Attentional Resource Allocation and Mental Retardation

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I. INTRODUCTION

Various aspects of attention have long been assumed to play an important role in intellectual functioning. As is obvious from the amount of research and theory available that focuses on the comparison of the attentional processes of mentally retarded and nonretarded individuals (e.g., Bryant, Deckner, Soraci, Baumeister, & Blanton, 1988; Fisher & Zeaman, 1973; Heal & Johnson, 1970; Krupski, 1977; Nettelbeck & Brewer, 1981; Soraci, Barlean, Haenlein, & Baumeister, 1986; Zeaman & House, 1963, 1979), the nature of this potential relationship has also been evident to researchers gathering data about cognitive aspects of mental retardation. The fundamental reasons for this belief are clear. Because mentally retarded individuals exhibit performance deficits relative to nonretarded individuals across a wide range of cognitive tasks, researchers are compelled to consider the possibility that these deficits are at least partially the result of deficiencies in some fundamental cognitive abilities that are involved in the performance of many different activities. Attentional processes are presumed to mediate virtually all cognitive activities and are therefore logical candidates for the source of retarded–nonretarded differences in cognitive performance.

When considering the possibility of attentional deficits in mentally re-

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tarded individuals, it is important to recognize that over the years the concept of attention has referred to a variety of processes (see Parasuraman & Davies, 1984). These processes can be divided into two major categories. According to one view, attention can be described as a process of selection (Pick, Frankel, & Hess, 1975). In this view, attention operates to determine which stimuli from the internal and external environments are perceived and receive additional analysis and which stimuli are ignored. This conception of attention implies that individuals have both the ability to determine relevant from irrelevant aspects of the environment and some mechanism for filtering irrelevant aspects of the stimulus array, with performance deficits resulting from either a failure to attend to the relevant dimensions of the stimulus array or the inefficient execution of the filtering system. In a very different conceptualization, attention is described as a "capacity" rather than a process (e.g., Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975). In this view, attention is described as a limited supply of processing resources that can be allocated to cognitive activities in a flexible manner. Cognitive processes can be activated simultaneously but, if they are, they must share the cognitive resources that are available for processing. In this case, performance deficits would result when the requirements of particular processes demand resources to an extent that obstructs the performance of other ongoing activities.

The majority of empirical and theoretical work on the attentional capabilities of mentally retarded individuals has focused on selective attention. In particular, Zeaman and colleagues (Fisher & Zeaman, 1973; Zeaman & House, 1963, 1979) have amassed considerable data detailing differences between the selective attention abilities of mentally retarded and nonretarded individuals on discrimination learning tasks. In discrimination learning, the basic procedure is to present a series of two or three stimuli that differ from each other along one or more stimulus dimensions (e.g., color and shape). The subject's task is to determine which of the stimuli is "correct" on the basis of feedback about the correctness of his or her choices on previous trials. It is common for mentally retarded individuals to take longer than nonretarded individuals to learn which stimulus is correct when confronted with this kind of task. Zeaman and House (1963) concluded that this difference between retarded and nonretarded individuals is primarily a function of differences in selective attention; that is, mentally retarded individuals are much slower than nonretarded individuals at selecting the stimulus dimension targeted by the experimenter that is a prerequisite to determining the correct stimulus. Once the correct dimension has been specified, the learning of mentally retarded and nonretarded individuals appears to proceed in a very similar

fashion (Zeaman & House, 1963, 1979). Additional work has suggested the possibility that "breadth of attention," or the number of stimulus dimensions that can be considered on each trial, may also covary with intelligence (see Zeaman, 1978). However, the details of this relationship have not been as well documented as those associated with the direction of attention.

There is also some evidence to suggest that the efficiency of selection mechanisms is different for mentally retarded and nonretarded individuals (Hagen & Huntsman, 1971). For example, subjects may be shown a series of item pairs with instructions to attend to and try to remember the "animals" of the object pairs (the central information) without instructions to learn the other object, for example, a piece of furniture, of each pair (the incidental information). Current evidence suggests that older and more intelligent individuals exhibit a greater difference between the amount of central relative to incidental information that they are able to remember in comparison to younger and less intelligent individuals (Hagen & Huntsman, 1971; Hagen, Meacham, & Mesibov, 1970; Maccoby & Hagen, 1965). Apparently, the ability to focus on relevant information, even after that information has been singled out for further processing, is sensitive to differences in both developmental and intellectual level.

In as much as a significant amount of information processing occurs in the absence of competing stimuli, it would appear that mechanisms of selectivity are not likely to be the only central component of the information-processing system associated with retarded—nonretarded differences in general information processing. Another possibility focuses on attention viewed as a capacity for processing (e.g., Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975). However, in contrast to selective attention, there are relatively few studies that address retarded–nonretarded differences associated with attention when attention refers to a capacity for processing rather than a mechanism for the selection of stimuli. The major exceptions are studies that have focused on potential differences between retarded and nonretarded individuals associated with some aspect of the orienting response (see Luria, 1963), a relatively complex set of central and autonomic nervous system responses to novel and/or meaningful stimuli that are associated with an increased ability to perceive and take in sensory information. For example, Krupski (1975) assessed the relationship between changes in heart rate and the performance of mentally retarded and nonretarded adults in a fixed reaction time procedure. Heart rate deceleration is generally assumed to reflect some aspect of attentional processing associated with preparing for the presentation of a stimulus or the generation of a response. Krupski found that, overall, mentally retarded subjects were slower to exhibit heart rate

deceleration during the reaction time task than were nonretarded subjects, and the retarded subjects exhibited a lower magnitude of heart rate deceleration than did the nonretarded subjects. The implication is that mentally retarded individuals are less efficient in making attentional resources available for the performance of reaction time tasks (see also Runcie & O'Bannon, 1975).

There are many other aspects of attentional resource allocation that warrant research attention. The major premise of this article is that a significant portion of retarded–nonretarded differences in semantic processing speed may be the result of the inefficient execution of one or more components of the attentional resource allocation system. In the sections that follow the rationale underlying the development of the attentional resource hypotheses is reviewed, a conceptual framework in which to consider these hypotheses is presented, and the results of several preliminary studies designed to address the relationship between attentional resource allocation and retarded–nonretarded differences in cognitive performance are discussed.

II. DEVELOPMENT OF THE ATTENTIONAL RESOURCE HYPOTHESES

It is common to observe a consistent relationship between measured intelligence and the speed of information transmission through the human information-processing system (see Jensen, 1982; Nettelbeck & Brewer, 1981), with individuals who score lower on standardized tests of intelligence commonly performing information-processing tasks more slowly than individuals who score higher on these tests. When comparing the performance of mentally retarded and nonretarded individuals this relationship is particularly evident (see Baumeister & Kellas, 1968; Sperber & McCauley, 1984). Some of the specific cognitive processes that have received a great deal of research attention include searching short-term memory (e.g., Dugas & Kellas, 1974; Harris & Fleer, 1974; Maisto & Jerome, 1977; McCauley, Kellas, Dugas, & DeVillas, 1976), retrieving information from long-term memory (e.g., Hunt, 1978; Hunt, Frost, & Lunneborg, 1975; Keating & Bobbitt, 1978) and making decisions about semantic category membership (e.g., Davies, Sperber, & McCauley, 1981; Merrill, 1985; Sperber, Davies, Merrill, & McCauley, 1982).

The generality of differences in semantic processing speed between mentally retarded and nonretarded individuals has been particularly conspicuous. In fact, one is hard pressed to find conditions in which mentally retarded and nonretarded individuals do not differ in processing speed.

More remarkable, however, is the obvious similarity in the relative magnitude of retarded–nonretarded differences in processing speed across the different stimuli and cognitive processes tested in the various experiments. This has been most noticeable in the results of studies in which researchers have attempted to isolate individual components of the processing system and have tested mentally retarded subjects who have measured IQ test scores roughly between 50 and 70.

Several investigators have used the Sternberg memory search procedure to examine differences between mentally retarded and nonretarded individuals in the rate at which information can be located in short-term memory (e.g., Dugas & Kellas, 1974; Harris & Fleer, 1974; Maisto & Jerome, 1977). The majority of these studies have reported reliable differences between mentally retarded and nonretarded subjects in memory search rate (cf. Silverman, 1974). In addition, the magnitude of this retarded–nonretarded difference has been very similar across studies. Dugas and Kellas (1974) reported that nonretarded subjects were able to search short-term memory twice as fast as were mentally retarded subjects (45 msec/item for the nonretarded and 90 msec/item for the retarded subjects). The relative magnitude of the group difference observed by Harris and Fleer (1974) was virtually identical to that of Dugas and Kellas (42 msec for nonretarded subjects and 88 msec for retarded subjects). Of course, this is as expected because these researchers used both similar stimuli (alphanumeric symbols) and similar subjects. However, Maisto and Jerome (1977) employed anomalous shapes as stimuli rather than alphanumeric symbols. These were irregularly shaped line drawings that did not have common names. Despite the fact that these new stimuli decreased memory search rate for all subjects, and the absolute value of the retarded–nonretarded difference was increased, the relative magnitude of this difference was essentially unchanged (65 vs. 126 msec for nonretarded and retarded subjects, respectively), with nonretarded subjects again performing at approximately twice the speed of mentally retarded subjects.

Davies *et al.* (1981) examined differences in the ability of mentally retarded and nonretarded individuals to determine the category membership of common objects. Subjects were asked to determine whether or not pictures of common objects matched verbal labels provided by the experimenter, where the relationship between the label and the pictured object varied across several stimulus dimensions. For example, the labels were either the basic level names (e.g., dog, table) or the superordinate category names (e.g., animal, furniture) of the objects (see Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976), or the pictured object was either a typical or atypical exemplar of the superordinate category

(Rosch, 1975), that is, a *dog* is usually considered to be a better exemplar of the superordinate category *mammal* than is the exemplar *walrus*, even though both are mammals by definition. Further, deciding that a less typical exemplar belongs to a particular category has proved to be more difficult than deciding that a more typical exemplar is a member of the category (see Smith, Shoben, & Rips, 1974). In the Davies *et al.* experiment, nonretarded subjects were faster than retarded subjects at making decisions about category membership in every condition, with the absolute difference in category decision time between the retarded and nonretarded subjects increasing with increases in decision difficulty. Nevertheless, the ratio of the difference between groups was again very similar across the various conditions, with the performance of the mentally retarded subjects ranging from 1.7 to 1.9 times slower than that of the nonretarded subjects throughout the experiment. In addition, the relative magnitude of the retarded–nonretarded differences is very close to that observed for short-term memory search, as discussed above. The general similarity of group differences in semantic processing speed across stimulus materials and these two domains of semantic processing provide some measure of support for the suggestion that retarded–nonretarded differences in semantic processing speed are the result of the inefficient execution of a component of the information-processing system that is common to different cognitive activities.

The consistency of retarded–nonretarded differences in semantic processing across the domains of short-term and long-term memory was subsequently assessed in a single study using a within-subjects design (Merrill, 1985). In this study, a modified Sternberg memory search procedure was used (Sternberg, 1969). In one condition, subjects were presented with memory sets that were composed of basic level object names and probes that were also basic level object names (e.g., dog, table). The subjects' task in this condition was simply to determine if the probe was a member of the memory set. This condition is analogous to the standard Sternberg memory search procedure and assessed the subjects' rate of searching short-term memory. In a second condition, subjects were presented with memory sets that were composed of superordinate category labels (e.g., animal, furniture) and probes that were basic level object names (e.g., dog, table). The subjects' task in this condition was to decide whether or not the probe stimulus was a member of one of the categories in the memory set. This condition assessed the subjects' ability to retrieve category information from long-term memory and make decisions about category membership. It was therefore possible to compare directly the relative difference in processing speed between mentally retarded and

nonretarded subjects in immediate memory versus long-term memory processing.

As expected, across the two conditions mentally retarded subjects performed more slowly than did the nonretarded subjects, and the absolute difference in response times obtained for category decision times (long-term memory processing) was greater than that obtained for short-term memory processing (35 msec for immediate and 100 msec for long-term memory processing). Of primary importance to the argument presented here, the same kind of consistency in the relative magnitude of the retarded–nonretarded difference was observed across the two domains of processing, with the mentally retarded subjects being 1.9 times slower than the nonretarded subjects in short-term memory processing and 2.2 times slower in long-term memory processing. In conjunction with a significant correlation obtained between the measures of immediate and long-term memory processing for the mentally retarded subjects (r = .75), these data lend additional support for the suggestion that retarded–nonretarded differences in semantic processing speed across different tasks may be mediated by a common component of the information-processing system.

The results of several additional studies converged on the possibility that a likely candidate for a difference in central processing between mentally retarded and nonretarded individuals may be some component of the attentional resource allocation system. Over the last 10–15 years, there have been numerous studies that suggest that differences between retarded and nonretarded individuals in semantic processing are observed primarily when subjects must actively use the semantic information and not under conditions that involve automatic or noneffortful processing (e.g., Cody & Borkowski, 1977; Meador & Ellis, 1987; Sperber, Ragain, & McCauley, 1976). For example, Meador and Ellis (1987) used a stimulus priming procedure developed by Posner and Snyder (1975) to examine differences in automatic versus effortful processing in mentally retarded and nonretarded individuals. Subjects were presented with pairs of letters and had to determine whether or not the two letters were the same. While the letter pairs matched half the time and did not match half the time, the most relevant data were obtained on the matching trials. Matching trials were preceded by the presentation of a letter that was identical to the letters in the matching pair, a letter that was different from the letters in the matching pair, or a plus sign. In general, the presentation of the same letter would be expected to facilitate matching times and the presentation of a different letter would be expected to interfere with matching times. In the Meador/Ellis procedure, the interval between the presentation of

the letter or plus sign (the prime) varied from 100 to 2000 msec. According to current views of automatic and effortful processing, the facilitating effect of a same letter prime on matching times at short intervals is assumed to reflect the operation of an automatic process and does not rely on an individual's available processing resources. In contrast, the presence of facilitation from a same letter prime and/or the buildup of inhibition from a different letter prime on matching times at the long intervals is assumed to reflect the operation of an effortful or resource-demanding process. Meador and Ellis report that facilitation resulting from automatic processing was very similar for mentally retarded and nonretarded individuals. However, facilitation and inhibition due to effortful processing were slower to develop in mentally retarded than in nonretarded subjects. These findings seem to implicate the attentional resource allocation system as an important source of retarded–nonretarded differences in semantic processing speed.

Ellis and colleagues (Ellis & Allison, 1988; Ellis, Katz, & Williams, 1987; Ellis & Meador, 1985; Ellis, Meador, & Bodfish, 1985; Ellis, Palmer, & Reeves, 1988; Woodley-Zanthos & Ellis, 1989) have, in fact, conducted an extensive series of investigations examining potential intellectual and developmental level differences in automatic aspects of memory. In their early work, the researchers sought to examine the memory processes of mentally retarded and nonretarded individuals under conditions that minimized the use of cognitive strategies (Ellis & Meador, 1985; Ellis *et al.*, 1985). For example, Ellis and Meador (1985) used a delayed matching-to-sample procedure using squares of eight differing sizes as stimuli. The subjects were presented pairs of stimuli that were separated by retention intervals ranging from 0 to 20 seconds. Subjects simply had to report whether or not the squares were the same size. While some strategy use, possibly in the form of verbal labeling, was reported for the extreme sizes (e.g., "smallest" and "largest"), the authors convincingly argued that strategy use was much more difficult for the intermediate sizes. Hence, it was possible to examine the role of strategy use in memory for size by comparing differences between the relative abilities of mentally retarded and nonretarded individuals to remember easy versus hard to discriminate size differences. The results of this study indicated that, even under conditions of minimal strategy use, mentally retarded individuals performed more poorly than did nonretarded individuals on the matching-to-sample task. The authors therefore concluded that memory differences between mentally retarded and nonretarded individuals were not entirely the result of inefficient strategy use on the part of the mentally retarded individuals. However, while the authors were able to

rule out the potential influence of cognitive strategies, it was not possible to conclude that the observed retarded–nonretarded differences in memory were definitely the result of differences in the execution of automatic aspects of memory processes. It is quite possible to exert cognitive effort in the performance of a task without translating that effort into a well-defined strategy. For example, one group of subjects simply may have concentrated more than the other groups. If the exertion of effort influenced memory performance, then the memory processes were not operating automatically.

In subsequent research, Ellis and collaborators (Ellis & Allison, 1988; Ellis *et al.*, 1988; Ellis, Woodley-Zanthos, & Dulaney, 1989; Woodley-Zanthos & Ellis, 1989) focused on intelligence-related differences in memory for incidentally learned attributes of stimuli such as frequency of occurrence and spatial location. The theoretical importance of these attributes is that Hasher and Zacks (1979) have shown that they both may be successfully encoded without a subject's awareness or intention (i.e., automatically). Therefore, a comparison of mentally retarded and nonretarded individuals' relative abilities to remember spatial location and frequency information under incidental learning instructions would represent a comparison of automatic processing in mentally retarded and nonretarded persons. In general, Ellis found that mildly retarded individuals estimate frequency of occurrence as well as do nonretarded individuals and process spatial information as well as college students. Therefore, the available evidence supports the view that cognitive performance differences between mentally retarded and nonretarded individuals are obtained under task conditions that require effortful (not necessarily strategic) processing but not under conditions of automatic processing. This is as expected if retarded and nonretarded individuals differ in their abilities to use their attentional resource allocation system.

There is one additional piece of evidence that deserves mention. It has become increasingly clear that retarded and nonretarded individuals exhibit larger differences in semantic processing when faced with more difficult activities. This has been reported in Davies *et al.* (1981) and Merrill (1985) as discussed above, as well as by a number of other investigators (see, e.g., Merrill *et al.*, 1987; Mulhern & Baumeister, 1971; Sperber *et al.*, 1982). If we can assume that one of the primary differences between easy decisions and difficult decisions is the degree of effort or attentional processing capacity that is required to complete the cognitive task, then the implication is again that some aspect of the attentional resource allocation system may mediate retarded–nonretarded differences in semantic processing speed (Merrill, 1982; Sperber & McCauley, 1984). The evi-

dence appears sufficient to offer this possibility as a general hypothesis that may help to explain differences in semantic processing speed between mentally retarded and nonretarded individuals.

III. ATTENTIONAL RESOURCE ALLOCATION

A. General Framework

One general approach for conceptualizing potential difference between mentally retarded and nonretarded individuals in the allocation of attentional resources was briefly outlined in Sperber and McCauley (1984). What is presented here is an extension of that work. It is based on the principles of many current "capacity theories" of attention (e.g., Kahneman, 1973; Navon & Gopher, 1979; Norman & Bobrow, 1975). In these capacity theories, attention is viewed as one or more reservoirs of cognitive processing resources that can be allocated to particular tasks and their components in a flexible and continuous fashion (Wickens, 1984). An important feature of these theories is that the amount of cognitive resources that can be made available for the transmission and manipulation of information is limited in some way; that is, there is not an endless supply of these resources. If cognitive processes are activated at the same time, as is common in most complex cognitive activities such as reading (e.g., LaBerge & Samuels, 1974), then the activated processes must share the available resources. Limits on performance are observed when the amount of cognitive processing resources required to execute successfully one or more ongoing process fails to leave enough resources for other processes to be performed. So we find, for example, that less skilled readers who must devote a substantial portion of their available resources to decoding individual words relative to the requirements of more skilled readers would, as a result, exhibit severe problems with the comprehension of text (e.g., Vipond, 1980).

Individual differences in the amount of processing resources needed to execute component processes of cognitive tasks may actually indicate differences in the acquisition of "automatic processing" (e.g., Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). It is generally accepted that, with practice, processes that initially require a large portion of an individual's available resources in order to be completed can come to require fewer and fewer of these resources without a corresponding decrease in level of performance. After quite extensive practice, a process may be successfully executed without the need for any cognitive resources (cf. Schneider, Shiffrin, & Dumais, 1984). When this occurs, pro-

cessing is described as automatic, where automatic processing is characterized by fast, parallel, relatively effortless processing that is not limited by memory capacity and is not under an individual's direct control (Hasher & Zacks, 1979; 1984; Posner & Snyder, 1975). Because of these characteristics, automatic processes are assumed to be extremely effective when used in the performance of well-developed skilled behaviors (Ackerman, 1987; Logan, 1985; Schneider, 1985). Most skilled behaviors require that a variety of simple and complex cognitive operations be executed simultaneously or in close succession. The efficiency of these behaviors may depend on the resource requirements of the component processes (see Ackerman, 1987).

Since automatic processing is often the result of learning and has been found to vary with developmental level (Manis, Keating, & Morrison, 1980), it is quite possible that the rate at which processes become automated is slower for mentally retarded relative to nonretarded individuals. The result would be that fairly basic processes of information transmission would require more time and cognitive resources for their completion by these individuals. As a consequence, the amount of resources remaining to perform higher order cognitive activities like problem solving would be correspondingly small, thereby resulting in the less successful completion of the higher order activity (Sperber & McCauley, 1984). Hence, according to this argument, some of the cognitive deficits in the execution of complex tasks exhibited by mentally retarded individuals can be traced to the relatively high resource requirements of fundamental processes like stimulus encoding. In this sense, the deficit is stimulus driven because the cognitive processing requirements of particular stimuli limit the performance of mentally retarded individuals in more complex cognitive behaviors.

Alternatively, because it is assumed that the allocation of cognitive processing resources is under some degree of cognitive control (Kahneman, 1973; Wickens, 1984), it is possible to conceptualize retarded–nonretarded differences in resource allocation as person variables as well. For example, we know that young children relative to older children exhibit less control and less flexibility in the manner in which they allocate cognitive resources under dual-task conditions (Lipps Birch, 1976; 1978). This may also be characteristic of mentally retarded relative to nonretarded individuals. So, rather than simple stimuli and basic processes requiring more of the attentional resources available to mentally retarded individuals, it may be that the mentally retarded actually allocate fewer of their available resources to the processing of simple stimuli (Sperber & McCauley, 1984). The result would be very similar to that described previously in that basic processes would be executed less efficiently as a

result of the allocation of insufficient resources, thereby interfering with the performance of more complex cognitive tasks.

Further, in light of the well-known metacognitive deficits associated with mental retardation (e.g., Borkowski & Cavanaugh, 1979; Bray, 1979; Campione & Brown, 1978; Ellis, 1978), it is also important to recognize that metacognitive skills are likely to play a role in attentional resource allocation. In order to allocate the appropriate amount of cognitive resources to the various component processes of any task, an individual must have a great deal of knowledge about his or her own limitations and abilities. For example, it is necessary to be able to assess the resource demands of those processes and monitor task performance to determine when sufficient resources have been allocated. To the extent that mentally retarded individuals are unable to do this accurately, allocating too large or too small a portion of their available resources to the basic processes of information transmission, performance deficits in the tasks that rely on the efficient execution of those processes are again the likely result.

There is at least one other way that cognitive processing capacity can be related to mental retardation. It may be that mentally retarded individuals simply have a smaller pool of processing resources at their disposal than do nonretarded individuals. If this is the case, then performance deficits would still be observed, even though the particular processes involved may not require different amounts of the available resources of retarded and nonretarded individuals and even if mentally retarded individuals are just as effective as nonretarded individuals at allocating their resources across processes. The processing resources of mentally retarded individuals would simply be depleted at lower levels of processing complexity than would the resources of nonretarded individuals, and the same pattern of performance deficits would be observed for the retarded individuals.

Distinguishing between these alternative views will not be a straightforward assignment. Each alternative appears to predict the same general pattern of performance differences between mentally retarded and nonretarded individuals. It is also important that these different alternatives not be viewed as mutually exclusive. It is quite possible that any deficiencies that may exist in attentional resource allocation will exist in combination. We may therefore find that individuals allocate resources differently because executing basic processes actually requires a different amount of their available resources, or because they are inefficient at allocating their resources to basic processing operations, or as the result of some unique combination of both differences. In addition, we cannot rule out the possibility that all observed deficiencies are ultimately tied to metacognitive

differences without first exhausting the available methods of modifying the resource allocation skills of mentally retarded individuals.

B. Methodological Considerations

The most common methods that are used to address issues concerning the allocation of cognitive resources are based on some form of the dual-task method (see, e.g., Kerr, 1973; Posner, 1978). In general, this approach requires that subjects perform two tasks simultaneously. In one version of this method, the cognitive task of interest is designated as the primary task and the other task as the secondary task (see Posner & Boies, 1971). The subject is instructed to allocate the necessary cognitive resources to the primary task to maintain maximum performance levels, and then to use whatever resources are left to perform the secondary task. The measure of interest is the degree to which performance on the primary task interferes with performance on the secondary task (relative to performing the secondary task alone). It is assumed that as the processing demands of the primary task increases, the amount of spare capacity, or processing resources, left to allocate to the secondary task decreases. Hence, performance on the secondary task decreases, and the magnitude of this decrease is assumed to reflect the *relative* amount of processing resources required to perform the primary task under two or more conditions.

A second version of the dual-task method is exemplified by the concurrent memory load task (Logan, 1979). In this procedure, the cognitive task of interest is actually given secondary status. The subject is given a list of digits to commit to immediate memory just prior to performing the cognitive task. It is assumed that immediate memory operations make use of processing resources from the same source as other cognitive processes, and thus will interfere with the performance of the concurrent task (the task of primary interest) to the extent that this task also requires attentional resources. In this case, the degree of interference associated with performing the task of interest while maintaining a list of digits in immediate memory, relative to performing the task by itself, is taken as an index of the amount of resources required to perform the task of interest.

Both versions of the dual-task method have been used effectively in the study of cognitive processing limitations in single population studies (cf. Duncan, 1980). However, important methodological difficulties arise when adapting these procedures for studying group differences in resource allocation ability. These difficulties come about because we are only able to assess the allocation of these resources indirectly; that is, we

can only measure the amount of spare capacity left over from the processing of some cognitive task. One problem with group comparisons is that groups may differ in the amount of cognitive resources that they initially have at their disposal. Therefore, the amount of spare capacity that an individual has left over from performing a particular cognitive task may reflect either a difference in the amount of resources required to perform the task or a difference in the amount of resources initially available. In most respects, these two alternatives are functionally equivalent. Individuals who exhibit the fewest resources left over from the execution of basic information-processing operations will exhibit the greatest processing limitations when the processes are combined into more complex activities, regardless of the source of the differences. Ultimately, however, the choice of techniques for remediation will depend on which of these alternatives most accurately describes any observed retarded–nonretarded differences in attentional resource allocation.

A second problem that must be mentioned also exists in single group studies, but is aggravated by group comparisons. It is essentially a measurement scale problem and has no obvious resolution. The issue is that there is no assurance that equivalent changes in the magnitude of interference exhibited by individuals in these studies reflect equivalent changes in resource allocation either within the same individual or across groups of individuals. A reasonable analogy may be to consider the relationship between the speed of an automobile and the amount of fuel being consumed. The automobile necessarily increases fuel consumption as speed increases 10 mph from 20 to 30 mph. However, the amount of this change in fuel consumption is probably not the same if we increase speed 10 mph from 30 to 40 mph. Hence, using speed changes to infer fuel consumption changes potentially converts interval scale data to ordinal scale data. This problem will be further aggravated if we try to make inferences about fuel consumption on the basis of speed measures across different makes of automobiles that start out with different rates of fuel consumption. Automobile manufacturers solve the problem by measuring fuel consumption directly. This would also be the preferred way to measure the allocation of attentional resources. Unfortunately, we are not in a position to do this and must continue to infer attentional resource allocation from performance indices.

There are no known methodologies that will eliminate these difficulties. It is obviously important that researchers in this domain remain sensitive to the interpretive difficulties that are likely to arise. To minimize these problems it will be essential to obtain data using a variety of procedures that converge on a single issue. For example, it will be important to use both versions of the dual-task approach discussed earlier, as well as a

variety of different secondary tasks (e.g., concurrent memory load, counting backwards, signal detection) in order to ensure that the results are not stimulus and/or task specific. This will at least provide a stronger basis for inferences to be drawn concerning attentional resource differences between mentally retarded and nonretarded individuals.

IV. PRELIMINARY RESEARCH

This section includes the initial results of four studies that begin to assess the nature of the relationship between cognitive resource allocation and cognitive performance differences between mentally retarded and nonretarded individuals. All of the studies involve a comparison of the performance of mentally retarded and nonretarded adolescents or young adults matched on chronological age (CA). Across the various studies, the mentally retarded subjects had an average IQ of 60.9 (SD = 6.7) and an average CA of 19.6 years (SD = 3.3). The mentally retarded subjects were recruited from public high schools and local rehabilitation centers. The nonretarded subjects were recruited from public high schools and universities.

A. Mobilization of Cognitive Processing Resources

In order for cognitive processing resources to be effectively used in information-processing activities, an individual must be able to make them available for processing. One important aspect of cognitive resource allocation involves preparing for the presentation of upcoming stimuli (Posner and Boies, 1971). Attentional resources must be made available and directed toward the processing of particular stimuli, whether the stimuli are selected by an experimenter or the individual. Processing is facilitated by presenting a warning signal and allowing subjects time to prepare before a stimulus is presented. As discussed earlier, there is some evidence based on heart rate measures that mentally retarded and nonretarded individuals differ in their efficiency of making attentional resources available for stimulus processing in reaction time tasks (Krupski, 1975; Runcie & O'Bannon, 1975). Merrill and McCauley (1988) focused on the extent to which potential retarded–nonretarded differences in this ability help to account for previously reported group differences in stimulus encoding speed (Merrill *et al.*, 1987).

The general procedure used in Merrill and McCauley (1988) was adapted from a technique first used by Posner and colleagues (Posner & Mitchell, 1967) to examine parameters of stimulus encoding in a letter-

matching task. In the Merrill/McCauley version of the procedure, mentally retarded and nonretarded subjects were presented pairs of photographic slides of black-and-white line drawings. The stimulus pairs were presented sequentially, with the presentation of the two slides being separated by a variable stimulus onset asynchrony (SOA). The time between the slides varied from 0 to 1000 msec at 100-msec intervals. The subjects' task was to determine as rapidly as possible whether or not the two stimuli matched under either physical identity instructions or name identity instructions. Our ability to measure encoding times in this procedure is based on the SOA manipulation. When presented with short SOAs, subjects do not have enough time to encode the first stimulus of the pair completely prior to the presentation of the second stimulus. Hence, they must continue to process the first stimulus in order to make an accurate match–nonmatch decision. Therefore, response times, measured from the onset of the second stimulus of the pair, will include the time needed to complete the encoding for the first stimulus and will be relatively long. The performance of the subjects reaches maximum levels when the length of the SOA is just long enough to allow the first stimulus to be encoded prior to the appearance of the second. There is no further decrease in response times associated with the SOA manipulation after the first stimulus is encoded. Any additional processing requires the presentation of the second stimulus of the pair, and this coincides with the onset of the timing interval and is identical across all of the remaining SOAs. Thus, the shortest SOA at which subjects exhibit maximum performance levels corresponds to the time required to encode the first member of the stimulus pair.

Using this procedure, Merrill *et al.* (1987) found that mentally retarded subjects are generally slower than nonretarded subjects matched with the retarded subjects on either CA or MA at both physical identity encoding (410 vs. 300 msec for the retarded and nonretarded, respectively) and name identity encoding (480 vs. 385 msec). To examine the extent to which these retarded–nonretarded differences in encoding speed could be attributed to corresponding differences in mobilizing cognitive processing resources, Merrill and McCauley (1988) assessed the encoding speed of mentally retarded and equal-CA nonretarded subjects when the length of time given between the presentation of a warning signal and the first stimulus of the stimulus pair was systematically varied. Four different *alerting intervals* were tested: 0, 250, 500, and 1000 msec. It was assumed that if differences in the ability to alert for incoming stimuli were responsible for differences in encoding speed, then the magnitude of the encoding speed difference between the retarded and nonretarded subjects would vary as a function of the length of the alerting interval. More specifically, it was

TABLE I
MEAN RESPONSE TIMES (IN DEVIATION SCORES) AT THE 0-MSEC STIMULUS ONSET ASYNCHRONY

	Alerting interval			
Group/encoding	0	250	500	1000
Mentally retarded				
Physical identity	271	201	198	202
Name identity	341	279	222	215
Nonretarded				
Physical identity	162	114	124	113
Name identity	308	135	132	131

expected that the difference between retarded and nonretarded subjects would be largest at the short alerting intervals and smallest at the long alerting intervals.

First, it was necessary to determine the effectiveness of the manipulation of cognitive processing resources; that is, did varying the length of the alerting interval influence any aspect of the subjects' performance? To examine this issue, we examined the effect of alerting interval on response times at the 0-msec SOA. This SOA interval was chosen for comparison because it is the only interval for which the length of the alerting interval is the only variable that determines the amount of processing resources being deployed by the subjects. At all longer intervals, the presentation of the first stimulus of the pair also serves to alert the subject for an upcoming response. Thus, the effectiveness of the alerting interval manipulation is clearest at the 0-msec SOA (see Merrill and McCauley, 1988). In order to eliminate any unrelated differences between subjects in overall response times from influencing the results of the analyses, the raw response times were converted to difference scores (see Merrill *et al.*, 1987). These scores were obtained by simply subtracting each subject's response times at their fastest SOA from those of the 0-msec SOA. The obtained data are presented in Table I.

Several aspects of these data are worth noting. First, under physical identity instructions, the length of the alerting interval had essentially the same influence on the performance of mentally retarded and nonretarded subjects. Both mentally retarded and nonretarded subjects were able to activate sufficient resources within 250 msec to perform at maximum levels. However, there was a difference between the two groups in the length of the optimal alerting interval under name identity instructions. The non-

retarded subjects were again able to mobilize sufficient resources to perform at maximum levels within 250 msec. In contrast, the mentally retarded subjects did not reach maximum performance levels until the length of the alerting was 500 msec. We therefore concluded that the alerting interval manipulation did influence performance in the matching task and, at least for name identity decision making, mentally retarded individuals required a longer time to mobilize their processing resources in preparation for the processing and manipulation of information. This conclusion is consistent with the results of Krupski (1975). In addition, because group differences were restricted to the name identity condition, it appears that accessing basic level object names and/or matching on the basis of name identity may be more susceptible to the influence of attentional resources than is physical identity encoding and matching on the basis of physical identity.

One additional difference in the performance of mentally retarded and nonretarded subjects was observed. The retarded subjects exhibited less improvement in response time performance as the alerting interval increased relative to the nonretarded subjects (119 vs. 173 msec, respectively). This difference was only marginally significant ($p < .10$), but is consistent with the possibility that some aspect of name identity matching in mentally retarded individuals is limited by the availability of cognitive resources. Either the operation requires more resources for mentally retarded relative to nonretarded individuals to execute or mentally retarded individuals allocate fewer resources to the name identity matching task.

To obtain encoding times, the shortest SOA at which maximum performance levels were achieved was determined for each subject for both physical identity and name identity matches. This was done by comparing the subject's response times at each SOA to those of the next three longer SOAs using t tests. An individual's encoding time was defined as the shortest SOA for which the mean response time was not significantly greater than each of the next three SOAs. The mean encoding times obtained for subjects in each condition are presented in Table II. As can be seen from these data, the length of the alerting interval had no effect on encoding times. Indeed, the overall differences between mentally retarded and nonretarded individuals were essentially identical to those reported in Merrill *et al.* (1987). The mentally retarded subjects were approximately 100 msec slower than the nonretarded subjects at physical identity encoding (372 vs. 281 msec, respectively) and name identity encoding (481 vs. 375 msec). Apparently, the resource requirements of encoding are substantially lower than those of some other aspects of the matching task. This does not necessarily mean that physical and name identity encoding does not require any cognitive resources to be exe-

TABLE II
AVERAGE ENCODING TIMES FOR SUBJECTS AS A FUNCTION OF ALERTING INTERVAL

	Alerting interval			
Group/encoding	0	250	500	100
Mentally retarded				
Physical identity	388	362	362	375
Name identity	500	475	475	475
Nonretarded				
Physical identity	275	288	275	288
Name identity	388	350	375	388

cuted. It may simply be that a sufficient amount of attentional resources was continuously being allocated to the experimental task to permit encoding to take place without interference. Issues concerning the resource requirements of basic encoding operations are addressed more directly in the next experiment. Nevertheless, on the basis of this experiment, it was tentatively concluded that retarded–nonretarded differences in encoding speed are not directly related to differences in the ability to prepare for the presentation of an upcoming stimulus event.

B. Cognitive Resource Requirements of Basic Processes

As mentioned earlier, differences between mentally retarded and nonretarded individuals in the amount of cognitive resources allocated to the basic processes of information transmission are likely to impact upon the performance of more complex tasks that rely on the efficient execution of these basic processes. It is therefore important to examine group differences in the resource requirements associated with the execution of these basic processes. The purpose of Merrill (1990) was to assess differences between mentally retarded and nonretarded individuals in the amount of cognitive resources needed to execute basic encoding and decision-making processes. These were studied in a task requiring matching stimuli on the basis of physical identity and name identity while maintaining a concurrent-memory-load (Logan, 1979). Mentally retarded and nonretarded subjects were required to memorize a series of numbers, and, while maintaining these numbers in memory, they performed the stimulus matching task described in the previous experiment (see Merrill & McCauley, 1988). An important feature of this version of matching task is that it is possible to separate the encoding from the decision portions of

the matching task. The time needed to execute encoding operations is dependent on the subjects' performance on the first stimulus of the pair and is therefore reflected in the SOA at which maximum response time performance is first observed. In contrast, the time needed to decide whether or not the two stimuli match is dependent on the subjects' performance on the second stimulus of the pair, which is identical across all SOAs and thus is reflected in the overall level of the response time function. It was therefore possible to separate the influence of the concurrent-memory-load task on encoding processes from its influence on decision-making processes.

In this experiment, subjects were initially given a test of digit span. On each trial, the subjects were required to memorize either a full memory load, defined as the subjects' digit span minus one, or half that amount prior to performing the matching task. The cognitive resource requirements of the stimulus matching task were assumed to be reflected in the degree of interference associated with performing the task while retaining a full memory load relative to a half memory load. To the extent that encoding operations require cognitive resources, the SOAs at which maximum performance levels are first reached will be longer when individuals are maintaining a full memory load relative to a half memory load. If decision processes require cognitive resources, then overall response times (independent of SOA) will be greater when individuals are maintaining a full memory load.

The data from the experiment are presented in Fig. 1. For purposes of data analysis, encoding times were again computed separately for each subject (see Merrill *et al.*, 1987). They are reflected in the inflection point of the response time functions relating response time to SOA in the graphs. Encoding times were not substantially changed for the mentally retarded subjects under physical identity matching instructions (408 vs. 392 msec for full and half memory loads, respectively), whereas encoding times under name identity instructions were slower for mentally retarded individuals maintaining a full memory load relative to those maintaining a half load (575 vs. 467 msec, respectively). In contrast, the encoding times for the nonretarded subjects suffered as a function of memory load under both sets of matching instructions. Physical identity encoding slowed from 298 to 342 msec, and name identity encoding slowed from 408 to 450 msec.

These results are in contrast to the commonly held belief that highly familiar stimuli are encoded automatically into memory (e.g., Keele, 1973; LaBerge & Samuels, 1974; Posner & Rogers, 1978). The results are more consistent with recent data suggesting that even the encoding of stimuli as familiar as letters of the alphabet (e.g., Ogden, Martin, & Paap,

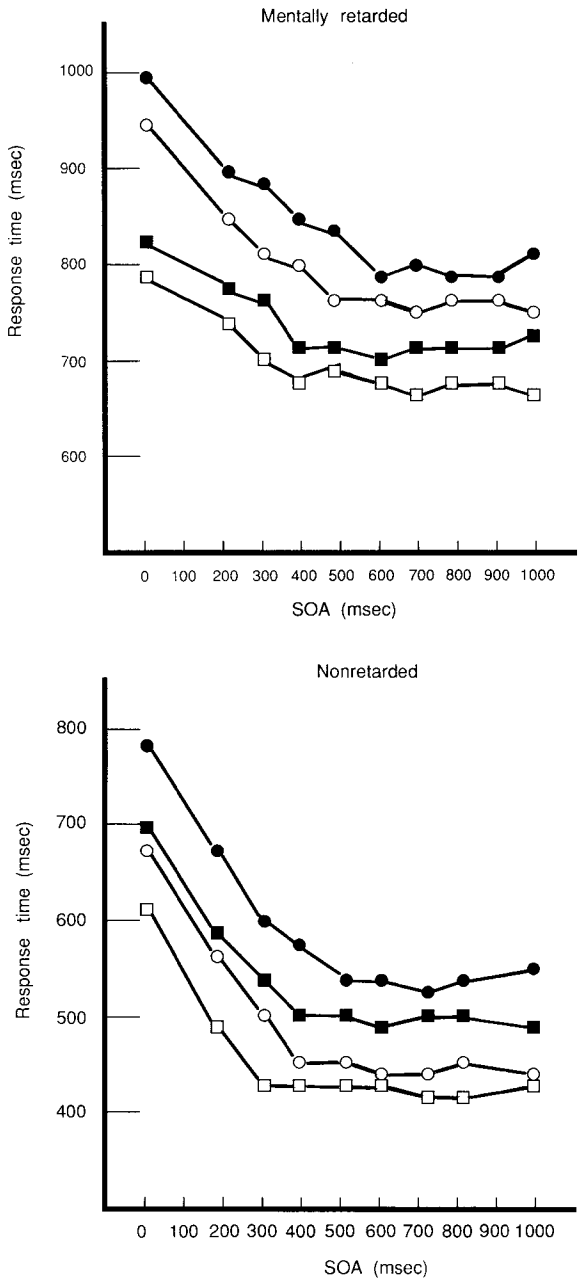

FIG. 1. Encoding functions relating response time to SOA as a function of type of encoding and memory load. Key: □, ■, physical identity encoding while maintaining a full memory load or a half memory load, respectively; ○, ●, name identity encoding while maintaining a full memory load or a half memory load, respectively.

1980) and the identification of common objects (Kahneman, Treisman, & Burkell, 1983) may involve attentional resources for nonretarded adults. Perhaps the type of process assessed in this experiment can be viewed as what has come to be referred to as "partially automatic" (see Kahneman & Treisman, 1984). A partially automatic process is one that can be executed while attentional resources are focused elsewhere, but is facilitated when these resources are focused on completing that process (LaBerge, 1973, 1975). It may be that cognitive resources are not required for physical identity and name identity encoding in this experiment. However, subjects who did allocate some of their resources to encoding performed better than those who did not.

In light of this possibility, the patterns of group differences in encoding times observed as a function of memory load were quite interesting. The nonretarded subjects exhibited essentially the same degree of interference under both physical identity and name identity matching instructions (44 vs. 42 ms, respectively). In contrast, the magnitude of interference exhibited across encoding conditions by the mentally retarded subjects was quite different. These subjects exhibited an interference effect of only 16 msec for physical identity encoding, but an effect of 108 msec for name identity encoding. It is therefore tempting to speculate that the locus of the interference effects was different for the two groups. For the nonretarded subjects, the resource limitations appear to be associated with some general aspect of encoding. Perhaps it is common for these subjects to generate effortfully some expectation for the second picture of the stimulus pair. When cognitive resources were limited by requiring subjects to maintain a full load in memory, they were unable to do this and performance suffered under both instruction conditions. In contrast, the resource limitation exhibited by the mentally retarded subjects appeared to be stimulus specific. Resource limitations were only observed under name identity matching instructions. Therefore, it would seem that mentally retarded individuals do not routinely make attentional resources available for stimulus encoding. Rather, they allocate resources only if it is essential, or at least obviously important, for the completion of the encoding process. For the retarded individuals it must have been necessary to allocate resources to name identity and not physical identity encoding. The one obvious difference between name identity encoding and physical identity encoding as examined in this experiment was that name identity encoding required access to semantic memory whereas physical identity encoding did not. It therefore seems reasonable to suggest that the difference exhibited by the mentally retarded subjects reflects a difference in the resource requirements associated with accessing semantic memory and identifying pictures of objects at the basic level; that is, there may be a difference in the degree to which identifying objects at the basic

level is automatic for mentally retarded relative to nonretarded individuals. However, since automatic processing is most often associated with particular stimulus–response relationships, it is important to recognize that this conclusion may turn out to be different for different sets of stimuli. Nevertheless, it is interesting to observe group differences in the resource requirements of such very basic information-processing operations. The next step will be to examine whether or not these differences are maintained across different basic level categories and if they truly impact upon the performance of more complex cognitive tasks.

By comparing the absolute level of the response time function, it is also possible to examine the effects of memory load on the decision and response components of the stimulus matching task. As can be seen in Figs. 1 and 2, the pattern of results across groups was quite different from that observed for encoding times. In this case, a significant effect of memory load was observed for physical identity and name identity encoding for both the mentally retarded and nonretarded subjects. However, for both types of decision the effect of memory load was clearly greater for the nonretarded subjects than for the retarded subjects. Deciding whether or not two objects match apparently requires attentional resources for both groups of subjects, but the nonretarded subjects appear to allocate more of their available resources to this decision component than do the retarded subjects. Hence, when attentional resources are diverted elsewhere the nonretarded subjects exhibit greater interference than do the retarded subjects. It is not possible to ascertain the locus of this difference. It may be that the mentally retarded subjects did not efficiently allocate resources that were available to them. However, it may also be that the mentally retarded subjects were left with fewer resources available after encoding was completed. Distinguishing between these two possibilities will require a somewhat different experimental method.

C. Individual Differences in the Development of Automaticity

The notion of automaticity is central to models of skilled performance across many cognitive and noncognitive domains (e.g., Fisk & Schneider, 1984; Neuman, 1984; Pew, 1974; West & Stanovich, 1978). Understanding how basic processes become relatively automatic and the extent to which the development of automatic processing differs for mentally retarded and nonretarded individuals is therefore an important topic for investigation. The assumption here is that if mentally retarded individuals differ from nonretarded individuals in the manner or rate at which automaticity develops, then these groups will also differ in the rate at which

complex skills develop, if they develop at all. The comparison of encoding times in the previous experiment led to the suggestion that mentally retarded and nonretarded individuals may differ in the degree to which basic information-processing operations can be automatically executed. To the extent that this is true, it is reasonable to hypothesize that automatic processing develops at a slower rate for mentally retarded relative to nonretarded individuals. Merrill, Goodwyn, and Gooding (1990) examined this possibility.

The general method used in the experiment involved a visual search task in which subjects determined the category membership of common objects (see Fisk and Schneider, 1983). Single slides contained either two, three, or four pictures of common objects from different natural language categories. Eight categories were used in the experiment (clothing, four-legged animals, fruit, furniture, musical instruments, tools, toys, and vehicles). All of the pictures were highly typical exemplars (Rosch, 1975) from these categories. Four categories were designated as target categories and were learned by the subjects. The remaining categories were designated as nontarget categories. The subject's task was to determine whether or not one of the objects pictured in the presented slide stimulus was a member of one of the target categories.

The data of interest in the experiment were the slope values of the regression lines relating category decision times to the number of objects pictured in the visual search set. Under conditions in which stimuli are responded to in a consistent manner, the slope values obtained for nonretarded adults gradually decrease as a function of extended practice and become nonlinear, with subjects exhibiting no effect of set size (Fisk & Schneider, 1983). This is one of the characteristics of automatic processing. Automaticity allows for parallel processing (see Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). Hence, it was used in this experiment as an index of the development of automaticity. Evidence for retarded–nonretarded differences in the rate at which automaticity develops would be obtained if the mentally retarded and nonretarded individuals exhibit a different rate of decline in slope values as a function of amount of practice.

There is one important issue that had to be dealt with in this experiment. Category decision making was chosen as the learning task because it was felt that all of the subjects would be reasonably familiar with the process and, as a result, automaticity would develop fairly rapidly. In fact, under the right conditions, automaticity appears to develop within hours (see Ackerman & Schneider, 1985). However, this choice was also problematic in that mentally retarded and nonretarded individuals were likely to differ in the degree of knowledge (automaticity) that they would

exhibit at the start of the experiment. At the very least, we know that category decision times of mentally retarded and nonretarded individuals are likely to differ (e.g., Davies *et al.*, 1981; Merrill, 1985; Sperber *et al.*, 1982). To alleviate this problem, it was necessary to create conditions under which the retarded and nonretarded subjects exhibited equivalent performance levels. The development of automaticity could then be traced from this point. One method of equating groups was built into the basic procedure. Since both groups of subjects received extensive practice, it was possible to assess the development of automaticity from both the actual starting point of the experiment and from the point at which mentally retarded subjects performed at levels equivalent to those of the nonretarded subjects at the start of the experiment. Therefore, two sets of analyses were performed.

The data from the experiment are presented in Figs. 2 and 3. Figure 2 presents slope values of the mentally retarded and nonretarded subjects as a function of trial blocks from the start of the experiment, and Fig. 3 superimposes the performance of the mentally retarded subjects on that of the nonretarded subjects from their point of initial equivalence. Each trial block included 72 trials (36 target and 36 nontarget trials). Only the data from the target trials are included in the figures.

An initial comparison was made between the average performance of the mentally retarded and nonretarded individuals in the first trial block. This was done to determine the degree to which the current procedure yielded results similar to those obtained in previous studies of category decision making. As expected, the average slope value for the retarded subjects was approximately twice that obtained for the nonretarded subjects (163 vs. 80 msec, respectively). The slopes of this visual search task were necessarily steeper than those of the memory search task of Merrill (1985) because in the current experiment subjects actually had to perform two searches at the same time: a memory search of the target category labels and a visual search of the slide stimulus. However, the ratio of retarded to nonretarded performance was quite similar to previous group comparisons of category decision making (Davies *et al.*, 1981; Merrill, 1985), so it was assumed that the current experiment had not created an entirely new experimental situation.

As can be seen in Fig. 2, the nonretarded subjects achieved a nonsignificant slope value and, hence, exhibited signs of automatic processing much more rapidly than did the mentally retarded subjects. For the nonretarded subjects, the effect of set size was no longer significant after five trial blocks. This was not evident for the mentally retarded subjects until the 15th trial block. We therefore reached the tentative conclusion that nonretarded individuals acquire automatic processing at a much faster

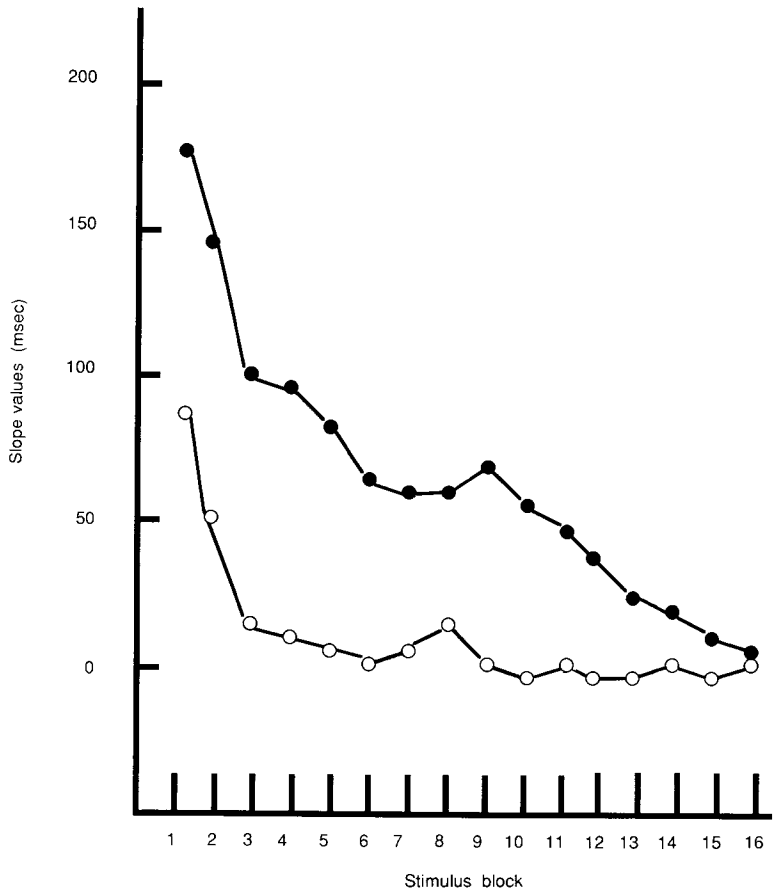

FIG. 2. Slope values of mentally retarded (●) and nonretarded (○) subjects over all sessions.

rate than do mentally retarded individuals. As mentioned earlier, however, a portion of this effect may be associated with the initial differences between the two groups. To compensate for this, the data were reexamined after equating groups on initial performance levels. This was done in a relatively arbitrary manner for this experiment. The trial block selected as the initial block for the mentally retarded subjects was simply the earliest one in which these subjects exhibited an average slope value that was smaller than that obtained in the first trial block by the nonretarded subjects. This was Trial Block 5, in which the retarded subjects achieved an average slope value of 70 msec. As can be seen in Fig. 3,

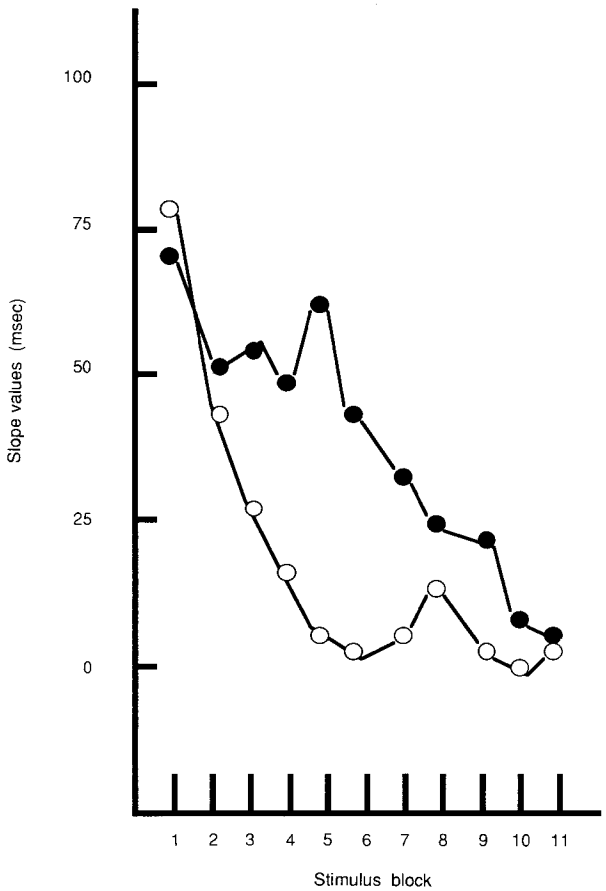

FIG. 3. Slope values of mentally retarded (●) and nonretarded (○) subjects from point of initial equivalence.

even if we consider Trial Block 5 to be the starting point for the mentally retarded subjects we still find that they exhibit signs of automatic processing much later than do the nonretarded subjects (Trial Block 11 vs. Trial Block 5, respectively). Thus, on the basis of both sets of analyses we were forced to conclude that mentally retarded individuals require considerably more practice at a given task to achieve automaticity than do nonretarded individuals.

This conclusion clearly needs to be confirmed across a variety of task and stimulus manipulations before it can be generally accepted. In the case of this experiment, there was a problem in trying to equate the initial

performance levels of the two groups. It is possible that a recently acquired familiarity with stimuli is quite different from a long-standing familiarity, and that our effort to equate group performance in this experiment was inadequate. In fact, the difference in the shapes of the response time functions after equating group performance levels suggests that the two groups may have differed in some important ways. There are at least two other ways to equate initial performance levels that may prove more suitable. For example, it may be reasonable to examine the acquisition of automatic processing using artificial categories that are equally unfamiliar to all subjects. Another possibility may be to equate initial performance by varying exemplar typicality systematically across groups. Presenting high typical exemplars to the mentally retarded subjects and low typical exemplars to the nonretarded subjects may provide the two groups with equally familiar category/exemplar relationships. Nevertheless, the results of this initial experiment support the general hypothesis that mentally retarded individuals acquire automaticity at a slower rate than do nonretarded individuals.

D. Resource Allocation and the Development of Automaticity

If mentally retarded and nonretarded individuals actually differ in the rate at which processes become automatic, then it will be important to consider the possible causes of this difference. Some of the factors that influence the acquisition of automatic processing by nonretarded adults in search and detection tasks have been studied extensively by Schneider and colleagues (e.g., Fisk & Schneider, 1983; Schneider & Fisk, 1982a, 1982b; Shiffrin, Dumais, & Schneider, 1981). The most important factors appear to be the extent of the practice, the consistency with which the to-be-automated process is executed, the nature of the response required, and previous learning history.

One factor that seems particularly relevant to individual differences in the development of automaticity has not been the focus of single group investigations. It is reasonable to suggest that the transition from effortful to automatic processing depends, in part, on how much effort is devoted to the cognitive task during the period of extended practice. When describing individual differences we must consider the possibility that some individuals devote less effort, or fewer processing resources, to practice than do other individuals. In the case of mentally retarded individuals, it may be that they allocate their resources poorly or have fewer resources available at the start of practice. In either case, this may result in mentally retarded individuals acquiring automaticity at a slower rate than do non-

retarded individuals. Cha and Merrill (1990) conducted an experiment to determine whether or not there is a relationship between the amount of cognitive resources devoted to practice and the rate at which automatic processing develops.

Only nonretarded subjects were used in this experiment. The general procedure combined a category decision task with the concurrent memory load procedure (Logan, 1979). Subjects were shown a series of slides picturing one common object per slide and were required to determine whether or not the object belonged to one of four natural language categories designated as target categories. At the same time, they were required to maintain a list of numbers in immediate memory. The number lists contained either two or eight numbers. The amount of cognitive resources that were available to perform the category decision task throughout the experiment was manipulated by varying the percentage of the time subjects were required to learn eight- versus two-number lists. One group of subjects received eight-number lists 50% of the time and two-number lists 50% of the time, a second group received eight-number lists 75% of the time and the two-number lists 25% of the time, and a third group received eight-number lists 100% of the time (excluding 24 test trials at two digits in each experimental session). The difference in category decision times when subjects were performing the category decision task with eight numbers relative to two numbers in memory was used as the measure of automatic processing in this experiment. Since automatic processes can be executed without attentional resources, diverting resources from the category decision task should not influence performance. Therefore, there should be no difference between the eight- versus two-number memory load conditions after automatic processing has developed. Further, if the rate of development for automatic processing depends on the amount of resources that can be devoted to practice, than subjects who received eight-number lists only 50% of the time would be expected to exhibit evidence of automaticity sooner than would the other two groups of subjects.

All subjects took part in the experiment on four consecutive days. The first day was devoted entirely to practice in coordinating the two tasks. Therefore, subjects received a different category set every 10 trials during the first experimental session. Automaticity does not develop unless the same set is used consistently over trials, so this procedure afforded practice in the two tasks without changing the effort required to perform just the category decision task. Subjects received the same category set on each of the next three days of the experiment. Midway through and at the end of each experimental session subjects were tested for the develop-

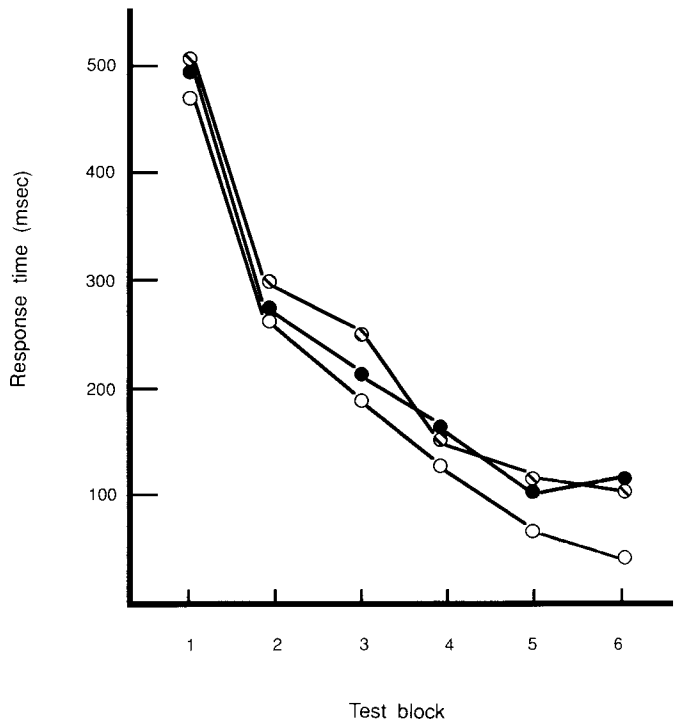

FIG. 4. Response time differences between two-number and eight-nunber memory load conditions as a function of trial blocks. Key: ○, ●, ⊘, received eight-number memory load 50, 75, or 100% of the time, respectively.

ment of automaticity. During this phase, they received 24 category decision trials, 12 while retaining a two-digit memory set and 12 while retaining an eight-digit memory set.

Figure 4 presents the difference in performance of each group in the eight-number versus two-number memory load conditions across these six testing blocks. As can be seen in this figure, the difference between these two conditions decreases rapidly at first and then gradually stabilizes over blocks. While these differences never reached zero, they did continue to approach zero throughout the sessions. Of primary interest was the finding that this difference was no longer significant for the 50% group in the fifth and sixth sessions. In contrast, the difference in response times between the eight- and two-number memory load conditions remained significant throughout this experiment for the 75 and 100% groups. It will be necessary to conduct longer duration experiments to determine when, if at all, automaticity develops under conditions in

which attentional resources are diverted from the primary task. Still, the results of this experiment suggest that the amount of resources available during practice does influence the rate at which automatic processing develops. Understanding the nature of this relationship may provide some insight into individual differences in the development of automatic processing.

This study only examined the relationship between effort devoted to practice and the rate at which automaticity develops for nonretarded subjects. It will be important to ascertain whether or not this relationship also holds for mentally retarded individuals, and whether or not the relationship takes the same form for mentally retarded and nonretarded individuals. As these investigations continue, there are some important issues that must be considered. The relationship between the allocation of attentional resources to practice and the rate at which automatic processing develops will not be a simple one to evaluate. Again, the desire to assess this relationship across different groups of subjects magnifies the difficulties. For example, we should expect that the nature of this relationship may change as a function of the resource requirements of the process that is undergoing practice. In the experiment reported here, a category decision task was selected in which subjects were required to perform an already well-learned activity. Under these task conditions, relatively small but consistent differences were found between groups. It is reasonable to suggest that these differences would be greater if we had selected some process that required a significantly greater amount of the subjects' available resources to be successfully completed. Similarly, starting with different groups of subjects with potentially different resource demands associated with the processing operation under investigation may make it difficult to distinguish the degree to which the relationship between resource allocation to practice and the development of automaticity is stimulus dependent or person dependent. Therefore, it will be important to proceed with caution when evaluating differences between individuals who may have different amounts of processing resources at the start of practice, but may also differ in the degree to which the process of interest demands access to those resources.

V. DISCUSSION AND CONCLUSIONS

The research described in this article illustrates some of the ways in which the cognitive performance differences of mentally retarded and nonretarded individuals may be related to their relative abilities to allocate attentional resources effectively to various semantic processing op-

erations and their components. The effective allocation of these attentional resources is central to the successful completion of a wide variety of simple and complex cognitive activities (e.g., Ackerman, 1987; Logan, 1985). It is therefore essential that we understand how individuals may differ in this ability. It is clear from the studies reported in this article that this relationship may, and probably will, take many forms. The results of the studies reported here are quite promising at this early stage of the research program. Nevertheless, the conclusions that can be drawn from them must remain tentative. Still, it appears likely that mentally retarded and nonretarded individuals differ in many aspects of resource allocation.

There were two major differences between mentally retarded and nonretarded individuals that were observed in the series of experiments reported here. First, mentally retarded and nonretarded individuals differed in the degree to which attentional resources were needed to complete some of the very basic information-processing operations associated with stimulus encoding and decision making. Second, mentally retarded and nonretarded individuals appeared to differ in the rate at which information-processing operations become automatic. These two related group differences may have profound effects on the ability of mentally retarded individuals to learn and efficiently execute complex cognitive tasks. As mentioned earlier, it is important that relatively basic processes be executed without depleting the individual's available resources to ensure that a sufficient amount of resources is left to perform other aspects of the cognitive activity. To the extent that mentally retarded and nonretarded individuals differ in the resource requirements of these relatively basic processes, we should expect group differences in the performance of more complex tasks that rely on the efficient execution of these basic processes. However, this logical relationship has not been demonstrated empirically, and it is important that this be accomplished in the near future.

One of the important implications of this "cumulative deficit" hypothesis is that the remediation of relatively complex skills in mentally retarded individuals will require some focus on improving cognitive activities that are already seemingly well learned. Individuals can perform tasks at 100% accuracy, and yet not be able to combine them in the performance of more complicated activities because each individual activity requires high levels of attentional resources to be completed. Trying to coordinate two or more component processes at this stage would only lead to failure. The coordination of component activities will be successful only when these activities can be executed with sufficiently reduced amounts of cognitive processing resources.

Despite the general tone of this argument, it is important to recognize

that it is unlikely that the cognitive difficulties of mentally retarded individuals will be overcome by simply giving sufficient training on the component processes of complex activities. In fact, automatic processing carries a cost as well as a benefit. When a process is executed automatically, it is no longer under the individual's voluntary control and can actually interfere with the ability to perform other required activities. An early demonstration of this can be found in the work of Stroop (1935). As a function of the automatic nature of word reading, it is generally extremely difficult to ignore the meaning of a printed word and respond to some other aspect of the word stimulus that is inconsistent with the meaning. Hence, there is a great deal of interference associated with trying to name the color in which a word is printed when the word represents a different color name (e.g., saying blue to the word red printed in blue ink). Some recent work (Ellis, Woodley-Zanthos, Dulaney, & Palmer, 1989) suggests the possibility that the ability to override an automatic process may be much more difficult for mentally retarded individuals than it is for nonretarded individuals. So, an increase in the efficiency of specific activities associated with an increase in the relative automaticity of some basic operations may also decrease the relative flexibility of processing for mentally retarded individuals in particular; cognitive flexibility is often considered one of the hallmarks of intelligent behavior (see Sternberg, 1984).

It is also important to acknowledge one serious deficiency in the work completed thus far. None of the research described in this article directly addressed the possibility that differences between mentally retarded and nonretarded individuals in resource allocation ability may reflect differences associated with metacognitive skills. This is an important consideration and needs to be addressed in the near future. It is quite possible that all of the retarded–nonretarded differences in performance described here may result from a failure to evaluate accurately the resource demands of information processing and then to allocate resources accordingly. To the extent that it is possible to teach mentally retarded individuals to use their attentional resource system effectively, many deficiencies in general cognitive performance may be alleviated. A full understanding of the causes of retarded–nonretarded differences in semantic processing speed will have to include an analysis of how differences in metacognitive skills influence the allocation of attentional resources to semantic processing.

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