

Detection of Changes in Naturalistic Scenes: Comparisons of Individuals With and Without Mental Retardation

Michael T. Carlin, Sal A. Soraci, and Christina P. Strawbridge
Shriver Center of the University of Massachusetts Medical School

Nancy Dennis
Catholic University

Raquel Loisel and Nicholas A. Chechile
Shriver Center of the University of Massachusetts Medical School

Abstract

Abilities of individuals with and without mental retardation to search for and detect salient changes to naturalistic scenes were investigated using the flicker paradigm. Located in areas of central or marginal interest, changes involved an object's color, shape, or presence. Individuals with mental retardation required more time to detect changes of all types, and the magnitude of the group difference was more pronounced for marginal-interest changes. Supplemental eye-tracking data from 6 participants suggested that the basis of this effect was that individuals with mental retardation tended to maintain gaze in the region of central interest for longer periods of time prior to sampling the other areas of the scene. Implications for intelligence-related differences in visual attention are discussed.

Visual search skills are critical for acquiring visual information from the environment efficiently and accurately. Their importance for understanding performance differences between individuals with and without mental retardation has been the focus of research for more than 30 years. Early visual search studies involving individuals with mental retardation provided important information about the influences of stimulus structure on search performance (e.g., Spitz, 1969), eye and head movement patterns (e.g., Atkin, Bala, Herman, & Rogowitz, 1981; Berkson, 1966), and search strategies (Winters, Gerjuoy, Crown, & Gorrell, 1967). More recent development of standardized visual search methodologies for assessing feature, guided, and conjunction search has provided the opportunity for systematic assessments of basic visual search skills in individuals with and without mental retardation.

Using standard feature-search tasks, Carlin, Soraci, Goldman, and McIlvane (1995) showed that individuals with mental retardation were much less efficient than those without mental retardation. Their mean search times were much higher. However, interesting patterns of similarities and differences in search efficiency emerged when Reaction Time (RT) \times Set Size (i.e., the number of elements in the visual array) slopes were compared for the dimensions of color, form, and size. For the color dimension, target detection times were independent of set size for *both* groups. However, for the form and size dimensions, both of which instantiate geometrical disparities between target and distractor stimuli, significant Group \times Set Size interactions were evident. Detection times for the participants with mental retardation were positively correlated with set size, whereas detection times for individuals without

mental retardation were, again, independent of set size. This pattern of differences was true for only half of the individuals with mental retardation, however. Half of them demonstrated $RT \times$ Set Size functions with near-zero slopes, whereas the other half had significant positive slopes. Thus, individual differences in search efficiency emerged across dimensions within- and between-groups. These subgroup differences may arise from differential sensitivities to particular stimulus features or from response constraints used in the experimental tasks (cf. Soraci, Carlin, & Wiltse, 1998). Thus, all participants may have been able to demonstrate efficient, parallel search for form-based stimuli if the disparity between the two forms was sufficiently large.

Given the search efficiency differences between individuals with and without mental retardation, Carlin, Soraci, Dennis, Strawbridge, and Chechile (2002) assessed whether individuals with mental retardation could benefit from a structural manipulation designed to "guide" visual attention to the stimuli that were most likely to be the target of the search. Results indicated that they could utilize information about the identity of a target (i.e., its color) to limit search to a small subset of the elements in a visual array (i.e., those sharing the target's color), while inhibiting attention to elements that were unlikely to be the target (i.e., elements of other colors). Thus, the search efficiency of individuals with mental retardation was enhanced significantly. These findings demonstrated that individuals with mental retardation could use sophisticated top-down control of visual search when tasks were structured appropriately.

The present study represents an extension of this research to more complex and more ecologically valid arrays. In the present study, we assessed the abilities of individuals with and without mental retardation to detect salient changes to naturalistic scenes. Several recent investigations (Rensink, O'Regan, & Clarke, 1997; Simons & Levin, 1998) have demonstrated that individuals without mental retardation often fail to detect obvious changes that take place in their everyday surroundings. The inability to detect salient changes to objects in scenes is referred to as *change blindness*. Change blindness has been induced experimentally by introducing various types of interruptions into the processing of a scene.

One method for inducing change blindness has been to introduce changes during saccadic eye movements (e.g., Grimes, 1996; Henderson, 1997;

Henderson & Hollingworth, 1999). Henderson and Hollingworth demonstrated that salient object changes were not detected when the changes were made during saccades. Further, their results indicated that detection rates varied by the type of change (i.e., deletions were easier to detect than were rotations) and by the type of eye movement (e.g., toward or away from the target object). For example, they showed that detection rates were highest when an object about to be fixated was deleted from the scene. Similar demonstrations of change-detection failures or delays have been made utilizing motion pictures (e.g., Hochberg, 1986; Levin & Simons, 1997), and, perhaps most strikingly, in real-world situations (Simons & Levin, 1998). The importance of the change detection paradigm is that these studies demonstrate that the impression of a veridical representation of our visual environment is inaccurate. A clear representation is maintained only of those aspects of the scene that receive focal attention (cf. Mack & Rock, 2000).

The methodology that we employed to assess visual search skills for changes in naturalistic arrays is the flicker paradigm (Rensink et al., 1997). In this paradigm, two versions of a scene are constructed, and a single object is altered in one of the versions. The two versions then are presented briefly and alternately with an intervening blank field. The resulting impression produced by the presentation sequence is that the scene appears to be flickering. The insertion of the blank frame creates the flicker necessary to remove motion cues and other residual information from visual short-term memory, thus rendering detection more difficult. Without the brief interruption, detection of changes in the scenes would be nearly instantaneous. In the initial application of the flicker paradigm, Rensink et al. (1997) modified their pictures in three ways: presence/absence of an object, location of an object, or change in the color of an object. The changes occurred to objects either of central interest or marginal interest. Results indicated that the changes were more difficult to detect with the intervening blank field present and that detection times were longer for marginal-interest changes than for central-interest changes.

Several investigators have used eye-tracking methodologies to determine the nature of the differences observed across conditions in these flicker paradigm experiments. Zelinsky (2001) concluded that strategy use (e.g., purposefully attending to objects deemed most likely to change) was

critical for rapid detection of the changing object. However, Zelinsky also provided evidence that eye movements are directed by detection of extra-foveal information about the change. Thus, change detection is not entirely dependent on focal attention. Rather, some information regarding the location of the change does seem to be detected prior to directing focal attention to the target's position. Hollingworth, Schrock, and Henderson (2001) also presented evidence to support this point. They recorded times to fixate an object when it was and was not changing. Results indicated that objects were fixated more quickly when they were changing than when they were not changing. Thus, some information from peripheral vision must be directing attention to objects when they are changing. The outcomes of these two experiments utilizing eye-tracking technologies, therefore, converge on the conclusion that changes may be detected in the periphery of the visual field at a subthreshold level (see Hollingworth et al., 2001), but accurate identification of the change requires focal attention. These studies also demonstrate the usefulness of eye-tracking methodologies for separating the visual, memory, strategic, and decision components of the search process and begin to identify the roles that each of these processes plays in the rapid and successful detection of changes in naturalistic visual arrays.

Though the present experiment derives from work on basic visual search and change detection, the procedures utilized differ in important ways from each of these areas. With regard to our previous visual search work (Carlin et al., 1995, 2002), the present experiment does not have a clearly defined target stimulus (e.g., a blue circle). Rather, the participant is simply required to search for an object that is changing in a specific way (e.g., color). Only the nature of the change (e.g., color) is revealed. Further, the visual arrays in the present experiment are more complex, are larger, and are renderings of naturalistic scenes. These differences likely make the task much more difficult and more likely to be dependent on strategy use.

With regard to studies on change detection that utilized the flicker paradigm (e.g., Rensink et al., 1997), in the present experiment we use different temporal constraints. Because we are most interested in the allocation of attention during a systematic search for a target object, we have lengthened the durations of the scene frames and the blank frame. Thus, the memory demands of

our task are quite different than those of many of the earlier experiments using the flicker paradigm (e.g., Rensink et al., 1997). Those earlier researchers were interested in perceptual phenomena in populations of individuals without mental retardation and not in systematic visual search differences among individuals differing in intelligence. Functionally, these changes were designed to make our detection task more difficult so that rapid detections would be eliminated and comparisons between individuals with and without mental retardation would be more informative.

The types of changes that we employed were color, form, and presence (i.e., appearance/disappearance). These changes could occur either to objects in the area of central interest or to objects in other regions of the scene. Based on past research, we expected that color changes would be detected more rapidly than would form changes (Carlin et al., 1995) and that central-interest changes would be detected more rapidly than would marginal-interest changes (e.g., Rensink et al., 1997). With regard to intelligence-related differences, we were most interested in comparisons between identification times for marginal-interest targets. We assumed that both groups would identify central-interest targets more rapidly because that was where attention was likely to be directed initially. However, identification of marginal-interest changes was likely to be governed by strategic processes and/or low-level visual processes (Hollingworth et al., 2001; Zelinsky, 2001). Groups of individuals with mental retardation have been shown to have deficiencies in each of these types of processing (e.g., Borkowski, 1985; Bray et al., 1998; Carlin et al., 1995; Fox & Oross, 1992). Therefore, we expected that individuals with mental retardation would have elevated identification times for marginal-interest changes.

Method

Participants

Forty-nine individuals (28 with mental retardation and 21 without mental retardation) were recruited. The individuals with mental retardation attended day programs at Cardinal Cushing School and Training Center, Braintree St. Coletta's Day School, The Mercy Center, or the Protestant Guild Learning Center. Of the 28 subjects with mental retardation, only 21 completed the study. Of those who did not participate, 6 failed the preassessment task and 1 was dropped from

the study due to behavioral problems. These participants ranged in age from 142 to 248 months ($M = 201.29$, standard deviation [SD] = 34.59). The mean IQ of these individuals, calculated using the average standard score from the Peabody Picture Vocabulary Test (PPVT-III) and the Test of Nonverbal Intelligence (TONI-3) was 66.58 ($SD = 8.59$, range = 54 to 84). The individuals with mental retardation who did not participate were older ($M = 210.43$ months, $SD = 17.55$) than were the participants but had lower IQs ($M = 52.36$, $SD = 6.32$). The participants without mental retardation were 21 undergraduate students from Tufts University who ranged in age from 219 to 312 months ($M = 239.29$, $SD = 27.52$).

To provide supplemental data, we asked 3 individuals in each group to complete the experiment while wearing an eye-tracking apparatus. These 6 participants were run subsequent to the others. The 3 individuals with mental retardation had a mean age of 237.00 months ($SD = 3.61$) and a mean IQ of 71.33 ($SD = 4.73$). The 3 individuals without mental retardation were staff members from the center at which eye-tracking testing was performed. These individuals had a mean age of 289.33 months ($SD = 21.20$). Eye tracking was done with this subset of individuals to provide additional data regarding the potential bases of the effects observed in the original 36 participants. Change-detection latencies from all 42 participants are reported together because procedures were identical with the exception of the presence of the ISCAN headgear.

Stimuli

The 32 scenes that were used were gathered from home-decorating catalogues, travel magazines, and photographs. The pictures were scanned into Adobe Photoshop and edited using various tools in the program. In each scene, an object was altered in one of three ways: color, form, or presence versus absence. In the color condition, an object's color was changed from one frame to the next. For example, a jacket that was red in the first presentation would be green in the next. In the form condition, an object's shape was altered. In one scene, for example, the shape of a decorative wall hanging changed from star-shaped to diamond-shaped (see top half of Figure 1). Finally, for the presence condition, an object that was present in the initial scene was absent when the scene was presented the second



Figure 1. Examples of scenes and scene changes. The upper two pictures show two versions of a scene in which a form change (i.e., shape of wall hanging) occurred. The lower two scenes represent an example of a presence/absence change (i.e., lighthouse window).

time. For example, in the lighthouse scene in the bottom half of Figure 1, one of the windows on the lighthouse appears and disappears.

Location of the changed object also was manipulated. In half of the scenes, the change occurred to an object of central interest. As in previous research (e.g., Rensink et al., 1997), central interest objects did not necessarily occur in the physical center of the scene. Areas of central interest were determined initially by a group of seven raters. These individuals either were students at Tufts University or employees of the Shriver Center. Raters were shown a booklet containing all of the scenes to be used. A single scene appeared on each page. The raters were instructed to indicate the area in the scene that they believed was of primary interest. Scenes for which at least five of the raters did not agree were eliminated from the study. Marginal-interest changes were made to objects outside the designated area of central interest and were never made to objects that had been designated as of central interest by any of the raters. A second group of seven raters was shown each scene, and the object that was to be changed was identified for them. These raters

simply had to indicate whether the object was located centrally (i.e., "at or adjacent to the primary focus" of the scene) or marginally. Scenes for which there was not at least 80% agreement across raters were eliminated. Remaining scenes were used as experimental stimuli or for the preassessment task.

Salience of changes was matched as closely as possible across locations. For the color dimension, the matching involved making changes of the same magnitude (e.g., red to green) for pairs of central-interest and marginal-interest changes. For the form and presence dimensions, we matched as closely as possible for the total area (i.e., size and shape) that was changed. Across dimensions, however, matching was more problematic. Though all changes were highly salient when identified, we did not match precisely for salience of color, form, and presence changes. Thus, differences in detection times across dimensions should be interpreted with caution.

Apparatus

Two Macintosh Power PC computers with touch-screens were used to control stimulus presentations and to record participants' responses. The eye-tracking laboratory comprised an ISCAN head-mounted tracking system (ISCAN Corp.), a testing computer, and a second computer that ran the ISCAN Point-of-Regard Data Acquisition software (see Dube et al., 1999, for a more complete description of the apparatus, laboratory, and calibration procedures). The head-mounted recording system allowed us to record eye movements accurately without need for mechanical restraint. A real-time video recording of the participant's field of view with a superimposed cursor indicating the point of gaze was generated for each testing session. The video recording included time coding that allowed experimenters to code events frame-by-frame for analysis. Analyses were conducted using the OCS Tools software and a computer equipped to read time codes directly from videotapes.

Procedure

Each testing condition (color, form, presence) began with a preassessment block consisting of 4 trials. This was done to ensure that each person was able to understand and perform the task. Before beginning these trials, participants were informed of the nature of the change (e.g., color,

form, or presence) for that specific block of trials. The first two trials in each of the three preassessment blocks included arrays of seven geometric forms (e.g., stars, circles, triangles) that varied in color and form. In these trials one object was changed across the frames, and the individual was instructed to touch it and explain how it was changing. In the last two trials of each preassessment block, the individual was presented with two naturalistic scenes similar to those to be encountered in the experimental task. Once again, each individual was instructed to search for a changing object in the scene, identify it, and explain to the experimenter how it was changing. If the individual was able to identify all of the changing objects in the preassessment block, then they continued with the remainder of the study. Six individuals with mental retardation did not pass the preassessment block for at least one of the three dimensions. These individuals were not included in the experiment.

All participants were presented with the same set of 36 scenes. The scenes were divided into three blocks (i.e., color, form, and presence) of 12 trials. Each block included the 4 preassessment trials and 8 experimental trials. Each scene was presented in a flicker sequence that consisted of the original picture, a blank screen, the altered picture, and another blank screen. The scenes were displayed for 583 msec and the blank screen, for 200 msec. The sequence looped until the individual identified the object that was changing. Touching the changing object paused the flicker sequence as well as the timer. If participants correctly identified the changing object, then the experimenter advanced the program to the next trial. If the participant paused the program but did not correctly identify the changing object, then the experimenter restarted the flicker program and the timer, and the participant continued with the trial. This sequence lasted until the correct object was identified. Presentation order of the 12 scenes was held constant within each condition (e.g., color, form, presence) across participants, but condition order was counterbalanced across participants. Individuals without mental retardation were administered all three conditions on the same day, whereas individuals with mental retardation only received one condition per day. This was necessary due to testing constraints at the various sites.

Design and Analysis

A 2 (group: with mental retardation, without mental retardation) \times 3 (dimension: color, form,

presence/absence) \times 2 (location: central, peripheral) mixed factorial design was employed, with the latter two variables manipulated within-subjects. The dependent measure was time (in seconds) to detect the changing object in each scene. Due to the presence of positively skewed distributions of detection times, median detection times for each condition were utilized. The primary analysis was a $2 \times 3 \times 2$ factorial ANOVA, performed using the SPSS 10.0 statistical package. Tests with significant violations of the sphericity assumption utilized corrected degrees of freedom that were calculated using the Greenhouse-Geiser epsilon. Post hoc comparisons were conducted using the Student Neuman-Keuls method. The measures of effect size utilized were η , a measure of nonlinear correlation, and d , the number of SD s between means.

Results

Change Detection Times

Descriptive statistics are shown in Figure 2. The ANOVA indicated that there were significant main effects of Group, $F(1, 40) = 38.83, p < .001, \eta = .94$, Dimension, $F(1, 63) = 13.90, p < .001, \eta = .51$, and Location, $F(1, 40) = 37.84, p < .001, \eta = .70$. The group and location main effects supported the expectations that individuals with mental retardation would respond with greater latencies ($M = 24.23$ seconds, $SD = 9.33$) than individuals without mental retardation ($M = 10.98$ seconds, $SD = 2.78$) and that both groups would locate central-interest changes more rapidly ($M = 13.17$ seconds, $SD = 8.9$) than marginal-interest changes ($M = 22.05$ seconds, $SD = 12.50$). The dimension main effect indicated that detection times for color changes ($M = 11.30$ seconds, $SD = 11.14$) were significantly faster, $p < .01$, than detection times for form ($M = 19.30$ seconds, $SD = 10.35$) and presence ($M = 22.22$ seconds, $SD = 15.19$) changes. The difference between the detection times for the latter two dimensions was not statistically significant. This dimension main effect should be interpreted with caution, however, as discriminability of changes across dimensions was not controlled.

The Group \times Location, $F(1, 40) = 10.83, p = .002, \eta = .46$, and Dimension \times Location, $F(2, 77) = 5.46, p = .007, \eta = .35$, interactions also were statistically significant. The Group \times Location interaction is depicted in Figure 3. Post hoc analyses indicated that both groups demonstrated

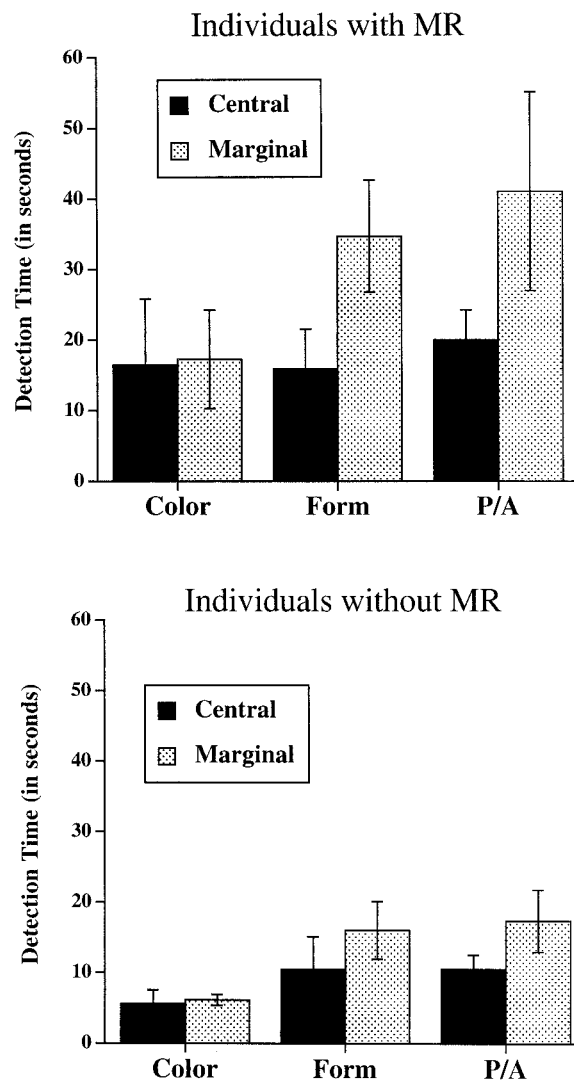


Figure 2. Mean change detection times with 95% confidence intervals by group (individuals with and without mental retardation), location (central, peripheral), and dimension (color, form, presence/absence).

significantly slower detection times for marginal-interest changes than for central-interest changes, $p < .05$, but the magnitude of this effect for individuals with mental retardation, 13.54 seconds, $d = 1.16$, was much greater than that for individuals without mental retardation, 4.26 seconds, $d = 0.69$. The Dimension \times Location interaction showed that there was no location effect for the color dimension (0.52 seconds), but there were significant location effects for the form (12.17 seconds) and presence (13.94 seconds) dimensions. The Group \times Dimension interaction, $F(1, 63) =$

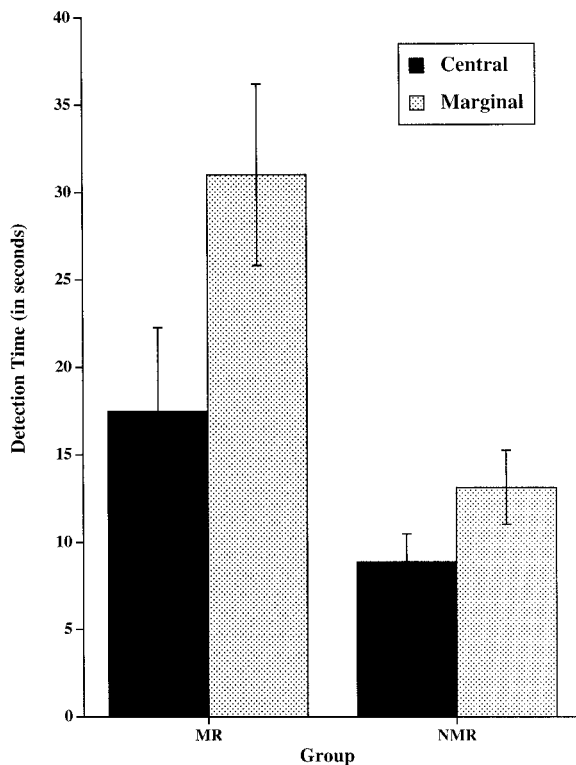


Figure 3. Depiction of the Group \times Location interaction. Error bars represent 95% confidence intervals.

1.05, $p = .342$, $\eta = .16$, and Group \times Dimension \times Location interaction, $F(2, 77) = 1.57$, $p = .216$, $\eta = .19$, were not statistically significant.

False Alarms

It was possible for participants to stop the flicker presentation and select an incorrect object. When such false alarms occurred, the program was re-started by the experimenter and the trial continued until a correct response was made. This ensured that participants identified all of the changes. However, it also allowed for potential strategic differences across groups. Analyses of false alarms indicated that the mean number of false alarms on each trial for the participants with mental retardation was 0.36 ($SD = 0.37$). Individ-

uals without mental retardation did not commit false alarms. Thus, all false alarms were committed by participants with mental retardation, but they were not so common as to raise concerns about differences in task understanding or speed-accuracy trade-off differences across groups.

For the individuals with mental retardation, false alarms did not vary for central- ($M = 0.26$, $SD = 1.07$) and marginal-interest ($M = 0.30$, $SD = 1.00$) changes. Mean numbers of false alarms also did not vary dramatically across the color ($M = 0.31$, $SD = 1.18$), form ($M = 0.40$, $SD = 1.23$), and presence ($M = 0.15$, $SD = 0.52$) dimensions.

Correlational Analyses

Because the groups differed to some degree in chronological age, we conducted supplemental correlational analyses to determine whether age had a significant effect on performance. First, for the individuals with mental retardation only, we assessed the correlations between age and IQ and the performance measures of mean central-change detection time, mean marginal-change detection time, and mean overall detection time. Results are shown in Table 1. These correlations indicate that age is not highly correlated with performance. We also assessed correlations between age and group and the same three performance measures (see Table 2). Finally, we assessed partial correlations between (a) group and the performance measures with age controlled and (b) age and the performance measures with group controlled. These partial correlations also are shown in Table 2. The correlations in Table 2 clearly demonstrate that group membership (i.e., level of intelligence) is much more highly correlated with change detection performance than is age.

Eye-Tracking Measures

These data provide important supplementary information for guiding future studies with the specific purpose of determining the bases of the intelligence-related performance differences observed in change-detection times. The participants

Table 1. Correlations Between Descriptive Variables and Performance Measures for Participants With Mental Retardation

Variable	Age	IQ	Central	Marginal	Overall
Age	—	+.236	-.113	+.140	+.022
IQ	—	—	+.014	-.307	-.181

Table 2. Correlations Between Group (i.e., Level of Intelligence) and Age and Detection Times for Central-Interest Changes, Marginal-Interest Changes, and Overall

Variable	Central	Marginal	Overall
Group	+.47*	+.73*	+.70*
Group _{Age} ^a	+.41*	+.71*	+.67*
Age	–.26	–.29	–.31*
Age _{Group} ^b	–.01	+.17	+.10

^aPartial correlations with age controlled. ^bPartial correlations with group controlled.

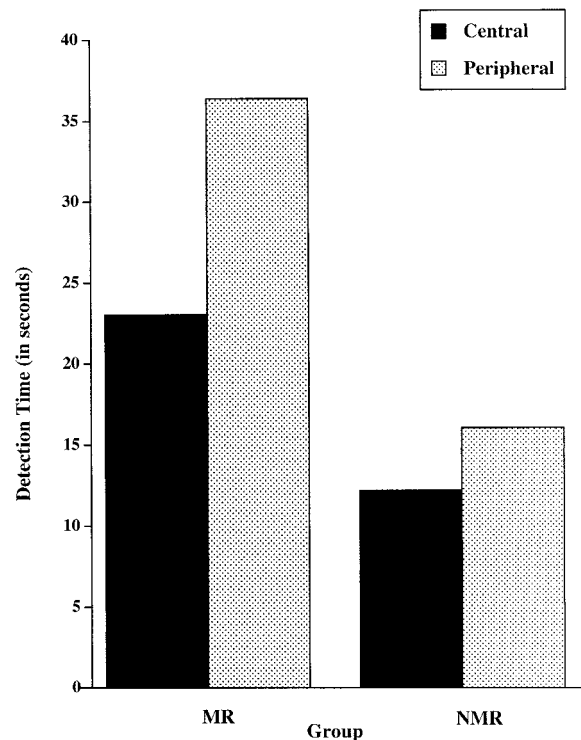
* $p < .05$.

in this part of the experiment were somewhat older than were the other participants, but, as discussed above, it does not appear that age affects performance on this task, particularly in the age ranges involved here. To determine whether the results of this subset of the participants were similar to the full sample, we assessed the general pattern of the results for these 6 individuals. Change-detection times by group and location are shown in Figure 4. When compared to the complete data set shown in Figure 3, it can be seen that these individuals showed the same general performance pattern as the complete sample.

We derived several measures to provide information about scanning strategies and patterns of the two groups of individuals. The first three measures reflect the participants' maintenance of gaze across frames.

Cross-blank gaze maintenance. For participants to detect a change, gaze must be maintained on the target object across the blank screen so that both versions of the object can be compared. Thus, differences in use of this strategy across groups or locations (i.e., central, marginal) would be expected to greatly influence target detection times, particularly in terms of the Group \times Location interaction. The number of *isolated target contacts* was defined as the number of times the target object was contacted by the cursor in one frame but not the subsequent frame. Thus, identification of the change would not be possible. *Contiguous target contacts* were instances in which the target was contacted by the cursor in successive frames. Finally, the percentage of opportunities to maintain gaze on the target across blank screens was calculated for each of the 6 participants.

The mean numbers of isolated target contacts

**Figure 4.** Depiction of the Group \times Location interaction for the eyetracking participants only.

for the individuals with ($M = 0.84$, $SD = 0.38$) and without ($M = 0.55$, $SD = 0.11$) mental retardation did not differ dramatically. In fact, these data indicate that fewer than one such event occurred on each trial for both groups. The numbers of contiguous target contacts for the individuals with ($M = 2.67$, $SD = 0.56$) and without ($M = 2.72$, $SD = 0.28$) mental retardation did not differ. The mean percentage of opportunities to maintain gaze on the target across blank screens for individuals without mental retardation was 82.99 ($SD = 4.26$), whereas the mean for individuals with mental retardation was 76.33 ($SD = 6.65$). Thus, significant group differences did not seem to emerge on these measures. Both groups appeared to maintain gaze across blanks a significant proportion of the time, thus increasing their chances of detecting the change once the target was fixated.

Decision time. The measure of decision time we employed was the number of frame alternations during which the target was fixated at the end of each trial. This measure was the same as the contiguous target contacts measure, but included only contiguous contacts at the end of a trial. The mean for individuals with mental retar-

dation was 2.25 ($SD = 0.42$). The mean for individuals without mental retardation was 1.81 ($SD = 0.14$). Thus, overall, 75% of the contiguous target contacts occurred at the end of a trial. Interestingly, the percentage of contiguous target contacts occurring at the end of a trial was greater for the individuals with mental retardation (84%) than for the comparison group (67%).

The general pattern that emerged from the gaze maintenance and decision-time eye-tracking measures was that individuals in both groups tended to maintain gaze across the blank field, thus increasing target detection probability, and they identified the target rapidly (approximately two alternations) once it was fixated. The target object was not viewed in isolation very often by the participants, and once the target was viewed, it required only about two alternations for the decision and manual response to be made.

Spatiotemporal measures. To assess spatial-scanning strategies, we computed the percentage of time that the participants maintained focus within particular areas of each picture. Percentage of time looking in each cell of a 4×4 grid was calculated for 6 of the 24 pictures. Because the location of the target varied across pictures, data are shown for individual pictures. Results for two of the scenes are shown, though the general pattern was consistent across all scenes assessed. The scenes shown are examples in which the targets were of marginal interest. We have focused on marginal-interest changes because these were the locus of the intelligence-related differences in the behavioral data.

For the street scene (see Figure 5), the top grids demonstrate percentages of time spent looking in each of the 16 cells during the first two frames of the trial. The area of central-interest in this picture included cells in the second column of the grid. As can be seen, this is the primary area of focus for *both* groups during the initial two frames. The participants spent the majority of the time looking in these cells, with many cells not being searched. The nine-frames grids demonstrate percentages of time spent looking in cells for the initial nine frames of the presentation. This was a span in which the individuals without mental retardation had identified the target (i.e., the car in the lower right corner). Thus, all individuals without mental retardation had already shifted attention from the area of central interest to the target in the periphery of the scene. Note that many cells were not sampled, and the shift



		Without Mental Retardation				With Mental Retardation			
2 FRAMES		0	0	0	0	0	0	0	0
		0	26.5	17.7	0	0	17.2	0	0
		0	20.6	2.9	0	0	27.6	0	0
		2.9	29.4	0	0	19.6	28.8	5.0	1.0
9 FRAMES		0	0	0	0	0.3	0.3	0	0
		0	6.9	5.3	0	3	11.8	8.4	0
		0	21.7	5.6	14	0	18.6	6.9	8.5
		5.8	21.5	4.4	14.8	7.6	26	1.9	6.9
TOTALS		0	0	0	0	0.1	3.2	0	0
		0	6.9	5.3	0	3.5	7.6	7.9	0.5
		0	21.7	5.6	14	6.5	8.6	3.2	6.3
		5.8	21.5	4.4	14.8	10.6	21.9	3.8	16.2

Figure 5. Grid analysis for the street scene. The target is the car in the lower right corner that was changing color across frames. Grids show percentages of looking time in each of the 16 cells after two frames, 9 frames (time within which participants without mental retardation had identified the target), and total. Numbers in bold type indicate percentages greater than 10.0, an arbitrary criterion used to highlight cells that received the most attention.

to the target region occurred relatively quickly (i.e., nine frames or less). This implies that selection of objects for inspection is not random, but likely is guided by strategies (e.g., selecting objects deemed likely to change) or basic perceptual processes (e.g., Zelinsky, 2001). In this same time span, the individuals with mental retardation continued to look primarily in the "central" region of the scene. They had not yet shifted attention to other areas of the scene, at least not to the extent of the individuals without mental retardation. The total looking times demonstrate that individuals without mental retardation restricted looking to fewer cells (i.e., 9 of 16) than did the individuals with mental retardation (13 of 16). This may be representative of different strategies for performing the task and/or a better use of non-

focal vision for selecting objects to inspect by individuals without mental retardation.

For the kitchen scene (see Figure 6), a similar pattern emerged. Both groups initially focused in the region of central interest (i.e., the middle quarter of the grid). By Frame 9, 2 of the 3 individuals without mental retardation had already identified the target (i.e., a towel in the lower left corner). The individuals with mental retardation, on the other hand, still maintained gaze in the central-interest region for the majority of the time. Total looking times again showed that individuals without mental retardation sampled fewer cells (13 of 16) than did individuals with mental retardation (16 of 16). There also was a striking difference between groups in the time spent in the right half of the scene. Individuals without mental retardation spent about 10% of their time in the right half, whereas participants with mental retardation

spent approximately 45% of their time in that region of the scene. These observations likely are indicative of differences in strategy use or basic visual processing across groups. Specifying the nature of these differences will require further research employing eye-tracking measures and larger samples of participants.

These examples demonstrate differential patterns of visual search across groups. Individuals with mental retardation appear to maintain fixation in a more restricted area of the scene for a prolonged period of time. It also appears that individuals without mental retardation shift attention from the central-interest region to other areas of the scene more quickly and, therefore, identify the marginal-interest changes more efficiently. The latter observation is based on the fact that marginal changes were detected more quickly, shifting of attention to the target occurred more rapidly, and attention to noncritical regions of the scenes was more limited (i.e., fewer of the cells were scanned) by individuals without mental retardation.

Discussion

As expected, the individuals with mental retardation responded more slowly to the stimuli than did the participants without mental retardation. Independent of this effect, however, the general pattern of results was similar for each group. Both groups demonstrated more rapid change detection times for color targets than for form or presence targets, and there was a significant marginal-interest change decrement for the form and presence dimensions. No significant marginal-interest decrement was evident for the color dimension for either group of participants. These results are consistent with previous studies using the flicker paradigm (e.g., Rensink et al., 1997) and with visual-search work comparing individuals with and without mental retardation (Carlin et al., 1995). Carlin et al. showed that search times for individuals with mental retardation were longer than were those for individuals without mental retardation, and detection times for color-based targets were more rapid than detection times for form-based targets. Thus, there are similarities between results from basic visual-search studies that employ arrays of discrete forms varying in color, shape, or size, and the present change-detection study using naturalistic visual arrays. We note, however, that these dimension-based differences



		Without Mental Retardation				With Mental Retardation			
2 FRAMES		0	6.1	0	0	0	0	0	0
		0	37	8.2	3	0	11.3	26	0
		0	18.5	19.1	8.2	9.5	41.9	2.9	0
		0	0	0	0	0	8.4	0	0
9 FRAMES		2.9	8.3	0	0	4.5	4.1	0	0
		15	16.6	1.8	0.7	3.9	16.7	24.4	3.3
		9.8	8.1	4.2	1.8	17.1	16.3	4.1	3.7
		24.6	4.7	1.5	0	0	2	0	0
TOTALS		2.4	6.9	0	0	2.1	4.2	0.6	1.8
		12.5	16.5	1.5	0.6	3.0	11.5	11.6	2.2
		11.6	7.5	3.5	1.5	12.0	10.4	4.9	9.0
		29.9	4.3	1.3	0	10.4	3.4	4.8	7.9

Figure 6. Percentages of looking time spent in each of the 16 cells of the kitchen scene after 2 frames, 9 frames, and total. Numbers in bold type indicate percentages greater than 10.0, an arbitrary criterion used to highlight cells that received the most attention.

may be dependent, at least in part, on differences in salience of changes across dimensions.

Though the similarity of findings across these methodologies and stimulus types supports the argument that findings from basic visual search tasks generalize to more naturalistic contexts, use of the naturalistic arrays did result in the emergence of a novel finding. The significant Group \times Location interaction indicated that individuals with mental retardation were particularly slow in identifying marginal-interest changes. Both groups detected marginal changes more slowly than they did changes in areas of central interest, but the decrement was three times larger for individuals with mental retardation (13.54 seconds) than for individuals without mental retardation (4.26 seconds).

The inclusion of 6 individuals who performed the task with eye-tracking technology allowed for some insight into the likely nature of this group difference. Decision time did not seem to be a likely locus for group differences because both groups responded rapidly (i.e., approximately two alternations of the scene) once attention was directed to the target. We expected that individuals with mental retardation would require more alternations to make a decision; however, the data did not support this hypothesis.

Eye-tracking data also were used to assess potential search-strategy differences across groups. One important strategy for detecting changes efficiently was to maintain focus on an object through the blank period. The changes could only be detected reliably if both versions of the critical object were viewed successively. Failure to systematically maintain gaze would increase detection time or, in the extreme case, prevent detection from occurring.

Our analyses of cross-blank gaze maintenance indicated that slight group differences may have been present, but not of sufficient magnitude to explain a significant portion of the variability in peripheral-target detection times. Therefore, we limited our analyses to target-object gaze maintenance only, assuming the effect would generalize to nontargets as well; there would be no basis for differentiating targets from nontargets until the gaze had been maintained through the blank period. Overall, individuals with mental retardation demonstrated the gaze-maintenance strategy on 76% of opportunities and participants without mental retardation did so 83% of the time. Thus, slight group differences may have been evident

with more focused and powerful tests of this effect, but this difference did not seem to be large enough to explain the Group \times Location interaction.

The analyses of spatial allocation of attention across time demonstrated significant differences between the groups with and without mental retardation. Though specific locations of targets and areas of central interest varied across trials, a general pattern emerged. As shown in the examples in Figures 5 and 6, both groups initially directed attention to the area designated as the area of central interest. This finding supported the ratings from the pilot subjects and served as a manipulation check for location (central vs. peripheral). The most obvious group difference that emerged from these analyses was that individuals without mental retardation shifted attention to marginal-interest areas more quickly than did participants with mental retardation. For the examples shown, the individuals with mental retardation were still focused primarily in the area of central interest in the scene, while those without mental retardation had shifted attention to the periphery and identified the target. This difference in time to shift attention from the point of central interest to the periphery of the scene was the most dramatic difference between groups in this experiment and the type of difference that may explain a large portion of the Group \times Location variance.

There are several potential explanations for the Group \times Location interaction observed in this experiment. One explanation would be that individuals with mental retardation require more time to make a decision about whether an object is or is not changing. The decision time data indicate that group differences in deciding whether an object is changing are not dramatic. However, differences in deciding that an object is *not* changing may vary across groups differing in intelligence. This aspect of visual search performance has not been studied as extensively as target detection (i.e., positive responding). Given the complexity of the scenes in the current experiment, doing this type of analysis would be quite problematic. The varied nature of the objects in the scene in terms of basic attributes such as size and shape, and other complicating factors (e.g., occlusion), makes such an analysis difficult. We are planning future research using more controlled stimuli and simple search arrays (e.g., discrete forms) to assess both target detection time and distractor rejection time. Such research should be

informative in the context of both basic visual search and scene analysis.

Another possible explanation for the Group \times Location interaction is that individuals with mental retardation sample more stimuli in a given region of the scene than do individuals without mental retardation (cf. Stoffregen, Baldwin, & Flynn, 1993). Individuals with mental retardation may focus on parts of objects rather than whole objects, or may attend to all objects in a region rather than objects deemed likely to change. Such differences in object selection would affect overall detection times for peripheral changes and may not increase efficiency of detection of centrally located objects.

Finally, a perceptual explanation for the Group \times Location interaction is that individuals with mental retardation may not be as sensitive to extra-foveal visual cues (e.g., Zelinsky, 2001) as are individuals without mental retardation. As discussed in the introduction to this paper, several recent studies (Hollingworth et al., 2001; Zelinsky, 2001) have shown that direction of attention to the changing object in a flicker sequence occurs more rapidly than would be expected by chance. Thus, some visual cue(s) must be directing attention to the critical area of change, or some cue(s) related to the change must be “capturing” (cf. Yantis, 1996) attention. If differences in sensitivity to such cueing exist across groups differing in intelligence, then significant differences in overall change detection times would be expected, and the larger group differences for peripheral changes would be expected. This is the pattern demonstrated by the present data.

Consistent with earlier studies of visual search performances of individuals with and without mental retardation (e.g., Carlin et al., 1995, 2002), the present data demonstrate substantial similarities and differences between groups of individuals with and without mental retardation. The general patterns of change detection times for the groups with and without mental retardation are similar. Both groups detected color changes more rapidly than form or presence/absence changes, and changes in areas of central interest were detected more quickly than changes in areas of marginal interest. Also, eye-tracking data indicated that members of the groups performed similarly in terms of number of target contacts, decision time, and use of the cross-blank gaze-maintenance strategy. The significant group difference that emerged was that individuals with mental retardation were

particularly slow to detect marginal-interest changes. The magnitude of the effect and the fact that it was evident using naturalistic stimuli argue for its importance for understanding selective visual attention in individuals with mental retardation. Future research should be directed toward identifying the basis of the effect and its potential for remediation.

References

- Atkin, A., Bala, S., Herman, P., & Rogowitz, B. (1981). Organicity and mental retardation: Analysis of eye and head movements. *American Journal of Mental Deficiency, 25*, 17–24.
- Berkson, G. (1966). Eye fixation responses of profoundly defective children. *American Journal of Mental Deficiency, 71*, 492–500.
- Borkowski, J. G. (1985). Signs of intelligence: Strategy generalization and metacognition. In S. R. Yussen (Ed.), *The growth of reflection in children* (pp. 105–144). New York: Academic Press.
- Bray, N. W., Reilly, K. D., Fletcher, K. L., Huffman, L. F., Grupe, L. A., Villa, M. F., & Anumolu, V. (1998). Memory competencies and deficiencies: A conceptual framework and the potential of connectionist models. In S. A. Soraci & W. J. McIlvane (Eds.), *Perspectives on fundamental processes in intellectual functioning* (Vol. 1, pp. 3–44). Greenwich, CT: Ablex/JAI Press.
- Carlin, M. T., Soraci, S. A., Dennis, N. A., Strawbridge, C., & Chechile, N. A. (2002). Guided visual search in individuals with mental retardation. *American Journal on Mental Retardation, 107*, 237–251.
- Carlin, M. T., Soraci, S. A., Goldman, A. L., & McIlvane, W. (1995). Visual search in unidimensional arrays: A comparison between subjects with and without mental retardation. *Intelligence, 21*, 175–196.
- Dube, W. V., Lombard, K. M., Farren, K. M., Flusser, D. S., Balsamo, L. M., & Fowler, T. R. (1999). Eye tracking assessment of overselectivity in individuals with mental retardation. *Experimental Analysis of Human Behavior Bulletin, 17*, 8–14.
- Fox, R., & Oross, S. O., III (1992). Perceptual deficits in mildly mentally retarded adults. In N. W. Bray (Ed.), *International review of research in mental retardation* (Vol. 18, pp. 1–27). New York: Academic Press.

- Grimes, J. (1996). On the failure to detect changes in scenes across saccades. In K. Akins (Ed.), *Vancouver studies in cognitive science: Vol. 5. Perception* (pp. 89-109). New York: Oxford University Press.
- Henderson, J. (1997). Transsaccadic memory and integration during real-world object perception. *Psychological Science*, 8, 51-55.
- Henderson, J. M., & Hollingworth, A. (1999). The role of fixation position in detecting scene changes across saccades. *Psychological Science*, 10, 438-443.
- Hochberg, J. (1986). Representation of motion and space in video and cinematic displays. In K. R. Boff, L. Kaufman, & J. P. Thomas (Eds.), *Handbook of perception and human performance: Vol. 1: Sensory processes and perception* (pp. 22.21-22.64). New York: Wiley.
- Hollingworth, A., Schrock, G., & Henderson, J. M. (2001). Change detection in the flicker paradigm: The role of fixation position within the scene. *Memory & Cognition*, 29, 296-304.
- Levin, D. M., & Simons, D. (1997). Failure to detect changes to attended objects in motion pictures. *Psychonomic Bulletin and Review*, 4, 501-506.
- Mack, A., & Rock, I. (2000). *Inattention blindness*. Cambridge: MIT Press.
- Rensink, R. A., O'Regan, J. K., & Clarke, J. J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8, 368-373.
- Simons, D., & Levin, D. (1998). Failure to detect changes to people during real-world interaction. *Psychonomic Bulletin & Review*, 5, 644-649.
- Soraci, S. A., Carlin, M. T., & Wiltse, L. J. (1998). Facilitating visual attention. In S. Soraci & W. J. McIlvane (Eds.), *Perspectives on fundamental processes in intellectual functioning: A survey of research approaches* (pp. 45-65). Stamford, CT: Ablex.
- Spitz, H. H. (1969). Effects of stimulus information reduction on search time of retarded adolescents and normal children. *Journal of Experimental Psychology*, 82, 482-487.
- Stoffregen, T. A., Baldwin, C. A., & Flynn, S. B. (1993). Noticing of unexpected events by adults with and without mental retardation. *American Journal on Mental Retardation*, 98, 273-284.
- Winters, J. J., Gerjuoy, I. R., Crown, P., & Gorrell, R. (1967). Eye movements and verbal reports in tachistoscopic recognition by normals and retardates. *Child Development*, 38, 1193-1199.
- Yantis, S. (1996). Attentional capture in vision. In A. F. Kramer, M. G. H. Coles, & G. D. Logan (Eds.), *Converging operations in the study of visual selective attention* (pp. 45-76). Washington, DC: American Psychological Association.
- Zelinsky, G. J. (2001). Eye movements during change detection: Implications for search constraints, memory limitations, and scanning strategies. *Perception & Psychophysics*, 63(2), 209-225.

Received 6/17/02, accepted 11/11/02.

Editor-in-charge: Frances Connors

This publication was made possible by Grant HD25995 awarded to the Shriver Center of the University of Massachusetts Medical School by the National Institute of Child Health and Human Development (NICHD). The contents are solely the responsibility of the authors and do not necessarily represent the official views of the NICHD. Requests for reprints should be sent to Michael Carlin, Psychological Sciences Division, E. K. Shriver Center, University of Massachusetts Medical School, 200 Trapelo Rd., Waltham, MA 02452. E-mail: michael.carlin@umassmed.edu.