Imagery and comprehension latencies as a function of sentence concreteness and structure*

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The relation between imagery and comprehension of sentences was investigated in two experiments using reaction time measures. Consistent with predictions from a two-process approach to meaning and mediation, one experiment showed that Ss took longer to generate images to abstract than to concrete sentences, but comprehension latencies did not differ significantly as a function of concreteness. A second experiment showed that sentence processing time (reading, paraphrasing, comprehending, and imaging) generally increased with complexity of either surface structure or deep structure, with some qualification of the effect depending upon how sentence meaning was defined in the instructions given to Ss. Mean imagery and comprehension latencies for sentences were highly correlated ($r_s = .81$ and $.83$) in both experiments, despite a reversal in overall means; imagery latencies exceeded comprehension latencies in Experiment 1 but were shorter than the latter in Experiment 2.

This study was designed to investigate the relation between imagery and the comprehension of sentences. Prior research has supported the view that imagery can mediate learning and recall of verbal material, extending in length from word units to connected discourse (e.g., Begg, 1971; Begg & Paivio, 1969; Bower, 1970; Paivio, 1969, 1970, 1971; Reese, 1970; Rohwer, 1970; Yuille & Paivio, 1969). However, the possible role of imagery in the comprehension of language has rarely been investigated empirically, although it has long been a matter of speculation and controversy (see Brown, 1958). Early research on the temporal relation between meaning and imagery (Moore, 1915; Tolman, 1917), recent research by Huttenlocher (1968) on the role of spatial images in syllogistic reasoning, and Rosenfeld's (1967) investigation of coding processes in same-different comparisons of objects and descriptions are among the few studies that touch on the problem.

The present study used a reaction-time measure to compare latencies of imagery and comprehension to sentences varying on dimensions of meaning and syntax. It has been shown that latency measures of comprehension are sensitive to both meaningfulness and grammaticality of sentences (e.g., Danks, 1969; Foss & Lynch, 1969).

Use of such a measure also makes direct contact with recent studies comparing the latencies of imaginal and verbal reactions to words that vary in concreteness or in some other relevant meaning attribute (Ernest & Paivio, 1971; Paivio, 1966; Yuille & Paivio, 1967). The latter studies stemmed from a two-process approach to cognition (Paivio, 1971) which distinguishes between verbal and nonverbal (imaginal) coding systems as the bases of meaning and mediation phenomena. The central point for present purposes is that imagery is assumed to be an important component of the associative meaning of concrete but not necessarily of abstract language: the former readily arouses nonverbal imagery, the latter does not. However, concrete and abstract language need not differ on other dimensions of meaning, such as familiarity and verbal associative meaningfulness, which could play a functional role in language behavior. Consistent with such an analysis, the latency of image arousal is much longer for abstract than for concrete nouns or noun pairs, but the two word types do not differ in latency of recognition (Simpson, 1970) or of verbal associative reactions (e.g., Ernest & Paivio, 1971; Yuille & Paivio, 1967) when the items were equated on other meaning attributes.

The theoretical reasoning can be extended readily to the analysis of imagery and comprehension as reactions to sentences. Comprehension, however it may be defined operationally, is closely linked to meaning as a theoretical construct: a sentence must have meaning to be understood, and different dimensions of meaning could be the basis of such

understanding. Since imagery is assumed to be an important component of the meaning of concrete sentences, it follows that the ease of comprehension should be closely related to ease of image arousal in the case of such sentences. However, the meaning of abstract sentences, like that of abstract nouns, is presumably tied more closely to the intraverbal structure itself and to verbal associative reactions rather than to imagery. Thus, abstract sentences should not arouse images readily although they can be easily understood on the basis of their intraverbal or associative meaning. These relations should be reflected in reaction time indices of imagery and comprehension. Specifically, image arousal latencies should be more comparable to comprehension latencies in concrete sentences than in abstract sentences, both in absolute and relative terms. The absolute comparability should be reflected in an interaction between image and comprehension times in concrete and abstract sentences. That is, the time required to image a concrete sentence should not differ appreciably from the time required to comprehend it, while in abstract sentences image arousal latency should be considerably longer than comprehension latency. The relative comparability should be reflected in a higher correlation between imagery and comprehension latencies in concrete sentences than in abstract sentences.

The direction of the difference between imagery and comprehension latencies in the expected interaction is, of course, a relative effect, since the response criterion may differ for the two conditions. The problem is analogous to an early one on the temporal relation between image and meaning reactions. Both Moore (1915) and Tolman (1917) found that Ss reacted faster, on the average, to concrete-word stimuli under meaning than under imagery instructions (although Tolman found that individuals differed in this regard). The finding that meaning reactions occurred faster than reported image arousal is not damaging to the imagery position, since reaction time data do not reflect directly the nominal mental events of either imagery or comprehension, but reflect instead the time required for the S to decide that the mental event has terminated. This decision could include a different criterion level or response bias for one process than for the other, with a consequent difference in decision time not present in the mental events themselves. Be that as it may, because of Moore's findings, we did not expect absolute correspondence between

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imagery and comprehension latencies to concrete sentences. Instead, in the first experiment, we expected an interaction of the concreteness level of sentences with instructions designed to arouse imagery and comprehension and strong correlations between the two kinds of reactions, especially in the case of concrete sentences.

A second experiment investigated the effects of surface syntactical structure and deep structure on the latencies of comprehension, imagery, paraphrasing, and reading. Based on a distinction made by Chomsky (e.g., 1965), surface structure refers to the grammatical structure of sentences as described, for example, by a phrase-structure analysis, whereas deep structure refers to an abstract underlying structure from which the sentence is derived and which presumably determines its semantic interpretation. Both levels have formed the conceptual basis of models of sentence comprehension and memory. Thus, Yngve (1960) presented a surface structure model which relates the difficulty of sentence processing during both listening and reproduction to the structural complexity of the sentence. Deep structure, on the other hand, has been related to comprehension in models that emphasize either the number and nature of the transformations that separate a sentence from its underlying structure or kernel sentence (e.g., Gough, 1965; Miller, 1962; Slobin, 1966) or the propositional complexity of the abstract structure from which the sentence is derived (e.g., Rohrman, 1968; Wanner, 1968).

Both surface structure and deep structure complexity were varied in the present study in order to determine their relative effects on comprehension and imagery. Latency of paraphrasing was also measured to provide a further behavioral index of comprehension. Imagery, comprehension, and paraphrasing latencies should all be sensitive to grammatical variables that affect meaning. Reading latencies should be relatively less dependent on meaning. Thus, latencies should be generally fastest under reading instructions, and correlations among average latencies for sentences should be higher among the three meaning-related reactions than between any of the latter and reading.

EXPERIMENT 1

Method

Subjects. Twenty female introductory psychology students served as Ss as part of a course requirement.

Materials. Fifty concrete and 50 abstract sentences, controlled on such

variables as length and word frequency, had been constructed for an earlier study (Begg & Paivio, 1969). Examples of the concrete sentences are *The rich physician carried a black umbrella*, *The jagged stone shattered a clear window*, and *The alert fisherman swatted a buzzing mosquito*, while the abstract were of the type *The actual quotation lacked a rational foundation*, *The national election indicated a secure future*, and *The entire episode prefaced a foreign affair*. Each sentence was typed in capital letters on a 4 x 6 in. card.

A tachistoscope was set up to be run by the Ss, who pushed a button to expose a sentence and released the button upon completion of the experimental task. A timer recorded the length of time the button was depressed, in milliseconds.

Procedure. The 100 sentences were ordered randomly, in a constant order for all Ss. The first 10 sentences, 5 of which were abstract, were considered practice trials and were not included in any analyses.

The basic design was a 2 by 2 factorial, with sentence concreteness (high or low) a within-Ss factor and instructional set (imagery or comprehension) a between-Ss factor. Ten Ss were instructed to depress a button to expose each successive sentence and to release the button when they understood the sentence, while the remaining 10 were asked to release the button upon consciously picturing what the sentence was about.

Each S's processing time for each sentence was recorded in milliseconds for the 45 concrete and 45 abstract sentences. The intertrial interval was about 15 sec, during which the E recorded the time, reset the timer, and changed the cards on which the sentences were typed. The session lasted about 40 min.

Results

The mean latency for the 45 concrete and 45 abstract sentences was calculated for each of the 10 Ss in each set condition. A 2 by 2 (Set by Concreteness) analysis of variance, with the latter measure repeated, yielded significant effects of set, $F(1, 18) = 10.39$, $p < .01$, concreteness, $F(1, 18) = 18.99$, $p < .01$, and the interaction between the two, $F(1, 18) = 8.69$, $p < .01$. The interaction is presented in Fig. 1. Using Scheffé's test and $p < .05$ level of significance, it was found that abstract sentences took longer to image than to understand and longer to image than did concrete sentences, while concrete sentences did not take less time to understand than did abstract sentences nor did they take less time to understand than to image.

Fig. 1. Mean imagery and comprehension reaction times as a function of sentence concreteness.

When the same analysis was conducted using logarithmic transformations, all comparisons except that between the comprehension latencies of concrete and abstract sentences were again significant; thus both analyses yielded equivalent results.

A correlational analysis was conducted in which each sentence was given as a score the mean imagery latency over 10 Ss and the mean comprehension latency over the other 10 Ss. Within the 45 concrete sentences, in which the mean comprehension latencies ranged from about 1.5 to 2.25 sec, the correlation between comprehension and image latencies was .71; within the abstract sentences, where comprehension ranged from about 1.75 to 2.75 sec, the correlation was .60. Across the total range of concreteness the correlation was .81. The correlation of .71 for concrete sentences significantly exceeds the r of .60 for abstract ($t_z = 8.4$, $p < .01$), as predicted. However, both correlations are quite high, and the correlation over the entire range is larger still, indicating that a strong common factor underlies the comprehension and imagery reactions.

EXPERIMENT 2

The relation between imagery and comprehension was examined further in a second experiment using sentences in which grammatical structure was varied systematically. Additional groups of Ss were also required to read and paraphrase the sentences. The stimulus sentences varied in surface structure and in the propositional

Fig. 2. Mean latencies for paraphrasing (P), comprehension (C), imagery (I), and reading (R) as a function of sentence type and verb type.

content of deep structure. Right branching sentences, such as *The rumor was false that Marcia lied* are presumably simpler at the surface than are center-embedded sentences such as *The rumor that Marcia lied was false*, since the latter variety of sentence separates the subject (*rumor*) from its completion (*was false*) (cf. Bever, 1968, pp. 490-491). Embedded sentences should thus require more processing time than branching sentences (cf. Foss & Lynch, 1969).

The deep propositional content of sentences can be altered by changing the sentence verb. Wanner (1968) discussed cease verbs (*The governor asked the detective to cease drinking*) as opposed to prevent verbs (*The governor asked the detective to prevent drinking*). Respectively, the deep propositions are (*The governor asked the detective*) (*the detective ceases it*) (*the detective drinks*) and (*The governor asked the detective*) (*the detective prevent it*) (*someone drinks*). Since the noun *detective* is included in all three propositions in the cease case, and only in two in the case of prevent verbs, the latter deep structure can be considered more complex, inasmuch as the pronoun *someone* must be deleted from the sentence before the sentence can be transformed to a surface structure isomorphic to the original sentence (cf. Rohrman, 1968). At the surface level, the relational inclusiveness of *detective* does not differ, so any performance differences between the two sentences can be attributed to deep structural variation. Thus, the cease verbs should result in faster processing latencies than prevent verbs.

Method

Subjects. Twenty introductory students served as Ss in the main experiment as part of a course requirement. Twenty additional Ss were tested with the meaning instructions modified (see below).

Materials. Twelve basic sentences were constructed. All were of the type, "The report was emphatic that the preaching friars forbade (refrained from) the whistling of melodies." Each sentence of the above right-branching (B) type was rewritten with the italicized segment inserted between "report" and "was" in order to be center-embedded (E). The sentences were again rewritten using verbs of the type illustrated, namely, "prevent" (P) verbs (e.g., forbade, required, demanded) or "cease" (C) verbs (e.g., refrained from, attempted, began). The subject of a C verb is involved in a larger number of deep propositions (roughly, *the friars refrained from, the friars whistle*) than is the subject of a P verb (*the friars forbade it, someone whistles*), although the relational inclusiveness of the subjects does not differ at the surface. B and E sentences only differ at the surface, where E sentences are more complicated than B sentences. Thus, four types of sentences were used, namely, EP, EC, BP, and BC sentences.

As in Experiment 1, a tachistoscope was set up to be run by the Ss.

Procedure. The basic design was a 2 by 2 by 4 factorial, with sentence type (B or E) and verb type (C or P) as repeated factors, and instructional set (reading, imaging, comprehending, or paraphrasing) as the independent factor. The 12 basic sentences were divided randomly into two groups, one

to be B and one E. Each was presented twice, once with a P verb and once with a C verb, with equal numbers of each order. Thus, there were 24 sentences presented, 6 of each kind, as well as 11 practice sentences that were not scored.

Five Ss received each instructional set. They were instructed to release the button when they had read the sentence, understood the meaning of the sentence, pictured what the sentence was about, or could express the meaning of the sentence in other words. The release of the button was the only overt response required. The same procedure was followed with a further group of 20 Ss, with a modification in the meaning instructions: They were told that sentences could have meaning without making sense. For example, the sentence "The small green elephant played marbles" does not "make sense," since there are several impossibilities included in the sentence, while it has "meaning" in a bizarre way. The experimental manipulation was included because it seemed possible that Ss in the comprehension condition were trying to "make sense" of the sentences, a task which is quite difficult in artificial sentences.

Results

The mean latencies for the six sentences of each type were calculated for each S in the main experiment and analyzed by a 2 by 2 by 4 (Sentence Type by Verb Type by Set) analysis of variance with the first two measures repeated. Set produced a significant main effect, $F(3,16) = 3.35$, $p < .05$, reflecting a latency increment from reading to imaging to comprehending to paraphrasing. Prevent verbs required more processing time than did C verbs, $F(1,16) = 8.11$, $p < .05$, and B sentences were processed faster than were E sentences, $F(1,16) = 10.47$, $p < .01$. The results are shown separately for verb type and sentence type in Fig. 2.

The results were analyzed separately for the Ss who were instructed that sentences could have a meaning without necessarily making sense. The pattern of results changed drastically for the linguistic variables. The P-C difference was present only under reading and comprehending sets, $F(3,16; \text{Set by Verb}) = 8.03$, $p < .01$, and in B sentences, $F(1,16; \text{Verb by Sentence}) = 6.45$, $p < .05$. The E-B difference was only present in imaging and comprehending sets, $F(3,16; \text{Set by Sentence}) = 4.33$, $p < .05$. The set effect, $F(3,16) = 8.23$, $p < .01$, reflected a constant reading, imaging, paraphrasing, comprehending order in all sentence and verb types. This order

parallels the results obtained in the main experiment, with the difference that the relative order of comprehension and paraphrasing was reversed. However, the "meaning-sense" instructions generally made the results difficult to interpret.

As in Experiment 1, correlational analyses were performed with sentences as subjects, collapsed across the main experiment and the "sense-meaning" experiment. Imagery and comprehension latencies were correlated .83, with paraphrasing correlated .76 with imagery and .79 with comprehension; reading was less highly correlated with all three of imagery (.58), comprehension (.66) and paraphrasing (.44) latencies. Partialing out reading left the remaining correlations high, viz, imagery and comprehension .73, imagery and paraphrasing .69, and comprehension and paraphrasing .77.

A comparison of the imagery and comprehension latencies in Fig. 2 shows, contrary to Experiment 1, that imagery latencies were generally faster than comprehension. This was so for all 12 basic sentences, so the unexpected difference is undoubtedly reliable.

DISCUSSION

The findings from the two experiments are significant theoretically, specifically in regard to the comprehension-imagery relation and more generally in regard to the problem of approaches to the study of language comprehension.

The interaction of Instructional Set by Sentence Concreteness in Experiment 1 indicates that imagery and comprehension cannot be equated as constructs, although they are more closely related in the case of concrete sentences than in the case of abstract sentences, as predicted from the two-process approach to meaning. Despite the distinction suggested by the interaction, however, the correlational analysis in both experiments indicates that imagery and comprehension (as measured by response latencies) are highly related variables ($r_s = .81$ and $.83$) across the entire range of concreteness values involved in the study. The question that immediately arises from such a correlational analysis concerns the uniqueness of imagery as a close correlate of comprehension when the latter is taken as the criterion performance variable to be predicted. How many theoretically relevant sentence attributes can be found that are at least as good predictors as imagery? It would be a relatively straightforward empirical problem to investigate by a factor-analytic procedure patterned after the one

conducted by Paivio (1968) to investigate word attributes in relation to learning scores as the criterion variables. The latter study involved measures of 27 semantic and associative attributes of 96 nouns. The analysis yielded a strong imagery-concreteness factor, which was clearly the best predictor of paired-associate learning and free recall scores for the same items. The question in the present case is whether or not a similar factor would be found for sentences and whether it would be a superior predictor of direct measures of comprehension.

A consideration of the absolute latencies of imagery and comprehension also has specific theoretical significance, particularly in regard to the question of whether or not imagery could play a part in comprehension behavior. On the basis of latencies reported by Moore (1915) for image arousal, Wickens and Engle (1970) argued that it takes too long to conjure up an image to words for imagery to be useful as an encoding dimension in language behavior. Specifically, they state, "Ordinary speech . . . flows too rapidly to permit one to dawdle over an item while awaiting its image [p. 271]." As pointed out in the introduction to the present paper, however, raw image latencies cannot be taken as an estimate of the speed of the mental process itself, otherwise the logic must be extended to other hypothetical processes as well. In the present instance, for example, Ss took considerable time to comprehend the sentences, according to their average comprehension reaction times. The values in Experiment 2 approximated 5 sec, which is not only long in an absolute sense but exceeds the latency of image arousal. Clearly such latency data cannot be taken as representative of the average speed of the comprehension process in ordinary language behavior, although in some instances it might take 5 sec or even longer to understand a complicated sentence.

In any event, the general point is that the absolute latency of imagery, as that of comprehension, depends on a variety of stimulus factors, such as the length, complexity, and abstractness of the stimulus material, as well as the precise experimental instructions and contextual cues that are involved in the experiment. While Moore reported an average value of about 1.5 sec for image arousal, Tolman obtained values under 1 sec for many Ss, using a somewhat different procedure. Paivio (1966) obtained a mean latency of about 2.5 sec for image arousal to concrete words, whereas Simpson (1970)

obtained raw image latencies of about .9 sec using well-practiced Ss. Such reports indicate that imagery can indeed occur quickly enough to verbal material to be functional in language behavior, including the complex process called comprehension. This conclusion is reinforced by the observation that the imagery latencies obtained in the present experiments (e.g., 2.75 sec in Experiment 1) with sentences as stimuli are not inordinately longer than the latencies obtained to single word stimuli. The implication of this is that the S presumably generates an image while the sentence is being read, not when reading is completed. Something of this kind may be the explanation of the finding that imagery latencies were faster than comprehension in Experiment 2: Ss may have generated an image to only part of the sentence but understood it only after the entire sentence had been processed.

The general significance of the findings for psycholinguistic research is revealed by the sensitivity of the latency measures to meaning and the structural attributes of sentences. Reliable effects of the abstractness-concreteness of sentences were obtained for the imagery and comprehension measures, and surface and deep structure variables were shown to influence these as well as reading and paraphrasing latencies. These results extend Danks's (1969) findings that the speed of understanding is affected by the degree of grammaticality and meaningfulness of sentences but not by the frequency of the words or the associative connections between the words contained in the sentences. They also confirm and extend Foss and Lynch's (1969) finding concerning the effects of surface structure on comprehension and decision time. Latency measures have been used frequently, of course, in comprehension studies involving verification of the truth or falsity of a sentence with reference to another sentence or a picture as the referent situation (e.g., Gough, 1965; Slobin, 1966). The type of procedure used in the present experiment is not a substitute for the verification task, but it does have the special advantage that it is a simpler and more direct approach to the measurement of comprehension processes than is the latter. In the present experiment, for example, the method permitted a direct comparison of the effects of particular surface and deep structure variables and revealed that they had similar effects on imagery and comprehension. The suggestion that such variables might have differential effects under different instructional

sets merits further study.

Finally, the results are directly relevant to an earlier experiment by Begg and Paivio (1969), which involved the same concrete and abstract sentences as were used here in Experiment 1. Begg and Paivio found that Ss detected meaning changes more readily than they did synonym substitutions in concrete sentences, whereas the reverse occurred in the abstract sentences. The interaction was predicted from the theory that also guided Experiment 1 in the present study. That is, the meaning of a concrete sentence is represented cognitively as a nonverbal image, so that changes in meaning will be readily detected because the image is changed. Wordings changes that do not substantially alter the image will be less readily detected. The reverse was expected in the abstract case. Since the meaning of abstract sentences is more closely tied to the specific wording, the substitution of a word will be more noticeable than will a change in meaning resulting from a reordering of the sentence words. However, it could also be argued that the abstract sentences were simply more difficult to understand than the concrete sentences and that the interaction was a result of comprehension difficulty rather than differential imagery. Such an interpretation is ruled out by the results of Experiment 1 in the present study, which showed that the concrete and abstract sentences do not differ in comprehensibility as measured by the reaction time task.

REFERENCES

- BEGG, I. Recognition memory for sentence meaning and wording. *Journal of Verbal Learning & Verbal Behavior*, 1971, 10, 176-181.
- BEGG, I., & PAIVIO, A. Concreteness and imagery in sentence meaning. *Journal of Verbal Learning & Verbal Behavior*, 1969, 8, 821-827.
- BEVER, T. G. Associations to stimulus-response theories of language. In T. R. Dixon and D. L. Horton (Eds.), *Verbal behavior and general behavior theory*. Englewood Cliffs, N.J.: Prentice-Hall, 1968.
- BOWER, G. H. Mental imagery and associative learning. In L. Gregg (Ed.), *Cognition in learning and memory*. New York: Wiley, 1970.
- BROWN, R. W. *Words and things*. Glencoe, Ill: Free Press, 1958.
- CHOMSKY, N. *Aspects of the theory of syntax*. Cambridge, Mass: M.I.T. Press, 1965.
- DANKS, J. H. Grammaticalness and meaningfulness in the comprehension of sentences. *Journal of Verbal Learning & Verbal Behavior*, 1969, 8, 687-696.
- ERNEST, C. H., & PAIVIO, A. Imagery and verbal associative latencies as a function of imagery ability. *Canadian Journal of Psychology*, 1971, 25, 83-90.
- FOSS, D. J., & LYNCH, R. H., JR. Decision processes during sentence comprehension: Effects of surface structure on decision times. *Perception & Psychophysics*, 1969, 5, 145-148.
- GOUGH, P. B. Grammatical transformations and speed of understanding. *Journal of Verbal Learning & Verbal Behavior*, 1965, 4, 107-111.
- HUTTENLOCHER, J. Constructing spatial images: A strategy in reasoning. *Psychological Review*, 1968, 75, 550-560.
- MILLER, G. A. Some psychological studies of grammar. *American Psychologist*, 1962, 17, 748-762.
- MOORE, T. V. The temporal relations of meaning and imagery. *Psychological Review*, 1915, 22, 177-225.
- PAIVIO, A. Latency of verbal associations and imagery to noun stimuli as a function of abstractness and generality. *Canadian Journal of Psychology*, 1966, 20, 378-398.
- PAIVIO, A. A factor-analytic study of word attributes and verbal learning. *Journal of Verbal Learning & Verbal Behavior*, 1968, 7, 41-49.
- PAIVIO, A. Mental imagery in associative learning and memory. *Psychological Review*, 1969, 76, 241-263.
- PAIVIO, A. On the functional significance of imagery. In H. W. Reese (Chm.), *Imagery in children's learning: A symposium*, *Psychological Bulletin*, 1970, 73, 385-392.
- PAIVIO, A. *Imagery and verbal processes*. New York: Holt, Rinehart, & Winston, 1971.
- REESE, H. W. Imagery and contextual meaning. In H. W. Reese (Chm.), *Imagery in children's learning: A symposium*. *Psychological Bulletin*, 1970, 73, 404-414.
- ROHRMAN, N. L. The role of syntactic structure in the recall of English nominalizations. *Journal of Verbal Learning & Verbal Behavior*, 1968, 7, 904-912.
- ROHWER, W. D., JR. Images and pictures in children's learning: Research results and instructional implications. In H. W. Reese (Chm.), *Imagery in children's learning: A symposium*. *Psychological Bulletin*, 1970, 73, 393-403.
- ROSENFELD, J. B. Information processing: Encoding and decoding. Unpublished doctoral thesis, Indiana University, 1967.
- SIMPSON, H. M. Inferring cognitive processes from pupillary activity and response time. Colloquium presented at the University of Western Ontario, January 1970.
- SLOBIN, D. I. Grammatical transformations and sentence comprehension in childhood and adulthood. *Journal of Verbal Learning & Verbal Behavior*, 1966, 5, 219-227.
- TOLMAN, E. C. More concerning the temporal relations of meaning and imagery. *Psychological Review*, 1917, 24, 114-138.
- WANNER, H. E. On remembering, forgetting, and understanding sentences: A study of the deep structure hypothesis. Unpublished doctoral dissertation, Harvard University, 1968.
- WICKENS, D. D., & ENGLE, R. W. Imagery and abstractness in short-term memory. *Journal of Experimental Psychology*, 1970, 84, 268-272.
- YNGVE, V. A model and an hypothesis for language structure. *Proceedings of the American Philosophical Society*, 1960, 104, 444-466.
- YUILLE, J. C., & PAIVIO, A. Latency of imaginal and verbal mediators as a function of stimulus and response concreteness-imagery. *Journal of Experimental Psychology*, 1967, 75, 540-544.
- YUILLE, J. C., & PAIVIO, A. Abstractness and the recall of connected discourse. *Journal of Experimental Psychology*, 1969, 82, 467-471.

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