Guided Visual Search in Individuals With Mental Retardation

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Abstract
The ability of individuals with mental retardation to focus on task-relevant elements of complex visual arrays and increase visual-search efficiency was investigated. Initial assessments of visual-search efficiency were conducted to identify pairs of features for the form and size dimensions for which each participant demonstrated serial search. Subsequently, color was added as a defining feature that could guide search to a subset of the elements in the array. Results indicated that all of the individuals with mental retardation were able to limit attention to the task-relevant items on the guided search task, thus greatly reducing overall target identification times. Results show that individuals with mental retardation can demonstrate sophisticated visual selective attention skills when visual arrays are structured appropriately.

The structure of visual arrays is a critical factor that affects not only the detection of similarities and differences among stimuli, but also the acquisition of rule-based behaviors (Serna & Carlin, 2001; Soraci, Carlin, & Wiltse, 1998). Although most studies of intelligence-related differences on attentional and cognitive processing tasks are based on the assumption that the sensory information available for higher processing is identical in quality and quantity across groups, our studies have involved no such assumption. Rather, we have emphasized how the structure of visual arrays facilitates the detection of relevant stimulus relations, an approach that highlights perceptual/attentional variables rather than cognitive mediation (Soraci, Carlin, & Chechile, 1998). Our general contention is that differential sensitivities to structural properties of visual arrays may underlie a wide range of intelligence-related differences, affecting performances on tasks considered preattentional in nature (Carlin, Soraci, Goldman, & McIlvane, 1995; Carlin, Soraci, Hobbs, & Bud, 1999), as well as those involved in sophisticated rule acquisition and transfer (e.g., Soraci et al., 1991).

The ability to focus attention on task-relevant features in visual arrays while limiting attention to irrelevant elements is fundamental for performing accurately and efficiently on most experimental and educational tasks. Dempster (1991) suggested that knowledge of individual differences in inhibitory processing is critical for understanding intelligence and differential performances on numerous experimental tasks, including visual search. Empirical support for this premise was reported by Aks and Coren (1990). In a study involving undergraduates, these authors found that highly distractible participants showed deficits on measures of crystallized and verbal intelligence. Based on these findings, they cautioned that performance differences on measures of intelligence may reflect, at least in part, individual differences in visual selective attention.

Experimental evidence for inhibitory deficits in individuals with mental retardation has been found across many experimental tasks. In an early study, Terdal (1967) reported evidence that individuals with moderate to mild mental retardation were less able to inhibit attention to background stimuli during a simple looking task involving checkerboard stimuli. More recently, Merrill and O'Dekirk (1994), using a flanker task, found that individuals with mental retardation were affected negatively by flanking stimuli at much greater eccentricities than were individuals without mental retardation. These authors asserted that the differences observed may have resulted from the differential use of top-down processing resources across groups. Similar findings of susceptibility to distraction or interference have been reported on Stroop tasks (Ellis & Dulaney, 1991; Ellis, Woodley-Zanthos, Dulaney, & Palmer, 1989) and identity-based negative-priming tasks (e.g., Cha & Merrill, 1994). Importantly, Merrill, Cha, and Moore (1994) demonstrated that individuals with and without mental retardation show similar negative-priming effects on a location-based task. Thus, individuals with mental retardation may be able to utilize top-down processing to inhibit attention to irrelevant information but do not do so in all experimental contexts (see also Crosby, 1972). The challenges facing researchers, therefore, are to identify the circumstances in which individuals with mental retardation do and do not demonstrate the ability to limit attention to task-irrelevant distractions and to develop methods and/or presentation formats that facilitate adaptive attending behavior.

An important issue for consideration in reviewing the studies just described and the present experiments is the extent to which active inhibition of attention is involved. In the previously mentioned negative-priming studies, researchers interpreted results based on the assumption that attention to distractors and/or distractor locations was being actively inhibited. Some authors have questioned whether the negative-priming methods employed in those studies actually demonstrate distractor inhibition (e.g., Park & Kanwisher, 1994) or whether other processes (i.e., feature mismatching) are involved. In fact, Park and Kanwisher claimed that information about "unattended" items (e.g., identity and location) is obtained in a negative-priming context. Further, Milliken, Tipper, and Weaver (1994) proposed a multiple-process account that included inhibition and retrieval processes.

With regard to visual search, an analogous dilemma arises. Researchers have not established that guided search necessitates active inhibition of certain elements in the visual arrays. Rather, it may be that preattentive processes "label" particular elements as worthy of attention, and the remaining elements simply do not receive the same degree of attention as do the selected elements (Wolfe, Cave, & Franzel, 1989; Wolfe & Cave, 1990). The guided search model, in fact, posits no inhibitory component but explains enhancements in search efficiency as a consequence of the guidance of attentional allocation to locations or objects that are most likely to be the target. Given this debate, in this paper we focus on visual-search efficiency and minimize use of inhibition as a necessary explanation or component of the effects being tested.

In the present experiment, we were interested in determining the extent to which the visual-search behaviors of individuals with mental retardation are governed by the structure of the search task presented. Our goal was to determine whether a task designed to "guide" attention to only a subset of the elements in the array could be used to facilitate search for a predefined target stimulus. That is, given a particular search goal (e.g., "find the blue circle"), can individuals with mental retardation focus attention on a goal-related subset of items (e.g., all blue items) and limit attention to goal-irrelevant items (e.g., red items)? If so, this would be an important demonstration of an ability (i.e., visual selective attention) often reported to be deficient in individuals with mental retardation (e.g., Cha & Merrill, 1994; Dempster, 1991). Further, knowledge of the effects of task and stimulus structure on an important basic skill such as visual search could have important applications for the design of computerized educational programs and augmentative communication systems.

The development of the literature on visual-search processes in individuals with mental retardation has been inadequate. However, visual-search processes have theoretical importance for understanding the nature of mental retardation and, further, have applied relevance for the design of effective training procedures for this group. A series of studies in the 1960s (e.g., Rosenberg, 1961; Spitz, 1969) and 1970s (e.g., Das, 1971; Hagen & Huntsman, 1971; Spitz & Borland, 1971) formed the basis for a systematic study of this phenomenon, but the lack of a standardized methodology for studying visual-search efficiency and the general lack of systematic studies in the ensuing 20 years limited the knowledge gained. This occurred despite the recognition of the importance of this work by several influential authors (e.g., Fisher & Zeaman, 1973; Stanovich, 1978).

In the past 15 years, however, significant methodological and theoretical improvements have occurred in the study of the visual-search behaviors of individuals without mental retardation. Treisman and her colleagues (Treisman, 1988; Treisman & Gormican, 1988) were the leaders in the development and use of a standardized methodology for studying preattentive and attentive visual search. In a prototypical study, sets of simple stimuli representing contrasting values (e.g., circle vs. triangle) on a specific dimension (e.g., form) are presented. The specific feature that serves as the target is identified for the participant, who is asked to indicate its presence or absence in each visual array by pressing particular keys on the keyboard. A feature is said to be coded early in visual processing (i.e., preattentively) if it is detected with little or no increase in search time as the number of stimuli in the display increases. The assumption is that a parallel search of the display occurs; all stimuli are assumed to be processed simultaneously. If the target is not identifiable immediately, then a focused and effortful serial search of the array is required to determine whether the target stimulus is present or not. Application of this general methodological framework to the study of visual search in individuals without mental retardation led to significant theory development in the area.

Theorists interested in the processes involved in visual search generally posit the existence of two separate processing stages: (a) an initial broad-based preattentive processing stage that only involves distinctions between disparate features on a particular dimension and (b) a subsequent serial-processing stage that allows for finer discriminations among the stimuli presented. Performance on feature-search tasks, those in which the target and distractors differ along a single dimension only, seems to be governed primarily by the degree of difference between the features on the target dimension. Highly disparate features can be identified rapidly and independently of sample size (i.e., parallel search), whereas serial search of an array is required to differentiate less disparate features on the relevant dimension (e.g., Duncan & Humphreys, 1992). For example, in resolution theory (Tsal, Meiran, & Lamy, 1995) an initial preattentive low-resolution process is suggested that makes only coarse discriminations among items and a secondary attentive process is posited that can "resolve" finer distinctions between items. If the distinction between the target and distractors is of a sufficient magnitude, the initial low-resolution filter will be sufficient to differentiate the stimuli, resulting in the rapid identification of the target without need for a more-focused search of the array.

Several theorists, however, have questioned whether the parallel and serial-processing stages are truly independent. Wolfe et al. (1989) forwarded the notion that the preattentive- and attentive-processing stages may not be autonomous, but, rather, the preattentive processing stage may inform or "guide" the subsequent attentive-processing stage to particular items in the array that are most likely to be the target. Thus, the initial phase may serve to segment the visual array into subsets of stimuli that may vary with regard to their probability of containing the target stimulus. As in the example cited earlier, search for a blue circle could result in segregating the visual array into blue and red items initially. Then, attentive search for the blue circle could be limited to the set of blue stimuli only. This ability to rapidly eliminate certain items as possible targets would greatly enhance search efficiency and is what seems to occur for individuals without mental retardation (Tipper, 1985; Wolfe, 1994, 1998). The question remains as to whether individuals with mental retardation, who have been known to be more distractible (e.g., Aks & Coren, 1990; Cha & Merrill, 1994; Dempster, 1991), can regulate search in this manner.

An important consideration in evaluating visual-search performance is the degree to which search behaviors are controlled by top-down (endogenous) and bottom-up (exogenous) factors. Top-down factors include verbal instructions, strategies, and other factors that determine the search goal of the participant. Once established, these factors allow the participant to exert some voluntary control over the spatial allocation of attention (e.g., "look for blue items and ignore all other colors"). Bottom-up factors include physical (i.e., structural) attributes of the visual array (e.g., perceptual salience) that determine which elements in an array are most likely to receive attention. These operate automatically and may override the participant's voluntary control of attention (e.g., Yantis, 1996). Thus, visual-search efficiency is determined both by the search goal and strategies of the observer (top-down processes), and the physical features of the array (bottom-up factors) that determine the relative saliences of the multiple elements in the visual array. When both factors highlight the same element in the array, search will be very efficient (i.e., parallel search). When bottom-up activations do not differentiate items substantially, then search will be much less efficient (i.e., serial search).

Carlin et al. (1995) utilized the feature-search methodology just outlined to demonstrate that individuals with mental retardation have longer visual-search times for simple objects defined by their unique color, form, or size. Their results indicate that individuals with mental retardation responded more slowly than did individuals without mental retardation, and many of the participants with mental retardation performed serial searches for target stimuli in conditions in which those without mental retardation could identify the target rapidly and independently of the number of objects in the array (i.e., parallel search). Such inefficient visual-search behavior would be expected to influence performances on many tasks encountered in educational settings and in daily living environments because selective visual attention is critical for providing coherent information to subsequent mediational processes.

In the present study, therefore, we employed guided-search methods to determine whether the search efficiency of individuals with mental retardation could be facilitated. We employed an individualized approach in which each participant was assessed for his or her ability to identify targets along several dimensions (color, form, and size). We individualized this process because previous results (Carlin et al., 1995) indicated substantial individual differences in search efficiency within a group of individuals with mental retardation. Thus, using our current methodology we could substantially reduce variability due to differential sensitivities to the particular features used on the visual-search tasks.

The guided-search tasks that we utilized were structured in a manner that allowed participants to greatly enhance target-identification times if they were able to reduce attention to elements in the visual array that were irrelevant to the search goal. Although this differs from the classic guided-search task in which the target is defined by a conjunction of features (e.g., Wolfe et al., 1989), the notion of the guidance of attention by a basic preattentive-processing stage is preserved. We believe that the basic processes underlying these two types of guided-search tasks are the same. In the context of our methods, we assumed that knowledge of the target's color (i.e., top-down activation) and the salience of the color cues (i.e., bottom-up activation) allows for a preattentive segmentation of the array elements by color. Thus, the preattentive-processing stage "guides" attention to a subset of the elements in the array. Focused visual search for the target then would be limited to this subset. In Experiment 1, the number of search-relevant items in the arrays was held constant across set sizes. Thus, an ability to restrict attention to relevant items would be shown by consistent search times across changes in the total number of elements in the arrays.

EXPERIMENT 1

Method

Participants

Six individuals (1 female, 5 males) with mental retardation participated. They were recruited from local schools in Massachusetts that serve individuals with mental retardation only. Their mean chronological age (CA) was 214.17 months (standard deviation [*SD*] = 31.01) and their mean mental age (MA), as measured using the Peabody Picture Vocabulary Test-Revised (PPVT-R), was 88.33 months (*SD* = 32.12). The participants had normal or corrected-to-normal visual acuities and were not colorblind.

Apparatus

The testing apparatus consisted of a Macintosh Power PC 4400/200 computer fitted with a Studioworks 57I monitor. All responses were recorded automatically by the computer and saved in disc-based files.

Stimuli

The color features selected were red and blue because we expected them to result in parallel search for all participants (Carlin et al., 1995). The features used for the form-based search tasks were circles (radius = 3 mm), triangles (sides = 6 or 8 mm), squares (8 mm × 8 mm), diamonds (sides = 6 mm), rectangles (5 mm × 9 mm), and hexagons (sides = 3 mm). For the size search tasks, three forms were used on the final tests: rectangles, squares, and triangles. The small rectangle measured 2.5 mm × 5.5 mm and the large rectangle, 3 mm × 7 mm. The small square measured

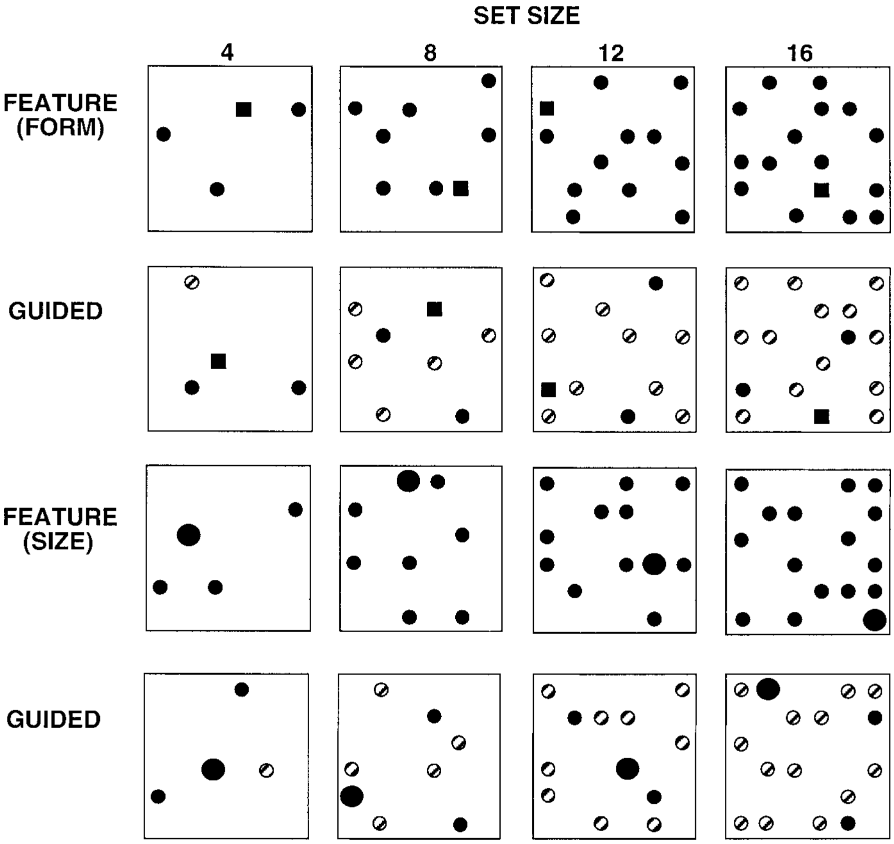

Figure 1. Examples of the feature- and guided-search arrays utilized in Experiment 1. The target for the form examples is the square; the target for the size arrays is the large circle. The filled elements represent blue and the cross-hatched elements represent red.

4 mm × 4 mm and the large square, 6 mm × 6 mm. Finally, the small triangle had sides of 6 mm and the large triangle, 8 mm.

Visual arrays were presented in the center of the computer screen, both horizontally and vertically. The array comprised an imaginary 6 × 6 grid. The gridlines and borders of the grid did not appear on the screen. The gap between stimuli in adjacent cells of the grids was approximately 5 mm. Stimuli were placed in cells of the grids such that they were aligned horizontally and vertically. Example arrays are shown in Figure 1 (note that the borders shown in the figure did not appear on the computer screen).

Visual-Search Task

Participants were seated approximately 50 cm from the computer screen, with the keyboard placed within arms' reach. The experimenter sat to their right also within arms reach of the keyboard. Each trial began with the presentation of a centralized 1 cm × 1 cm fixation cross. Trials were initiated by the experimenter pressing the control key when the participant was ready and his or her eyes were directed toward the fixation point. The array was presented immediately following the depression of the control key. Participants were told that if the target object was present, they were to respond by pressing the space bar as rapidly as possible, and the array would be removed from the screen. If the target was absent, they were instructed to do nothing, and the program would advance to the next trial after 4 seconds. Both speed and accuracy were emphasized. Extensive practice with the task was provided prior to initiation of the experimental trials to acclimate the participants to the task and ensure that stable performances were attained prior to introduction of the formal test trials. The minimum allowable accuracy score for a session was defined as 90%. This criterion was required to be attained for both target-present and target-absent trials. A correct response (i.e., pressing the space bar when the target was present or doing nothing when the target was absent) was followed by a high-pitched pleasant tone. Incorrect trials were followed by a low buzz.

Prior to introducing a new set of stimuli for a search task, we presented the features to the participants on index cards. When the cards were shown, the experimenter labeled the features and explained the differences between the two stimuli. The card with the target then was placed in front of the individual and was in view during the computerized trials as well. Also, several sets of practice trials utilizing the new features were conducted to acclimate the participant to the new search task and to ensure that accuracy remained at a high level for those particular features.

Each block consisted of 80 trials. Equal numbers of trials (i.e., 10) of each set size (4, 8, 12, 16) and target presence/absence were included in each block. Order of trials was quasi-randomized by the computer prior to each block, with the restriction that no more than two trials of any type could occur consecutively. Two blocks of trials were completed for each visual-search task so that reaction time (RT) estimates were based on the median performance across 20 trials in each of the eight conditions formed by a factorial combination of target presence (present vs. absent) and set size (4, 8, 12, 16).

Procedure

Feature-search assessments. Participants were initially assessed for their ability to detect a color target, either a blue or red circle, among a set of distractors of the opposing color. This assessment was conducted to ensure that all participants demonstrated parallel search for these features, as would be expected based on past research (Carlin et al., 1995). This assessment justified use of these features to "guide" attention on the subsequent form- and size-based guided-search tasks.

For the dimensions of form and size, however, it was necessary to identify pairs of features that differed in form only and size only that resulted in serial search. Each participant was presented with various pairings of features until serial search was demonstrated (i.e., RT $\times$ Set Size slope $>$ 10 msec/item) for a particular pairing. Specific pairs of features identified (i.e., targets and primary distractors) and utilized in the subsequent phases of the experiment for each individual are shown in Appendix A. Again, this variation of specific feature pairs used across participants was designed to reduce error variability due to differential sensitivities to particular feature pairs used. In typical group designs, a single feature pair is shown to all participants and search efficiency is recorded. For individuals with mental retardation, this typical procedure is problematic due to the large degree of variability in sensitivity to particular feature pairs across participants (see Carlin et al., 1995). This individualized approach also should serve to both increase the construct validity of our manipulations and the power of the tests of the effects of interest.

Guided search. On the guided-search task, stimuli differed along two dimensions: the target dimension (form or size) and color. The target and primary distractors identified in the feature-search assessments were maintained, but only two primary distractors were presented on target-present trials. The remaining distractors in the 4-, 8-, 12-, and 16-element arrays were secondary distractors as listed in Appendix A. Secondary distractors differed from the target with regard to color and form (or size). Thus, if the instruction regarding the target (e.g., "find the blue circle") was utilized effectively, search should have been limited to the three blue elements (the target and the two primary distractors), and search of the red elements should have been limited. On target-absent trials, three primary distractors were presented along with the appropriate number of secondary distractors. If visual search was limited to the target-color items only, all arrays should have been three-element arrays functionally. That is, regardless of set size, only the three blue items should have been attended to, and search times should not have varied across set sizes (see Figure 1 for example target-present arrays).

Design and Analysis

The design was a 2 (dimension: form, size) $\times$ 2 (task: feature, guided) $\times$ 4 (set size: 4, 8, 12, 16) within-subjects design. The primary dependent variable was search time (in msec) for target-present trials. The search-time estimate used for each condition was the median RT for the 20 trials in that condition. Medians were used because of the presence of outliers and/or skew in the RT distributions. There was a tendency to have one or two slow RTs in each set of 20 trials. Thus, the median was judged to be the most valid indicator of central tendency. The most significant predictions were that visual-search times would be much faster on the guided-search tasks than the feature-search tasks and that search times on the guided-

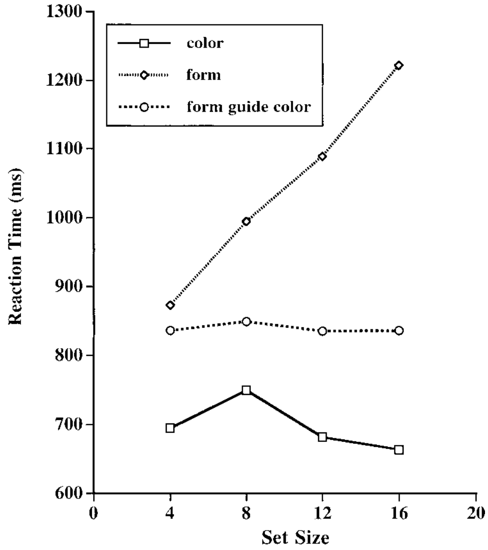

Figure 2. Mean search times for the form-based search tasks by set size.

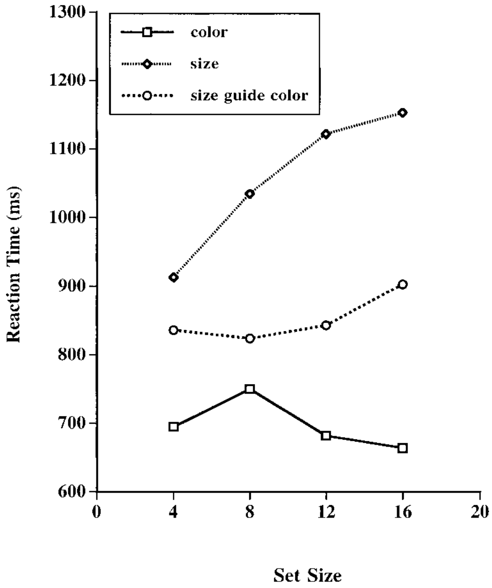

Figure 3. Mean search times for the size-based search tasks by set size. Note that the same color data are presented in both Figures 2 and 3.

search tasks would be independent of set size. The expected near-zero slope for the RT × Set Size function for the guided-search data would reflect the expectancy that participants would limit search to the task-relevant items (i.e., those sharing the targets color) only, making the task functionally a three-element search task in all conditions.

Analyses were conducted using the SPSS/PC+ statistical package. Given the aforementioned predictions, we expected that there would be a significant main effect of task and a significant Task × Set Size interaction in the omnibus ANOVA. The interaction comparison of theoretical interest was that testing the hypothesis that search times would increase linearly with set size on the feature-search tasks but no differences across set sizes would be evident on the guided-search tasks.

Results

Feature and Guided Search

Results for the color-based feature search task indicated that RTs did not differ across set sizes, $F(3,15) = 2.93$, $p > .05$, $\eta^2 = .04$. This result (shown in Figure 2), combined with the fact that this result was true for each individual, justified the use of these color features (i.e., red and blue) as the vehicles for the guided-search tasks. This analysis, however, did indicate that there were significant differences in search times across participants, $F(5, 15) = 41.75$, $p < .001$, $\eta^2 = .90$. This is somewhat surprising given the basic nature of this color-based search task. This is further evidence for substantial individual differences across participants with mental retardation on a task that assesses very rapid (i.e., preattentive) visual-search abilities. The overall search times for the 6 individuals with mental retardation ranged from 532 msec to 961 msec ($M = 703$, $SD = 159.47$).

Results for the feature- and guided-search tasks for the form and size dimensions are shown in Figures 2 and 3, respectively. The 2 (dimension: form, size) × 2 (task: feature, guided) × 4 (set size: 4, 8, 12, 16) within-subjects analysis of variance revealed statistically significant main effects of task, $F(1, 5) = 20.86$, $p = .006$, $d = 1.86$, and set size, $F(3, 15) = 26.09$, $p < .001$. The task main effect indicated that search times were significantly faster overall on the guided-search tasks ($M = 845.25$ msec, $SD = 145.95$) than the feature-search tasks ($M = 1050.17$ msec, $SD = 232.23$ ms). A trend analysis for the overall set size data indicated that search times increased linearly with increases in set size, $F(1, 5) = 30.14$, $p < .01$. The latter effect, however, was qualified by a statistically significant interaction between task and set size, $F(3, 15) = 11.30$, $p < .001$. The planned interaction comparison assessing the prediction of a positive linear trend for feature-search data and a flat RT × Set Size function for the guided-search data was statistically significant, $F(1,15) =$

Table 1. Percentage Correct for Target-Present and Target-Absent Trials by Set Size

	Set size									
	4		8		12		16		Overall	
Trial type	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*	Mean	*SD*
Target present	98.83	1.47	99.33	.82	98.17	1.83	98.67	1.75	98.75	.89
Target absent	96.83	2.93	97.17	1.47	98.33	2.07	98.17	2.56	97.63	2.08

39.38, $p < .001$. No other effects were statistically significant.

One of the requirements of the current methodology is that error rates are low and consistent across conditions. Thus, any differences in search times cannot be attributed to speed–accuracy tradeoffs. Error rates were consistently low across all conditions in this experiment for all participants. The mean accuracy rates for the target-present and target-absent trials for each set size are shown in Table 1. As can be seen, accuracy rates were quite high and did not vary appreciably across conditions.

Individual Differences in Search Efficiency

A general finding in our studies of visual-search efficiency has been that intragroup variability is greater for individuals with mental retardation than for groups of individuals without mental retardation (e.g., Carlin et al., 1995). In the present study, several instances of this intersubject variability were evident. First, the particular features identified during the preassessments for which the individuals could perform parallel and serial searches varied significantly (see Appendix A). For example, Participant 5 demonstrated serial search for the most disparate feature pairing (i.e., triangle vs. circle). Participants 2 and 3 demonstrated parallel search for the triangle–circle combination but not for the triangle–diamond pairing. Finally, the remaining 3 participants required much more difficult stimulus pairings before demonstrating serial search. This degree of intragroup variability in search speed for particular pairs of features on a single dimension (i.e., form) typically is not evident for individuals without mental retardation. Indeed, in our pilot tests of these features with groups of approximate CA- and MA-matched peers, search modes (serial vs. parallel) were generally consistent within a group for a particular pairing of features, as was true for the individuals without mental retardation in the Carlin et al. (1995) study.

A second demonstration of marked variability across the individuals with mental retardation tested was the range of intercept values obtained. Across the feature and guided-search tasks for the form and size dimensions, we found generally that the highest intercept value was approximately twice that of the quickest individual. This difference was particularly striking when Participants 2 and 3 were compared. These 2 individuals were exposed to identical stimuli across the four search tasks. However, Participant 2's average intercept value was 883 msec, and Participant 3's average intercept was 545 msec. Importantly, however, the general effects tested with regard to guided search were consistent across individuals, despite these individual differences in overall search time. An important purpose for future researchers will be to determine the basis of these intragroup differences in search speed and sensitivity to featural differences within dimensions.

Discussion

The important findings in Experiment 1 were that visual-search efficiency was greatly increased on the guided-search tasks relative to the feature-search tasks, and participants were able to limit attention effectively to the target-relevant elements in the visual displays. The latter finding indicates that the participants with mental retardation were able to limit attentional processing to the items in the visual arrays that were of the predefined target color. Thus, the instructional set established by the verbal instructions was sufficient to allow for top-down (i.e., goal-directed) control of visual search. This is an important demonstration that individuals with mental retardation can reduce attention to certain irrelevant items in a visual display when specific search goals are established. Stated another way, the structure of a visual-search task can be manipulated systematically and strategically to significantly enhance search speeds by guiding attention to only a subset of the stimuli in the full visual array.

EXPERIMENT 2

Experiment 2 was an additional test of the guided-search hypotheses assessed in Experiment 1. However, in this experiment, we also varied the number of relevant stimuli rather than maintaining a constant number of relevant stimuli (i.e., 3) across all arrays. This methodology allowed us to assess the prediction that participants were serially searching for the target stimulus among the task-relevant stimuli. If so, then the results of this experiment should show increasing search times as the number of relevant stimuli increases. As in Experiment 1, evidence of attentional guidance would be shown by a lack of an effect of total set size because the number of relevant stimuli was equivalent across set sizes. Thus, if the participants are able to limit attention to search-irrelevant stimuli and focus attention on task-relevant stimuli only, then guided search should be significantly faster than feature search, and there should be no effect of total set size on the guided-search task. If search among the search-relevant items proceeds in a serial fashion, then search times should increase as the number of relevant stimuli increases from two to four. Thus, the three major predictions were that (a) search times would be significantly faster for guided-search arrays than for feature-search arrays, (b) search times would be independent of total set size, and (c) search times would increase as the number of relevant stimuli increased. This pattern of results would establish, again, that individuals with mental retardation can focus attention to task-relevant items in visual arrays and that search for the target proceeds in a serial fashion among these search-relevant items.

Method

Participants and Apparatus

Participants included 8 individuals with mental retardation from local schools. Their mean CA was 176.50 months ($SD = 40.21$) and mean MA, as measured using the PPVT-R, was 91.38 months ($SD = 34.37$).

The testing apparatus consisted of a Macintosh Power PC 4400/200 computer fitted with a Studioworks 57I monitor. All responses were recorded automatically by the computer and saved in disc-based files.

Stimuli

The stimuli and arrays employed (see Appendix B) were identical to those used in Experiment 1. Stimuli for the feature-search preassessment task were the targets and primary distractors listed for each individual. On the guided-search tasks, the targets remained the same, the primary distractors were the search-relevant stimuli (i.e., shared the color of the target), and the remainder of the stimuli in the arrays were secondary distractors (i.e., differed from the target in color and form).

Procedure

The procedures utilized were similar to those of Experiment 1, with three notable exceptions. First, all search tasks in this experiment were form-based. Second, the number of relevant stimuli varied across trials rather than being held constant (at 3). The number of stimuli sharing the target's color (i.e., relevant items) was either two, three, or four (see Figure 4 for example arrays) on each trial. Third, participants in this experiment were exposed to 480 guided-search trials. Six blocks of 80 trials were required to meet the criterion that search-time estimates in each condition be based on the average of 20 trials. Thus, each participant was exposed to 20 trials in each of the 24 conditions formed by a factorial combination of set sizes (4, 8, 12, 16), numbers of relevant stimuli (2, 3, 4), and target presence (present vs. absent).

Design and Analysis

The primary design was a 3 (number of relevant stimuli: 2, 3, 4) × 4 (set size: 4, 8, 12, 16) within-subjects design. The dependent variable was search time (in msec) for target-present trials. In addition, search times from the guided-search tasks (i.e., two, three, and four relevant elements) were compared to the search times on the feature-search preassessment. The most significant predictions were that (a) visual-search times would be much faster on the guided-search tasks than the feature-search tasks, (b) search times on the guided-search tasks would be independent of set size, and (c) search times would increase linearly with increases in the number of relevant stimuli in each array. The expected near-zero slope for the RT × Set Size function for the guided-search data would

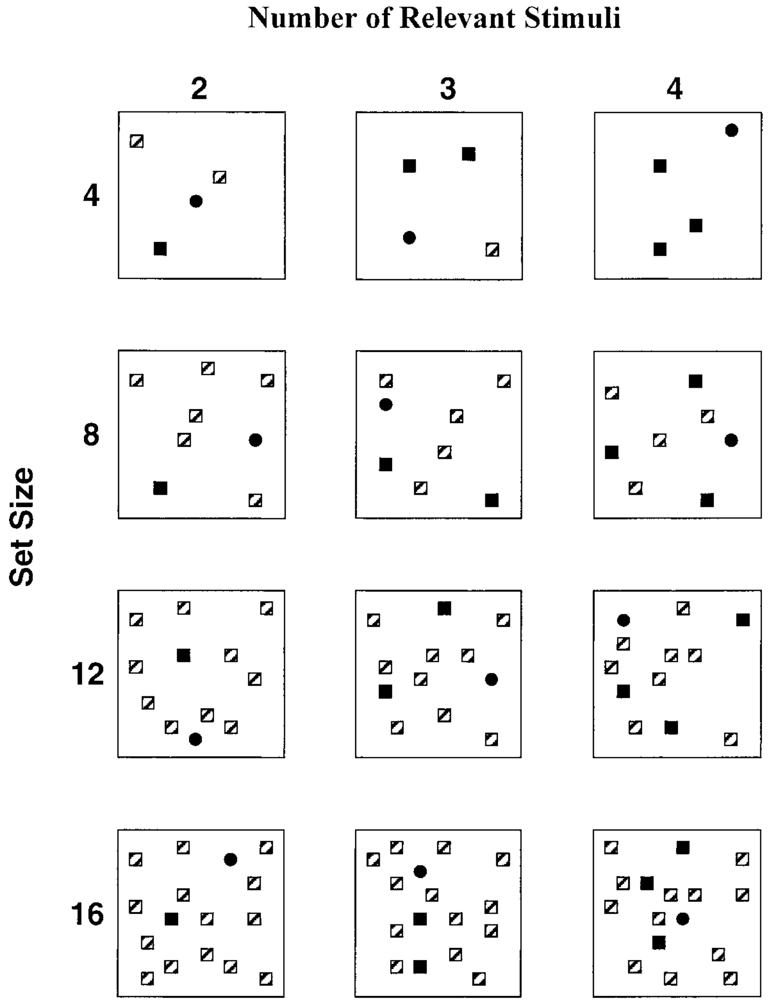

Figure 4. Examples of the guided-search arrays utilized in Experiment 2. Note that the number of relevant stimuli varies across columns of the figure.

reflect the expectancy that participants would limit search to the task-relevant items (i.e., those sharing the target's color) only. The linear increase in search times with increases in the number of relevant stimuli would indicate that individuals would be serially searching through the target-relevant subset of items in each array. Thus, flat RT × Set Size functions would not be indicative of parallel search, only that search was limited to the same number of items in each array, despite variability in the total numbers of items in each array.

Analyses were conducted using the SPSS/PC+ statistical package. We expected that there only would be a significant main effect of number of relevant stimuli in the 3 × 4 ANOVA. Further, we expected that RT × Number of Relevant Stimuli Slopes would be greater than 0 and that the slopes of the RT × Set Size functions would be significant for the feature-search task only. These slopes were assessed using one-tailed significance tests for theoretical reasons based on past findings with individuals without mental retardation and to increase the power of these comparisons.

Results

Feature and Guided Search

The form preassessment was designed to identify pairs of features for each individual that resulted in serial search. The success of this endeavor is indicated by the increase in search times across set sizes, seen in Figure 5, and a statistically significant positive linear trend in these data, $F(1, 7) = 38.41$, $p < .001$. The comparison of the means for the feature search task ($M = 992$ msec, $SD = 214$) and the guided-search task ($M = 828$

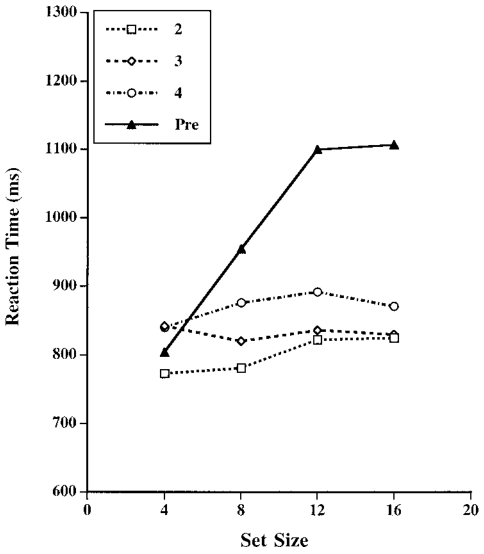

Figure 5. Mean search times for the feature-search and three guided-search conditions in Experiment 2.

msec, *SD* = 177) indicated that the difference was significant, $t(7) = 2.51$, $p < .05$ (one-tailed), $d = 0.89$.

We expected that the guided-search data would demonstrate a statistically significant effect of the number of relevant stimuli and no effect of set size. Search results by number of relevant stimuli and set size are shown in Figure 5. The omnibus ANOVA indicated that the effect of the number of relevant stimuli approached statistical significance, $F(2,14) = 3.37$, $p = .06$, and the set size effect, $F(3, 21) = .84$, $p =..49$, and interaction, $F(6, 42) = .44$, $p = .85$, were not statistically significant. The slope (M = 26.25 msec/item, SE = 5.19) of the RT × Set Size function for the feature-search task was greater than 0, $t(7) = 5.06$, $p < .01$ (one-tailed), $d = 1.79$, whereas that for the guided-search task was not (M = 2.25 msec/item). For the guided-search task, the slope of the RT × Number of Relevant Stimuli function *(M* = 34.13 msec, SE = 15.39) was significantly greater than 0, $t(7) = 2.22$, $p < .05$ (one-tailed), d = .78, These results support the predictions that set size would have an effect only on the feature-search task and that number of relevant stimuli would have an effect on the guided-search task.

As in Experiment 1, participants were instructed to respond as rapidly as possible while maintaining a high degree of accuracy. Error rates varied little across set sizes or the two types of trials. Accuracy rates for the one-relevant (97.57%), two-relevant (97.75%), and three-relevant (97.57%) stimuli conditions were virtually identical. These data indicate that results are not likely affected by differential speed–accuracy trade-offs across conditions.

Discussion

The findings of Experiment 2 replicate the general finding of Experiment 1 that individuals with mental retardation can limit attention effectively to task-relevant items in a visual array. This is accomplished through the exertion of top-down control of attention governed by the instructional set (e.g., target definition) provided to the participant. Results from Experiment 2 also provide evidence that the participants conducted a serial search among only the *relevant* items in each array. In support of this contention was the finding that RTs increased as the number of relevant stimuli increased. Finally, the data indicate that participants did not attend to the irrelevant items in the arrays. Specifically, RTs for the two- and three-relevant-stimuli conditions were less than the RTs for the four-element feature-search task and the four-relevant-stimuli conditions. This indicates that the participants were attending to less than four elements in the arrays with fewer than four relevant items. The latter two inferences based on the obtained data could be more directly assessed using eye-tracking technologies that allow for real-time recording of eye movements, and we plan to conduct these studies.

One exception to these findings was the elevated mean RT in the condition involving four elements with three relevant stimuli. Performance in this condition was equivalent to that in the four-element array feature-search task. This elevation may have resulted from a form of bottom-up control of attention referred to as "attentional capture" (Yantis, 1996). This is the only condition in the present experiment in which a single irrelevant item was present. This odd singleton may have "captured" the attention of the participants due to its increased bottom-up activation. The high salience of this item, particularly given that the participant was searching for a singleton target, may have drawn attention to it, despite the goal of attending only to items of the target color. Investigation of differential susceptibility to this type of perceptual distraction is another avenue for research on intelligence-related differences in inhibitory processing.

Finally, we note that the samples in Experiments 1 and 2 differed with respect to CA and IQ. The two samples were approximately equal in terms of MA assessed by the PPVT-R, but differed by approximately 3 years in CA. The similarity of the findings across the two experiments indicates that the processes under study were operative for these individuals with mental retardation across these age and IQ ranges.

GENERAL DISCUSSION

The findings from the present experiments demonstrate the ability of individuals with mental retardation to focus attention on task-relevant stimuli and to exert control over the allocation of visual selective attention. All individuals tested were able to limit attention to a subset of elements in a visual array that matched the search goals provided by the experimenter. Evidence indicated that the participants did not attend to the irrelevant items, except perhaps for the one condition that had a single, highly salient, irrelevant stimulus. This segregation of the visual array into relevant and irrelevant items occurred rapidly, perhaps preattentively, for the participants involved.

This demonstration of sophisticated visual selective attending contrasts with numerous reports (e.g., Cha & Merrill, 1994; Dempster, 1991) of inhibitory deficits in individuals with mental retardation. The challenge is to reconcile the findings to determine the circumstances in which individuals with mental retardation can and cannot exert such control over their visual selective attending. The current experiments involved the explicit setting of search goals that allowed for selection of some items for further processing and reduction of attention to other items in the arrays that were not consistent with the search goal. This demonstrates the ability to exert top-down control of visual selective attention; the search goal (e.g., "find the black square") was utilized to focus attention on certain items and limit attention to items that were inconsistent with that search goal.

Melnyk and Das (1992) divided visual selective attention into three components: selection of the target, resistance to distraction, and the ability to shift strategies. The experiments presented here deal with the selection and distractibility components. In this regard, the work of Merrill and his colleagues (Cha & Merrill, 1994; Merrill et al., 1994) on negative priming is quite relevant. In two of these studies, evidence was presented that individuals with mental retardation demonstrate negative-priming effects for location but not identity (i.e., form). This was taken as evidence that such individuals have an inhibitory deficit when the task involves processing of the identity of forms. Our experiments, however, involved segmentation of arrays based on the color of the elements presented. Thus, the inconsistency with regard to the ability of individuals to limit attention to particular visual stimuli may be the result of the dimensions tested. Perhaps color is a dimension that can be used to rapidly segment arrays and guide attention to particular stimuli, but form is not such a dimension. This would be consistent entirely with the finding of Carlin et al. (1995) that search efficiency for forms is much worse than that for colors. A natural next step to resolve these issues would be to utilize identity-based negative-priming tasks to compare patterns of performance for form- and color-based stimuli. This would help to ascertain whether differences across these experiments were due to the dimensions utilized or perhaps other methodological differences (e.g., memory demands) across negative-priming and visual-search tasks. Alternatively, guided-search methodologies could be used to determine whether form differences can be utilized to segment visual arrays in the same manner as was evidenced in the current experiments involving color differences. These types of studies would be important for determining whether the efficiency of visual selective attention is affected by the particular visual dimensions utilized on the experimental tasks. This could be important potentially for understanding the basis of the intelligence-related differences (e.g., identifying visual pathways or brain regions involved) and for the design of practical applications for enhancing the performances of individuals with mental retardation (e.g., Carlin, Soraci, & Strawbridge, in press).

The approach taken in the current experiments also demonstrates the utility of using standard methodologies to assess the functioning of individuals with mental retardation. The refinement of methodologies for assessing visual search, through the study of individuals without mental retardation, provides a unique opportunity for advancement in this area with individuals who have mental retardation. There are now established methods and experimental designs for studying feature search (e.g., Treisman & Gormican, 1988), guided search (Wolfe et al., 1989), attentional capture (Yantis, 1996), and conjunction search (e.g., Bacon & Egeth, 1997; Quinlan & Humphreys, 1987) among individuals without mental retardation. The explosion of published studies on these topics in the psychological literature evolved from these methodological advances, and similar advances can be realized in the understanding of visual-search behaviors of individuals with mental retardation. The promise of applying these methods to the study of individuals with mental retardation is an opportunity not available to those who studied visual search 30 years ago and, further, is a chance for studies of individuals with mental retardation to advance theoretical development regarding visual search in general.

One consistent finding across all of our visual-search studies involving persons with mental retardation has been individual variability in search rates for particular pairings of stimuli. Carlin et al. (1995) found that half of the individuals with mental retardation performed serial searches for the form- and size-based search tasks, whereas the remainder searched very efficiently, regardless of the number of stimuli presented (i.e., parallel search). Because of this intragroup variability, in the present experiments we utilized an alternative methodology in which the particular forms used on the search tasks varied across individuals. This option decreased effects of stimulus selection across individuals and allowed for a more direct and valid assessment of the focal manipulations. In the present experiments, the intragroup variability was demonstrated by the range of stimulus pairings used across participants. In each experiment, several participants searched very efficiently for pairings for which other individuals needed to use a serial search. These individual differences appear to reflect differential sensitivities to differences along the dimensions tested. Individuals who fail at a basic pairing (e.g., circle–triangle) cannot detect more difficult pairings (e.g., triangle–diamond) efficiently either. However, individuals who perform efficiently for difficult pairings can perform efficiently for all more basic pairings. Thus, the differences are related to the disparity between the two stimuli presented and not to differential sensitivities to particular stimulus pairings.

In summary, the present experiments demonstrate that individuals with mental retardation possess the ability to restrict attention to particular items in a visual array to increase the efficiency of search for a predefined target. As these findings are inconsistent with other studies that have found visual selective attention deficits in this population, there is a need to identify the circumstances in which individuals with mental retardation can exert such control over attentional allocation and circumstances in which they can or do not. Such systematic research will advance our understanding of the nature of mental retardation and, perhaps, visual selective attention in general. Further, such knowledge may allow for the design of visual formats that promote such adaptive attending in individuals with mental retardation (e.g., Carlin, Soraci, Dennis, Chechile, & Loiselle, 2001; Carlin et al., in press).

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Appendix A. Features Utilized on the Form and Size Search Tasks for Each Participant in Experiment 1

	Form-based search			Size-based search		
Part	Target[a]	Primary distractor[a]	Secondary distractor[b]	Target[b,c]	Primary distractor[b,d]	Secondary distractor[a,d]
1	circle	hexagon	hexagon	rectangle	rectangle	rectangle
2	triangle	diamond	diamond	square	square	square
3	triangle	diamond	diamond	square	square	square
4	circle	hexagon	hexagon	triangle	triangle	triangle
5	triangle	circle	circle	square	square	square
6	square	rectangle	rectangle	square	square	square

Note. Secondary distractors were used on the guided-search tasks only.
[a]Forms were blue. [b]Forms were red. [c]Forms were small. [d]Forms were large.

Appendix B. Stimuli Presented to Each Participant on the Guided Search Task in Experiment 2

Participant	Target	Primary distractor	Secondary distractor
1	blue pentagon	blue hexagon	red hexagon
2	blue hexagon	blue pentagon	red pentagon
3	blue pentagon	blue hexagon	red hexagon
4	blue circle	blue hexagon	red hexagon
5	blue triangle	blue circle	red circle
6	blue pentagon	blue hexagon	red hexagon
7	blue hexagon	blue pentagon	red pentagon
8	blue hexagon	blue circle	red circle

