Comparing objects in memory: Evidence suggesting an internal psychophysics*

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In this experiment, Ss were visually presented with the names of two animals and were required to throw a switch under the name of the larger animal. Although error rates were relatively low (4.5%), reaction time (RT) was largely an inverse linear function of the logarithm of the estimated difference in animal size. Since RT is similarly related to size differences when Ss make direct perceptual comparisons (e.g., of lengths of line), it was argued that Ss compare animal names by making an "internal psychophysical judgment." A more general model was then proposed for answering, from memory, questions of the form, "Which is /X/, /A/ or /B/?" where /X/ is any comparative adjective and /A/ and /B/ are any concrete nouns.

We often compare objects by retrieving information from memory rather than by direct perceptual inspection. For example, people can quickly and accurately answer numerous questions of the form, "Which is /X/, /A/ or /B/?" where /A/ and /B/ are concrete nouns and /X/ is the comparative form of an adjective. Despite the obvious importance of these memorial comparative judgments, we know very little about how they are accomplished.

One hypothesis is that the mental process involves an "imagined perceptual comparison" of the objects along the dimension in question. This hypothesis makes an easily tested prediction about the time required for such judgments. For example: substituting /larger/ for /X/ and animal names for the concrete nouns /A/ and /B/ produces questions of the form, "Which is larger, moose or roach?" "Which is larger, moth or flea?" etc. According to this imagined perceptual comparison model, the time required for comparing these names should vary inversely with difference in size of the animals they represent, much as judgment time is related to the magnitude of physical differences in a psychophysical task (Welford, 1960; Woodworth & Schlosberg, 1954, p. 33).

The present experiment is designed to provide an empirical test of this simple prediction about the time required for comparing objects in memory. Since size is a salient property of objects, and animals are familiar objects which vary greatly along this dimension, this experiment attempts to supply information about the more general issue of comparing objects in memory by exploring the influence of differences in animal size on the speed of comparing animal names.

METHOD

Subjects

The Ss were 24 undergraduates at Bates College who fulfilled a course requirement by participation in the experiment. They were offered a monetary incentive for fast but accurate responding.

Stimuli, Apparatus, and Procedure

Three different sets of seven animal names, which appear in Table 1, were used for stimuli. Each stimulus consisted of a pair of animal names drawn from the same set and typed side by side on a white card. On each trial, a stimulus card was positioned behind a half-silvered mirror and was not visible until a light and timer were simultaneously activated. Ss were required to throw a switch on the same side as the name of the larger animal, and reaction times were recorded in milliseconds on a Hunter Model 1520 digital clock. Each S was presented with all possible pairs of animal names drawn from within two of the three columns in Table 1, and agreed in advance on the size orderings within the columns. The order of presentation was random, and each pair appeared twice in a left-right order and twice in a right-left order, making 168 trials per S. The Ss were given speed and accuracy feedback after each trial, and each S's total session

Table 1
Animal Names Used in the Experiment¹

Ordinal Position on Size Dimension	Three-Letter Names	Four-Letter Names	Five-Letter Names
1	ANT	FLEA	LOUSE
2	BEE	MOTH	ROACH
3	RAT	FROG	QUAIL
4	CAT	DOVE	SHEEP
5	HOG	DUCK	HORSE
6	COW	WOLF	MOOSE
7	ELK	BEAR	WHALE

Note—The names are ordered according to size from smallest (top row) to largest (bottom row). Both names in a pair were always drawn from the same column (i.e., a S might be presented with ANT-CAT but never with ANT-DOVE).

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Fig. 1. Mean RT and percent errors as a function of ordinal position difference between animals.

lasted approximately 50 min. Over the whole experiment, every possible within-set pairing of the animal names in Table 1 appeared equally often. At the conclusion of the reaction time trials, each S was asked to assign a number to each animal name, indicating his estimate of that animal's size.

RESULTS

Since Ss agreed in advance on the size orderings in Table 1, on the average the greater the ordinal position difference between animal names, the greater the

estimated difference in animal size. For example, any two animals in adjacent positions in the size ordering (illustrated by the columns in Table 1) have an ordinal position difference of one, while ANT-ELK, FLEA-BEAR, and LOUSE-WHALE represent ordinal position differences of six.

Figure 1 presents overall mean RT as a function of ordinal position difference (error RTs are not included here or elsewhere in the paper). It is clear by inspection that RT is inversely related to ordinal position difference, and this is confirmed by analysis of variance, which reveals a highly significant main effect of ordinal position difference [$F(5,225) = 119.29$, $p < .001$]. The main effect of word length was not significant [$F(2,45) = 1.32$, $p > .10$], nor was the interaction between word length and ordinal position difference [$F(10,225) = 1.42$, $p > .10$].²

To obtain a more sensitive estimate of the relation between RT and difference in animal size, the animal size estimates made by each S were converted to Z units, separately for each set of animals, and averaged over Ss. Then, for each animal name pair, the estimated size of the smaller animal in Z units was subtracted from the estimated size of the larger animal in Z units. Figure 2 presents mean RT as a function of the logarithm of this estimated difference in animal size. Mean RT is an approximately linear inverse function of the logarithm of the estimated difference in animal size. The r^2 values in the upper portion of the figure provide an estimate of the proportion of variance accounted for by linear regression ($p < .001$ in each case).

Before discussing the results, several possible sources of artifact must be examined. One potential problem

Fig. 2. Mean RT as a function of mean estimated difference in animal size. The scale for the abscissa is logarithmic. Each point represents the mean correct RT (64 observations per point, barring errors) for a unique animal pair (21 pairs at each word length).

arises from the fact that the ordinal position of an animal is closely tied to the probability that the animal will have been correct (i.e., larger) on previous trials. Thus, over a number of trials, Ss may develop response biases such that the tendency to choose a given animal as the larger member of a pair is a direct function of that animal's history of being correct on previous trials. Animals which differ in ordinal position by a small amount will also, on the average, differ by a small amount in their incidence of being correct on previous trials. This could well produce high conflict between response tendencies and result in long RTs. By the same argument, animals which differ in ordinal position by a large amount could produce low response conflict and short RTs.

But at least two lines of evidence suggest that this hypothesis cannot account for the major effects in the present experiment. Moyer and Landauer (1967) used a design structurally identical to that of the present experiment to study the time needed to choose the larger of two digits. They found RT to be an inverse nonlinear function of numerical difference between digits, even in a control experiment where a digit's size and previous history of being correct were independent. Parkman (1971) and Sekuler, Rubin, and Armstrong (1971) reported variations of the Moyer and Landauer (1967) study and they, too, found RT to be relatively unaffected by holding constant the probability of a particular digit's being correct. Thus, conditions which eliminate the possibility of the kind of response bias discussed above apparently do not change the pattern of results in these experiments. Although Ss in these studies compared digits in memory rather than animals, the strong structural similarities between these tasks and the present experiment should not be overlooked.

But we can test more directly for the presence of such an artifact by examining data from the first trial in the current experiment.³ RTs on the first trial cannot be due to response biases developed over previous trials since there are no trials prior to the first. Twenty-one Ss responded correctly on the first trial. Their RTs were grouped, according to ordinal position difference between the animals in each stimulus pair, so as to establish a roughly equivalent number of observations at each of three ordinal position differences.⁴ A simple one-way analysis of variance (the observations are completely independent) revealed a significant main effect of ordinal position difference [$F(2,18) = 6.982$, $p < .006$]. Thus, ordinal position difference is inversely related to RT even on the first trial of the experiment, and the size of the effect (see Note 4) is at least as large as it is in the complete experiment. It therefore seems very unlikely that a response-bias artifact of the sort described above has contaminated the data.

These results could, of course, be due to a spurious correlation between animal size difference and some other variable. However, partialing out two such possible sources of artifact, estimated size of the smaller animal

Fig. 3. Mean RT as a function of difference in line length. The scale for the abscissa is logarithmic. (Average of data from three Ss reported by Johnson, 1939, p. 41.)

and word frequency, did not produce statistically significant reductions in the size of the reported relationships.⁵

DISCUSSION

The time needed for comparing the size of animals in memory is an inverse linear function of the logarithm of estimated difference in animal size. This finding is particularly interesting because similar data are obtained when people perceptually compare stimuli that differ in some physical property. For example, Johnson (1939) studied the time required to discriminate between lines of two different lengths. Ss were asked to throw one of two switches depending on which of two simultaneously presented lines was longer. Figure 3, based on data reported by Johnson (1939, p. 41),⁶ shows mean RT as a function of the difference in size of the lines which Ss compared. Here RT is an inverse linear function of the logarithm of the difference in line length. A comparison of this figure with data from the present experiment (Fig. 2) strongly suggests that a similar mechanism is involved in perceptual and memorial size comparisons.⁷

This suggestion of a similarity between perceptual and memorial judgments is not unique. Perhaps most relevant are data recently reported by Shepard and Chipman (1970). Their Ss ordered pairs of states along a similarity of shapes dimension in a perceptual condition (outline drawings of the states were displayed) and in a memorial condition (names of the states were

presented). Their results led them to argue that Ss make similar kinds of comparisons under perceptual and memorial conditions and, furthermore, that judgments under both conditions are based on geometrical properties of the actual shapes of the states.

The present findings can be fairly well accounted for by postulating that Ss first convert the animal names to analogue representations that preserve animal size, and then compare these analogues by making an "internal psychophysical judgment." Smaller size differences between animals are presumably represented as smaller differences between the internal analogues, and the resulting decreased discriminability is reflected by lengthened RTs and increased error rates. A similar model was proposed by Moyer and Landauer (1967) to account for the data in a task in which Ss chose the numerically larger of two single digits. (Although there are similarities between comparing objects and comparing numbers, and close parallels exist between the two sets of data, these issues will be treated in a later paper.)

A serious deficiency in this formulation is, of course, that the nature of the postulated analogue representations is not specified. They may be positions along an imagined spatial dimension (De Soto, London, & Handel, 1965), temporal patterns in neural "ensembles" (John, 1967, 1972), rich images, or an as yet unimagined possibility.⁸ But for present purposes, their essential feature is that they function as analogue devices which preserve information about animal size.

Although at present the data are limited to one dimension (size) and one group of concrete nouns (animal names), the model that is proposed to account for the data can be stated in more general terms; this permits two clear predictions which are subject to test. First, animals are certainly only a subset of objects which vary in remembered size. It is therefore predicted that the time required to answer, "Which is larger, /A/ or /B/?" where /A/ and /B/ are concrete nouns, will vary inversely with the size difference between the objects represented by /A/ and /B/. Second, size is only one dimension on which objects can be compared in memory. It is therefore predicted that the time required to answer, "Which is /X/, /A/ or /B/?" where /X/ is the comparative form of an adjective, will vary inversely with the difference between /A/ and /B/ on the dimension designated by /X/.

These predictions follow from the assumption that in deciding "Which is /X/, /A/ or /B/?" a person proceeds as follows: First, /A/ and /B/ are converted to internal analogues that preserve information about the positions of /A/ and /B/ along the dimension designated by /X/. S then makes an "internal psychophysical judgment" about the analogues to determine which is /X/. This formulation suggests a common underlying comparative stage in memorial and perceptual object comparisons.⁹

REFERENCES

- De Soto, C. B., London, M., & Handel, S. Social reasoning and spatial paralogic. *Journal of Personality & Social Psychology*, 1965, 2, 513-521.
- John, E. R. *Mechanisms of memory*. New York: Academic Press, 1967.
- John, E. R. Switchboard versus statistical theories of learning and memory. *Science*, 1972, 177, 850-864.
- Johnson, D. M. Confidence and speed in the two-category judgment. *Archives of Psychology*, 1939, No. 241, 1-52.
- Moyer, R. S., & Landauer, T. K. Time required for judgments of numerical inequality. *Nature*, 1967, 215, 1519-1520.
- Parkman, J. M. Temporal aspects of digit and letter inequality judgments. *Journal of Experimental Psychology*, 1971, 91, 191-205.
- Sekuler, R., Rubin, E., & Armstrong, R. Processing numerical information: A choice time analysis. *Journal of Experimental Psychology*, 1971, 89, 75-80.
- Shepard, R. N., & Chipman, S. Second-order isomorphism of internal representations: Shapes of states. *Cognitive Psychology*, 1970, 1, 1-17.
- Thorndike, E. L., & Lorge, I. *The teacher's word book of 30,000 words*. New York: Bureau of Publications, Teachers College, Columbia University, 1944.
- Welford, A. T. The measurement of sensory-motor performance: Survey and reappraisal of twelve years' progress. *Ergonomics*, 1960, 3, 189-230.
- Woodworth, R. S. & Schlosberg, H. *Experimental psychology*. New York: Holt, Rinehart & Winston, 1954.

NOTES

1. These size orderings were determined by pretesting with 20 other Bates undergraduates. Each set of animal names was randomly ordered and the (pretest) Ss were asked to arrange them according to size. At least 17 of the 20 pretest Ss produced the size orderings which appear in each column in Table 1. All 24 Ss run in the reaction time experiment agreed with the orderings in the columns they were tested on (six Ss were not tested due to failure to meet this criterion).

2. The absence of a significant effect of word length need not be surprising since no attempt was made to match the three series on word frequency, pronounceability, intralist discriminability, etc. The main effects of, or the variability associated with, these factors might easily eliminate a small effect due to word length. Several word lengths were used to provide internal replication rather than to permit assessment of the effect of word length.

3. I thank Tom Landauer for pointing out the relevance of the first-trial data.

4. The table below presents the total number of observations and overall mean RT at each ordinal position difference.

Ordinal position difference	1	2	3, 4, 6
Total number of observations	8	7	6
Mean RT (seconds)	2.186	1.460	1.152

5. Size of the smaller animal was considered since Parkman (1971) has recently argued that a sizable portion of the RT variance in a task where Ss choose the larger of two digits can be attributed to the smaller digit. As to word frequency, the frequency of occurrence in English of each animal name was estimated by the Thorndike-Lorge (1944) count. Since it is not clear how the frequency of occurrence of a pair of animal names is best represented, several possibilities were explored. The logarithm of the sum of the frequencies of occurrence of the names in a pair correlated best with RT, and this number was used in computing partial correlations (as this would seem to be a conservative test of the relationship between RT and animal size difference).

6. Johnson reports data for three Ss in his Table XV, p. 41. The data which appear in Fig. 3 were obtained by averaging RTs

reported for these three Ss under what he calls "usual" conditions.

7. Welford (1960) has proposed a general equation for discrimination RTs when Ss judge differences between physical quantities. This equation, $RT = a + K \log \left[\frac{\text{larger}}{\text{larger} - \text{smaller}} \right]$, although not independent of $\log (\text{larger} - \text{smaller})$, also provides a fair fit to the present data. The r^2 values are .656, .687, .618, respectively, for three-, four-, and five-letter animal name pairs ($df = 19$ and $p < .001$ in each case). For this computation, the size of each animal was based on the mean of the numbers assigned to it by the Ss.

8. These possible modes of internal representation are not necessarily completely independent. For instance, temporal patterns in neural ensembles might result in rich images arranged along an imagined spatial dimension.

9. Alternative explanations for how we compare objects in memory need to incorporate these data, but this experiment does not, of course, preclude the possibility of accounting for the data without postulating an internal psychophysics.

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