INTELLIGENCE **11**, 169–191 (1987)

Picture Encoding Speed and Mental Retardation

EDWARD C. MERRILL,
RICHARD SPERBER,
CHARLEY MCCAULEY,
JOAN LITTLEFIELD,
ELIZABETH A. RIDER, AND
DAVID SHAPIRO
Vanderbilt University

Using a modified Posner ''encoding function'' methodology, we assessed group differences in semantic encoding speed under conditions in which subjects encoded pictures of common objects to determine physical identity (PI) matches, name identity (NI) matches, and superordinate identity (SI) matches. Mildly retarded adults; Chronological Age (CA)-matched, nonretarded adults; and Mental Age (MA)-matched, nonretarded children were presented pairs of stimuli in which the two stimuli within the pairs were separated by a variable stimulus onset asyncrony (SOA). Subjects were required to determine as rapidly as possible whether or not the two stimuli matched. A subject's encoding time corresponded to the shortest SOA at which optimal response time performance on the matching task was achieved. The results of primary interest revealed group differences in basic encoding speed and indicated that the magnitude of the group differences increased with increases in the degree to which accessing semantic knowledge was necessary to encode the stimuli. In addition, our data suggested that differences in basic encoding speed are IQ rather than MA related, whereas the degree to which accessing semantic knowledge increases encoding times is related to MA.

In recent years, a number of investigators have reported data that reveal a rather consistent negative relationship between measured intelligence and the speed with which stimulus information can be selected and manipulated mentally (see Jensen, 1982; Nettelbeck & Brewer, 1981). This relationship is especially obvious when the performance of mentally retarded individuals is compared to that of nonretarded individuals (see Baumeister & Kellas, 1968; Sperber & McCauley, 1984). One important goal of this latter comparative research is to

This research was supported by Grant Number HD-15051 from NICHD awarded to Al Baumeister, Vanderbilt University.

Correspondence and requests for reprints should be addressed to Edward C. Merrill, Peabody College, Box 154, Vanderbilt University, Nashville, TN 37203.

identify the particular processes for which individual differences in processing speed are systematically related to retarded-nonretarded differences in the performance of more complex cognitive tasks. The implicit assumption is that an understanding of retarded-nonretarded differences in processing speed will make a significant contribution to the development of empirically based theories of mental retardation in particular, and intelligence in general (cf. Brewer & Smith, 1984; Campione & Brown, 1978).

Most of the research relating processing speed to intelligence has focused on the speed with which individuals are able to detect, evaluate, and respond to external stimulation. For example, Jensen (1979; 1981) has used both simple and choice reaction time paradigms to investigate intelligence-related differences in the speed of general decision making. In addition, Lally and Nettelbeck (1977; Nettelbeck & Lally, 1976) have used a backward masking paradigm to examine the speed of sensory registration in individuals of different levels of intelligence. These studies have yielded correlations between various measures of processing efficiency and IQ that range from approximately $-.30$ to $-.80$.

Some researchers are also beginning to obtain promising results from studies that examine the relationship between intelligence and the speed with which individuals are able to execute processes that operate on internally stored information (see Sperber & McCauley, 1984 for a review). The specific processes that have received the most attention include scanning information in short-term memory (Dugas & Kellas, 1974; Harris & Fleer, 1974; Maisto & Jerome, 1977; McCauley, Kellas, Dugas, & DeVellis, 1976), retrieving information from long-term memory (Keating & Bobbitt, 1978; Hunt, 1978; Hunt, Frost, & Lunneborg, 1975; Hunt, Lunneborg, & Lewis, 1975), and semantic decision making (Davies, Sperber & McCauley, 1981; Merrill, 1985; Sperber, Davies, Merrill, & McCauley, 1982).

In the experiments reported below, our primary focus was on potential retarded-nonretarded differences in the speed with which information can be visually encoded. Across the various experiments we assessed the relative abilities of subjects to encode pictures to three different levels of abstraction: physical identity (PI), basic level name identity (NI), and superordinate identity (SI). We chose these levels of encoding because we felt they would enable us to assess encoding under conditions that vary in the degree to which accessing semantic knowledge is required to perform the experimental task. PI encoding does not specifically require any access to semantic knowledge. NI encoding for pictures probably requires access, and SI encoding definitely requires access to and retrieval of semantic knowledge of the conceptual category variety. Hence, we were able to assess potential group differences in the speed of encoding pictures of common objects as well as in the way in which any obtained differences in encoding speed may vary as a function of the type of knowledge required to complete the encoding process.

GENERAL PROCEDURES

The procedures we used were adapted from a methodology developed by Michael Posner and his colleagues (Posner & Boies, 1971; Posner & Mitchell, 1967). In the standard procedure, subjects are presented two stimuli sequentially that are separated by a variable stimulus onset asyncrony (SOA). The subjects' task is simply to determine whether or not the two stimuli match. The logic underlying the SOA manipulation is straightforward. If subjects are not given enough time to complete the encoding of the first stimulus prior to the appearance of the second stimulus (as is the case at the short SOAs), then they must do so subsequent to the appearance of the second item in order to make an accurate same/different judgement. Hence, response times, measured from the onset of the second stimulus, will reflect the time needed to complete the encoding of the first stimulus and will be relatively long. As the length of the SOA increases, response times will continue to decrease until the length of the interval is sufficient to allow the encoding of the first item to be completed before the second item appears. At this point, response times no longer improve with increases in the length of the SOA because nothing more can be done with the first stimulus of the pair, and what is done with the second stimulus of the pair is identical across all subsequent SOA intervals. Thus, the SOA at which the response time function reaches asymptote (referred to here as the point-of-asymptote, or POA) corresponds to the time required to encode the first member of the stimulus pair. Using this procedure, it is possible to measure encoding time independently of the time required to perform other operations involved in the matching task, since the time required to perform these other operations is reflected in the overall level of the response time function, rather than the POA.

Because our procedure yields data that reflect two very different aspects of performance, the data analysis is conducted in two phases. One phase of the analysis is designed to statistically determine POAs for the response time functions generated by plotting response time as a function of SOA for each level of encoding (PI, NI, and SI). During the experiments, SOAs were varied from 0 to 1000 ms at 100 ms increments. We determined the POA by comparing (using *t*-tests) response times at each SOA, against those of the next three longer SOAs. We defined the POA of the response time function as the shortest SOA for which the mean response time is not significantly greater than the mean response time of any of the next three longer SOAs. Once a POA is established for each subject, these data can then be analyzed using standard analysis of variance procedures, thus permitting a direct comparison of encoding times between groups.

We should mention that there is no preferred method for determining the inflection point of a curve generated from data of this type. Typically, this point is chosen on the basis of visual inspection (e.g., Posner & Boies, 1971; Thomas, 1974). However, since our primary interest in these experiments was in comparing encoding times across groups, we felt it was necessary to find some statistical method to determine the inflection point. The sequence of planned comparisons we have devised does this successfully, but also presents a problem of interpretation that we encountered with approximately 30% of our subjects. For example, it is possible to find that response times at the 300 ms SOA are not statistically different from those at the 400 ms SOA and have the 400 ms SOA selected as the POA of the response time function. This would happen if, using our procedure, we found that response times at the 300 ms SOA were not significantly different from those at the 400 ms SOA, but were different from either or both the 500 and 600 ms SOA, and response times at the 400 ms SOA were not different from the 500, 600, and 700 ms SOAs. We think that, given this pattern of results, the choice of the 400 ms SOA as POA makes the most sense. Clearly the 300 ms interval does not reflect maximum performance levels on the matching task because significantly faster response times are observed at longer SOAs. By choosing the 400 ms SOA as the POA, we are not claiming that response times at the 400 ms SOA are faster than those at the 300 ms SOA, but, rather, that response times at the 400 ms SOA are closer to maximum performance levels than are those at the 300 ms SOA. Since there are no SOAs at which response times are significantly faster than the 400 ms SOA, the pattern of results suggested above would support this claim. Despite this interpretive difficulty, we feel that the method we have chosen is a good one because it does not bias our results in favor of any particular group of subjects.

A second phase of the analysis compares response times obtained post-POA. These analyses reveal the effect of manipulations that are defined by the nature of the second stimulus of each stimulus pair (e.g., whether or not the second stimulus matched the first, or in the PI condition whether or not nonmatching second stimuli had the same basic level names as the first stimuli). The primary purpose of these manipulations is to provide some way to determine the strategy that subjects use to encode the first stimulus of the pair. For example, under instructions to match on the basis of SI it is possible for subjects to encode stimuli to the NI level first and bring superordinate processes to bear on the decision only after the second stimulus appears, or they may encode the first stimulus to the superordinate level and simply match stimuli on that basis. Since group differences in processing speed are only meaningful when similar processes are being compared, manipulations and analyses to determine how subjects are performing the experimental task are essential in studies of this nature. How we dealt with these issues is detailed in the pilot study described below.

PILOT STUDY

In an extensive pilot study, we sought to determine how mentally retarded and nonretarded subjects normally encoded pictures of common objects under our different instruction conditions (i.e., to match on the basis of PI, NI, or SI). We will briefly describe the results of that study because they bear on the nature of the specific manipulations chosen for our subsequent experiments.

Following the general logic of the encoding function methodology described above, subjects were presented pictures of common objects in pairs, with the presentation of the two pictures being separated by SOAs varying from 0 to 1000 ms, at 100 ms intervals. Subjects performed in various instruction conditions in which they were to base same/different judgements on whether or not the two pictures were physically identical, had the same basic level names (e.g., both dogs), or were from the same superordinate category (e.g., both animals). Of major importance to the design of our subsequent studies was the inclusion of a variable we refer to as stimulus type. This variable was included to allow us to determine the level of abstraction at which subjects encoded the pictures in order to make their same/different judgements. Stimulus type refered to the two possible types of nonmatching pairs under PI instructions (same-name and different-name pairs), the two possible types of matching pairs under NI instructions (physically identical and nonidentical pairs), and the two possible types of matching pairs under SI instructions (same basic level name and different basic level name pairs).

The POAs obtained in our pilot work as well as the post-POA response times obtained for the variable of stimulus type are presented in Table 1. It is the post-POA data that is of primary importance to our present discussion. Looking first

TABLE 1
POAs and Post-POA Mean Response Times for Pilot Study

Physical Identity Instructions

Post-POA Mean Response Times

	POA	True	False Same Name	False Different Name
Retarded	500	965	1007	884
Nonretarded	300	502	533	535

Name Identity Instructions

	POA	True Identical	True Nonidentical	False
Retarded	500	800	790	864
Nonretarded	400	496	541	528

Superordinate Identity Instructions

	POA	True Same Name	True Different Name	False
Retarded	500	842	965	984
Nonretarded	400	558	603	618

at the data obtained under PI instructions, it is evident that two groups of subjects exhibited a different pattern of post-POA response times when asked to match pictures on the basis of physical identity. The nonretarded subjects exhibited the pattern of response times that would be expected if they were, in fact, following instructions and attending only to the physical characteristics of the stimuli; that is, they exhibited equivalent response times to same-name and different-name nonmatching stimulus pairs. In contrast, the retarded subjects took longer to determine that same-name pairs were not identical than to determine that different-name pairs were not identical. In addition, different-name pairs were responded to faster than matching pairs. This pattern of data suggests that the retarded subjects very likely generated name codes for the first picture of the pair and responded immediately if the names did not match. If however, the stimuli did have the same name, they then processed the stimuli more visually to determine if the two pictures were also physically identical. Hence, we observed some difference in the abilities or tendencies of retarded and nonretarded individuals to flexibly encode pictures of common objects under circumstances in which PI encoding would be beneficial. To encourage PI encoding in Experiment 1 below, we chose to use stimuli that included nonsense forms, as well as pictures of common objects as stimuli.

On the surface, the post-POA response times under NI instructions also suggest a difference in the way the two groups perform when asked to match on the basis of name identity. The nonretarded subjects responded faster when the matching stimuli were also physically identical relative to the nonidentical matching stimuli. The mean response times for the retarded subjects exhibited the opposite trend. However, closer inspection of the data revealed that 8 of 10 retarded subjects performed in a manner that was equivalent to the nonretarded subjects, exhibiting a mean difference between conditions of 38 ms in the appropriate direction. The remaining 2 subjects were apparently confused momentarily by the pictures being identical and, therefore, averaged a 240 ms difference between conditions in the opposite direction (i.e., nonidentical pairs being responded to faster than identical pairs). Therefore, we think it is appropriate to conclude that the majority of both groups performed the task in the same way. Still, since response times for physically identical pairs were faster than those for nonidentical pairs it is not clear that the stimuli were being encoded to the basic name level by our subjects. However, two aspects of our data converged on the conclusion that subjects did encode the pictures to the basic name level. First, the average POA obtained by the nonretarded subjects under NI instructions was longer than that obtained under PI instructions, indicating that something other than PI encoding was taking place. Second, POAs did not vary as a function of the stimulus type manipulation. Nevertheless, we decided not to include physically identical pairs under NI matching instructions in Experiment 2 to minimize problems of interpretation and eliminate problems of subject confusion.

The pattern of data obtained under superordinate identity instructions was very similar for the two groups, although the magnitude of the difference between the same-name and different-name matching conditions was greater for the retarded than for the nonretarded subjects. This particular pattern of data matches some of our earlier superordinate picture verification studies (e.g., Sperber, et al., 1982) and is what would be expected if both groups of subjects were encoding the first stimulus of the pair to the basic name level and bringing superordinate decision processes into the task when necessary after the appearance of the second stimulus. The design modifications discussed in Experiment 3 were introduced to encourage superordinate level encoding by our subjects.

EXPERIMENT 1

The purpose of Experiment 1 was to assess retarded-nonretarded differences in the time required to encode pictures of common objects under instructions to match on the basis of physical identity. As mentioned earlier, our pilot work indicated that mentally retarded individuals tend to establish name codes for these stimuli rather than match on the basis of physical characteristics alone. We therefore included pictures of nonsense forms (random shapes without names) as stimuli in addition to pictures of common objects in the hopes of encouraging the retarded subjects to establish physical codes for all stimuli. Our thinking was that our subjects would opt to use physical codes because a name would be difficult to generate for half of the trials and not useful for making match/nonmatch decisions on most of the remaining trials. Pilot testing indicated that this change in procedure would produce the desired result.

Using the basic encoding function method described earlier, we compared the performance of mentally retarded individuals with that of both an equal-MA comparison group and an equal-CA comparison group. We assumed that if the differences in encoding speed between retarded and equal-CA nonretarded subjects suggested by our pilot work were not simply the result of differences in their respective rates of cognitive development, but, rather reflected differences of a more permanent nature, then encoding speed differences between the retarded subjects and their equal-MA counterparts should also be observed.

Method

Subjects. The subjects in the experiment were 10 mentally retarded adults (IQ = 58.2: CA = 23.4 yrs.: estimated MA = 9.3 yrs.), 10 nonretarded adults, (CA = 24.3 yrs.) and 10 nonretarded fourth grade students (CA = 9.4 yrs.). The nonretarded adults served as an approximate CA matched comparison group and the fourth grade students as an approximate MA matched comparison group to the retarded sample. Although no IQ information was available on the fourth grade sample, their MA's were estimated to be roughly equivalent to their CA's on the basis of their placement in the appropriate school grade and the absence of any major learning problems as indicated by teachers.

Materials. The stimuli were pictures of black and white line drawings of common objects and black and white line drawings of nonsense forms. The nonsense forms were drawn by an artist so as to be approximately equal in visual complexity to the real objects. Examples of the nonsense stimuli are presented in Figure 1. There were 8 different pictures of real objects and 8 different pictures of nonsense forms. Thirty-two stimulus pairs were presented at each SOA. These consisted of 8 matching, real object pairs; 8 matching, nonsense form pairs; 4 nonmatching, real object pairs (2 same-name and 2 different-name pairs); 4 nonmatching, nonsense form pairs; 4 nonmatching, real object-nonsense form pairs; and 4 nonmatching, nonsense form-real object pairs.

Apparatus. Two Kodak carousel slide projectors equipped with tachistoscopic lenses were used for presenting stimuli. A Tascam two-channel tape recorder was used to present auditory warning signals and to initiate each trial via an inaudible signal placed on the unattended channel of the tape recorder. The interval between stimuli within each pair was controlled by a LaFayette Model 50013 ms timer. A LaFayette clock/counter was interfaced with the ms timer and a voice-operated relay so that the onset of the timing cycle of the clock coincided with the presentation of the second stimulus of each pair and the subject's vocal response stopped the timing cycle.

Design and Procedure. The variables in the experiment were population (mentally retarded, equal-CA, and equal-MA), SOA (0, 100, 200, 300, 400,

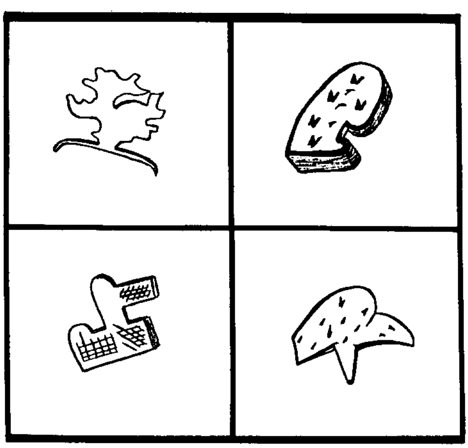

FIG. 1. Examples of nonsense forms used as stimuli in Experiment 1.

500, 600, 700, 800, and 1000 ms), and response type (match and nonmatch). SOA and response type were manipulated within subjects. A variable of stimulus type, referring to the possible combinations of real objects and nonsense forms within stimulus pairs, was included but analyzed independent of the other variables, because stimulus type could not be fully crossed with these variables (e.g., a real object paired with a nonsense form could never match).

All subjects were tested individually in two 1 hour sessions, receiving half of the trials at each SOA per session. Trials at each SOA were presented in blocks, with the presentation order of SOAs being randomly determined for each subject. In the second session, the presentation order of SOAs was the reverse of that received in the first session. Each session began with 24 practice trials: 20 at SOA = 500 ms, 2 at SOA = 1000 ms, and 2 at SOA = 100 ms. This was done to familiarize subjects with the SOA manipulation. Subjects were told about the nature of this manipulation and were given 2 additional practice trials at the appropriate SOA prior to the presentation of each block of trials. Each trial began with an auditory warning signal followed 750 ms later by the presentation of the first stimulus in the left visual field. The second picture of the stimulus pair appeared in the right visual field at the appropriate SOA after the first picture. Both pictures remained in view until a response was made. Subjects were instructed to respond "yes" if the two pictures were physically identical, and "no" if they were not, as rapidly as possible without error. The subject's response ended the trial. Response times, measured from the onset of the second stimulus in each pair, were recorded to the nearest ms.

Results and Discussion

The analyses of this experiment (as well as Experiments 2 and 3) were conducted in two separate phases. First, we analyzed the post-POA data to determine whether or not the subjects were all performing the matching task in the same general fashion. This analysis was conducted on the mean response times for each condition collapsed across the three longest SOAs (700–1000 ms). Error rates were low (< 3.0% for each group) and trials on which errors occurred were not included in the calculation of means. The data used in the analysis are presented in Table 2.

A population × response type analysis of variance (stimulus type was analyzed separately for matching and nonmatching pairs) revealed only a significant main effect of population, $F(2,27) = 7.28$, $p < .01$, with the mentally retarded subjects responding more slowly (741 ms) than both the equal-MA (595 ms) and equal-CA subjects (542 ms), who did not differ from each other (both significant p's $< .05$ using Newman-Keuls). A population × stimulus type (real objects vs. nonsense forms) analysis of response times for the matching pairs yielded a similar main effect of population; however, there was neither a difference in response times to the real object relative to nonsense form pairs (624 ms for both) nor a significant population × stimulus type interaction (both F's < 1.0). The

TABLE 2
Post-POA Means for Experiment 1

	True		False				
	R-R	**N-N**	**R-R**		**N-N**	**R-N**	**N-R***
			Same Name	Different Name			
Retarded	746	749	838	745	741	730	713
Equal MA	587	602	658	593	594	586	576
Equal CA	539	540	580	524	542	546	541

*R designates a real object picture and N designates a nonsense form picture.

analysis of the nonmatching pairs revealed a significant effect of stimulus type, $F(3,81) = 7.71, p < .01$, as well as the main effect of population. The effect of stimulus type resulted from response times for real object-real object pairs being greater than those obtained for nonsense form-real object pairs ($p < .05$ using Newman-Keuls). No other differences were significant. Apparently, the response times for the same-name, nonmatching, real object pairs sufficiently increased the overall mean of the real object-real object condition to yield the significant main effect. In fact, the mean response time of the different-name pairs was virtually identical to that of the other nonmatching stimulus types.

The statistical comparison of same-name versus different-name nonmatching pairs revealed that the means in these conditions were significantly different, $F(2,17) = 11.20$, $p < .01$, with the magnitude of this effect not varying as a function of population ($F < 1.0$). On the surface, these data suggest the possibility that all of our subjects were encoding the real object stimuli to the name identity level the same way as the mentally retarded subjects in the pilot study. However, several other aspects of our data converged on the conclusion that our subjects were encoding the pictures in accordance with PI instructions. First, we found that the POA for the encoding functions generated for stimulus pairs, in which a real object was the first stimulus of the pair, were identical to those generated for stimulus pairs in which a nonsense form was the first stimulus of the pair. Since the nonsense forms did not have names and therefore were assumed to be encoded to the PI level, it seems reasonable to conclude that both types of stimuli were encoded to this level. Additional support for this conclusion is obtained by comparing the POAs calculated from the data of Experiment 1 with the pilot study. For both the mentally retarded and equal-CA subjects, encoding times in this experiment were 100 ms faster than they were under NI instructions in the pilot study, and for the equal-CA subjects encoding times were identical to that obtained under PI instructions in the pilot study (300 ms). Taken together, these results strongly suggest that subjects were encoding the pictures to PI rather than NI level in Experiment 1. We therefore concluded that the response time difference between the same-name and different-name nonmatching pairs probably resulted from some form of interference from an automatically activated and unattended name code.

It is not clear, however, why the nonretarded subjects of the pilot study did not also exhibit interference of this nature. It may be that these subjects were able to actively inhibit the name code in the pilot study where same-name pairs occurred 25% of the time at each SOA. They may not have attempted to do so in Experiment 1 because same-name nonmatching pairs occurred only twice at each SOA. Nevertheless, since the data favored the conclusion that all subjects were encoding the stimuli to the PI level, we considered it appropriate to continue with our POA analyses.

Our procedure was to statistically determine a POA for each subject and subsequently analysize the obtained POAs using standard analysis of variance procedures. The actual data used in the individual POA analyses were not the raw response time data of the individual subjects but, rather, deviation scores calculated for each stimulus type × response type condition across all SOAs. These scores were obtained by simply calculating (for each subject) an overall mean separately for each condition and then subtracting each condition mean from all of the individual response times of their respective conditions. In this manner we obtained a set of scores on the same scale for which the variability associated with SOA was retained; the variability associated with the factors of stimulus type and response type was eliminated. We chose this method of analysis because we felt it would yield results more representative of the data taken as a whole. Preliminary analysis revealed that variables defined by the second member of the stimulus pair (i.e., stimulus type and response type) did not interact with SOA. However, when we used more conventional methods of analysis, such as conducting multi-factor anovas on the raw response time data to compare pairs of SOAs, we often obtained significant interactions between one or both of these variables and SOA; that is, variability that was determined to be random across all 10 SOAs was found to be systematic and reliable when pairs of SOAs were compared. We were able to eliminate this discrepancy by conducting our analysis on deviation scores.

The group response time functions obtained in this experiment are presented in Figure 2. Errors were extremely rare across all SOAs (< 3.0%) for each group and trials on which errors occurred were excluded from the analyses. The POA analyses were conducted on the data from individual subjects as previously described. The mean POA obtained for the mentally retarded subjects was 410 ms (range = 200–500 ms; SD = 88.8); for the equal-MA subjects was 310 ms (range = 200–400 ms; SD = 74.4); and for the equal-CA subjects was 290 msec (range = 100–400 ms; SD = 74.4). The comparison of these means revealed a significant effect of population, $F(2,27) = 6.68, p < .01$, with the mean POA of the mentally retarded subjects being significantly greater than that of both the equal-MA and equal-CA subjects (both p's < .05, using Newman-Keuls). The

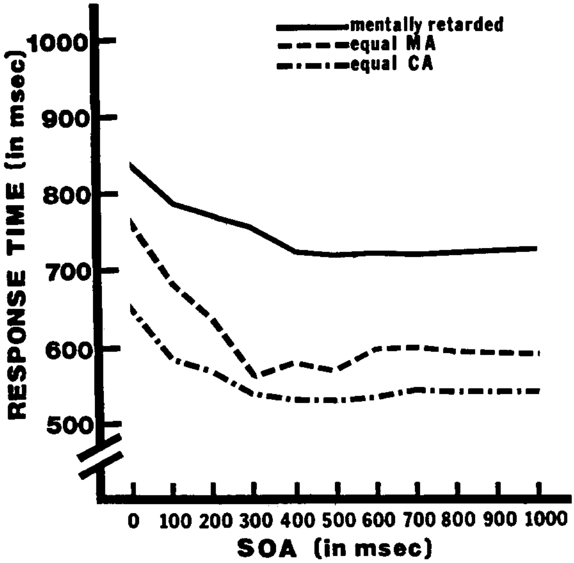

FIG. 2. Encoding functions obtained in Experiment 1 under physical identity (PI) instructions.

two nonretarded groups did not differ. These results indicate that the mentally retarded subjects required approximately 100 ms more time to physically encoded the nonsense forms and pictures of common objects used in this experiment than did the nonretarded subjects. Furthermore, it appears that this encoding time difference is related to IQ rather than to MA since the fourth grade subjects were faster at encoding than were the mentally retarded subjects and were virtually identical in speed to the college students.

EXPERIMENT 2

Experiment 2 was designed to assess retarded-nonretarded differences in the time required to encode pictures of common objects under instructions to match on the basis of NI. Mentally retarded, equal-CA nonretarded, and equal-MA nonretarded subjects performed the matching task under conditions essentially identical to Experiment 1, except that all stimuli were pictures of common objects and subjects were instructed to match on the basis of name identity. As in the previous experiment, group differences in encoding speed would be evidenced by differences in the SOA at which maximum performance levels are reached.

Method

Subjects. The subjects in Experiment 2 were 10 mentally retarded adults (IQ = 63.4: CA = 26.1 yrs.: estimated MA = 10.1 yrs.), 10 nonretarded adults (CA

= 25.1), and 10 nonretarded fourth grade students (9.6 yrs.) selected in a manner similar to that of Experiment 1.

Materials. The stimuli were photographic slides of black and white line drawings of common objects. Two different drawings of each of 16 objects were used. Thirty-two picture pairs, 16 matching and 16 nonmatching, were constructed for use at each SOA.

Design and Procedure. The variables in the experiment were population, SOA, and response type, with SOA and response type manipulated within subjects. The apparatus and general procedure were identical to that of Experiment 1, except that all subjects were instructed to match on the basis of NI rather than PI.

RESULTS AND DISCUSSION

Again, error rates were low (< 2.0% across SOAs) for each group, and data from these trials were not included in the analyses. The post-POA analysis under NI instructions included the variables of population and response type. This analysis revealed a significant main effect of population, $F(2,27) = 4.90$, $p < .05$, a significant main effect of response type, $F(1,27) = 33.20$, $p < .001$, as well as a significant population × response type interaction, $F(2,27) = 8.34$, $p < .001$. The main effect of population was due to the equal-CA subjects responding significantly faster (497 ms) than both the equal-MA subjects (650 ms) and the mentally retarded subjects (719 ms; both p's < .05). The equal-MA and mentally retarded subjects did not differ. The main effect of response type resulted from matching responses being made faster than nonmatching responses (597 vs. 647 ms, respectively). However, as evidenced by the significant two-way interaction, the magnitude of the response type effect was not identical across the three groups of subjects. The magnitude of this difference was 14 ms for the equal-CA subjects, 45 ms for the equal-MA subjects, and 102 ms for the mentally retarded subjects, suggesting the possibility of a difference in criteria for making match-nonmatch decisions among our groups of subjects. As expected, however, response type did not interact with SOA ($F < 1.0$), since SOA reflects the amount of time the first stimulus of the pair is viewed, prior to the appearance of the second stimulus, and response type is defined by the nature of the second stimulus. Thus, the manipulation of response type did not influence the manner in which the stimuli were encoded, and the interaction of population and response type does not interfere with our ability to establish POAs for the response time functions.

The group response time functions for Experiment 2 are presented in Figure 3. The analyses of individual subject data yielded a mean POA for the mentally retarded subjects of 480 ms (range = 300–600 ms; $SD = 79.8$ ms), a mean POA

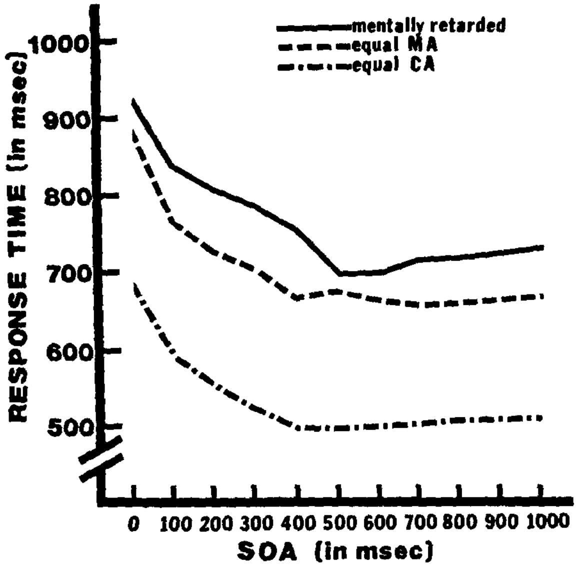

FIG. 3. Encoding functions obtained in Experiment 2 under name identity (NI) instructions.

for the equal-MA subjects of 370 ms (range = 300–500 ms; SD = 67.5), and a mean POA for the equal-CA subjects of 360 ms (range = 200–500 ms; SD = 84.4). The comparison of these means revealed a significant effect of population $F(2,27) = 7.44, p < .01$. As was the case under PI instructions, the mean POA of the mentally retarded subjects was significantly greater than that of both nonretarded groups (p's $< .05$) who did not differ significantly from each other. The mentally retarded subjects required approximately 100 ms longer to access the names of pictures of common objects than did the nonretarded subjects. It also appears that accessing the basic level name codes of common objects, as was true of PI encoding in Experiment 1, may be more sensitive to IQ differences than to MA differences.

EXPERIMENT 3

Experiment 3 examined retarded-nonretarded differences in the speed of encoding pictures of common objects under instructions to match on the basis of SI. The general procedure was similar to that of the previous experiments except that the second stimulus in each stimulus pair was an auditorally presented superordinate category label. This procedural change forced subjects to base their judgments on superordinate information. We encouraged the adoption of a superordinate encoding strategy in the following two ways. First, we had subjects perform a superordinate labeling task for 10 minutes prior to the start of the experimental trials. Second, we used a fixed presentation order of SOAs beginning with the longest SOA interval and working backwards through the shortest. This latter change was made because pilot work indicated that when subjects received the shortest SOAs, they often discontinued the encoding of the first stimulus, encoded the subsequently presented superordinate label, and then determined whether or not the pictured object was a member of that superordinate category without ever encoding it to the superordinate level. However, when subjects received the longest SOAs, they exhibited a tendency to encode the picture to the superordinate level and then match the generated code with the superordinate label. The variable that seemed to determine a subject's choice between these two strategies was whether they received primarily short SOAs early in the session or primarily long SOAs early in the session. When short SOAs dominated the early part of the session, subjects appeared to use the first strategy and not encode the picture to the superordinate level. In contrast, when long SOAs dominated the early part of the session, subjects did appear to use the superordinate level encoding strategy. Since it was the strategy of generating a superodinate code that we wanted to encourage, we decided to present the longest SOA intervals first, assuming that subjects would continue to use this encoding strategy until they were presented SOA intervals that were too short to complete the encoding of the picture. At that time we expected subjects to exhibit a rather abrupt change in the response times, reflecting a change in the way the task is performed.

One additional manipulation was included in Experiment 3. It seemed desirable to have a way to check whether or not subjects were, in fact, encoding the pictures to the superordinate level. We therefore varied the degree to which the pictured objects were considered to be typical members (Rosch, 1975) of their respective superordinate categories. Since typicality influences how rapidly an individual can determine the category membership of an object (e.g., Smith, Shoben, & Rips, 1974), it is possible to ascertain how subjects performed the task by determining the processing stage at which typicality influences response times. If subjects generated a superordinate code when encoding the picture, then typicality would influence the length of time needed to encode the picture. Hence, optimal performance levels on the matching task would be reached at shorter SOAs for highly typical exemplars relative to less typical exemplars of the superordinate categories. In addition, since the code against which the category label is compared would be identical for the more and less typical stimulus items following their complete encoding, post-POA response times would be identical for both levels of typicality. If, on the other hand, subjects did not generate superordinate codes for the pictures and generated, for example, basic level codes as in the pilot study, then the opposite pattern of results would obtain. Since superordinate processes are brought into play only after the picture was encoded, differences between more and less typical stimulus items would be observed in post-POA response times and not in encoding times.

During the experiment, we found that some individuals in each group chose the superordinate encoding strategy and some chose basic level encoding. We therefore decided to test as many subjects as necessary to obtain 10 subjects per group who used the superordinate encoding strategy.

Method

Subjects. The subjects in Experiment 3 were 18 mentally retarded adults (IQ = 61.8: CA = 22.4 years: Estimated MA = 9.9 years.) 14 nonretarded adults (CA = 24.0 yrs.), and 15 nonretarded fourth grade students (CA = 9.4 yrs.). Subjects were selected in a manner similar to the previous experiments.

Again, the stimuli in the experiment were photographic slides of black and white line drawings of common objects. The objects were 4 highly typical and 4 less typical exemplars from each of 8 conceptual categories (animals, clothing, fruit, furniture, musical instruments, tools, toys, and vehicles). Typicality estimates were based on ratings obtained by Rosch (1975) and Young and Kellas (1976). Mean typicality ratings for the stimuli used in this study (on a 7-point scale) were 1.9 for the highly typical exemplars and 4.1 for the less typical exemplars.

A total of 32 pictures, consisting of 2 highly typical and 2 two less typical exemplars from each category, were presented at each SOA used in the experiment. Half of the exemplars at each SOA were designated to appear with the correct superordinate label and half to appear with an incorrect superordinate label. Across all SOAs, each exemplar appeared 4 times, twice with the correct label and twice with an incorrect label. Superordinate labels were tape recorded for presentation.

Apparatus. A Kodak carousel slide projector equipped with a tachistoscopic lens was used for presenting slide stimuli. A Tascam two-channel tape recorder was used for presenting auditory warning signals and the superordinate labels, as well as initiating the trials via a series of inaudible signals. Response times were measured using a LaFayette clock/counter. The clock/counter was interfaced with a voice-operated relay and the tape recorder so that the onset of the superordinate label started the clock and the subject's vocal response stopped it.

Design and Procedure. The variables in the experiment included population, SOA, response type, and typicality (highly typical and less typical). SOA, response type, and typicality were manipulated within-subjects. In this experiment we used 8 SOA intervals (0, 300, 400, 500, 600, 700, 800, 1000). Two intervals (100 and 200 ms) that our previous experiments indicated would be too short for our subjects to reach optimal performance levels were eliminated so that we could add the warm-up superordinate labeling task described earlier without increasing the length of the experimental sessions. The presentation order of

SOAs was fixed, beginning with the longest SOA and working backwards through the shortest.

Subjects were tested individually in 2 sessions that lasted approximately 1 hour each. At the start of each session, subjects took part in the superordinate labeling task for approximately 10 minutes. The procedure for the labeling task was simply to present pictures of common objects to the subjects and instruct them to label the pictures at the superordinate level as rapidly as possible without error. Forty-eight pictures that were not used during the matching task were presented as part of the labeling task. Immediately after completion of the labeling task, the matching task was begun. The general procedure was essentially identical to that of the previous experiments except that the second stimulus of each stimulus pair was an auditorally presented superordinate label. The subject was instructed to respond "yes" if the pictured object was a member of the superordinate category presented and "no" if it was not as rapidly as possible. During each session, the subjects received 32 practice trials at SOA = 1000 ms, followed by 1 practice and 16 experimental trials at each of the experimental SOAs. Response times, measured from the onset of the superordinate label, were recorded to the nearest ms.

Results and Discussion

As in the previous experiments, trials on which errors occurred ($< 3.5\%$ of the time) were not included in the analyses. The post-POA data in this experiment were used to determine which subjects were encoding the pictures at the superordinate category level. We selected from the original subject pool those subjects for whom the post-POA response times for the less typical exemplars were no more than 25 ms greater than those of the highly typical exemplars in the matching conditions. Ten subjects per group met this requirement. The group encoding functions for these subjects are presented in Figures 4 and 5.

Individual POAs were calculated separately for the highly typical exemplars and less typical exemplars. These data presented in Table 1, were analyzed in a 3 (population) $\times$ 2 (typicality level) analysis of variance, with typicality level treated as a within-subjects factor. The analysis revealed a significant main effect of population, $F(2,27) = 7.85$, $p < .05$. a significant main effect of typicality level, $F(1,27) = 149.02$, $p < .001$, and a significant population $\times$ typicality level interaction, $F(2,27) = 4.16$, $p < .05$. Breaking down the interaction, we found a significant effect of population for both highly typical, $F(2,27) = 4.66$, $p < .05$, and less typical, $F(2,27) = 12.55$, $p < .05$, category exemplars. However, the pattern of population differences was different at the two levels of typicality. For the highly typical exemplars, the mean POA for the mentally retarded subjects was again significantly greater than both the equal-MA and equal-CA groups (both p's $< .05$), with the latter two groups not differing. For the less typical exemplars, however, all three groups differed significantly from each other, with the mentally retarded exhibiting the largest mean POA and the

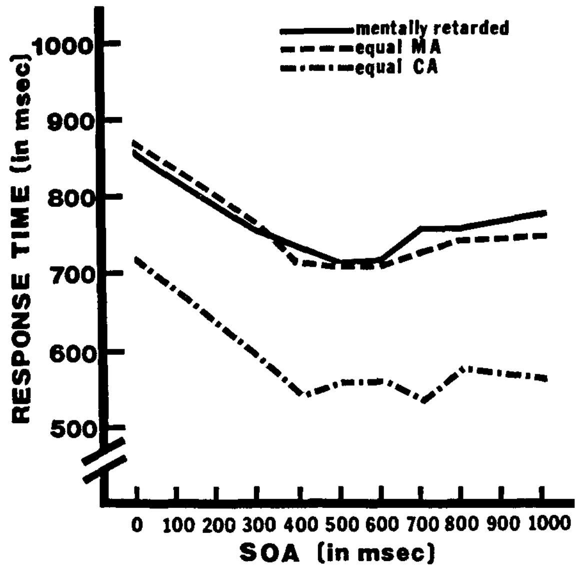

FIG. 4. Encoding functions obtained in Experiment 3 for highly typical category exemplars under superordinate identity (SI) instructions.

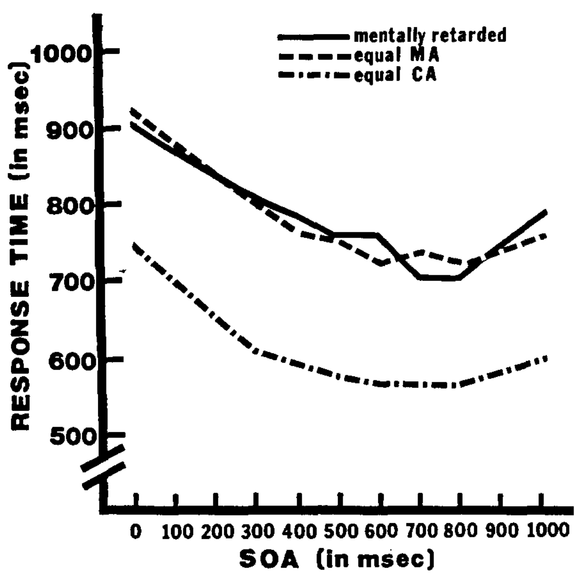

FIG. 5. Encoding functions obtained in Experiment 3 for atypical category exemplars under superordinate identity (SI) instructions.

TABLE 3
POA Data (in ms) for Experiment 3

		POA	*R*	*SD*
Retarded	Highly Typical	460	300–600	84
	Less Typical	650	500–700	79
Equal-MA	Highly Typical	380	300–500	36
	Less Typical	580	500–700	56
Equal-CA	Highly Typical	370	300–500	30
	Less Typical	480	300–600	56

equal-CA group exhibiting the smallest (all p's $< .05$). This particular pattern of results indicates that level of typicality had a greater effect on the mean POAs of the mentally retarded and equal-MA subject (190 and 200 ms, respectively) than it did on those of the equal-CA subjects (110 ms).

Taken together, these results suggest the following conclusions. As evidenced by the POA's obtained for highly typical exemplars, the mentally retarded subjects took 100 ms longer than both the equal-MA and equal-CA subjects to encode the pictures to the superordinate level. This pattern of results is essentially identical to that obtained under NI and PI instructions and may indicate that the superordinate identity of highly typical category exemplars was sufficiently well learned by all of our subjects to permit relatively direct access to the superordinate information. Hence, encoding time differences seem to reflect differences in basic encoding speed independent of access to semantic knowledge. As a result, these differences also seem to be related to IQ differences rather than MA differences. However, a different pattern emerged in our analysis of the encoding times obtained for the less typical exemplars. Encoding times increased as a function of typicality level for all subjects, but the magnitude of this increase was greater for the mentally retarded and equal-MA subjects than it was for the equal-CA subjects. This is the only instance in any of the experiments where the equal-MA and equal-CA groups differed. We think this difference was due to the fact that the superordinate encoding of less typical exemplars reflects an MA related difference in the degree to which the superordinate-exemplar relationships have been learned for the less typical exemplars. This interpretation receives some support from the finding that the magnitude of the effect due to typicality level was virtually identical for the two groups that were selected to be matched on MA (i.e., the mentally retarded and equal-MA groups). However, this conclusion must remain tenative since it is likely that the magnitude of the increase associated with typicality level and possibly the degree to which mentally retarded and equal-MA subjects exhibit similar increases will depend on the particular categories and exemplars used as stimuli.

GENERAL DISCUSSION

The experiments reported here were designed to investigate retarded-nonretarded differences in stimulus encoding speed. In general, our results are consistent with theoretical formulations of intelligence that posit a negative relationship between mental processing speed and measured intelligence (e.g., Eysenck, 1967; Jensen, 1979). The mentally retarded subjects were found to be approximately 100 ms slower than either the equal-MA or equal-CA subjects at encoding stimuli for the purpose of determining a physical identity match, and 100 ms slower than both groups of nonretarded subjects at encoding stimuli for the purpose of determining a name identity match. Under instructions to match on the basis of superordinate identity, however, the data are not so straightforward. Apparently, individuals do not readily encode stimuli to the superordinate level even when provided circumstances where doing so seems most appropriate. To the extent that those subjects who did encode stimuli in accordance with task instructions are representative of their respective groups, we can offer the following tentative conclusions about superordinate encoding. Superordinate encoding of very highly typical category exemplars takes approximately the same amount of time as basic level name encoding for all three groups, with the mentally retarded subjects again requiring approximately 100 ms longer than either nonretarded group to perform the task. But, a slightly different pattern of data emerged for the less typical category exemplars. The mentally retarded subjects were again 100 ms slower than their equal-MA counterparts, but the equal-MA subjects were also 100 ms slower than the equal-CA subjects.

The finding that the speed of encoding exhibited by the fourth grade subjects was virtually identical to that exhibited by the graduate students for PI encoding, NI encoding, and SI encoding of highly typical category exemplars is one of the important features of our data. Since the mentally retarded subjects were slower than both groups of nonretarded subjects in all of these conditions, it appears that basic encoding speed varies more systematically with IQ than with MA. These data further suggest that the cognitive processes involved in encoding that were tapped in our studies (e.g., sensory registration of the visual stimulus, accessing the names of common objects in semantic memory, and accessing the superordinate labels of highly typical category exemplars) are fully developed in the nonretarded population before 10 years of age. It is reasonable to assume that the encoding processes of the mentally retarded adult subjects will not develop beyond the levels reported in these experiments, since subjects were 25 years of age. We therefore believe that the deficiencies exhibited by our retarded subjects can not be attributed to simply a slower rate of perceptual development (relative to same age nonretarded individuals), but rather reflect more permanent and constant differences between mentally retarded and nonretarded individuals. However, our findings of a fundamental similarity between the two nonretarded groups must be interpreted with some caution because our results are based on interpolated data. The choice of a 100 ms interval between SOAs may make it difficult to measure small differences that do exist between groups and may also over- or underestimate the magnitude of the difference between the mentally retarded subjects and the two groups of nonretarded subjects by some unspecifiable amount.

Although there is some additional support for the conclusion that differences in encoding speed reflect fundamental and relatively permanent differences between retarded and nonretarded individuals (see Nettelbeck & Lally, 1979; Nettelbeck & Brewer, 1981), we are not prepared to conclude that the differences observed in these experiments are caused by "structural" differences (cf., Fisher & Zeaman, 1973) between the populations. To suggest that a population difference is of the structural variety is to make the strong claim that it is relatively impervious to remediation (see Campione, & Brown, 1977). Since we made no attempts to modify the speed with which our subjects encoded the experimental stimuli, no firm conclusion concerning a possible structural basis for this difference is warranted. However, the possibility for such a conclusion certainly presents itself.

Only when it came to the superordinate encoding of less typical category exemplars did the equal-CA subjects differ from the equal-MA subjects, with the older nonretarded subjects exhibiting a smaller difference between their encoding times of highly typical and less typical exemplars than did the younger nonretarded subjects. It seems likely that this difference reflects age-related differences in the consolidation of semantic category knowledge and it is consistent with previously reported age-related differences in semantic decision making (e.g., Sperber et al., 1982). These MA-related differences in semantic knowledge also tend to increase the magnitude of the processing speed difference between the retarded and equal-CA subjects accordingly. Hence, the group differences we observed in superordinate encoding of less typical category exemplars appear to include both MA-related and IQ-related components.

We should note that the accuracy of our conclusions depends entirely on the extent to which we have been able to successfully: (1) isolate the encoding processes under investigation, and (2) rule out the potential influence of confounding strategic processes on the magnitude of our group differences (see e.g., List, Keating, & Merriman, 1985). The first criterion seems to have been met by the selection of the general encoding function methodology. However, the second issue of ruling out the influence of confounding strategic encoding differences merits additional discussion. At a gross level, we feel we have also met this second criterion. The fact that our estimates of encoding times were different for each instruction condition indicates that we have tapped three different types of encoding for each group. And given the nature of our matching instructions, it is reasonable to assume that they reflect the amount of time needed for PI, NI, and SI encoding. But, the possibility that there are different ways to construct each of these codes clearly exists. For example, it may be that some subjects actually label a stimulus when encoding to the basic level, whereas other subjects construct a more abstract, conceptually based code to compare to the second stimulus. If we find that more subtle strategic differences of this type vary systematically with our different populations, then our conclusions will have to be modified accordingly. Nevertheless, the consistency of our results across the different levels of encoding is encouraging and suggests that future research along these lines may prove fruitful.

REFERENCES

Baumeister, A.A., & Kellas, G. (1968). Reaction time and mental retardation. In N.R. Ellis (Ed.), *International review of research in mental retardation (Vol. 3)* (pp. 163–193). New York: Academic.

Brewer, N., & Smith, G.A. (1984). How normal and retarded individuals monitor and regulate speed and accuracy of responding in serial choice tasks. *Journal of Experimental Psychology: General, 113,* 71–93.

Campione, J.C., & Brown, A.L. (1977). Memory and metamemory development in educable retarded children. In R.V. Kail & J.W. Hagen (Eds.), *Perspectives on the development of memory and cognition* (pp. 367–406). Hillsdale, NJ: Erlbaum.

Campione, J.C., & Brown, A.L. (1978). Toward a theory of intelligence: Contributions from research with retarded children. *Intelligence, 2,* 279–304.

Davies, D., Sperber, R.D., & McCauley, C. (1981). Intelligence-related differences in semantic processing speed. *Journal of Experimental Psychology, 31,* 387–402.

Dugas, J.L., & Kellas, G. (1974). Encoding and retrieval processes in normal children and mentally retarded adolescents. *Journal of Experimental Child Psychology, 17,* 177–185.

Eysenck, H.J. (1967). Intelligence assessment: A theoretical and experimental approach. *British Journal of Educational Psychology, 37,* 81–98.

Fisher, M.A., & Zeaman, D. (1973). An attention-retention theory of retardate discrimination learning. In N.R. Ellis (Ed.), *International review of research in mental retardation (Vol. 6)* (pp. 167–256). New York: Academic.

Harris, G.J., & Fleer, R.E. (1974). High speed memory scanning in mental retardates: Evidence for a central processing deficit. *Journal of Experimental Child Psychology, 17,* 452–459.

Hunt, E. (1978). Mechanics of verbal ability. *Psychological Review, 85,* 109–130.

Hunt, E., Frost, N., & Lunneborg, C. (1973). Individual differences in cognition: A new approach to intelligence. In G. Bower (Ed.), *The psychology of learning and motivation (Vol. 7)* (pp. 87–122). New York: Academic.

Hunt, E., Lunneborg, C., & Lewis, J. (1975). What does it mean to be high verbal? *Cognitive Psychology, 7,* 194–227.

Jensen, A.R. (1979). *g:* Outmoded theory or unconquered frontier. *Creative Science and Technology, 2,* 16–29.

Jensen, A.R. (1981). Reaction time and intelligence. In M.P. Friedman, J.P. Das, & N. O'Connor (Eds.), *Intelligence and learning* (pp. 39–50). New York: Plenum.

Jensen, A.R. (1982). The chronometry of intelligence. In R.J. Sternberg (Ed.), *Advances in the psychology of human intelligence (Vol. 1)* (pp. 255–310). Hillsdale, NJ: Erlbaum.

Keating, D.P., & Bobbitt, B.L. (1978). Individual and developmental differences in cognitive processing components of mental ability. *Child Development, 49,* 155–177.

Lally, M., & Nettelbeck, T. (1977). Intelligence, reaction time, and inspection time. *American Journal of Mental Deficiency, 82,* 273–281.

List, J.A., Keating, D.P., & Merriman, W.E. (1985). Differences in memory retrieval: A construct validity investigation. *Child Development, 56,* 138–151.

Maisto, A.A., & Jerome, M.A. (1977). Encoding and high-speed memory scanning of retarded and nonretarded adolescents. *American Journal of Mental Deficiency, 82,* 282–286.

McCauley, C., Kellas, G., Dugas, J., & DeVellis, R.F. (1976). Effects of serial rehearsal training on memory search. *Journal of Educational Psychology, 78,* 474–481.

Merrill, E.C. (1985). Differences in semantic processing speed of mentally retarded and nonretarded persons: Comparison of short- and long-term memory processing. *American Journal of Mental Deficiency, 90,* 71–80.

Nettelbeck, T., & Brewer, N. (1981). Studies of mind mental retardation and timed performance. In N.R. Ellis (Ed.), *International review of research in mental retardation (Vol. 10)* (pp. 61–106). New York: Academic.

Nettelbeck, T., & Lally, M. (1976). Inspection time and measured intelligence. *British Journal of Psychology, 67,* 17–22.

Nettelbeck, T., & Lally, M. (1979). Age, intelligence, and inspection time. *American Journal of Mental Deficiency, 83,* 398–401.

Posner, M.I., & Boies, S.J. (1971). Components of attention. *Psychological Review, 78,* 391–408.

Posner, M.I., & Mitchell, R.F. (1967). Chronometric analysis of classification. *Psychological Review, 78,* 392–409.

Rosch, E. (1975). Cognitive representations of semantic categories. *Journal of Experimental Psychology: General, 104,* 192–233.

Smith, E.E., Shoben, E.J., & Rips, L.J. (1974). Structure and process in semantic memory: A featural model for semantic decisions. *Psychological Review, 81,* 214–241.

Sperber, R.D., Davies, D., Merrill, E.C., & McCauley, C. (1982). Cross-category differences in the processing of subordinate-superordinate relationships. *Child Development, 53,* 1249–1253.

Sperber, R.D., & McCauley, C. (1984). Semantic processing efficiency in the mentally retarded. In P. Brooks, R. Sperber, & C. McCauley (Eds.), *Learning and cognition in the mentally retarded* (pp. 141–163). Hillsdale, NJ: Erlbaum.

Thomas, E. (1974). The selectivity of preparation. *Psychological Review, 81,* 442–464.

Young, M., & Kellas, G. (1976). *Typicality ratings for pictures of instances of superordinate categories.* Unpublished manuscript, University of Kansas.