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Isolating the effects of symbolic distance and semantic congruity in comparative judgments: An additive-factors analysis

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The time needed to compare two symbols increases as the cognitive distance between them on the relevant dimension increases (symbolic distance effect). Furthermore, when subjects are told to choose either the larger or the smaller of two stimuli, the response time is shorter if the instruction is congruent with the overall size of the stimuli (semantic congruity effect). Three experiments were conducted to determine the locus of these effects in terms of a sequence of processing stages. The developmental aspects of these effects were also evaluated, as the subjects were from kindergarten, first grade, third grade, fifth grade, and college. By varying the visual quality of the stimulus in each experiment, it was determined that the distance effect resides in a comparison stage, whereas the congruity effect is an encoding phenomenon. Both distance and congruity effects were present at all grade levels, but they decreased in magnitude as grade increased. The results were interpreted relative to recent models of comparative judgments.

When a subject is presented with two digits and asked to compare them, the speed and accuracy of the comparison is determined, in part, by the numerical difference between the digits (symbolic distance effect) and the relationship between the experimenter's instructions and the size of the digits (semantic congruity effect). The symbolic distance effect was first demonstrated by Moyer and Landauer (1967). They asked subjects to indicate which of two digits was larger and found that the time needed to respond was an inverse function of the difference between the numbers. This effect has been replicated consistently with adults (e.g., Banks, Fujii, & Kayra-Stuart, 1976; Buckley & Gillman, 1974; Parkman, 1971) and children (Sekuler & Mierkiewicz, 1977; Riley, Hu, & Hinrichs, Note 1). The semantic congruity effect for digit comparison was identified by Banks et al. (1976). When they presented two relatively large digits (e.g., 8 and 9), to adult subjects, response time was shorter if the instructions read "choose the larger" as opposed to "choose the smaller." Conversely, smaller digits (e.g., 1 and 2) elicited quicker responses when prefaced by "choose the smaller." This effect is also a well replicated finding and has been shown to occur under a variety of conditions (see Banks, 1977; Banks, Clark, & Lucy, 1975; Jamieson & Petrusic, 1975; Moyer & Bayer, 1976). In addition, the semantic congruity effect has been obtained with children (Trabasso, Riley, & Wilson, 1975).

The present experiments were conducted for two reasons. First, the experiments were designed to specify the locus of the symbolic distance effect and the semantic congruity effect in terms of a temporal sequence of independent processing stages. This approach was first described by Sternberg (1969, 1975, Note 2) and has been employed frequently to analyze the processes underlying comparative judgments (e.g., Banks, 1977, Banks et al., 1975; Moyer & Dumais, 1978). The logic employed here was labeled by Sternberg as the additive-factors method. Briefly, this method assumes that additive factors influence different stages of processing, whereas interactive factors influence the same processing stage. In this manner, the effect of a particular factor is isolated in a specific stage, a finding that helps to describe the nature of the stage, as well as to contribute to the understanding of the overall processing sequence involved in the specified experimental task.

Of particular interest in the present study are a perceptual encoding stage and a temporally subsequent memory comparison stage. The encoding stage is said to translate the stimulus into a cognitive representation

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that can be retained, manipulated, and compared with other mental representations. This stage is identified by a stimulus quality factor that involves degrading the stimulus item with visual noise on half of the experimental trials. Stimulus quality influences only the initial encoding stage, and any factor that interacts with it is also assumed to affect the encoding stage (Bracey, 1969; Hardzinski & Pachella, 1980; Miller and Pachella, 1973, 1976; Sternberg, 1967). The validity of this important assumption is most clearly demonstrated by Hardzinski and Pachella (1980). In a series of experiments, they generated strong evidence that an abstract internal code is established during stimulus encoding. The physical qualities of the stimulus do not affect subsequent comparison or scanning operations, since they are removed during encoding. Hardzinski and Pachella state flatly that "factors that interact with stimulus quality in memory scanning tasks can be assumed to have a locus within the encoding stage of processing" (1980, p. 232). The comparison stage follows initial stimulus encoding and involves a process whereby the mental representation of the stimulus is compared with or evaluated with information stored earlier in memory. The present study was designed to locate the effect of symbolic distance and semantic congruity within this framework. The decision and response stages that follow memory comparison will not be discussed here, as it is clear that the influence of distance and congruity occurs prior to the onset of these stages (cf. Banks et al., 1975).

The second purpose of the present experiment was to determine whether the developmental differences in time required to make comparative judgments are due to age-related changes in encoding or comparison processes. Both Sekuler and Mierkiewicz (1977) and Riley et al. (Note 1) have reported that the slope of the function relating comparative judgment times to the numerical difference between the stimulus digits decreased as age increased. Sekuler and Mierkiewicz interpreted these changes in terms of memory comparison processes that are affected by the symbolic distance between analog representations. Nonetheless, there is independent evidence indicating that encoding processes, as well as subsequent comparison processes, change with age. For example, Maisto and Baumeister (1975) found that older children were less affected by stimulus degradation than were younger children. They suggested encoding skills improve with age. A similar conclusion was reached by Keating and Bobbitt (1978). The rate of search following encoding also improves with age (Herrmann & Landis, 1977; Naus & Ornstein, 1977). Clearly, it is premature to implicate either the encoding or the comparison stage of processing to accommodate the finding that the magnitude of the symbolic distance effect reduces with age. The present experiments were designed to provide direct evidence concerning the processing stages responsible for developmental changes in comparative judgments. In all of the present experiments, children from kindergarten, first grade, third grade, and fifth grade, as well as adults, participated to determine if encoding or subsequent comparative processes change with age in comparative judgment tasks.

The present study consisted of three comparative judgment tasks. In all three experiments, the digit pairs were degraded on half of the trials by superimposing a line grid over the stimuli. In the first experiment, the subjects were instructed to decide which of the two digits was larger in value. The aim of the experiment was to determine if the effects of symbolic distance interact with those of stimulus degradation. The interaction would imply that the encoding of the digit pairs is affected by the numerical distance between the digits. In the second experiment, the subjects were asked to decide whether or not the two stimulus digits were identical. Theoretically, subjects in this task can base their decisions on the perceptual features of the stimuli rather than on the symbolic magnitude of the digits. The purpose of the experiment was to determine whether the numerical split between different digits would interact with stimulus degradation when only perceptual decisions were necessary. The focus of the third experiment was on the relationship between semantic congruity and stimulus degradation. Before the presentation of each stimulus pair, the subjects were instructed to choose the "larger" or the "smaller" digit. Subsequently, they were presented stimulus pairs composed of large digits (e.g., 8 and 9) or of small digits (e.g., 1 and 2). If the effects of semantic congruity are found to interact with those of stimulus degradation, it can be concluded that the instructions affect the encoding of the stimulus items.

The results of the present experiments are relevant to several different models of comparative judgments. Perhaps the simplest models are those that posit that a single stage underlies comparative judgments. For example, both Holyoak (1977) and Jamieson and Petrusic (1975) have presented single-stage models in which information is continuously retrieved from the relevant concepts. The symbolic distance effect is a result of the fact that the initial information retrieved is sufficient to distinguish between concepts very different in magnitude, but more precise information is needed to distinguish between concepts similar in magnitude. The semantic congruity effect appears because the retrieved information is thought to be compared with an ideal point located at one end of the continuum. The ideal point is determined by the instructions presented to the subjects. The important feature of these models is that they localize both the distance and congruity effects in the same processing stage. However, it is unclear from the formulation of the models whether stimulus degradation should interact with the distance and congruity effects. The only clear implication from these models is that both the distance and congruity effects should interact with stimulus degradation or that neither effect should interact with stimulus degradation.

A more clearly formulated model proposed by Banks and his associates (Banks, 1977; Banks et al., 1975, 1976) localizes the distance and congruity effects in two substages that are temporally subsequent to stimulus encoding. The model holds that to-be-compared stimuli are first translated into abstract linguistic representations and then compared in memory with the semantic code generated from the instructions given prior to the presentation of the stimulus pair. The encoding stage of the model is an "analog-to-digital" converter that generates semantic codes on the basis of the symbolic magnitude of the stimuli. A subsequent stage of the Banks' (1977) model is responsible for discrimination of the stimulus codes; it is here that the symbolic distance effect is thought to occur. Consequently, the model predicts an additive relationship between stimulus quality and numerical split. If these variables interact in Experiment 1, the model would be disconfirmed. According to the semantic coding model, the congruity effect is located in a matching stage that follows the discrimination stage. The congruity effect is said to result from a transformation of the generated semantic codes when they are not congruent with the coded instructions. For this reason, the semantic coding model predicts that the semantic congruity effect should not be influenced by the stimulus quality factor in Experiment 3. The magnitude of the congruity effect, an interaction between instructions and digit size, should be the same for both intact and degraded stimuli.

An alternative explanation of comparative judgments has been proposed by Moyer and his colleagues (Moyer & Bayer, 1976; Moyer & Dumais, 1978). As in other models, the "scan-plus-comparison" model of Moyer and his associates specifies that the symbolic distance effect is a result of cognitive activities involved in a memory comparison stage. The scan-plus-comparison model therefore predicts statistical additivity for numerical split and stimulus degradation in the first experiment. On the other hand, this model predicts that stimulus quality will interact with semantic congruity (Experiment 3). According to Moyer and Dumais (1978), the congruity effect is a result of the instructions, which bias the subject to begin his memory search either at the smaller end of the analog continuum ("choose smaller") or at the larger end ("choose larger"). When instructions are congruent with the stimulus pair, the subject is perceptually prepared to encode the stimuli. For this reason, stimulus degradation should have a greater effect on an incongruent instructions-digit relationship. The same prediction is made by an expectancy model proposed recently by Marschark and Paivio (1979).

GENERAL METHOD

Subjects

A total of 180 subjects from five age groups participated in the three experiments. Sixty subjects were randomly selected to participate in each of the three experiments, under the constraint that there be 12 subjects from each age group in each experiment. The children were recruited from the kindergarten, first grade, third grade, and fifth grade of elementary schools in the New Orleans public school system. The mean ages of the children from each of the kindergarten, first-grade, third-grade, and fifth-grade classes were 5.8, 6.9, 9.0, and 11.0 years, respectively. The mean ages of the children at each grade level did not differ across the three experiments. The adults were recruited from undergraduate psychology classes at the University of New Orleans

Stimulus Materials

The stimuli for all three experiments consisted of digit pairs constructed of the digits from 1 to 9. The digit pairs were prepared so that the digits were presented side by side in a horizontal row. Then different digits were paired together, the larger digit was presented on the right side for half of the stimulus pairs and on the left side for the remaining stimulus pairs.

Each digit pair was prepared twice, once in the intact condition and once in the degraded condition. In the degraded condition, a diagonal line grid was superimposed over the digit pair. To degrade the slides, Letratone contact paper (LT 924) was placed over the appropriate slides.

Apparatus

The stimuli were presented with a Kodak Carousel slide projector. The subjects' reaction time (RT) was measured in milliseconds by a Hunter timer activated by an impulse from a photoelectric cell mounted in front of the lens of the slide projector. The timer was activated by the presentation of the digit pair and stopped when a subject pressed one of two response keys.

EXPERIMENT 1

Method

Stimulus materials. Sixty-four pairs of digits from 1 to 9 were constructed so that the numerical differences of 1 to 8 between the digits were used eight times each. Particular pairs of digits did not occur with equal frequency, since (1) nearly any numerical difference could be produced by several different pairs and (2) it was necessary to present all possible numerical differences with equal frequency. Two lists of 128 trials were independently and randomly constructed so that, within each list, the 64 pairs of digits were presented twice, once in the intact condition and once in the degraded condition. Within each list, there were eight replications of each of the 16 unique conditions defined by degradation (intact and degraded) and numerical split (1, 2, 3, 4, 5, 6, 7, and 8).

Design and Procedure. The experimental design was a 5 by 2 by 8 mixed factorial with the between-subjects factor corresponding to grade level (kindergarten, first grade, third grade, fifth grade, and college) and the within-subjects factors corresponding to stimulus quality (intact and degraded) and numerical split (1, 2, 3, 4, 5, 6, 7, and 8).

Subjects were tested individually in a semidarkened room. Verbal instructions were presented to each subject, indicating that pairs of digits from 1 to 9 would be presented. The subjects were asked to decide as quickly as possible which digit was larger and to then press the left or right button, which was on the same side as the larger digit. The subjects were instructed to try to respond as quickly as possible but to avoid errors.

Following verbal presentation of the instructions, 148 trials (20 practice trials and 128 test trials) were presented in a single session of approximately 35 min. Each trial was initiated by the subject's ready signal, followed by the presentation of the stimulus pair. The trial was terminated by the subject's response.

Results

Mean RT for correct responses and the corresponding error proportions were obtained for each subject. Separate mixed analyses of variance were performed on these sets of data, with the main effects corresponding to grade level, stimulus quality, and numerical split. Prior to analysis, each subject's error proportion for each experimental condition was transformed with an arcsin transformation.

Mean RT for the experimental conditions can be viewed in Figure 1. The analysis demonstrated that RT decreased as grade level increased [$F(4,55) = 29.2$, $p < .001$], stimulus degradation slowed RT [$F(1,55) = 82.5$, $p < .001$], and RT decreased as numerical split increased [$F(7,385) = 105.2$, $p < .001$]. In addition, grade level proved to be inversely related to stimulus quality [$F(4,55) = 6.2$, $p < .001$], and numerical split [$F(28,383) = 7.4$, $p < .001$]. The range of the numerical split effect was 722, 720, 417, 259, and 147 msec for kindergarten, first grade, third grade, fifth grade, and adults, respectively. A trend analysis was performed on the effects of numerical split by the use of orthogonal polynomials. Both the linear [$F(1,55) = 185.8$, $p < .001$] and the quadratic [$F(1,55) = 39.6$, $p < .001$] portions of the main effect for split were found to be significant.

The lack of a significant interaction between stimulus quality and numerical split ($F < 1$) is important for evaluating the locus of the numerical split effects. This finding suggests that stimulus quality and numerical split have an additive relationship and therefore influence different stages of processing (cf. Sternberg, 1969, Note 2). The additivity of stimulus quality and numerical split are represented by the parallel lines associated with each grade level in Figure 1. The additivity was further supported in three ways. First, the standard error of the Stimulus Degradation by Numerical Split interaction was only 5.1 msec. Second, separate analyses of variance were conducted at each grade level because of the possibility of wide differences in variability between the different groups. The analyses indicated that the factors of stimulus quality and numerical split were additive at each grade level, although each analysis revealed significant main effects of stimulus degradation and numerical split.

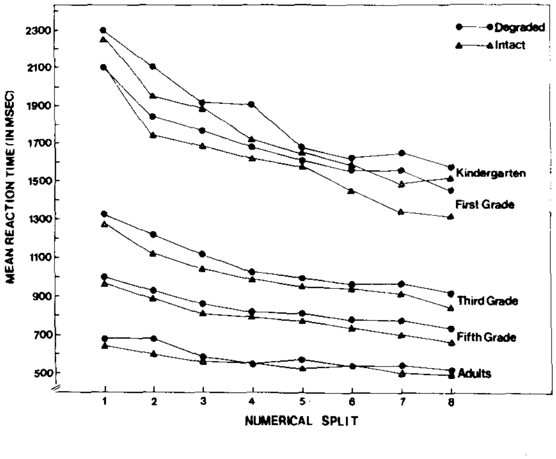

Figure 1. Reaction time (for correct responses) as a function of grade level, stimulus quality, and numerical split.

To further support the additivity between stimulus quality and numerical split, the best-fitting nonlinear parallel functions for the numerical split RT for both degraded and intact trials (collapsed over grade level) were obtained. The mean deviation between these functions and the data was 10 msec ($df = 7$) and represents the discrepancy from perfect additivity for the two factors (see Sternberg, 1969, Note 2). This deviation is clearly small enough to conclude additivity, particularly in view of the magnitude of increment for these RT functions and the typically large amount of variability present in data generated by children.

The mean error proportions were quite low (2.6% overall). Nevertheless, analysis of variance revealed that error rates were inversely related to numerical split [$F(7,385) = 12.6$, $p < .001$], and more errors were committed on degraded trials than on intact trials [$F(1,55) = 9.5$, $p < .005$]. It is clear that the error rates were directly related to RT, so there was no evidence of a speed-accuracy tradeoff (Pachella, 1974).

Discussion

The analyses of the present results revealed several findings of interest. Most important, stimulus quality proved to be statistically additive, with numerical split indicating that the symbolic distance effect is a product of comparison operations carried out following completion of stimulus encoding. This result supports the theoretical locus of the distance effect proposed by Moyer's scan-plus-comparison model (Moyer & Bayer, 1976; Moyer & Dumais, 1978), and by Banks' semantic coding model (Banks, 1977; Banks et al., 1975, 1976). In addition, the demonstrated additivity between stimulus quality and the numerical distance between two digits parallels the additivity others have found between stimulus quality and various other forms of semantic distance. For example, McFarland, Duncan, and Kellas (1978) found stimulus quality to be additive with the typicality of a category exemplar. Typicality is a measure of the semantic distance between a category exemplar and the prototypical representation of the superordinate category (cf. Rosch, 1975). The additivity between stimulus quality and typicality has been replicated with children by Duncan and Kellas (1978). Holyoak, Dumais, and Moyer (1979) have provided more direct evidence for the notion that the symbolic distance between two stimuli in a comparative judgment task is similar to the distance effects obtained in semantic memory tasks. Holyoak et al. presented adult subjects a comparative judgment task in which the size of the stimulus words' referents were to be compared (e.g., mouse-cat). They found that the semantic association between the to-be-compared items interacted with the symbolic size difference between the words. The facilitation provided by close semantic association diminished as the size difference increased; that is, semantic similarity was effective when item referents were close in size, but it was overridden by the distance effect when referents were dissimilar in size. The Holyoak et al. study brings the study of mental comparison into the realm of semantic memory. In a variety of semantic decision tasks, it is apparent that both symbolic and semantic distance influence comparison processes temporally subsequent to the encoding and registration of stimulus items.

The present analyses also revealed several developmental effects of interest. It was found that the effects of stimulus degradation were inversely related to grade level. The interaction of stimulus quality and grade level replicates earlier results reported by Maisto and Baumeister (1975). While it is clear that this interactive relationship reflects developmental changes in encoding processes, the basis for these changes is not clear. Other researchers (Harris & Fleer, 1974; Hoving, Morin, & Konick, 1970; Silverman, 1974) have suggested that children and adults employ similar strategies when encoding degraded stimuli. If this assumption is correct, it is the rate of stimulus encoding that increases with age, not its qualitative nature.

Finally, the magnitude of the symbolic distance effect was found to decrease as grade level increased, in much the same manner as that reported by Sekular and Mierkiewicz (1977) and Riley et al. (Note 1). Since this relationship was not altered by stimulus quality, it strongly suggests that the developmental decrease in the distance effect was a result of age-related differences in comparing coded information rather than of differences in the coding operation itself. The independence of the two developmental effects provides further evidence that stimulus encoding becomes more efficient with age, but this improvement has no direct effect on developmental differences in the symbolic distance effect.

EXPERIMENT 2

The first experiment was conducted to determine the nature of the relationship between stimulus quality and symbolic distance in a comparative judgment task. The subjects compared digits in memory on the basis of their numerical magnitude. It is important to note that distance effects have been found in perceptual judgment tasks also, as noted by Moyer and Landauer (1967). For example, Curtis, Paulos, and Rule (1973) recorded RT for visual size comparisons for subjects presented circles of different sizes. They found that RT increased systematically with increases in the physical similarity of the circles. The present experiment was conducted to test the possibility that numerical split may affect stimulus encoding in a task that allows subjects to make perceptual decisions based on the physical identity of numbers. A task in which decisions can be made on the basis of the perceptual features of digits rather than on the basis of their symbolic magnitude is a "same-different" task. In the task, subjects must decide whether or not two digits are identical. Presumably, identity decisions can be made on the basis of information generated during the perceptual encoding of the stimuli. In the present experiment, subjects of various ages were asked to make same-different judgments when presented two digits. On "same" trials, the digits were identical; on "different" trials, the stimuli differed either by small numerical splits (numerical differences of 1, 2, or 3) or by large numerical splits (differences of 6, 7, or 8). As in the first experiment, the digits were visually degraded on half of the trials.

It is possible that, if the symbolic distance effects appear in a same-different task, the effects are due to the processes involved in perceptual encoding rather than subsequent comparative processes. If so, then the effects of numerical split in the present task should interact with those of stimulus degradation. On the other hand, if the effects of numerical split and stimulus degradation are additive, the results would support the notion that perceptual and memorial comparisons involve a common underlying comparison stage (Moyer, 1973; Moyer & Bayer, 1976).

Method

Stimulus materials. Forty pairs of digits were constructed so that 20 pairs consisted of identical digits (e.g., 11, 22, etc.) and 20 pairs consisted of nonidentical digits. The nonidentical pairs consisted of 10 digit pairs of small numerical splits of 1, 2, and 3 (e.g., 12, 31, 58) and 10 digit pairs of numerical splits of 6, 7, and 8 (e.g., 17, 92, 19).

A list of 80 trials was constructed so that each digit pair was presented twice, once in the intact condition and once in the degraded condition. The method of stimulus degradation was identical to that used in the first experiment. Within the 80-trial list, there were 10 replications of each of the four unique conditions defined by stimulus quality and numerical split on "different" trials (different/small split and the different/large split) and 20 replications of the intact and degraded conditions on "same" trials.

Design and Procedure. The experimental design was a 5 by 2 by 3 mixed factorial, with the between-subjects factor corresponding to grade level (kindergarten, first grade, third grade, fifth grade, and adults) and the within-subjects factors corresponding to stimulus quality (intact and degraded) and match type (same, different/small split, and different/large split).

Subjects were tested individually in a semidarkened room. Verbal instructions were presented to each subject, indicating that pairs of digits from 1 to 9 would be presented. The subjects were asked to decide as quickly as possible whether the digits were the same or different and to press the button that was marked appropriately. For half the subjects in each age group, the response button on the right was marked "same" and the left button was marked "different." The marking was reversed for the remaining subjects. The subjects were instructed to try to respond as quickly as possible but to avoid errors.

Following verbal presentation of the instructions, 100 trials (20 practice trials and 80 test trials) were presented in a single session of approximately 25 min. Each trial was initiated by the experimenter's ready signal, followed by the presentation of the stimulus pair. The trial was terminated by the subject's response.

Results

A 5 by 2 by 3 mixed analysis of variance was performed on the mean RT for correct responses. A similar analysis was performed on the arcsin transformations of each subject's error proportion in each experimental condition. The main effects corresponded to grade level, stimulus quality, and match type.

The mean RT for each condition and grade level can be viewed in Figure 2. It is clear that RT was inversely related to grade level $[F(4,55) = 3.7, p < .001]$ and that stimulus degradation increased RT $[F(1,55) = 38.3, p < .001]$. Match type $[F(2,110) = 20.9, p < .001]$ was also significant, as "same" responses were the shortest, followed by different/large split, and then different/small split. These differences were all found to be statistically significant at the .05 level with the Bonferroni t statistic (df = 110, critical difference = 38.6 msec). There were no significant interactions.

Once again, the additive relationship between stimulus quality and numerical split $(F < 1)$ is the result of most interest. These factors apparently had independent influences on RT in the present experiment. The lack of a significant interaction was not due to high variability in the data, for the standard error of the interaction was only 6.4 msec. Furthermore, the additivity of the two factors was supported by separate analyses at each grade level. Finally, the best-fitting nonlinear parallel functions for the type of match were found for both degraded and intact trials. The mean deviation between these functions and the data was only 6.3 msec (df = 2).

The mean overall error rate for each subject was extremely low (1.6%). Analysis of the error data revealed only a significant main effect of stimulus degradation $[F(1,55) = 7.6, p < .005]$. More errors were committed on degraded trials than on the intact trials.

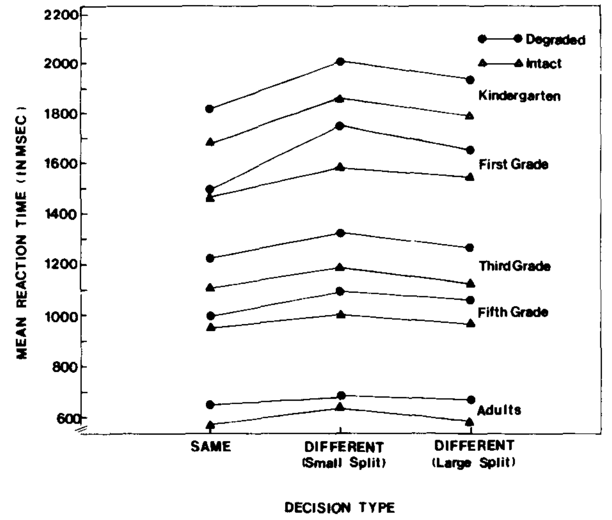

Figure 2. Reaction time (for correct responses) as a function of grade level, stimulus quality, and match type.

Discussion

The results of Experiment 2 clearly indicate that numerical split affected decision time when different digits were presented. The effect of numerical split suggests that both adults and children as young as 6 years use symbolic information, even in a task in which decisions can be based on perceptual information. In other words, despite the obvious parsimony of simple perceptual discrimination between two physically distinct numerals, subjects were nonetheless influenced by the numerals' relative positions on a symbolic dimension. It is important to note that the distance effects were as strong with children as with adults. Numerous theorists (e.g., Bruner, Olver, & Greenfield, 1966; Piaget & Inhelder, 1971) have argued that children's use of perceptual information predominates over symbolic information. Given these arguments, it might have been expected that the young children in the present task would have preferred to use perceptual information rather than symbolic information. Instead, it appears that all subjects used symbolic information to facilitate their decisions.

The results of Experiment 2 further indicate that the locus of the distance effect is a comparison stage of processing. The additivity of numerical split and stimulus degradation is clearly shown in Figure 2 and was supported by the analysis of best-fitting nonlinear parallel RT functions. The additivity shown in Experiment 2 replicates the results obtained in the first experiment and provides converging evidence that the distance effect is a result of processing that occurs subsequent to the perceptual encoding of the to-be-judged stimuli.

EXPERIMENT 3

The results of Experiments 1 and 2 do not disconfirm either the scan-plus-comparison model (Moyer & Bayer, 1976; Moyer & Dumais, 1978) or the semantic coding model (Banks, 1977; Banks et al., 1975, 1976). Both models locate the symbolic distance effect in a comparison stage temporally subsequent to a stimulus encoding stage. This theoretical locus of effect was supported by the data. The models provide different indications, however, for the locus of the semantic congruity effect. The congruity effect, it will be recalled, is an interaction between the instructions ("choose larger" vs. "choose smaller") and the numerical size of the to-be-compared digit pair. For example, a response to two large digits is faster under instructions to choose the larger as opposed to the smaller digit (Banks et al., 1976). The scan-plus-comparison model and other models (e.g., Marschark & Paivio, 1979) locate the congruity effect in a stimulus encoding stage of the processing sequence. When the subject is instructed to choose either "larger" or "smaller," such instruction elicits a perceptual set that biases him to begin comparison either at the smaller or the larger end of the analog continuum. This induced expectancy is influential because decisions concerning the relative magnitude of two items on the memory scale are based on the difference between the two items relative to one of the endpoints. The scan-plus-comparison and other similar models clearly predict that the magnitude of the semantic congruity effect (Instructions by Digit Size interaction) will be greater under degraded stimuli than under intact stimuli.

The encoding stage in the semantic coding model (Banks, 1977) differs from that proposed for the alternative models. The semantic coding model's initial stage generates a linguistic representation based on the magnitude value associated with each stimulus. In the second stage, a discriminative process is carried out on the linguistic codes. If necessary, more information is sought, so that each item is assigned a unique code. In the third stage (matching), the discriminated codes are compared with the prestored instructional codes. If the stimulus codes are not in the proper format to match the code for instructions, the stimulus codes must be transformed. It is this transformation to establish stimulus-instructions agreement that presumably produces the semantic congruity effect. The semantic coding model, therefore, predicts that the magnitude of the congruity effect will remain undisturbed by alterations in stimulus quality. The processing time added by stimulus degradation should be inserted prior to the operations responsible for the congruity effect.

Experiment 3 also allowed us to study the possible developmental aspect of the congruity effect. According to the proposed models, instructions either direct perception of subsequent stimuli or create a comparison mismatch on some trials. Irrespective of its locus, the congruity effect may be due to either conscious strategy adopted by the subject or automatic processes that are independent of a subject's intentions. It is known that the deliberate or conscious adoption of strategies is inadequate in the developmentally young (e.g., Brown, 1975; Flavell, 1970). If conscious strategy is involved in the semantic congruity effect, young children may not be as susceptible to such congruity effects as are older children and adults. On the other hand, Brown (1975) has pointed out that when no conscious strategy is required for efficient performance, the task will be relatively insensitive to developmental trends. If the congruity effect is based on automatic activation of a perceptual set or an instructional code, the congruity effect will be present even in kindergarten children.

Method

Stimulus materials. Thirty pairs of digits were constructed by randomly pairing the digits 1 to 9 under the following restrictions: (1) Numerical differences of 1, 2, and 3 between the digits were represented equally often, and (2) one-half of the stimulus digit pairs from each split consisted of digits of 5 or less ("small" digit pairs), and the remaining digit pairs consisted of digits of 5 or more ("large" digit pairs). A test sequence of 120 trials was constructed such that each of the 30 digit pairs was presented four times, once in each unique condition defined by stimulus quality (intact and degraded) and instructions ("choose the larger digit" and "choose the smaller digit").

Design and Procedure. The experimental design was a 5 by 2 by 3 by 2 by 2 mixed factorial, with the between-subjects factor corresponding to grade level (kindergarten, first grade, third grade, fifth grade, and adults) and the within-subjects factors corresponding to stimulus quality (intact and degraded), numerical split (1, 2, and 3), instructions ("choose smaller" and "choose larger"), and digit size (small and large).

The subjects were tested individually. They were told that pairs of digits from 1 to 9 would be presented and that they were to determine which of the digits was the larger or smaller, depending on the instructions to be presented prior to each stimulus pair. Upon presentation of a digit pair, the subjects were required to press the left- or right-hand button that was on the same side as the target digit. The subjects were instructed to respond quickly but to avoid making errors. Following verbal presentation of the instructions, subjects received 132 trials (12 practice and 120 test trials) in a single session of approximately 50 min. Each trial was initiated by a ready signal that was followed immediately by the experimenter's instruction of "choose larger" or "choose smaller." Approximately 2 sec later, the stimulus pair was presented. The trial was terminated by the subject's response.

Results

A 5 by 2 by 3 by 2 by 2 mixed analysis of variance was conducted on the mean RT for correct responses. A similar analysis was performed on the error data after the proportions for the various experimental conditions underwent arcsin transformation. The main effects corresponded to grade level, stimulus quality, numerical split, instructions, and digit size.

The mean response times (collapsed across numerical split) are presented in Figure 3. All five main effects

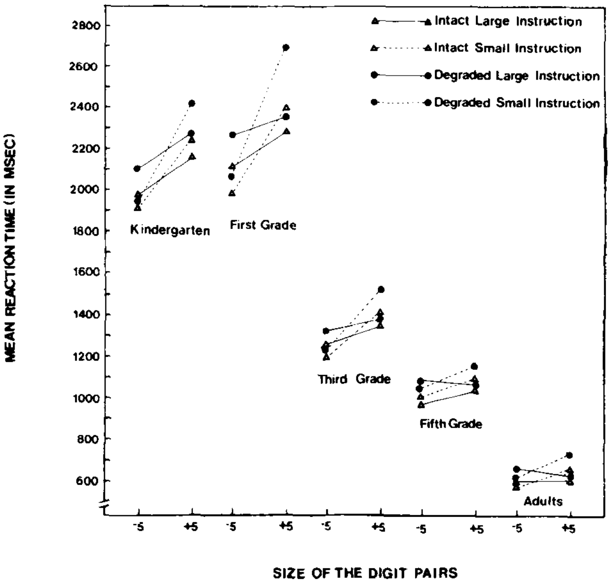

Figure 3. Reaction time (for correct responses) as a function of grade level, stimulus quality, instructions, and digit size.

Table 1
Mean Semantic Congruity Effect (in Milliseconds) Across Grades for Intact and Degraded Stimuli

Stimulus Quality	Kindergarten	First Grade	Third Grade	Fifth Grade	Adult
Intact	60	128	36	7	37
Degraded	164	270	139	46	68

proved significant. Response time was inversely related to age [F(4,55) = 52.6, p < .001], stimulus degradation lengthened RT [F(1,58) = 31.9, p < .001], RT reduced with size of numerical split [F(2,110) = 33.4, p < .001], small instructions elicited shorter RT [F(1,55) = 5.0, p < .05], and small digits produced faster response than did large digits [F(1,55) = 96.6, p < .001]. All of these effects are best viewed in the context of the interactions that qualified them. Grade level interacted with stimulus quality [F(4,55) = 3.3, p < .025], indicating that once again the effects of degradation reduced with age. As in Experiment 1, the effect of numerical split also reduced slightly with age [F(8,110) = 2.1, p < .05]. The most important developmental interaction was that involving grade level, instructions, and digit size [F(4,55) = 3.3, p < .025]. This interaction indicates that the semantic congruity effect varied in magnitude across grade level. In general, the effect was less pronounced in the older subjects.

The result of most interest to the present study was a four-way interaction among stimulus quality, numerical split, instructions, and digit size [F(2,110) = 5.3 p < .001]. The best manner in which to view this effect is in terms of the obtained congruity effects, defined as the mean deviation from parallel of the RT function for digit size at large and small instructions (cf. Banks et al., 1975) At a numerical split of 1, the congruity effect for degraded stimuli was a substantial 197 msec, whereas the effect was 20 msec for intact stimuli. At a split of 2, degraded and intact stimuli produced congruity effects of 135 and 77 msec, respectively, whereas a split of 3 produced effects of 108 and 48 msec for degraded and intact digits. It is clear that the magnitude of the congruity effect is significantly altered by the quality of the digit stimuli. This alteration in the instructions/digit size relationship was substantial at all levels of numerical split, although the effect was more pronounced at Split 1. The magnitude of the congruity did not differ significantly at numerical splits of 2 and 3. It is important to note that the effect of stimulus quality on the congruity effect was replicated at each grade level, as shown in Table 1.

The overall error rate was low (2.1%). Analysis of the data revealed that the error rates were directly related to RT, indicating that there was no tradeoff between speed and accuracy (Pachella, 1974).

Discussion

The results of Experiment 3 are supportive of any processing model that describes the semantic congruity effect as an encoding phenomenon (e.g., Marschark & Paivio, 1979; Moyer & Dumais, 1978). This support is limited to assumptions concerning temporal aspects of the processing sequence and is neutral with respect to the nature of the internal representation derived from the digit stimulus. The present findings are problematic for models that locate the congruity effect in a comparison or matching stage that follows an encoding stage (e.g., Banks, 1977). In Banks' semantic coding model, the congruity effect is a result of a mismatch between coded digits and coded instructions in a comparison stage of processing. The influence of stimulus quality occurs earlier in the sequence of stages and therefore should not have altered the basic congruity effect. This independence obviously did not obtain, as the magnitude of the congruity effect was much greater when stimuli were visually degraded than when they were visually intact. These data suggest, therefore, that the congruity effect is located in an encoding stage, as proposed by the scan-plus-comparison model of Moyer and Dumais (1978) and the expectancy model of Marschark and Paivio (1979). Instructions bias processing such that, for example, a subject is perceptually prepared to deal with numerically small digits if he has been told to choose the smaller member of a digit pair. To illustrate, consider Moyer's scan-plus-comparison model. Here, the instructions bias the subject to initiate processing at a specified end of the numerical symbol continuum. If the instructions direct processing to the wrong end of the continuum, a correct decision will take longer than when processing is directed toward the appropriate end of the continuum.

It has been demonstrated that stimulus quality is clearly additive with respect to numerical split and strongly interactive with respect to the semantic congruity effect. The additivity was shown in two separate experiments, and the interaction was shown to be quite substantial, in that the magnitude of the congruity effect was approximately three times as great with degraded stimuli as with intact stimuli. Given these findings, the four-way interaction involving stimulus quality, numerical split, instructions, and digit size ostensibly clouds the conclusions somewhat. One might assume, for instance, that the congruity effect is based partially on comparison phenomenon. Such a conclusion is a weak one at best. In the present experiment, the interactive relationship between numerical split and semantic congruity was present only for degraded stimuli. It is possible that this effect would disappear if subjects were given a substantial number of practice trials, in the same manner in which a slight Stimulus Quality by Set Size interaction disappears with practice in memory scanning studies (see Sternberg, 1967). Instead of employing a great amount of practice, which is not feasible in studies involving children, we can look at the adult data in the present experiment. Adults typically require much less practice to reach an optimum speed of responding. The data indicate no evidence of an interaction between split and congruity for either intact or degraded stimuli. The most reasonable conclusion appears to be that the semantic congruity effect is an encoding phenomenon, whereas symbolic distance is a comparison phenomenon.

A result reported by Banks et al. (1975) on a perceptual task is ostensibly contradictory to the present findings. They asked subjects to choose the higher or lower of two balloons or two yo-yos drawn on cards and viewed through a tachistoscope. When subjects were presented balloons, the instructions "choose the higher" led to faster responses than did "choose the lower." This result was reversed for the yo-yo stimuli. This congruity effect was essentially unaltered by the discriminability of the heights or lengths of the two stimuli. Discriminability was determined by variation in the height or length differences from 1 to 3 cm. On the basis of this additive relationship between discriminability and semantic congruity, Banks et al. (1975) concluded that, whereas discriminability influences encoding, congruity was located in a comparison stage. The major flaw in their argument is the assumption that this form of discriminability necessarily affects an encoding stage. In the model proposed by Moyer and Dumais (1978), for example, this perceptual variation in the height of the balloon stimuli would influence the comparison stage of processing. In fact, it appears to be closely analogous to numerical split, which we know has its influence in the comparison stage. Given that the discriminability in the Banks' et al. (1975) study influenced comparison processes, it would still have an additive relationship with semantic congruity, if the locus of the congruity effect was the encoding stage. This is precisely what is proposed here. It now seems likely that the model proposed in the Banks et al. (1975) study is temporally backward. Semantic congruity influences encoding and discriminability influences comparison, not the other way around. It may be a moot point, but there is no evidence that the form of discriminability used by Banks et al. (1975) has independent empirical support as an encoding effect, whereas stimulus quality has been shown to affect only perceptual encoding in several studies (e.g., Bracey, 1969; Hardzinski & Pachella, 1980; Miller & Pachella, 1973, 1976; Sternberg, 1967).

Experiment 3 tested for the presence of a semantic congruity effect in children as young as 6 years of age. The results provided evidence for a congruity effect at all age levels tested. In fact, grade level interacted with the congruity effect, in that the effect tended to decrease with age; however, the most pronounced congruity was found in first-grade rather than in kindergarten children. It is important to note that the interactive relationship between stimulus quality and semantic congruity was replicated at each of five age levels. The congruity effect found in the youngest children was altered significantly by variation in the visual quality of the stimuli. The data show that instructions do indeed bias the information processing exhibited by young children. Misleading information provided by the experimenter had an even greater effect on young children than it did on older children and adults. The fact that the congruity effect was affected by stimulus degradation in a similar manner at all grade levels indicates that the congruity effect occurs for the same reasons and at the same processing stage for children and adults. Moreover, the presence of this interaction at each grade level suggest that the congruity effect is a phenomenon based on underlying automatic processes not influenced by conscious strategies more prevalent in older subjects.

GENERAL DISCUSSION

The results of the experiments reported here support the models for comparative judgments proposed by Marschark and Paivio (1979), Moyer and Bayer (1976), and Moyer and Dumais (1978), or any model that locates the symbolic distance and semantic congruity effects in encoding and comparison stages, respectively. In Experiment 1, stimulus quality was found to have an additive relationship with numerical split, suggesting a comparison stage as the locus of the symbolic distance effect. The above models hold that the memorial comparison that elicits the distance effect is closely similar to the perceptual comparison required when judgments are made on actual physical stimuli. Thus, both memorial and perceptual comparison tasks should produce a distance effect located in a comparison stage that is temporally subsequent to stimulus encoding. Experiment 2 confirmed this prediction, as stimulus quality proved to be additive with numerical split in a perceptual task. The above models and the semantic coding model (Banks, 1977) led to clearly distinct predictions for Experiment 3. The Moyer and Paivio models describe the congruity effect as an expectancy phenomenon in which instructions bias stimulus encoding. The semantic coding model interprets the congruity effect as a mismatch of internal codes for instructions and stimulus items that occurs in a comparison stage of processing. A pronounced interaction between stimulus quality and the semantic congruity effect emerged, suggesting that semantic congruity is located in an encoding stage, as predicted by the models proposed by Moyer and Paivio and their associates. It should be pointed out that the present findings do not directly support the analog nature of mental comparison represented in these models, only the temporal sequence of processing stages proposed by them. Finally, the combined results from these experiments disconfirm any single-stage models of the comparison process (e.g., Holyoak, 1977; Jamieson & Petrusic, 1975), since multiple stages are necessary to accommodate the isolable effects of symbolic distance and semantic congruity.

Given that the semantic congruity effect is located in the encoding stage of the processing sequence, it is necessary to relate it to the larger framework of perceptual set (e.g., Haber, 1966; Pachella, Note 3). The general phenomenon of set involves the advanced preparations the processing system makes for the possible alternative stimuli to follow. As Neely (1977) and Posner and Snyder (1975) have argued, the effect of advanced information or a prime is due at least partially to the expectations developed either consciously or automatically prior to the presentation of stimuli. We suggest that the semantic congruity effect is one more manifestation of the phenomenon of set. It is interesting to note that the pattern of response times to a stimulus that follows a prime is similar to the pattern characterizing the congruity effect. Several authors (Duncan & Kellas, 1978; Posner & Snyder, 1975; Rosch, 1975) have demonstrated that a prime facilitates the processing of some stimuli but inhibits the processing of others. Similarly, in comparative judgment tasks, there is facilitation in the processing of stimuli near the end of the continuum specified by the instructions and inhibition for stimuli at the other end of the continuum.

Across the three experiments, it was demonstrated that the effect of stimulus quality, the symbolic distance effect, and the semantic congruity effect all decrease in magnitude as age increases. Two conclusions can be made from these results. First, it appears that the underlying mechanisms responsible for the distance and congruity effects are established early in life. Since young children usually show little evidence of conscious processing strategies (Brown, 1975), it is likely that the mechanisms determining these effects operate automatically to a large extent. For example, when a kindergartener is told to "choose the larger," his subsequent processing will be biased toward the large end of the continuum automatically, not as a result of a conscious desire to do so. The second point is that since stimulus quality and congruity affect encoding and distance affects comparison, it can be concluded that both encoding and comparison improve with age. Nonetheless, the similarity of the response time patterns across developmental levels suggests that the change is one that involves the rate of cognitive processes more than the nature of such processes.

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