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Hunting for individual differences in cognitive processes: Verbal ability and semantic processing of pictures and words

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Semantic category decisions were examined for single picture and word stimuli. Consistent with previous research, pictures yielded faster latencies than words and both showed significant taxonomic frequency effects for positive decisions. The results are interpreted in terms of general models for semantic verification, in which both pictures and words involve access to the same underlying semantic knowledge base. The latter conclusion was supported by correlation-regression analyses on individual item latencies. Variations in processing latency as a function of stimulus mode, taxonomic frequency, and type of decision were analyzed with respect to adult individual differences in verbal ability. The results uniformly failed to show a significant relationship between verbal ability and any processing speed measure. The lack of any significant relationship is discussed in light of previous results on verbal ability and processing speed, suggesting obvious qualifications of past results and possible reinterpretations of the meaning of previously obtained speed differences.

Recent research comparing the processing of pictures and words has clearly shown a superiority of pictures in the speed of both semantic category and physical size judgments (e.g., Pellegrino, Rosinski, Chiesi, & Siegel, 1977; Potter & Faulconer, 1975; Rosch, 1975). The processing speed inferiority of words within an adult college population may reflect additional acoustic-phonemic decoding processes that occur prior to higher level semantic processing. Evidence that is consistent with such an interpretation of word-picture differences in the speed of accessing semantic codes comes from additional developmental research. Rosinski, Pellegrino, and Siegel (1977) have shown that the superiority of pictorial processing speed declines with age, although it remains highly significant in an adult college sample. In a task where pairs of pictures or words were simultaneously presented for same-different category judgments, the picture stimuli showed advantages of 800, 484, and 185 msec for second-grade, fifth-grade, and college samples, respectively. These data suggest that as age and verbal ability increase there is a corresponding decrease in the additional time required to process verbal stimuli prior to accessing semantic codes in permanent memory. Further evidence consistent with this interpretation has been provided by Rader (Note 1), in a study where graduate students with high verbal aptitude scores (above-700 GREs) failed to show any significant difference in the semantic processing of picture and word pairs. The latter data suggest relatively direct access to meaning codes for both types of stimuli.

The relative and absolute decreases in semantic processing speed for words vs. pictures as a function of age and increasing verbal ability may be related to processing speed differences observed in the comparison of college students with high and low verbal aptitude scores (e.g., Hunt, Frost, & Lunneborg, 1973; Hunt, Lunneborg, & Lewis, 1975). Hunt et al. (1975) have shown that college students with high verbal aptitude scores are faster at accessing and comparing internal name codes for individual letter stimuli, while no processing speed differences exist for physical code comparisons. Given such individual difference data and the previously described developmental data on word-picture processing differences, it can be hypothesized that college students with high verbal aptitude scores should show an absolute superiority over students with low verbal scores in the speed of semantically processing verbal stimuli. Additionally, the word-picture difference should be inversely related to verbal ability. The present research was designed to investigate the existence of such effects in a task where single words and pictures were presented to subjects for simple category verification. The items represented several different semantic categories and varied in taxonomic and printed frequency within their respective categories. The experimental manipulations of frequency and mode of

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stimulus presentation permit the investigation of several possible sources of individual differences in semantic processing speed. Verbal ability may be correlated with the speed of processing both high- and low-frequency verbal stimuli or speed differences between such stimuli. Similarly, verbal ability may be correlated with word-picture differences in the speed of processing high- and low-frequency stimuli.

A second purpose of the present research was to further examine the relationship between picture and word decision latencies for individual items representing different degrees of category prototypicality. In previous research it has been shown that similarity of subcategory facilitates the speed of positive semantic decisions for both word and picture stimulus pairings and that there are significant correlations between picture and word decision latencies on individual concept pairings and single items (e.g., Pellegrino et al., 1977). Such results have been interpreted as further support for the argument that pictures and words have access to the same unitary knowledge base, as opposed to two separate knowledge bases (e.g., Paivio, 1975). Given such previous results and general models for semantic verification (e.g., Smith, Shoben, & Rips, 1974), it was predicted that taxonomic frequency, which is highly correlated with prototypicality ratings of individual items (Rips, Shoben, & Smith, 1973), would significantly affect picture and word decision latency, and that correlations between picture and word decision latencies on individual items would again be obtained. Such results would provide additional support for the argument that semantic decisions for both pictures and words are mediated by the same underlying knowledge base.

METHOD

Subjects

The subjects were 40 University of Pittsburgh undergraduates participating to fulfill a course requirement. Verbal aptitude scores from the Scholastic Aptitude Test (SAT) were available for 34 of the subjects. The mean verbal SAT score was 512, with a standard deviation of 93 and a range of 330-760. The corresponding percentile ranks for college-bound students were approximately the 72nd percentile for the mean and the 16th-99th percentiles for the range. The 10 subjects with the highest verbal scores had an average percentile rank of 93, with a range of 83-99. The 10 subjects with the lowest verbal scores had an average percentile rank of 39, with a range of 16-54.

Design and Materials

The present design included one between-subjects factor (order of category presentation) and four within subjects factors. The within-subjects factors were: stimulus form (pictures vs. words), frequency (high vs. low taxonomic frequency), decision type (positive vs. negative verifications), and category (10 different semantic categories).

Eleven categories and six instances per category were selected from the Battig and Montague (1969) norms. The furniture category was used for initial practice trials, and the experimental categories were: carpenter's tools, vehicles, body parts, four-legged animals, weapons, articles of clothing, kitchen utensils, musical instruments, insects, and fruits. Within each category, there were three high and three low taxonomic frequency instances. The average taxonomic frequencies of the high and low instances were 350 and 34, respectively. The Kučera and Francis (1967) average printed frequencies were 84 and 4.5 for the high- and low-frequency instances, respectively. The correlation between printed frequency and taxonomic frequency for the 60 unique category instances was .56 ($p < .01$). For each of the items, an unambiguous line drawing was produced. Slides were made for each line drawing and for lowercase printed words corresponding to each category instance.

The category instances were arranged in 11 category blocks of 24 items each. Each category block contained 12 instances requiring positive verifications and 12 requiring negative verifications. The positive instances consisted of the three high and three low taxonomic frequency members of the category represented as both pictures and words. The negative instances also consisted of six words and six pictures, where the instances were selected as follows. The first category block was a practice block and the negative instances were words and corresponding pictures chosen from categories outside the list. For the first five experimental category blocks, the negative instances were chosen from the positive instances of the remaining five categories. The 12 negative items that were chosen consisted of three high and three low taxonomic frequency items, again represented as both pictures and words. Thus, the structure of the positive and negative items within each block was identical. This procedure for selecting negative items was repeated for the remaining five category blocks so that the negative items in the second set of five categories were the positive items from the first five categories. Half the subjects were given one set of five categories first and the other half of the subjects were given the other set of five categories first. For each subset of subjects, the order of individual categories within each set of five categories was varied according to a Latin square design.

Procedure

The subjects were told that they would be given a category name by the experimenter and then presented both words and pictures that might or might not be instances of the category. Their task was to look at each of the items and press one of two response buttons indicating a "yes" or "no" response. The subjects were told to respond as quickly as possible and to avoid errors. A short rest followed each block while the experimenter changed slide trays.

All stimuli were back-projected onto a 30.5 x 25.4 cm translucent glass screen located approximately 46 cm from the subject. At the base of the screen was a 15.2 x 25.4 cm response panel containing two 2.5-cm response buttons separated by 15.2 cm. The subject rested the index finger of his/her preferred hand midway between the two buttons at the beginning of each trial. The trial was initiated when the subject said "ready." The projector beam activated a Hunter Klockcounter, which recorded response latency to the nearest millisecond. The intertrial interval was approximately 5 sec.

RESULTS AND DISCUSSION

Median Reaction Time

Of the 9,600 possible reaction times, 128 (1.3%) were eliminated from the analysis either because of equipment failures or subject errors. The medians for pictures and words of high and low taxonomic frequency were calculated for both positive and negative decisions for each subject. An analysis of variance for the median reaction times included the factors of

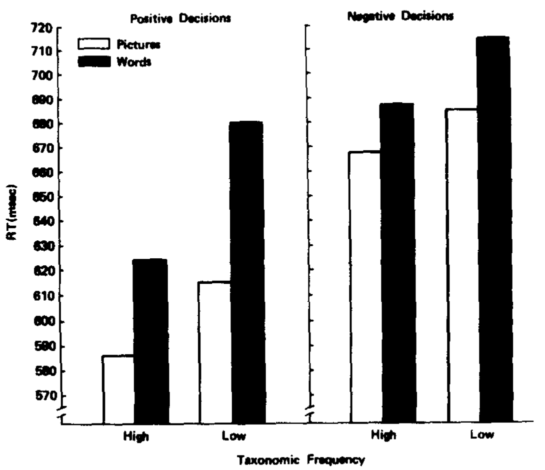

Figure 1. Mean RT as a function of stimulus form, taxonomic frequency, and decision type.

category order, stimulus form, taxonomic frequency, decision type, and subjects. The principal results of this analysis are shown in Figure 1. As can be seen in the figure, negative decisions (689 msec) took longer than positive decisions (627 msec) [$F(1,38) = 106.38$, $p < .001$]. Pictures (638 msec) were verified faster than words (677 msec) [$F(1,38) = 106.38$, $p < .001$], and the word-picture difference was larger for positive (51 msec) than for negative decisions (25 msec) [$F(1,38) = 26.10$, $p < .001$]. High taxonomic frequency instances (642 msec) were verified faster than low taxonomic frequency instances (674 msec) [$F(1,38) = 86.20$, $p < .001$], and the low-high frequency difference was larger for positive (41 msec) than for negative decisions (23 msec) [$F(1,38) = 9.63$, $p < .01$]. Finally, the word-picture difference was larger for low taxonomic frequency (47 msec) than for high taxonomic frequency instances (29 msec) [$F(1,38) = 10.66$, $p < .01$]. No other main effects or interactions approached significance.

A similar analysis was performed on mean reaction times, in which both subjects and categories served as random effects. The F' values obtained in this analysis showed that all the main effects and interactions previously described remained highly significant. The one discrepancy was the interaction between stimulus form and decision type ($p > .05$).

The relationship between the processing of pictures and words of varying taxonomic frequency was further examined in correlation-regression analyses. The median reaction time over 40 subjects for each of the 60 unique category instances was obtained for picture and word stimulus forms. This was done separately for positive and negative decisions, resulting in four medians for each item, which were used as both criterion and predictor variables in correlation-regression analyses. An inspection of the medians revealed only six items with reaction times over 750 msec when they appeared as either pictures or words. These items had abnormally long reaction times, and this was a function of either poor pictorial representation or other factors such as occupying the initial test position in a trial block. Thus, these six items were eliminated from the analyses. The remaining variables entering into the analysis as predictors included taxonomic frequency, printed frequency, and the $\log_{10}$ of each of these frequency counts.

The major results of the analyses are shown in Table 1. As is obvious from the table, negative decision times for both pictures and words were not significantly correlated with either frequency predictor variable, nor were picture and word times correlated with each other. The absence of any significant correlation with either frequency variable is consistent with the ANOVA results showing a substantially reduced effect of taxonomic frequency for negative decisions. This result is consistent with a general model of semantic verification such as that proposed by Smith et al. (1974). Taxonomic frequency is associated with the prototypicality of instances within their respective categories and thus should have no bearing on the outcome of first-stage global tests of semantic relatedness for negative category-instance comparisons. All negative items should fail the first-stage test. However, taxonomic frequency should be related to the speed of positive decisions for both pictures and words. Positive category-instance comparisons will vary in the probability of requiring a second-stage test, and such variations are associated with semantic relatedness, which is assessed by ratings of instance prototypicality and taxonomic frequency. The data in Table 1 clearly show that taxonomic frequency was significantly correlated with individual item reaction times when presented as either pictures or words.[1] This result is consistent with the ANOVA results showing substantial effects of taxonomic frequency on both picture and word positive decisions. The present results are also consistent with positive decisions for word stimuli

Table 1
Results of Correlation-Regression Analyses of Individual Item Response Latencies

		Log_{10}	
	Picture RT	Taxonomic Frequency	Printed Frequency
		Negative Decisions	
Word RT	.06	−.26	−.26
Picture RT		−.08	−.17
		Positive Decisions	
Word RT	.50*	−.52*	−.27
Picture RT		−.44*	−.26

$$\text{Word RT} = .34P_{RT} - 27.69\ \text{Log}_{10}\text{TF} + 494 \quad R_{Mult} = .60^*$$
$$\text{Picture RT} = .37W_{RT} - 18.58\ \text{Log}_{10}\text{TF} + 390 \quad R_{Mult} = .55^*$$

*$p < .01$

(e.g., Loftus, 1973; Smith, 1967; Wilkins, 1971) and extend those results to single pictorial stimuli (see Rosch, 1975, for related results with picture and word pairs). Of additional importance is the significant correlation between picture and word decision latencies on individual items, supporting previous results obtained by Pellegrino et al. (1977). The multiple regression analysis also showed that the correlation between picture and word reaction times on individual items was not completely accounted for by taxonomic frequency. The alternate form (either picture or word) latencies on individual items significantly increased the total variance accounted for when taxonomic frequency was the initial predictor entering the regression analysis.

The present results are consistent with the position that there is a quantitative rather than a qualitative difference in the processing of verbal and pictorial stimuli. Categorical decisions are faster for pictures than for words, not only when deciding that an item is a member of a category, but also when deciding that an item *is not* a member of a category (see also Potter & Faulconer, 1975). A general model for the verification of category membership (Smith et al., 1974) is applicable to the processing of both pictures and words, subsuming the taxonomic frequency effects and correlation-regression results for positive decisions as well as the absence of such effects for negative decisions. Thus, the data lend support to the hypothesis that pictures and words access the same underlying knowledge base and that the additional time associated with word processing may reflect decoding processes prior to semantic processing (e.g., Dhawan & Pellegrino, 1977; Pellegrino et al., 1977; Potter & Faulconer, 1975).

Individual Differences

Several different analyses were performed to determine if any relationship existed between verbal ability and semantic processing of pictures and words. For each subject, median latencies were obtained for high- and low-frequency items represented as both pictures and words. Separate medians were obtained for both positive and negative decisions, thus providing eight separate processing speed estimates. In addition, eight estimates of processing speed differences were obtained. These represented word-picture differences for high- and low-frequency instances and low-high frequency differences for pictures and words. Each difference estimate was separately obtained for positive and negative decisions. Verbal ability did not show a significant correlation with any of the 16 separate processing speed measures. This was the case when the entire sample of subjects was involved and also when the middle range of SAT scores was eliminated. The lack of any relationship between verbal ability and processing effects associated with the within-subjects factors was further confirmed in an ANOVA comparing the subjects with the 10 highest and 10 lowest verbal scores. While all the within-subjects factors showed highly significant main effects and interactions, paralleling those reported previously, verbal ability did not yield a significant main effect or enter into any significant simple or higher order interactions (all $Fs < 1$).

The conclusion seems inescapable that verbal ability in our college sample was totally unrelated to the speed of making simple semantic category decisions. This was the case even though a wide range of verbal ability was represented in the sample and the estimates of processing speed were highly reliable, giving rise to a number of highly significant statistical effects within subjects. The question remains as to why our results, which presumably reflect access to higher level semantic codes, differ from those of Hunt et al. (1975), where verbal ability was related to the speed of accessing name codes for letters. One obvious source of explanation is to consider the procedural differences between the name-matching task and the present semantic verification task. Among the most straightforward differences are: (1) the materials, letters vs. words and pictures; (2) the level of internal code representation, name vs. category; and (3) the number of stimuli, two vs. one. The first two differences are not very compelling, since any differences in letter processing for individuals with high and low verbal abilities might be expected to be increased in magnitude when "higher level" semantic processing of words serves as the basis for comparison. It is also unlikely that the number of stimuli is the most likely explanation, since physical matching of stimulus pairs failed to show any effect of verbal ability in the Hunt et al. (1975) study.

We would suggest the following tentative explanation for the present failure to find any significant effect of verbal ability on semantic processing speed. Requiring subjects to semantically process words or pictures is a task that presumably reflects the normal mode of processing such stimuli in everyday activity. In contrast, requiring subjects to match letters on the basis of identical names is presumably not the normal mode of processing letters in everyday reading activity. Thus, the differences obtained by Hunt et al. (1975) may not reflect general processing speed differences associated with high verbal ability, but instead may reflect a greater flexiblity of processing such that subjects with high verbal ability can more readily adapt to task demands. This admittedly post hoc explanation does not deny the fact that there are gross developmental differences in the speed of semantically processing verbal and pictorial stimuli (Rosinski et al., 1977) and that such differences may disappear in individuals with extremely high verbal ability (Rader, Note 1). The present results and explanation simply emphasize the difficulty of concluding that verbal ability is unambiguously associated with the speed of accessing long-term memory codes for a variety of verbal and nonverbal stimuli.

REFERENCE NOTE

1. Rader, N. L. *Developmental changes in getting meaning from written words.* Paper presented at the meeting of the Society for Research in Child Development, Denver, April 1975.

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NOTE

1. The correlation obtained for words is not an artifact of the longer word lengths associated with low taxonomic frequency items. Word length as measured by either the number of syllables or the number of letters did not correlate significantly with word categorization times ($rs < .23$).

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