 1972). However, this finding may be due to stimulus familiarity and the extent of practice which monkeys received with brief sample durations (Devine et al., 1977).

When repeated sample presentations are temporally spaced, as opposed to massed, matching accuracy decreases. This negative spacing effect has been found to occur in pigeons (Roberts, 1972; Roberts & Grant, 1974) and monkeys (Herzog et al., 1977), with the decrement being directly related to the length of the spacing interval. Facilitative effects of spacing in non-human primates have been reported by Robbins and Bush (1973) and Medin (1974). These discrepant findings with primates are most likely due to procedural differences (Herzog et al., 1977). The decay model predicts that greater matching accuracy should occur when sample presentations are massed, because spacing increases the amount of time the animal spends in the absence of the sample stimulus, allowing trace strength to decay between successive presentations of the sample stimulus.

The decay model is valuable in that it not only explains much of the STM data, but it lays a foundation for several other models. Most models of STM are based on the assumption that some aspect of the memory trace diminishes over time. Thus, while the following models center on other conditions which affect retention, they still retain much of the fundamental structure of the decay model.

Interference

Another prominent model of forgetting states that errors committed in memory tasks are due to competing memory traces which may occur either prior to sample stimulus presentation, in the case of proactive interference (PI), or following sample presentation, in the case of retroactive interference (RI). In both cases, the number of errors depends on the amount and type of interference, as well as the time separating interfering and sample stimuli (Grant & Roberts, 1973; Jarrard & Moise, 1971; Roberts & Grant, 1976).

Proactive interference has been demonstrated by several studies in which DMS errors increase when the non-matching comparison stimulus has been presented as the sample stimulus during a preceding trial or when the interfering stimulus immediately precedes the sample stimulus during the same trial. This effect has been found in pigeons (Grant, 1975; Grant & Roberts, 1973), monkeys (Worsham, 1975), and dolphins (Herman, 1975).

Grant and Roberts (1973) have proposed a model in which both trace decay and proactive interference are responsible for matching accuracy. Here it is assumed that memory traces for stimuli are established independently, and that one trace will not affect either the initial strength or the rate of decay of a second trace. Memory traces, thus, will not compete with each other until a choice between the comparison stimuli is required. At that time, the stimulus associated with the stronger trace will have the

greater probability of being chosen. This model was tested by manipulating the response frequencies to both the interfering and sample stimuli within the same trial (Grant & Roberts, 1973). Errors in DMS increased as the number of responses to the interfering stimulus increased. Increased responses to the sample stimulus and longer intervals between interfering and sample stimuli decreased errors. In general, interfering stimuli lowered overall performance relative to control conditions, but did not affect the rate of errors across retention intervals. Improved performance has also been noted when the interval following an interfering trial is lengthened (Grant, 1975). Although the authors assumed that the effect of an interfering stimulus may depend upon its trace strength relative to the strength of the sample trace, there is no critical evidence which distinguishes this model from other models of PI (e.g., Spear, 1971).

Retroactive interference occurs when events which transpire after presentation of a sample stimulus disrupt or compete with the memory trace for that stimulus. In support of this hypothesis, irrelevant stimuli presented during the retention interval have been found to increase DMS errors in pigeons (Zentall, 1973), monkeys (Moise, 1970), and dolphins (Herman, 1975). Both the amount and type of interference appear to be important. Matching accuracy is reduced following retention interval illumination in pigeons (Grant & Roberts, 1976; Maki, Moe, & Bierley, 1977), and monkeys (D'Amato & O'Neill, 1971; Etkin, 1972), although this effect may be dependent upon the level of illumination during training (Bauer & Fuster, 1978). In monkeys, presenting white noise has been reported to have no effect on DMS errors (Worsham & D'Amato, 1973). However, when monkey cries were introduced during the retention interval, matching errors were found to increase in one study (Fuster & Bauer, 1974) and decrease in another study

(Worsham & D'Amato, 1973). Free movement does not alter errors in monkeys (Jarrard & Moise, 1970), but requiring an operant response during the retention interval reduces matching accuracy (Moise, 1970).

The degree of similarity between the sample and the interfering stimulus has also been shown to affect matching performance in monkeys (Jarvik, Goldfarb, & Carley, 1969). Presentation of an interfering stimulus which was the same as the sample slightly facilitated matching while a neutral interfering stimulus had no effect. Matching errors increased when the interfering stimulus was also the non-matching comparison stimulus. Increased matching errors in the latter situation may have been due to animals matching the stimulus which was presented most recently, rather than being due to interference (Zentall, 1973).

Temporal Discrimination

Much of the evidence supporting other models of DMS performance can also be explained by a temporal discrimination deficit hypothesis (D'Amato, 1973; Mason & Wilson, 1974). In this model it is assumed that animals do not forget the correct cue, but instead, are unable to remember which comparison stimulus appeared most recently as the sample. The predictions based on the temporal discrimination model are that matching accuracy will improve following a decrease in the frequency with which (a) a sample stimulus has previously appeared as a non-matching comparison stimulus, and (b) a non-matching comparison stimulus has previously appeared as a sample stimulus. Matching accuracy should also improve following an increase in the length of time since (a) a sample last appeared as a non-matching comparison stimulus, and (b) a non-matching comparison stimulus last appeared as a sample stimulus. Temporal discrimination should be more difficult at longer retention intervals, since the relative amount of time following the last presentation of either comparison stimulus is more similar than at shorter intervals.

This model is supported by several studies. Worsham (1975) found that a large sample-set attenuated the number of errors made by monkeys when compared to a smaller sample set. Large sample-sets decrease the frequency with which non-matching comparison stimuli on current trials appeared as samples on previous trials (and with which samples on current trials appeared as non-matching comparison stimuli on previous trials). Mason and Wilson (1974) directly varied the frequency with which stimuli were presented and found that task performance decreased as the frequency of presentations increased. The temporal discrimination model can also account for the results of RI studies and the fact that, within limits, DMS performance improves as intertrial intervals increase (Jarrard & Moise, 1971).

Statement of the Problem

Results of the studies reviewed above indicate that there are species differences in DMS performance and that a number of variables affect matching accuracy. Pigeons with DMS experience have been found to retain information up to 60 sec (Grant, 1976), while experienced monkeys and dolphins are proficient at intervals exceeding 2 min (D'Amato, 1973; Herman & Gordon, 1974; Mello, 1971). Monkeys sometimes require only brief exposure to sample stimuli to adequately retain information (D'Amato & Worsham, 1972), whereas correct matching in pigeons is a function of presentation duration (Roberts & Grant, 1976). Spaced repetition of sample stimuli seems to have a more powerful effect on pigeons than on monkeys (Herzog et al., 1977), while monkeys appear to be more susceptible than pigeons to interference from events occurring during previous DMS trials (Grant, 1975; Worsham, 1975). At the present time, no single model can account for the complexities of animal STM or the differences between species.

The evidence suggests that STM processes may differ across species and that the application of separate memory models may be necessary. However, these results may also simply reflect differences in procedures, apparatus, differing degrees of task difficulty, or subject experience. Since these differences result in conflicting views, it has been suggested that new tests are needed to increase the scope and power of memory theories (Medin & Cole, 1975).

As indicated above, the vast majority of STM research with animals requires retention of visual cues. Therefore, an obvious extension of memory research with animals is to determine if the retention curves are similar for different sensory modalities. To a limited extent, both auditory and haptic memory have been investigated in recent years. Auditory DMS has been demonstrated in monkeys (Dewson & Burlingame, 1975) and dolphins (Herman, 1975; Herman & Gordon, 1974). Until recently, acquisition of auditory discriminations and DMS in monkeys has been regarded as being difficult and time-consuming relative to acquisition of comparable visual memory tasks. This is presently becoming a more practical task for studying memory processes (Dewson, Note 1). While dolphins have proven to be proficient at auditory DMS, the difficulty in maintaining these animals in most laboratories makes their general use prohibitive.

Monkeys are quite capable of performing discriminations using haptic cues, and in some instances, they acquire haptic discriminations at about the same rate as visual discriminations (Deuel & Mishkin, 1977; Oscar & Wilson, 1966; Semmes & Mishkin, 1965). Haptic discriminations have been examined with objects varying in shape, size, texture, hardness, and orientation. The degree of difficulty between pairs of objects has been measured by comparing the number of trials to criterion (Passingham & Ettlinger, 1972) and by

systematically varying the similarity of dimensions between two objects (Schwartzbaum, 1965). Long-term retention of haptic cues has been studied by computing savings scores during relearning of the same task (Iversen, 1967). Short-term retention was examined by assessing the number of trials taken to reach a standard level of performance in a 5-sec DA task (Ettlinger, Morton, & Moffett, 1966). All of these studies have been performed in conjunction with physiological intervention and no studies have investigated errors as a function of the interval between presentation of a haptic cue and a response to a comparison stimulus.

Since monkeys can perform haptic discriminations, they should acquire simultaneous matching-to-sample (SMS) and DMS for haptic cues. However, to my knowledge, animals have not yet been trained to perform matching with haptic cues. A major purpose of this study was to determine if monkeys could be trained in haptic matching-to-sample. Furthermore, examination of errors in haptic DMS would provide information concerning the similarity of retention curves in haptic, visual, and auditory DMS. This procedure can also provide a different task for testing models of animal memory as well as derivative problems in haptic cognition, perception, and physiology.

Another purpose of this study was to provide information concerning the effects of size and shape of haptic cues on matching-to-sample. In general, stimuli that are classified as being more different by human observers are learned more rapidly by non-human primates (Devine, 1970; Draper, 1965; Warren, 1954). This effect has been tested in primate visual DMS studies, but the results are inconclusive. Monkeys have been shown to match colors better than geometric patterns (Devine et al., 1977; Jarrard & Moise, 1971), but these results are not always consistent (Devine, Burke, & Rohack, 1979). Studies in which various combinations of colors and patterns were presented

have shown a tendency for monkeys to commit fewer errors when the comparison stimuli differed on two dimensions (color and pattern) than when the stimuli differed on only one dimension. However, the results of these studies were not statistically significant (Devine et al., 1979), and in another study the number of errors committed when the comparison stimuli were both colors did not differ from errors committed when the comparison stimuli were a color and a pattern (Devine et al., 1977). While the above studies suggest that matching accuracy depends on the properties of the sample and comparison stimuli, the results are neither consistent nor conclusive. The present study was designed to examine whether haptic matching is affected by stimuli differing in size, shape, or both size and shape.

Methods

Subjects

Three experimentally naive, male rhesus monkeys (Macaca mulatta) weighing 7-10 kg served as subjects. Throughout the experiment they were housed individually and had free access to Purina Monkey Chow, which was supplemented with fruit. On days of training and testing, all fluids were obtained as reinforcement and no fluids were available in the home cage. Daily fluid consumption during this period was approximately 60% of ad-libitum consumption.

Apparatus

Training and testing were conducted in a sound-attenuated room adjacent to the housing quarters. Monkeys were placed in a primate chair with a stainless steel tube positioned in front of their mouth for delivery of a mean of 1.6 ml grape juice reinforcement. The right hand was loosely chained, so that all responses were made with the left hand. Training and testing were conducted in a modified Lehigh Valley Electronics primate test chamber (60 x 60 x 73 cm). The chair was positioned in the chamber so the monkey could

easily reach through a triangular hole (15.0 cm wide, 8.5 cm from base to peak, and 26.5 cm above the chamber floor) in the front wall (Figure 1). Three manipulanda (10.5 cm long, .5 cm in diameter, and 5.0 cm apart), were attached by hinges to the outside wall immediately in front of the hole. The base of each manipulandum was connected to a microswitch. Closure of these microswitches required that the manipulanda be moved in any direction by 10° . The tips of the manipulanda formed an isosceles triangle with the center manipulandum 2.0 cm above the outer manipulanda (Figure 2).

Small objects (1.5 - 2.5 cm), such as spheres, cubes, knobs, hooks, and pieces of plexiglass cut into various shapes, served as the haptic stimuli during training. These objects were permanently attached to aluminum tubing (9.0 cm long) which could be easily slipped on and off the manipulanda. A metal plate, extending from the monkey's neck to a position above the hole in the chamber wall, prevented the monkeys from seeing the stimuli. The experimenter manually presented the manipulanda so that the stimuli were immediately in front of the hole (Figure 1). Retention intervals and intertrial intervals were measured by Hunter timers which were started by responses to the manipulanda. After initial training, a small, shaded 75 W bulb served as the only source of illumination. While adequate for data recording, illumination within the test chamber was minimal. A fan provided ventilation and masked extraneous noise.

Training Procedure

Monkeys were trained using a procedure analogous to that described in a visual DMS study by Moise and Jarrard (1969). Monkeys were first shaped by successive approximation to pull the manipulanda. Responses to the outer manipulanda were alternately extinguished until very few responses were made to the non-reinforced manipulandum. During the first few shaping

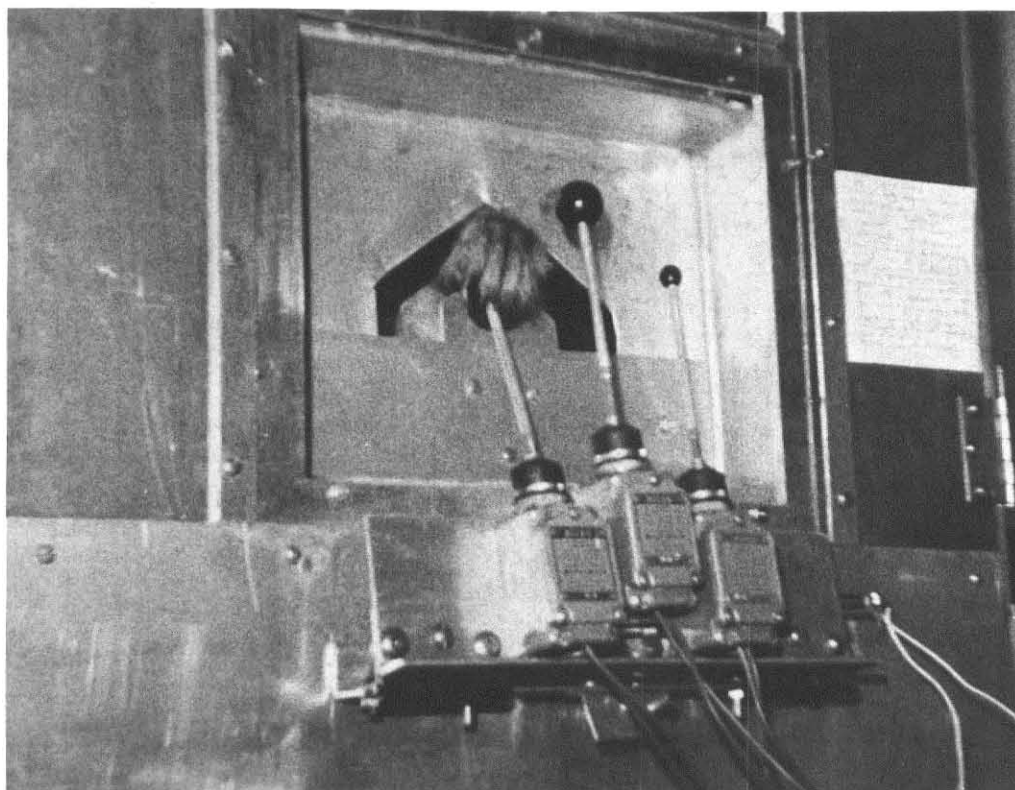
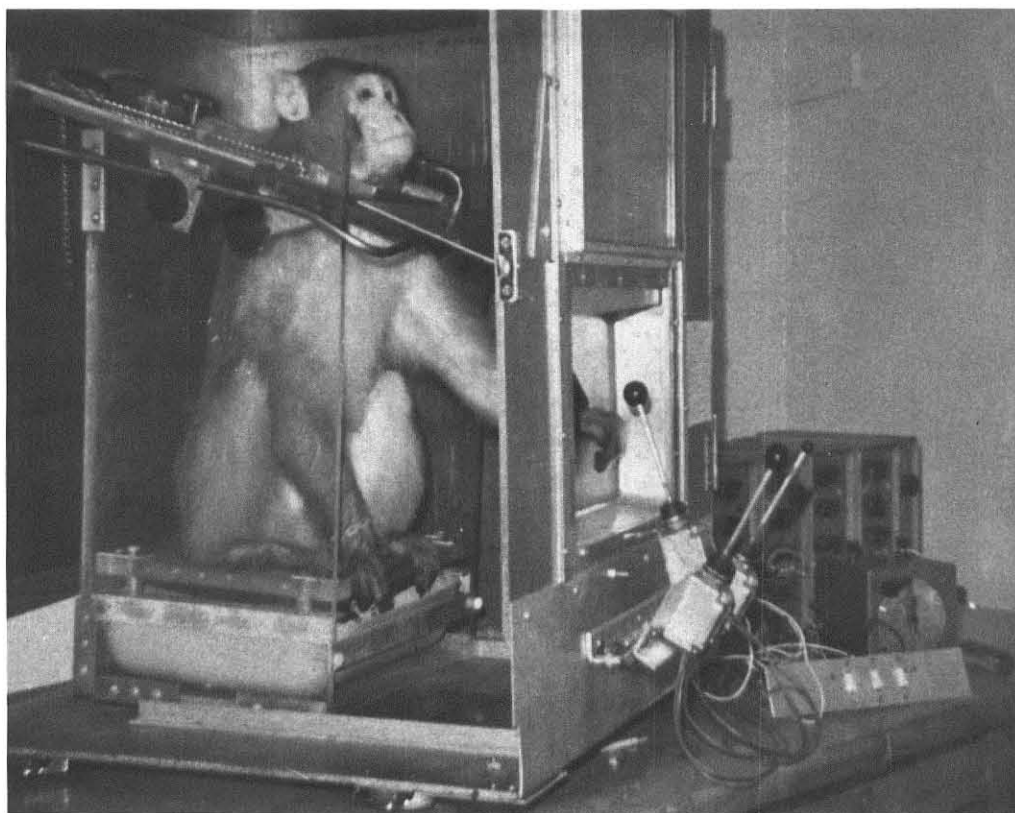
Figure Captions

Figure 1. The monkey and primate chair positioned within the test chamber.

(The side wall has been removed for viewing. Haptic stimuli mounted on microswitches are shown to the right. The sample stimulus has been moved forward and the comparison stimuli are retracted.)

Figure 2. Front view of the test chamber. (The tips of the manipulanda

form an isosceles triangle with the center manipulandum 2.0 cm above the outer manipulanda.)



sessions the neck plate was removed and the hole was widened to 24 x 29 cm so that monkeys had a clear view of the manipulanda. During the following sessions, the smaller triangular hole was restored and the neck plate was replaced in its original position so that the stimuli could not be seen. Monkeys were subsequently trained to discriminate between two objects placed on the outer manipulanda, and this was followed by 10 to 15 discrimination reversals. A criterion of 18 correct choices out of 20 consecutive trials was required.

Monkeys were next trained on an SMS task using the same two objects which were used during discrimination and reversal training. An object on the center manipulandum (the sample stimulus) was presented to the monkey. Presentation was signalled by tapping the center manipulandum on the outside wall of the test chamber. The monkey was allowed to feel the sample object and pull it with enough force to close the microswitch; this defined a response. After responding to the sample stimulus, the two objects on the outer manipulanda (the comparison stimuli) were presented as rapidly as possible (within .5 sec). Although actual simultaneous haptic perception of all three stimuli was not possible, this procedure was called SMS for purposes of comparison to other studies. One of the comparison objects was always identical to the sample stimulus and a response to this object was reinforced with grape juice. The trial terminated when a response was made to either comparison stimulus or if no response was made within 5 sec after presentation of the comparison stimuli. Monkeys were allowed to touch stimuli as often as was possible within the 5 sec time limit. The intertrial interval was 30 sec. Monkeys were required to reach a criterion of 90 correct choices out of 100 consecutive trials, followed by approximately 100 overtraining trials. A mean of 250 trials per session was given. The first monkey (Chompers) was

subsequently trained in seven more SMS problems with two different objects per problem. The other monkeys (Ollie and Harry) received two and three additional problems, respectively.

All monkeys were then given 13 to 27 daily sessions in which the stimuli were cubes and spheres with sides or diameters of 12-, 24-, and 36-mm. These objects were coated with polyester casting resin (Chemco), to assure that each had a uniform surface. Monkeys were first trained to make what appeared to be easy matches with spheres, such as large versus small. This was followed by either pairing the small with the medium sphere and the medium with the large sphere (for Chompers), or by presenting combinations of all three spheres (for Ollie and Harry). The same procedure was then followed with cubes. In the last several sessions, random presentation of all possible combinations of any two stimuli was given.

In the final training phase, a retention interval of .5-, 2-, 4-, 8-, 16-, 32-, or 64-sec was imposed between the response to the sample and presentation of the comparison stimuli. Monkeys received 12 daily sessions of 180 trials each. In the first 4 sessions the retention intervals increased from .5- to 8-sec and only one interval was given per session. The three longest retention intervals were presented in the next 8 sessions, with each session interspersed with trials of shorter intervals. The 16-sec interval was presented for 2 sessions, the 32-sec interval during the next 3 sessions, and the 64-sec interval during the final 3 sessions. Each retention interval was presented 340 times over the 12 sessions with the exception of the 64-sec retention interval, which was presented 120 times. During this training phase and testing, monkeys were allowed to touch the sample for a maximum of 1 sec.

Testing Procedure

The testing procedure was similar to the last training phase. The monkeys

were tested in DMS using the small, medium, and large spheres and cubes with retention intervals of .5-, 2-, 4-, 8-, 16-, 32-, and 64-sec. There were 24 daily sessions, each beginning with 7 consecutive warm-up trials (1 trial with each retention interval) followed by 175 testing trials (25 trials per retention interval).

In every session each of the 15 possible pairings of comparison stimuli was presented 11 - 12 times. The position of the correct choice was determined at random, with the exception that the same side was correct on no more than four consecutive trials. The order of sample presentation was determined at random, with the restriction that a particular sample was presented on no more than four consecutive trials. In each session, each sample and the position of the correct choice appeared an approximately equal number of times. Across trials, the order of the retention intervals was determined at random with the following restrictions: (a) the same retention interval was presented no more than three times in succession, (b) a maximum of four trials with short retention intervals (.5-, 2-, 4-, or 8-sec) and three trials with long retention intervals (16-, 32-, or 64-sec) was given consecutively, and (c) each block of 20 trials contained at least one trial with each retention interval.

In the 24 sessions, there were a total of 40 trials for every possible pair of comparison stimuli at each retention interval, without regard to which of the two stimuli served as the sample and which position held the correct choice. Monkeys were run about 6 days each week throughout training and testing.

Results

Training

One session was required to shape each animal to pull one of the manipulanda, and a mean of six sessions was required to pull each of the manipulanda

equally often. A mean of 994 trials (four daily sessions) was necessary to reach a criterion of 90% correct responses in 20 trials on the first discrimination problem (Chompers = 352; Harry = 1,476; Ollie responded at chance levels for 593 trials with a cylindrical knob and t-shaped bar but reached criterion in 561 trials with a knob and wingnut).

Training on the first reversal required a mean of 474 trials to criterion (Chompers = 328; Ollie = 541; Harry = 554). This dropped to a minimum mean of 31 trials to criterion during latter reversals. A mean of 2,725 trials (Chompers = 435; Ollie = 6,332; Harry = 1,408), or approximately 11 sessions, were taken to reach a criterion of 90% correct responses in 100 trials on the first SMS problem. The total procedure necessary to shape and train the monkeys in discrimination, reversals, and SMS took a mean of 30 daily sessions (Chompers = 18; Ollie = 38; Harry = 34). Not including shaping, this comprised a mean of 5,854 trials (Chompers = 2,106; Ollie = 9,353; Harry = 6,103).

To determine if fewer trials to criterion would occur across different SMS problems, Chompers was given seven additional problems. Ollie and Harry were given only two and three additional SMS problems, respectively, due to the extensive number of trials necessary to reach criterion on these problems. Different pairs of stimuli were used on each problem. No change in trials to criterion was observed across successive problems except for Ollie, who reached criterion on the second two problems after 1,835 and 1,966 trials (compared to 6,332 trials on the first problem).

SMS training with spheres and cubes had to be adjusted according to the progress of the individual monkeys. Chompers received pairings of small and large, small and medium, and medium and large spheres, respectively (1,054 trials). The same order of pairings was given with cubes (366 trials). Chompers reached criterion of 90 out of 100 correct matches in 162 trials when

all possible combinations of spheres and cubes were given. Ollie and Harry reached criterion with small and large spheres, but responded close to chance levels when small and medium spheres and medium and large spheres were presented. However, matching errors of Ollie and Harry decreased when all three pairings of spheres were presented in a mixed order. A similar problem occurred with cubes and the same correction was given. Ollie received 431 trials with spheres, 1,333 trials with cubes, and reached criterion in 169 trials with all combinations. Harry was given 1,964 trials with spheres, 2,258 trials with cubes, but did not meet criterion after 1,636 trials with all combinations.

Retention interval training covered 12 daily sessions. Since retention intervals were presented sequentially across sessions from shortest to longest, it would not be meaningful to represent the percentage of correct responses as a function of retention interval. However, the mean total percentage correct over all retention intervals was 85.5% (Chompers = 87.5%; Ollie = 84.7%; Harry = 84.3%).

Testing

For the first analysis, the data were converted to mean percentage correct responses for each subject, retention interval, and session. Since there was heterogeneity of variance across retention intervals, the percentage of correct matches for each cell was subjected to an arcsine square root transformation. However, in this analysis and in all other analyses reported, there were essentially no different significance levels between analyses of the raw or the transformed data. Therefore, all analyses reported are based on the non-transformed data.

Regression analysis showed that for Chompers and Harry the percentage of correct matches for each session did not significantly change over the

24 sessions at any of the retention intervals ($p < .05$ was considered to be statistically significant for all analyses reported). Across sessions, Ollie displayed a significant increase in the percentage of correct matches for four of the seven retention intervals. Collapsed over retention intervals, this represented a significant increase in correct matches of 10%, $F(1, 22) = 24.56$, $p < .001$. This change in one monkey across sessions did not appear to warrant further consideration in other analyses.

Retention interval and sample analysis. The mean percentage correct for each monkey, sample size, sample shape, and retention interval was determined. Figure 3 shows the mean percentage of correct responses for each monkey as a function of retention interval. (Each data point represents 600 trials.) A 3(monkeys) \times 3(sample size) \times 2(sample shape) \times 7(retention interval) mixed analysis of variance (the last three factors were treated as repeated measures variables) showed that the percentage of correct matches decreased as the retention interval increased, $F(6, 12) = 15.08$, $p < .001$. There was a significant main effect for subjects, $F(2, 12) = 4.23$, $p < .05$, and a significant subject \times retention interval interaction, $F(12, 24) = 8.58$, $p < .001$. This significant main effect and interaction are apparently due to a higher percentage correct by Chompers at longer retention intervals. The monkeys made significantly more correct responses when the sample stimulus was a sphere than when it was a cube, $F(1, 7) = 16.51$, $p < .005$. (See Figure 4.) A nonsignificant sample shape \times retention interval interaction suggests that the difference in percentage correct between sample shapes is relatively independent of the retention interval.

Although sample size did not significantly affect the percentage of correct matches, there was a significant subject \times sample size \times retention interval interaction, $F(24, 24) = 3.94$, $p < .005$. This significant interaction

Figure Caption

Figure 3. Mean percentage correct in DMS as a function of the retention interval for the three monkeys. (A vertical line at each data point indicates the standard error of the mean.)

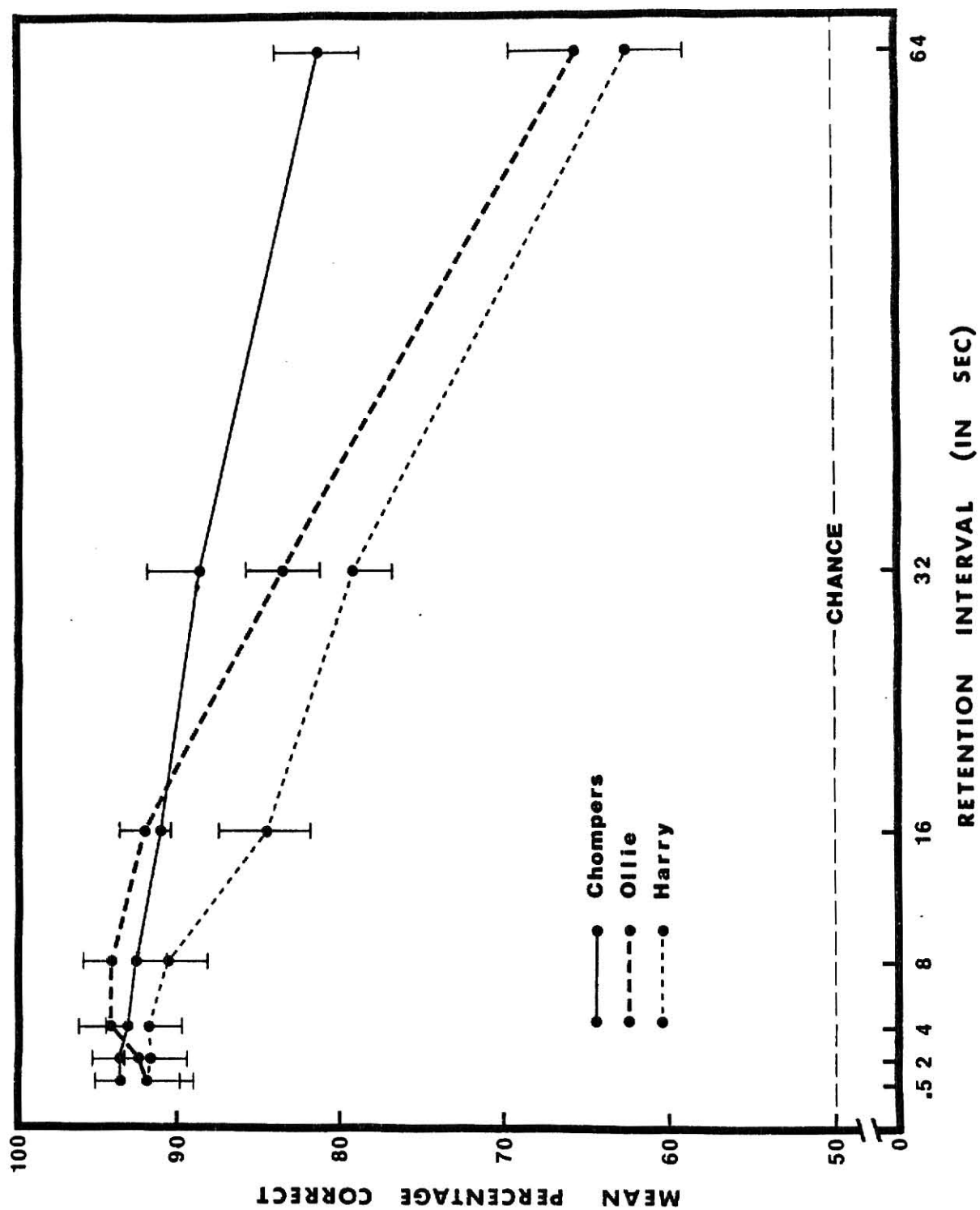
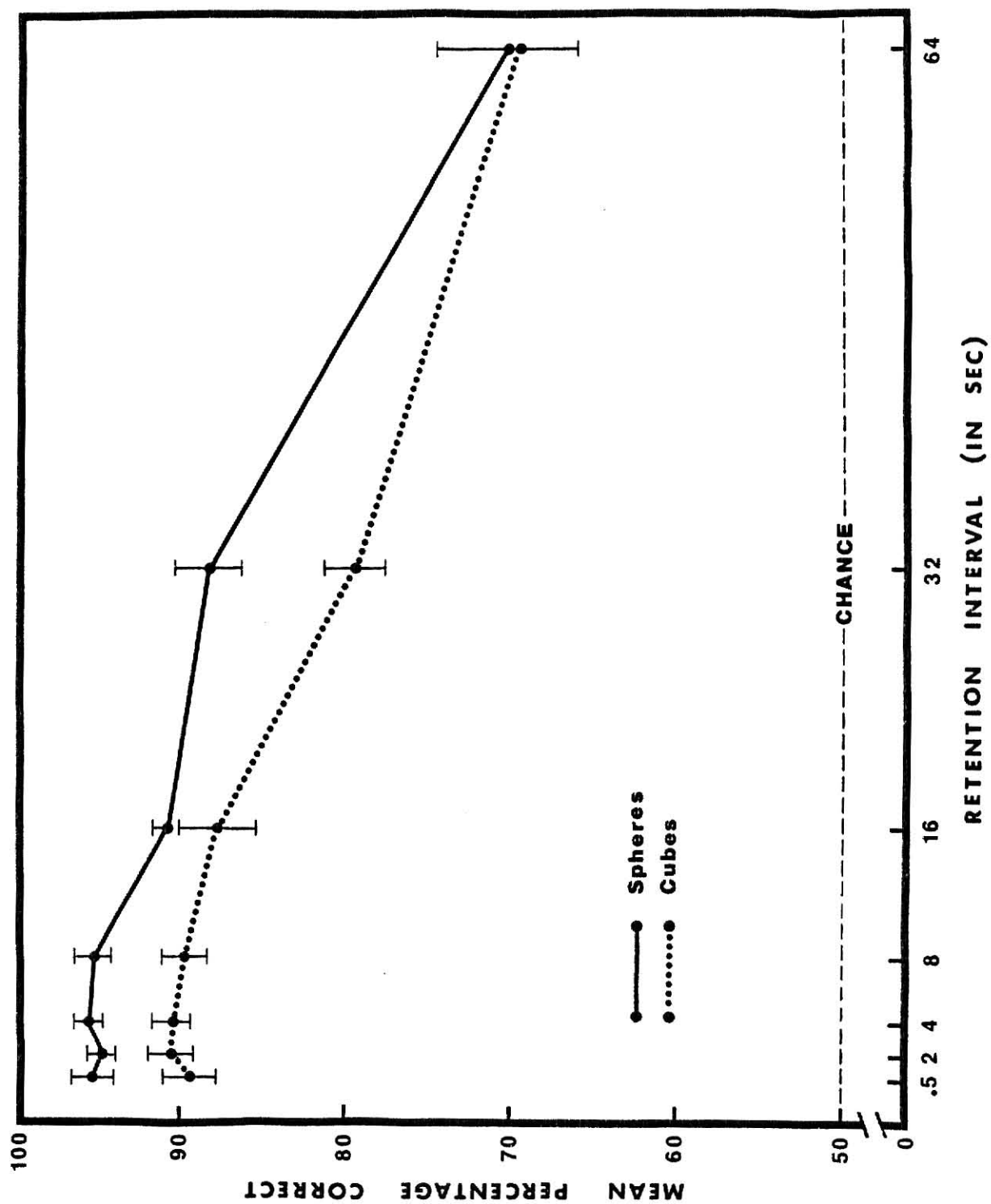


Figure Caption

Figure 4. Mean percentage correct across retention intervals with spheres or cubes as the samples.

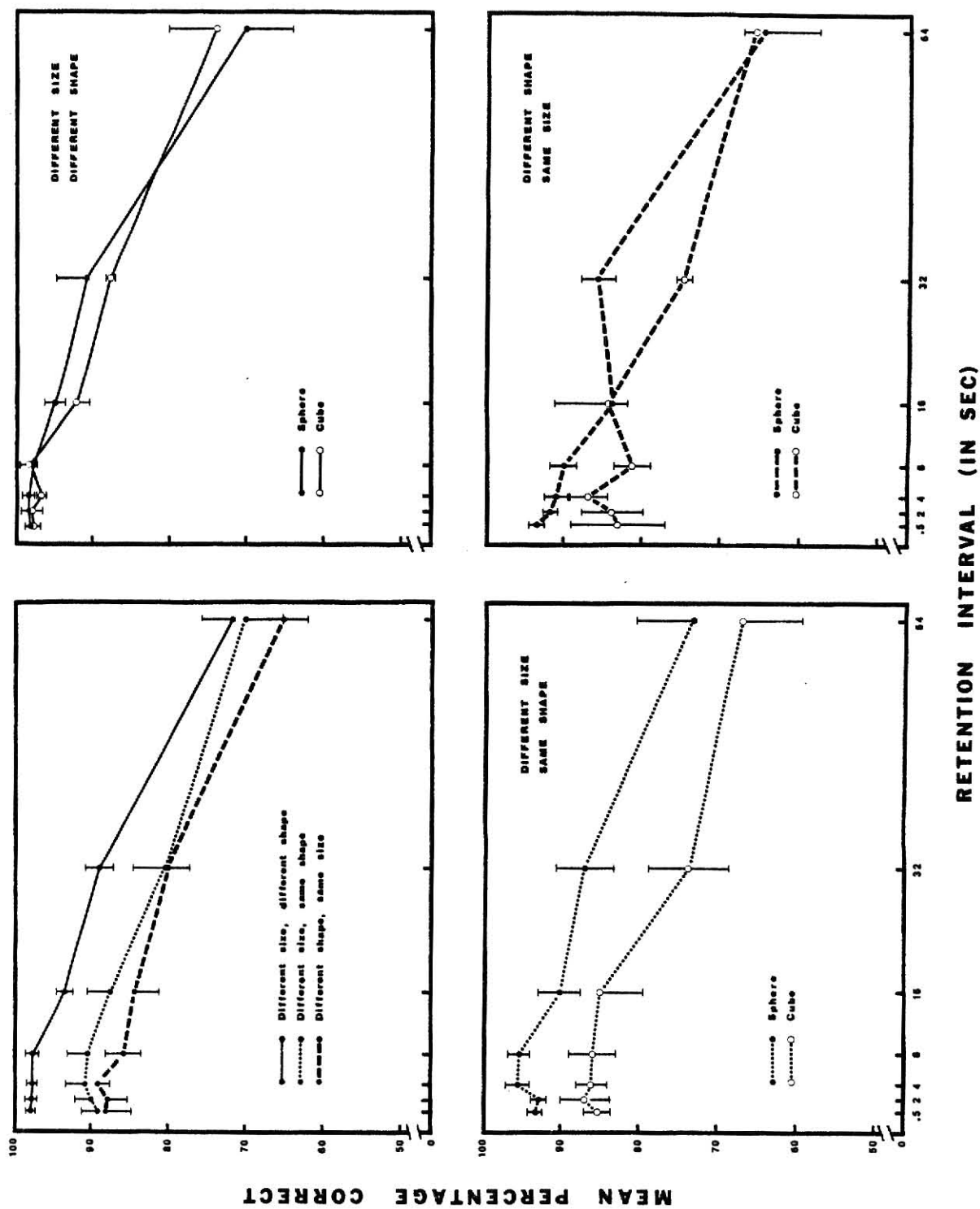


is apparently due to the higher percentage correct by Chompers at longer retention intervals, especially when the sample size was large.

Comparison stimuli analyses. The effect of size and shape differences between comparison stimuli on percentage correct was examined by the following two methods. In the first method, trials were separated into those in which (a) the shapes of the comparison stimuli were different (one stimulus was a sphere and the other a cube) but the size was the same (both were large, medium, or small), (b) the comparison stimuli differed in size but were the same shape (stimuli were either spheres of different sizes or cubes of different sizes), or (c) the comparison stimuli differed in both size and shape (i.e., a sphere of one size was paired with a cube of another size). The first two comparison combinations differed on one dimension only (either size or shape), while the last combination differed on two dimensions (both size and shape). The percentage correct for each monkey (3), comparison stimuli combination (3), and retention interval (7), was determined and the data were analyzed by a mixed factorial analysis of variance (the last two factors were treated as repeated measures variables). The results, collapsed over monkeys, are shown in the upper left panel of Figure 5. The percentage of correct responses decreased across retention intervals, $F(6, 12) = 18.24$, $p < .001$. More importantly, there was a significant main effect for comparison combinations, $F(2, 5) = 10.53$, $p < .05$, and orthogonal comparisons revealed that percentage correct was greater when the comparison stimuli differed on two dimensions (shape and size) than when the comparison stimuli differed on only one dimension (shape or size), $F(1, 2) = 34.41$, $p < .05$. There was no significant difference between comparison stimuli which differed only in size and comparison stimuli which differed only in shape. There was a significant subject \times comparison combination interaction, $F(4, 24) = 4.42$, $p < .01$, which was

Figure Caption

Figure 5. Mean percentage correct as a function of the retention intervals for combinations of comparison stimuli which are different in size and shape, different in size only, or different in shape only (upper left panel). Curves in this panel are shown separately in the remaining panels, where they are divided into trials in which the sample stimulus was a sphere or a cube.



apparently due to subject differences in correct matches for different comparison combinations.

Since the analysis of sample shapes revealed a higher percentage correct when the samples were spheres as opposed to cubes, the three comparison combination mentioned above were further separated into trials in which spheres or cubes were the sample. Figure 5 shows that the greatest difference between spheres and cubes occurred with comparison stimuli of different size only, and the least difference occurred with comparison stimuli of both different size and shape. A 3(monkey) x 2(sample shape) x 3(comparison combination) x 7(retention interval) mixed analysis of variance (the last three factors were treated as repeated measures variables) showed significant main effects for subjects, sample shape, comparison combination, and retention interval as well as significant interactions for subject x retention interval and subject x comparison combination (all which have been noted previously). The sample shape x comparison combination interaction was not significant. However, comparison of the means by a Newman-Keuls test showed that the following three groups of stimuli combinations were significantly different: (a) combinations in which the sample was a sphere and the comparison stimuli were different sizes and shapes (Sphere/Both Different), combinations in which the sample was a cube and the comparison stimuli were different sizes and shapes (Cube/Both Different), and combinations in which the sample was a sphere and the comparison stimuli were different sizes but the same shape (Sphere/Different Size), (b) combinations in which the sample was a sphere and the comparison stimuli were different shapes but the same size (Sphere/Different Shape), and (c) combinations in which the sample was a cube and the comparison stimuli were different sizes but the same shape (Cube/Different Size) and combinations in which the sample was a cube and the comparison stimuli were different shapes but the same size (Cube/Different Shape). (See Table 1.)

Table Caption

Table 1. Mean percentage correct as a function of sample stimulus shape (sphere or cube) and the relation of comparison stimuli in size and shape.

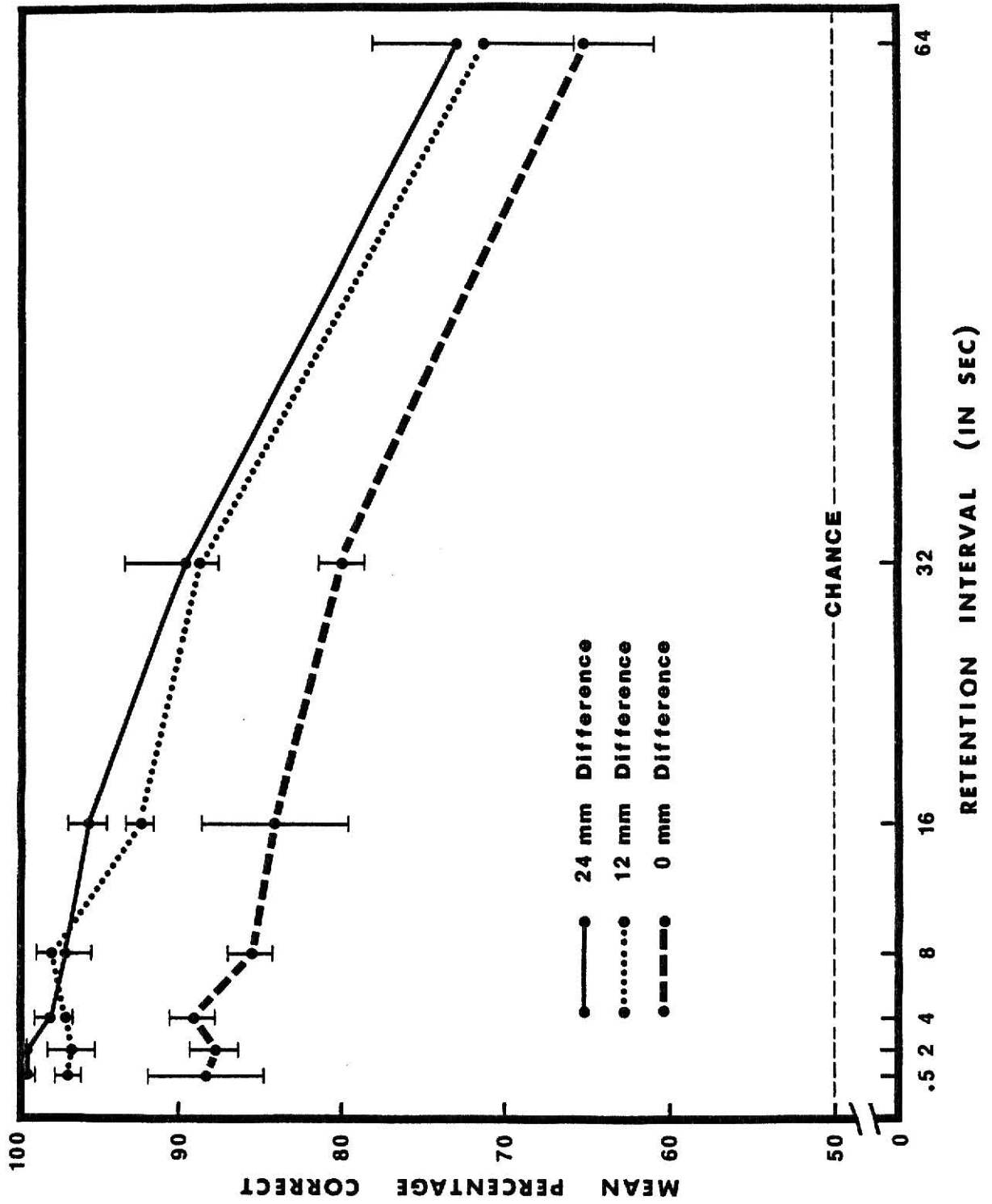
Relation of Comparison Stimuli

Sample shape	Different size,		Different size,		Different shape,	
	Different shape		Same shape		Same size	
Sphere	92.45		89.54		85.71	
Cube	91.87		81.34		80.05	

In the second method used to examine size and shape differences of comparison stimuli, trials were separated into those in which the diameter and length of the comparison stimuli were (a) equal (e.g., small sphere and small cube), (b) differed by 12 mm (e.g., small sphere and medium cube or medium sphere and large cube), or (c) differed by 24 mm (e.g., small sphere and large cube). For brevity, these categories are referred to as differences of 0-, 12-, and 24-mm, respectively. Comparison combinations in which the stimuli were not different in shape (e.g., small and large spheres), were not included in the analysis due to the confounding effect of shape similarity which would occur only in the last two categories (b and c). The percentage correct for each monkey (3), comparison stimuli combination (3), and retention interval (7), was determined and the data were analyzed by a mixed factorial analysis of variance in which the last two factors were treated as repeated measures variables. Figure 6 shows that the percentage of correct matches was highest at 24 mm and lowest at 0 mm. There were significant main effects for retention interval, $F(6, 12) = 28.01$, $p < .001$, and comparison combination, $F(2, 6) = 32.36$, $p < .001$. A Newman-Keuls test revealed that there were significant differences between 0- and 12-mm and 0- and 24-mm, but no significant difference between 12- and 24-mm. Comparison combinations in which diameter and length differ by 12 mm are comprised of both small and medium comparison stimuli and medium and large comparison stimuli. Since the size ratios are 1/2 and 2/3 respectively, it was possible that there would be a difference in the percentage of correct matches between these two comparison combinations. The percentage of correct responses was therefore determined for small and medium combinations (12 mm/S-M) and for medium and large combinations (12 mm/M-L). The percentages of correct responses for all categories, from highest to lowest, were 24 mm (93.25%), 12 mm/M-L (92.99%),

Figure Caption

Figure 6. Mean percentage correct across retention intervals for trials in which the comparison stimuli differed in diameter and length by 0-, 12-, or 24-mm. (Only combinations which are different in shape are shown.)



12 mm/S-M (90.26%), and 0 mm (82.85%), respectively. A Newman-Keuls test revealed that there were significant differences between all pairs of means except for the difference between 24 mm and 12 mm/M-L.

Table 2 shows the percentage of correct matches for comparison stimuli which were the same shape (spheres or cubes) but different sizes. For both spheres and cubes, the greatest number of correct responses were made when comparison stimuli were large and small. Fewer correct responses were made to medium and small comparison stimuli, and the least number of correct responses were made to large and medium stimuli.

Discussion

The present study demonstrates that (a) monkeys can be trained to perform SMS and DMS with haptic cues, (b) percentage correct in DMS decreases as a function of the retention interval, and (c) shape and size of the haptic stimuli are important factors in DMS performance. Although there are differences in apparatus and procedure, as discussed below, in many respects, SMS and DMS performance of monkeys with haptic and visual cues are comparable.

Training

Several problems were encountered with the training procedures. Occasionally monkeys did not respond to the stimulus objects, but instead, pulled the manipulanda beneath the objects. To correct this problem, after the animals were shaped to pull the manipulanda, the shape of the hole was adjusted so that the tips of the manipulanda were at the same level as the lower edge of the hole. (See Figure 2.) This made it more likely that the monkeys would touch the stimulus objects. Even with this modification, one monkey continued to pull the manipulanda below the objects. This problem was solved by placing the experimenter's hands loosely beneath the outer objects, thus obstructing responses to the manipulanda.

Table Caption

Table 2. Mean percentage correct as a function of comparison stimuli shape and comparison stimuli sizes. (Only combinations in which comparison stimuli were the same shape are presented.)

Comparison Stimuli Sizes

Comparison stimuli shape	Large & Small	Medium & Small	Large & Medium
Spheres	94.58	91.06	83.03
Cubes	90.29	81.91	71.80

Occasional position and object biases were eliminated by a correction procedure or by firmly holding the base of the manipulandum on the favored side, so that the object could be felt but not pulled. To improve correct responding during DMS training, intertrial intervals were sometimes shortened to 20 sec following correct responses and lengthened to 30 or 40 sec following incorrect responses. Since multiple responses to the sample decrease DMS errors (Jarrard & Moise, 1971), three or more responses to the sample stimulus were occasionally required to insure that the monkey was observing the stimulus. However, multiple responses seemed to have little effect on improving the monkeys' performance. Some of the training procedures used on the first monkey (Chompers), appeared to be unnecessary (or the length of time spent on a procedure was considered to be longer than needed), and were therefore shortened when training the second monkey (Ollie). However, this strategy may have been detrimental in SMS training with spheres and cubes. Because of his slow rate of acquisition, no procedures were shortened with Harry.

Discrimination of the haptic cues used in the present study are comparable to other experiments with haptic, visual, and auditory cues. Monkeys in the present experiment learned the first haptic discrimination (\bar{X} = 994 trials; range = 352 - 1,476), in a number of trials roughly comparable to that required in several other studies. Haptic discrimination for inverted solid figure C's was learned in a mean of 1,092 trials and range of 600 - 2,090 (Ettlinger et al., 1966), visual discrimination and one reversal for flickering lights was learned in a mean of 925 trials (Jarrard & Moise, 1971), and an auditory discrimination for frequency and intensity was learned in a mean of 862 trials and range of 180 - 2,520 (Wegener, 1964). Fewer trials were required to learn haptic discrimination for a cylinder and sphere (\bar{X} = 395; range = 270 - 560; Ettlinger et al., 1966), and a visual discrimination with one reversal

for colors ($\bar{X} = 146$) and patterns ($\bar{X} = 367$; Jarrard & Moise, 1971). A criterion level of 90% correct responses was required in all of the above studies, but there were a number of differences in apparatus and procedure in addition to the cue modality. Given the differences between these studies, the results are surprisingly consistent across studies. The consistency of these findings suggests that monkeys can learn haptic, visual, and auditory discriminations at about the same rate.

In some respects, SMS acquisition with haptic cues is comparable to SMS acquisition with other modalities. In the present study haptic SMS was acquired in a mean of 2,725 trials (range = 435 - 6,332). This is comparable to SMS acquisition with visual cues (Bauer & Fuster, 1978). There are apparently no primate studies which have examined SMS acquisition with only auditory cues. Although D'Amato (1973) and his coworkers have had extensive experience training monkeys in SMS with visual cues, they were unable to train monkeys to perform SMS with auditory stimuli. Dewson & Burlingame (1975) trained monkeys in a conditional matching task in which monkeys responded to a red panel after hearing a 1,000-hertz tone and to a green panel after hearing a burst of white noise. The first few animals trained in this task required approximately 49,500 trials to criterion, but after several years experience at training animals in this task, about 12,000 trials were necessary (Dewson, Note 1). The greater number of trials required in Dewson's task may be due to the conditional matching procedure (D'Amato & Worsham, 1974), or to the cross-modal nature of the task (Davenport, Rogers, & Russell, 1973). Although monkeys may acquire haptic, visual, and auditory SMS tasks at a faster rate with better training procedures, it is important to note that with currently available techniques, the amount of training necessary for monkeys to learn discriminations and SMS with haptic and visual cues was not

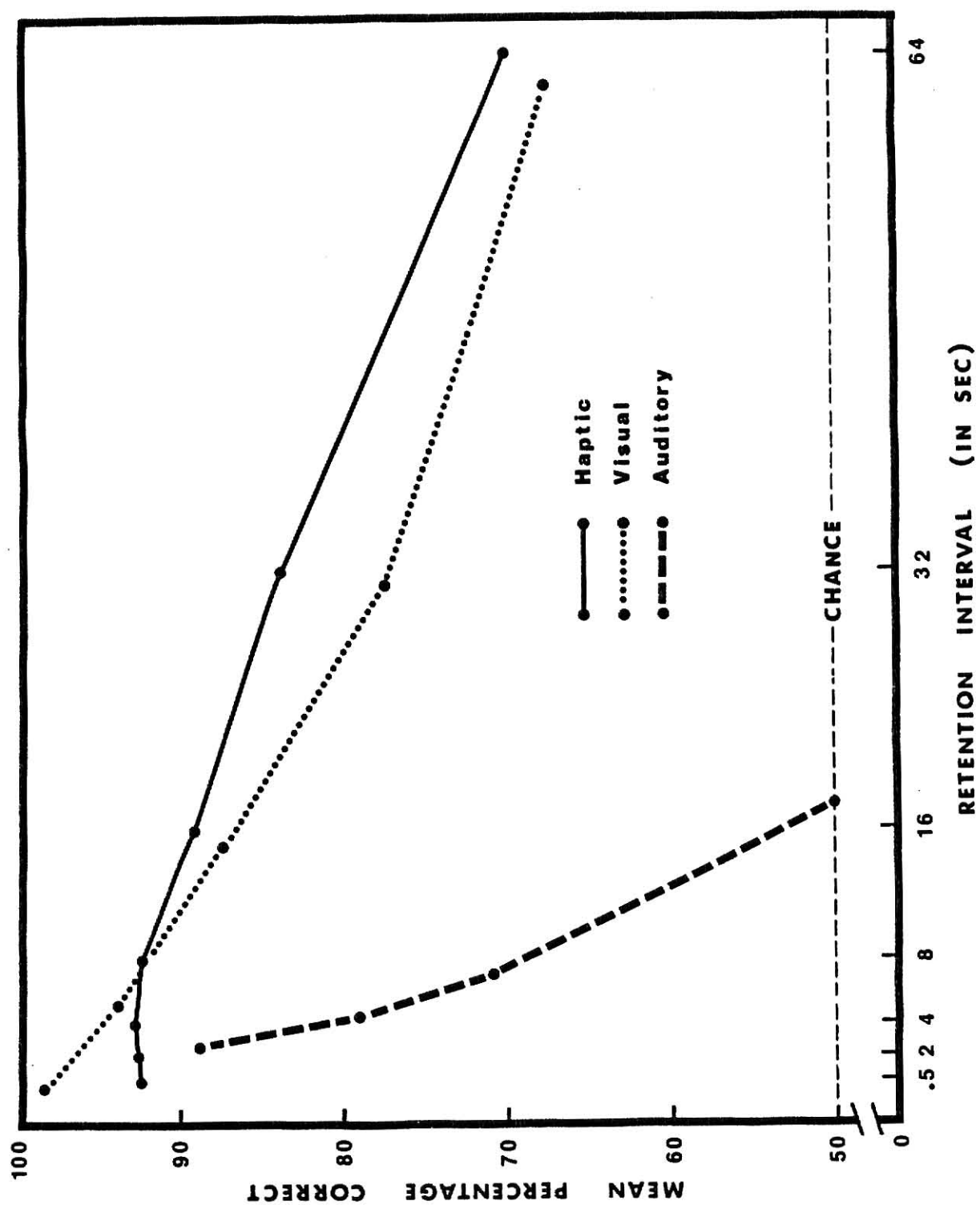
substantially different. This occurs in spite of the fact that visual cues are presented simultaneously, whereas haptic cues are presented sequentially and must be retained until a response is made.

Testing

The most consistent finding throughout all the DMS analyses was that the percentage of correct matches decreased as a function of the retention intervals. This decrease occurred for all monkeys, and the rate of decrease is fairly comparable for all sample stimuli and comparison combinations. Although matching errors did not reach chance levels even at the longest retention intervals, this may be due to the extensive training given to the monkeys (D'Amato, 1973). The decrease in percentage correct across retention intervals in the present study is similar to that found in visual DMS studies. Figure 7 shows the mean percentage correct for the monkeys in the present study and mean percentage correct for monkeys in a procedurally similar visual DMS task (Jarrard & Moise, 1971, Figure 9). Although there are a number of differences in procedure and apparatus between these two studies (making meaningful comparisons difficult), comparison of these curves indicates a striking similarity. Figure 7 also shows that the percentage correct in an auditory DMS task (Dewson & Burlingame, 1975) decreases more rapidly as a function of the retention interval than in haptic or visual DMS. As discussed above, in this auditory task, monkeys pressed a red panel after hearing a 1,000-hertz tone and a green panel after hearing a burst of white noise. This procedure was used to test recall capacity in monkeys as opposed to retrieval processes which are usually measured in non-conditional DMS tasks. D'Amato and Worsham (1974) found that the percentage of correct matches in visual DMS was only slightly higher when the sample and comparison stimuli were from the same set of stimuli (non-conditional DMS) than when samples from one set of stimuli

Figure Caption

Figure 7. Mean percentage correct in DMS as a function of the retention interval for haptic cues (present study), visual cues (Jarrard & Moise, 1971, Figure 9), and auditory cues (Dewson & Burlingame, 1975).



were conditionally matched to comparison stimuli from another set. Although this study indicates little difference between conditional and non-conditional DMS task when stimuli are presented in the same modality, the more rapid decrease over retention intervals in the Dewson and Burlingame study may be due to the cross-modal nature of the task. At this time there are no reports in which monkeys were trained to perform SMS or DMS with only auditory stimuli.

In the present experiment, there were two general predictions regarding the size and shape of the stimulus objects. First, the percentage of correct matches was expected to be independent of the size and shape of the sample stimulus. Although there were no significant differences in matching based on sample size (collapsed over comparison combinations), monkeys did make significantly more correct matches with spheres (89.95%) than cubes (85.24%). (See Figure 4.) Second, monkeys were expected to make fewer errors when the comparison stimuli differed on two dimensions (size and shape) compared to one dimension (size or shape). Matching was in fact higher for comparison stimuli which differed in both shape and size (92.15%) relative to stimuli which differed only in size (85.44%) or shape (82.87%). (See Figure 5, upper left panel.) However, as discussed below, these latter results are primarily due to performance with specific pairs of comparison stimuli.

Inspection of Figure 4 shows that the difference in percentage correct with spheres and cubes as samples is essentially the same across retention intervals. Therefore, it appears that higher matching errors with cubes is due to discrimination deficits and not due to differences in retention. One possible explanation for these unexpected results for sample shape is that the portion of the cube that is actually touched may not provide a discriminative cue for the monkeys, because the surfaces, edges, and/or corners that are touched may be the same for small, medium, and large cubes. For example,

on a given trial a monkey could touch only (a) one corner, (b) a portion of an edge, or (c) a portion of a flat surface. Any one of these cues would provide information that the sample was a cube but would not provide information on the size of the cube. This type of discrimination problem is less likely with spheres, since the curvature of a sphere of a particular size will be the same over the entire surface area while the curvature will not be the same for spheres of different sizes. Thus, when a sphere was the sample stimulus, a monkey would usually have information on both size and shape.

Based on the assumption that monkeys were not always provided with cues for stimulus size, and that this was more likely to have occurred when the stimuli were cubes, it was expected that this discrimination deficit would occur primarily when the sample and both comparison stimuli were cubes. A discrimination difficulty was not expected to occur (a) when a sphere was the sample, since size was available as a cue, or (b) for Cube/Both Different or Cube/Different Shape combinations, since sample shape was available as a cue for a correct match. It was thus anticipated that matching would be (a) highest for Sphere/Both Different and Cube/Both Different (since cues on two dimensions were provided for correct matching), (b) lower for Sphere/Different Size, Sphere/Different Shape, and Cube/Different Shape (since cues on only one dimension were provided), and (c) lowest for Cube/Different Size (because size cues may have been frequently unavailable).

As expected, when both size and shape of the comparison stimuli differed, sample shape was of little consequence. D'Amato (1973) has suggested that on a given trial an animal can respond correctly either because (a) the correct comparison stimulus is recognized as being the same as the sample, (b) the incorrect comparison stimulus is recognized as being different from the sample,

or (c) because of a combination of both processes. Therefore, even if the monkey did not acquire size cues when a cube was the sample, it may have recognized that the sphere comparison stimulus was not the same as the sample. Thus sample shape should have had little effect on these trials. The results also show that, as anticipated, monkeys appeared to have more difficulty matching when the comparison stimuli were cubes of different sizes (81.34%) than when they were spheres of different sizes (89.54%), because size cues for cubes may not always have been available. (See Table 1.) Furthermore, the probability of touching portions of cubes which do not provide size cues increases as the size of the compared cubes increases. In fact, more errors were committed when the sample and comparison stimuli were large and medium cubes than with large and small cubes or medium and small cubes (Table 2). This same effect can be seen to a lesser extent with spheres, since the curvatures of pairs of larger spheres were possibly more similar than curvatures of smaller spheres. The percentage of correct matches was lowest for large and medium spheres and highest for large and small spheres and medium and small spheres.

One of the results which was not expected was that matching for Cube/Different Shape (80.05%) was significantly lower than for Sphere/Different Shape (85.71%). (See Table 1.) This result may be specific to trials in which the comparison combinations were small spheres and small cubes. Correct matching for this comparison combination was 74.53% when the sample was a sphere and 61.60% when the sample was a cube. It is possible that cues for shape are not as salient when the stimuli are very small. However, the reason for a lower percentage of matches when the cube was the sample is not known. When trials in which small spheres and cubes served as the comparison stimuli were removed, the difference between Cube/Different Shape (89.25%) and Sphere/Different Shape (91.31%) was reduced.

The other unexpected result was that matching for Sphere/Different Size was not significantly different than Sphere/Both Different or Cube/Both Different. These results are not surprising if one assumes that information provided by cues of one dimension is as sufficient for making a correct match as information provided by cues of two dimensions. That is, information on size differences alone will allow a monkey to make as many correct matches as information on both size and shape differences. In fact, if one does not account for trials in which both comparison stimuli were small spheres and cubes (because of the confounding effect of small size discriminations), the percentage of correct matches is roughly equivalent for all combinations of comparison stimuli, excluding Cube/Different Size (in which size cues may not always have been available. Thus, although the original analysis indicated that matching was significantly higher for comparison stimuli which differed on two dimensions, as opposed to one dimension, closer inspection of the data suggests that such a conclusion may be spurious. These results are consistent with visual DMS studies (Devine et al., 1979; Devine et al., 1977), where matching on trials in which stimuli differed in both color and pattern was not always higher than trials in which stimuli differed only in color or pattern.

Although the number of dimensions on which cues vary may not be an important factor in the present experiment, the degree of size difference does appear to have an effect on matching performance (Figure 6). The greatest number of matching errors were committed when the sizes of the comparison stimuli were the same (82.85%). Fewer errors were made when the sizes of the stimuli differed by 12 mm (91.62%) and the least number of errors occurred when the sizes of the stimuli differed by 24 mm (93.25%). However, the difference between 12 mm and 24 mm was not significant. These results are

consistent with those in a study of haptic discrimination (Schwartzbaum, 1965), in which it was noted that when the differences between haptic stimuli are progressively reduced, the percentage of correct discriminations decreases. It should be noted that the percentage of correct matches was greater for medium and large as opposed to small and medium comparison stimuli. Although the difference in size was the same for both pairs of stimuli, for monkeys, the degree of discrimination difficulty between the pairs apparently was not the same.

Figures 4 through 6 show that the differences in the percentage of correct matches between sample stimuli or between combinations of comparison stimuli are essentially the same at most retention intervals. This suggests that these results are due to differences in discriminating between objects and not due to differences in retention. In terms of the trace decay model, the initial trace strength and rate of decay appear to be independent of discrimination differences. Although the purpose of the present study was not to compare and contrast animal STM models, but to provide an additional procedure for testing models of animal memory, the results of this experiment are consistent with a trace decay model. Furthermore, comparison of haptic and visual DMS in monkeys suggests that the memory trace for haptic and visual cues decays at a comparable rate, but at a slower rate than a trace for auditory cues. The concept of memory trace strength can be further examined in haptic DMS by manipulating the number of required responses to the sample stimulus. If the results in haptic and visual DMS are consistent, one would expect that the number of matching errors would decrease as the sample duration or number of responses to the sample increases (Devine et al., 1977; Jarrard & Moise, 1971). The effects of spacing or massing of sample presentations could also be tested (Herzog et al., 1977).

Proactive interference models of memory could be examined by manipulation of the events which occur prior to sample presentation (Worsham, 1975). These manipulations could include variations in the amount and types of interference, both within the haptic modality and across other modalities.

Similar manipulations can be used to study retroactive interference. A change in retention interval illumination during haptic DMS can provide insight as to whether the increase in errors occurring with visual cues are specific to that modality (Bauer & Fuster, 1978; D'Amato & O'Neill, 1971). Inconsistencies in visual DMS experiments regarding the consequences of auditory interference (Fuster & Bauer, 1974; Worsham & D'Amato, 1973), could also be examined. The effects of varying the degree of similarity between the sample and interfering stimulus and the effect of requiring operant responding during the retention interval are currently under investigation by the author.

Evidence for the temporal discrimination model has been provided by manipulation of the elapsed time between presentation of the comparison stimuli and their previous presentation as the sample or non-matching comparison stimulus. This has been accomplished by varying the intertrial interval (Jarrard & Moise, 1971), using the non-matching comparison stimulus as an interfering stimulus (Jarvik et al., 1969), changing the frequency with which both comparison stimuli are presented (Mason & Wilson, 1974), and by varying the size of the sample set (Worsham, 1975). These manipulations can also be accomplished with haptic stimuli, and comparisons of the effects of these manipulations can be made across modalities.

In conclusion, each of the models which have been presented to explain STM deficits can be examined in haptic DMS. Such tests will provide information on whether similar memory processes occur across modalities and may help determine whether there are any distinct differences between the various

models of STM or whether each model represents a different aspect of the same process. At least on the basis of results in haptic DMS, it is important to realize that no model can be sufficient in explaining the degree or type of errors which occur in a DMS task unless stimuli discriminability is also considered as a factor.

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HAPTIC MATCHING-TO-SAMPLE IN RHESUS MONKEYS

by

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Three rhesus monkeys (Macaca mulatta) were trained in simultaneous (SMS) and delayed matching-to-sample (DMS) tasks using haptic cues. The stimuli were spheres and cubes of three sizes. An SMS level of 90% correct responses was acquired in a mean of 2,725 trials. In DMS, monkeys made slightly greater than 90% correct matches on trials with short retention intervals. Percentage correct decreased uniformly as a function of the retention interval, until at the longest retention interval (64 sec), matching was 70% correct. A greater percentage of correct matches was made when the sample stimuli were spheres as compared to cubes. Fewer matching errors were made when the comparison stimuli differed in both size and shape than when the comparison stimuli differed only in size or shape. However, it is not clear whether there is a basic relationship between the number of available cues and matching performance, or whether these results are artifactual. This study indicates that monkeys can be trained to perform a task which requires retention of haptic cues and that performance with haptic cues is comparable to that found with visual cues.