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REPORT

The development of change detection

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Abstract

Changes to a scene often go unnoticed if the objects of the change are unattended, making change detection an index of where attention is focused during scene perception. We measured change detection in school-age children and young adults by repeatedly alternating two versions of an image. To provide an age-fair assessment we used a bimanual choice rather than open-ended verbal responses. The difference in detection speed and accuracy between 50 ms versus 250 ms blank screens between views indexed change detection in short-term visual memory independent of sensory and response processes. Younger children were significantly less efficient than older participants, especially when an object changed color or had a part deleted. Changes in object orientation were detected more readily. These results point to important differences in the perceptual reality of younger and older children.

Introduction

The development of attention during the first dozen years of life is thought to influence the way that objects and events are perceived (Brodeur, Trick & Enns, 1997; Burack, Enns, Iarocci & Randolph, 2000; Plude, Enns & Brodeur, 1994). Young children most probably experience the world in a different way from adults, although it has historically been difficult to document the perceptual reality or experience of any observer (Broadbent, 1958; James, 1890; O'Regan, 1992; Stroud, 1967).

In a recent review, Enns and Trick (2006) proposed a two-dimensional framework for studying individual differences in visual attention, especially those involving age-related changes. By combining the dimension of processing *control* (often referred to as 'automatic' or unconscious versus 'controlled' or conscious processing; Shiffrin & Schneider, 1977) with the dimension of processing *origin* (innate processes versus those acquired through experience, Posner, 1980), they identified four basic modes of visual selection. These included reflexive (automatic, innate), habitual (automatic, learned), explorative (controlled, innate), and deliberative modes of selectivity (controlled, learned). Enns and Trick noted a conspicuous lack of research on the way that the explorative mode of attention changed during childhood, despite the considerable developmental research on three of the four modes of attention (reflexes, habits, and deliberation). This is somewhat surprising because a basic tenet of developmental psychology is that humans, as 'infovores', constantly explore new environments and incorporate the new knowledge they gain from them. Yet, lab research is typically focused only on more highly circumscribed, deliberative tasks, in the study of the conscious or controlled aspects of attention.

The *change detection task* is a recently developed tool to better understand explorative attention (for reviews see Rensink, 2002; Simons & Rensink, 2005). In this task, two versions of the same scene are presented in rapid succession and the participant's task is to identify any differences between the two scenes. When no blank interval is presented between scenes, or when the interval is shorter than approximately 80 ms, detection of differences in a scene is effortless and automatic because the change creates a spatially local flicker or motion signal that is registered by the sensory system as a salient

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luminance transient (Phillips, 1974; Rensink, 2002). However, when the blank interval between scenes exceeds the temporal limits of visible persistence (also called iconic imagery) then the change is no longer available to the sensory system. Instead, the presentation of a new scene after 80 ms or more produces luminance transients everywhere in the display and change can, therefore, only be detected if the current object or feature at a given location is noticeably different from the representation of the scene already in short-term visual memory (Levin & Simons, 1997; Rensink, O'Regan & Clark, 1997; Shore & Klein, 2000). In this way, the change detection task is an index of the short-term memory of scenes, provided that the duration of the interval exceeds the limits of visible persistence or iconic imagery.

Attention contributes to successful change detection in several critical ways. One, accuracy in change detection is more likely for objects of central than of marginal interest in the scene (Rensink *et al.*, 1997; Shore & Klein, 2000). Two, when changes in objects and features are expected (Austen & Enns, 2003), or when attention is drawn reflexively to the location of change (Scholl, 2000), then change detection accuracy is substantially improved over changes that occur to unexpected objects or locations away from the focus of attention. Three, change detection accuracy decreases as the number of items in the display is increased, pointing to the limited capacity of short-term memory for scenes (Rensink, 2002; Smilek, Eastwood & Merikle, 2000; Richards, Jolicoeur & Stolz, submitted). Thus, change detection is a reliable index of where and to which objects and features attention is directed in the short-term memory representations of a visual scene.

Flickering two versions of a scene interleaved with a blank interval is not the only way to study change detection in visual short-term memory. Rather, the recent surge in research on this topic began with reports that observers did not notice changes made during an eye movement while inspecting a photograph. For example, two gentlemen wearing hats in one scene might have their hats switched in the altered version. Although a change such as this was readily detected it when occurred during a fixation, it was missed on a majority of trials when it occurred during an eye movement from one region of the scene to another (Grimes, 1996; McConkie & Currie, 1996). Other reports followed, indicating that similar results could be obtained if the changes occurred during a 'cut' in a videotaped sequence of real-world actions (Levin & Simons, 1997; Simons, 1996), during the unexpected presentation of small 'mudsplashes' added to the picture while it was being viewed (O'Regan, Rensink & Clark, 1999), and even if the changes occur during a real-world conversation between an unwitting participant and an actor. In the latter case, the actor exchanged places with another actor when a door that was being carried by two actors came between the participant and the initial actor (Simons & Levin, 1997). Finally, even large changes to a scene can go unnoticed without any accompanying scene interruptions (Simons, Franconeri & Reimer, 2000). Again, the critical ingredient is that observers must not be attending to the objects or regions of the scene that are undergoing gradual change while the scene is viewed.

In the present study, we used a modified form of the flicker method to examine age-related differences in explorative attention among children and adults (Rensink, 2002; Simons & Levin, 1997). First, as shown in Figure 1, a changing and an unchanging set of alternating images were presented side by side on the same screen so that the participants merely had to indicate the side of the screen in which a change occurred. The use of a forced-choice procedure rather than the typical open-ended verbal response minimized the potential for the results to be influenced by developmental differences in linguistic ability or in the response criteria used to indicate the detection of a change.

The second innovation was a direct comparison of performance between two conditions that differed only in the blank screen durations between views of the two scenes. A 50-ms blank condition was intended to permit sensory cues such as local motion and local flicker to signal the change. Thus, an accurate detection of change in this condition required that (1) a spatially local transient be detected by the sensory system, followed by (2) correct response selection (localizing the transient to the left or right side of the display) and then (3) correct response execution (pressing the spatially corresponding response key). In contrast, accurate change detection in a 250-ms blank condition could only be accomplished if the participants compared one scene with the other in short-term memory since 250 ms is longer than the duration of visible persistence (iconic imagery). When such a comparison was successful, the detected change could be indicated by selecting the correct response and executing it (processes 2 and 3 above).

Performance differences between the 50-ms and the 250-ms conditions could, therefore, be linked uniquely to the ability to detect change between a visual short-term memory of a scene and a scene presently on view. This interpretation is based on the assumptions that the task demands of response selection and response execution (processes 2 and 3) do not differ between these two conditions and that the detection of a spatially localized motion or flicker transient is not itself an error-prone process in school-age children. The latter assumption is consistent with considerable evidence that spatial attention is oriented

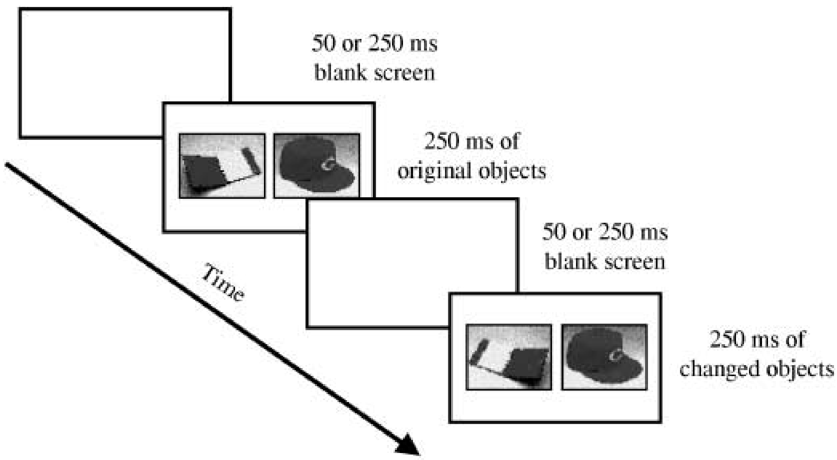

Figure 1 *The sequence of events on a single trial. Two images were shown, one on either side of fixation, for 250 ms, followed by a blank interval for either 50 ms or 250 ms. This was followed by an unchanged image on one side and a changed image on the other side. Changes could occur through a color change, part deletion, or change in object orientation and participants responded to indicate the side containing the change.*

reflexively and reliably to the location of unique luminance transients in observers of all ages (for a review, see Plude *et al.*, 1994). However, even if some of these assumptions are incorrect, and younger children are less able than older children to detect and respond to a local luminance transient in the 50-ms condition, then our proposed subtractive comparison will be conservative, as it will overestimate the 'true' ability of young observers to detect scene changes using visual short-term memory. This will work *against* our effort to document that younger children have a reduced ability in this regard.

Two different types of image were used in order to allow for the assessment of the generality of the findings. Half of the images were photographs of common objects and toys (see Figure 2); and the other half were colored line drawings of concrete objects (e.g. a truck, a baseball, a bat, a bicycle, etc.). Pilot testing with adult participants was used to help select images and object changes that were generally matched for task difficulty across these two types of images.

Another factor relevant to the presentation of these images was whether the change involved a switch in color, the disappearance and reappearance of an object part, or a change in orientation of one of the objects in the scene. The comparisons across these types of changes must be interpreted with caution, both in this and in previous studies (e.g. Rensink *et al.*, 1997), because baseline salience to observers has not been equated. Nonetheless, any differences that are identified may inform future research about the links and differences in the nature of scene memory between children and adults. For example, children and adults may be similar in their representation at the object level, but children may retain less detail at the level of specific features (e.g. colors) and parts.

The change detection task was administered to three groups of children with average ages of 6, 8, 10 years, and one group of young adults. The children's ages were selected both to study performance in an age range in which deliberative attention changes are noted and to ensure that the task that was understood by all participants. The dependent measures were correct response time (RT) and percentage errors.

Method

Participants

Eighty-five participants were recruited from a private elementary school in the Montreal area. Six of these participants were removed from the analyses because the average error rate for each was greater than 10%. This left 79 participants in four age groups, including 16 (six males) 5–7-year-olds ($M = 6.68$, SD = 0.93), 21 (10 males) 7–9-year-olds ($M = 8.55$, SD = 0.70), 22 (12 males) 9–12-year-olds ($M = 10.82$, SD = 0.93), and 20 adult (10 males) undergraduate and graduate students between 18 and 30 years of age ($M = 26.90$, SD = 2.34).

Stimuli

Each image measured 11.3° by 8.0° of visual angle. Displays were presented with VScope 1.2.7 software

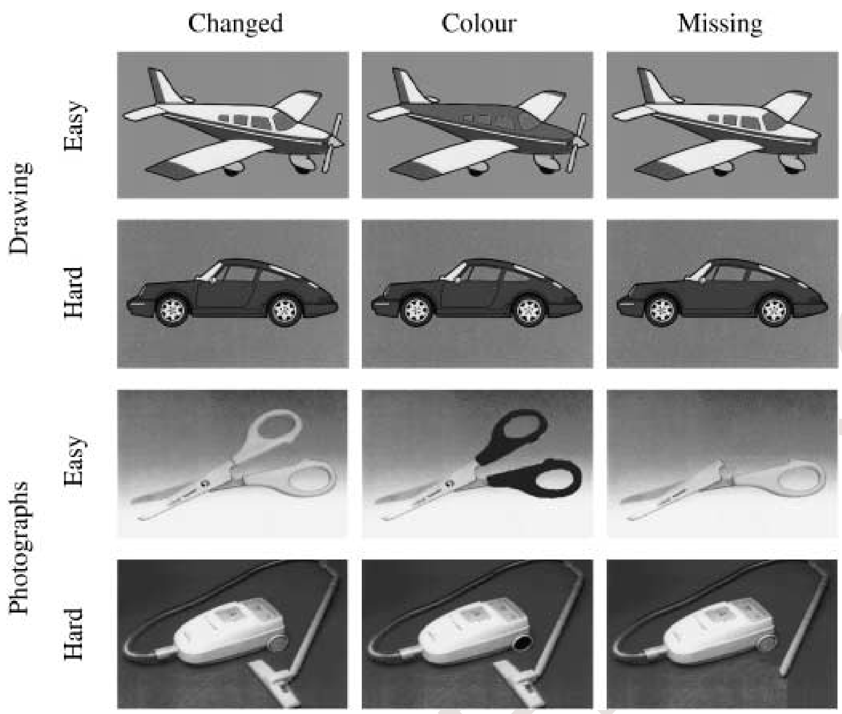

Figure 2 *Examples of display images, showing the original (changed) and two of the altered versions (color change, part deletion). The rotation condition is not shown because it is simply a mirror reversal of the original. The labels of Easy and Hard are given only for illustration purposes. Easy images shown resulted in the smallest mean correct RT for each media type (drawing, photograph); hard images shown resulted in the largest mean correct RT. Images scanned from Photo Language, manufactured by Nathan.*

(Rensink & Enns, 1992) on a 333 MHz Macintosh PowerBook G3 with a 14.1″ active LCD screen (approximately 30° of visual angle horizontally and 23.7° of visual angle vertically) at an approximate viewing distance of 50 cm. The '?' key and the 'Z' key were used for participant responses and were covered with colored stickers to facilitate learning. The images were adapted from a set of educational cards that were designed for individuals with language disorders (Photo Language, manufactured by Nathan). Each card contained a color image of an inanimate object. The images were scanned with an HP DeskJet scanner and were then modified with Adobe PhotoShop software. The main difference between the drawings and photos was the level of realistic detail and method of construction. Drawings had spot colors of constant gradient for each feature whereas the photos had realistic color gradients and naturalistic hues. The photos also appeared to have greater depth and realism than the drawings that were more akin to cartoons or picture book images.

Procedure

A total of 24 images of inanimate objects were selected (12 photographs and 12 drawings) and subjected to three different types of change: color, part deletion, and object orientation, resulting in a total of 96 different images. Images were displayed for 250 ms and separated by blank intervals of either 50 ms or 250 ms. The factors of image type (photo, drawing) and blank interval (50 ms, 250 ms) were varied across testing blocks whereas the type of change (color, part deletion, object orientation) was varied within a block of trials. Each participant was therefore tested in four blocks of 36 trials for a total of 144 unique trials. The testing session took approximately 25 minutes.

Each trial consisted of the repetition of four display screens, including the presentation of the side-by-side images for 250 ms, a blank interval of either 50 ms or 250 ms, the presentation of the images again (with an alteration randomly on the left or the right) for 250 ms, and then another blank interval of either 50 ms or 250 ms. This sequence was repeated until the participant responded or until 4 seconds elapsed. Responses were scored as errors if the unaltered side of the screen was selected or if 4 seconds elapsed without a response. Prior to testing, six practice trials were administered to the participants to assure comprehension of the task. If more than two errors were made, the practice trials were repeated.

Measurement issues

One complication in using RT to measure change detection is that a larger number of display alterations are presented within a fixed period of viewing time in the 50-ms condition than in the 250-ms condition. Since this makes more image comparisons possible in the 50-ms condition, at least in principle, some researchers have proposed using as the dependent variable the mean number of alternations required for successful change detection (Rensink, O'Regan & Clark, 2000). However, this measure introduces other potential confounds in a developmental study. For example, younger children invariably take longer to respond because of differences in sensory and response factors, which would artificially inflate the number of alternations counted for them, even if their perceptual processes were at adult levels. Thus, their change detection ability would be overestimated.

We approach this problem as follows. One, we do not make any claims about the absolute time required to detect change, as all comparisons between groups and stimuli are based on relative differences. Thus, if the RT measure is biased in favor of younger children in the 50-ms condition (because their generally slower RT gives them more 'looks'), the actual difference between the 50 ms and 250 ms conditions will be underestimated for them. In this way, our comparisons between age groups are *conservative*, since any reported differences would be even larger if we used the number of display alternations required for successful change detection. Two, each of our analyses of correct RT was mirrored by the same pattern in the analyses of proportion errors.

Results

The analyses of percentage errors (Figure 3) and correct RT (Figure 4) revealed a consistent and graded improvement in change detection with age over the four groups of participants. This is seen most clearly in the composite change detection index based on the differences between the 50-ms and 250-ms blank interval conditions (Figure 5).

Correct RT was submitted to a non-recursive outlier rejection procedure that based the long and short RT cut-off on the number of observations in the cell (Van Selst & Jolicoeur, 1994). This resulted in the removal of 307 observations (2.5% of all correct responses). The remaining RT and percentage error data were submitted separately to a four-factor mixed-design ANOVA with the between-subjects factor of age (6, 8, 10, 26 years) and the repeated measures factors of time (50 ms, 250 ms), image (photographs, drawings) and change

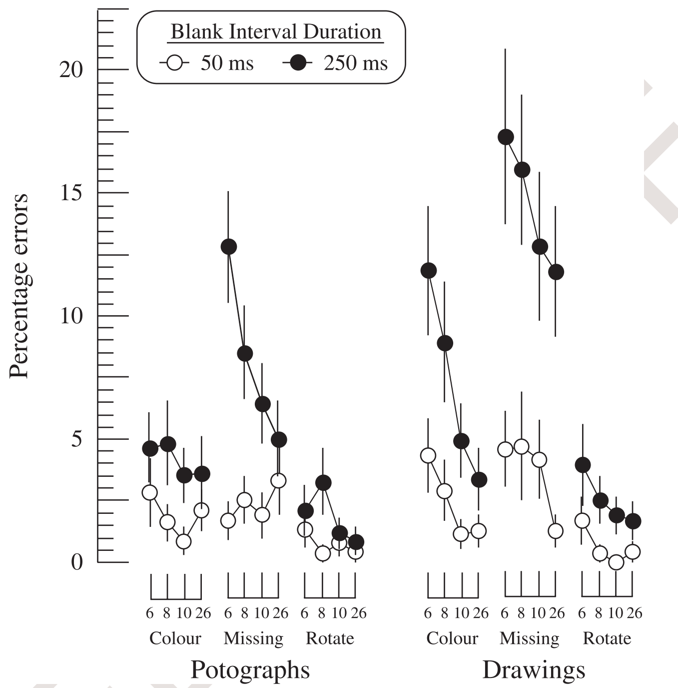

Figure 3 *Mean percentage errors for all ages (6, 8, 10, and 26 years), materials (photographs and drawings), and change types (color, missing, rotate) used in the experiment. Error bars represent the between-participants standard error of the mean.*

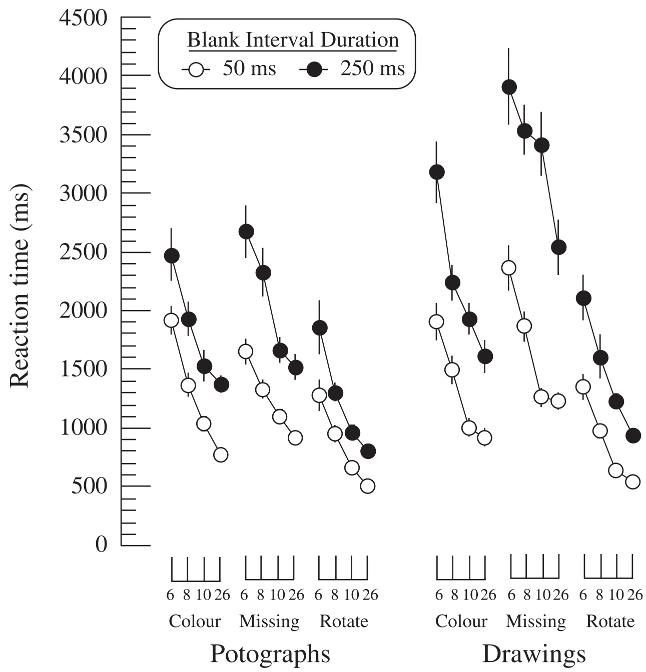

Figure 4 *Mean correct response time (RT) for all ages (6, 8, 10, and 26 years), materials (photographs and drawings), and change types (color, missing, rotate) used in the experiment. Error bars represent the between-participants standard error of the mean.*

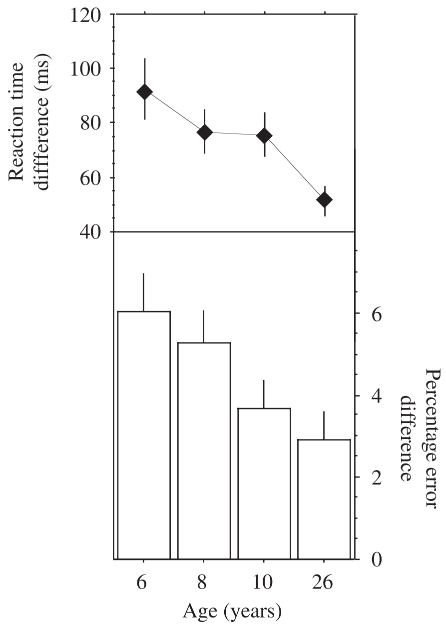

Figure 5 *Age-related improvements in change detection as measured in both RT and errors. Scores are the differences between the 50-ms and the 250-ms interval conditions, in order to index change detection independently from age changes in sensory, decision, and motor response processes. Error bars represent the between-participants standard error of the mean.*

(color, part deletion, object orientation). All p values were less than .001 unless otherwise noted.

The participants were generally faster and more accurate in responding in the 50-ms blank interval condition than in the 250-ms condition [$F(1, 81) = 111.74$ for errors; $F(1, 81) = 250.32$ for RT], replicating previous findings indicating that change detection based on sensory signals (motion and flicker) is more efficient than change detection based on short-term memory (Rensink, 2002). The size of this difference also decreased with increasing age of the participants [$F(3, 81) = 2.78$ for errors; $F(3, 81) = 3.09$ for RT; $p < .05$ for both], such that change detection was more efficient for older participants.

Detecting change was generally more difficult for all ages viewing drawings rather than photos [$F(1, 81) = 19.00$ for errors; $F(1, 81) = 143.52$ for RT]. In addition, the difference between the two blank interval conditions was larger for drawings than for photos [$F(1,81) = 11.94$ for errors; $F(1, 81) = 20.67$ for RT], consistent with generally less efficient change detection for the more difficult pictorial discriminations. The interaction of Image Type × Interval × Age group was not significant [$F(3, 81) < 1.0$ for both errors and RT].

Change detection was most difficult for deleted parts, followed by changes in color and then changes in object orientation [$F(1, 81) = 54.92$ for errors; $F(1, 81) = 195.65$ for RT] and these differences interacted with interval [$F(2, 162) = 33.98$ for errors; $F(2, 162) = 51.76$ for RT]. Specifically, the longer blank duration exaggerated the differences in detecting changes of different kinds. This two-way interaction was further modulated by the factor of age, but only for RT [$F(6, 162) = 2.34$, $p = .034$; $F(6, 162) = 1.07$, *ns* for errors]. Based on a simple effects analysis, this three-way interaction resulted from an age-related effect for part deletion [$F(3, 81) = 3.12$; $p = .028$] and color changes [$F(3, 81) = 2.84$; $p = .043$], but only a marginal effect of age for object orientation [$F(3, 81) = 2.46$; $p = .069$].

The pattern of change detection for the three change types also interacted with image type [$F(2, 162) = 8.48$ for errors; $F(2, 162) = 64.28$ for RT]. Once again, this interaction reflected the synergistic effects of task difficulty, such that change detection was generally least efficient for drawings with deleted features and easiest for photos containing rotated objects. This two-way interaction was further modulated by the interval condition in the same predictable way: the long interval exaggerated the differences in change detection already reported due to change type and image type [$F(2, 162) = 3.20$, $p = .043$ for errors; $F(2, 162) = 11.13$ for RT]. None of these higher-order interactions were involved in significant interactions with age.

Discussion

Change detection gradually improved across four groups of participants from 6 years of age to young adulthood. This finding was evident in both the analyses of correct RT and in errors made in change detection. The robustness of this finding is highlighted by the use of an analysis in which the comparison of performance in a sensory condition (50-ms interval) with a short-term memory condition (250-ms interval) led to a conservative estimate of change detection. Younger children were less able to detect changes using their short-term memory representations of a scene and a scene that is currently on view over and above any developmental differences in sensory change detection or in response selection and execution. This conclusion is consistent with findings from tasks of the detection of impossible figures (Enns & Girgus, 1986) and of the role of symmetry in pattern perception (Enns, 1987). However, it also extends these earlier findings that may have limited generality simply because young children are less able to stay on a deliberative task relative to older children (Enns & Trick, 2006), whereas the participants in this study did not need to maintain a experimenter-defined specific target image in short-term memory. In the present study, younger children were less able to detect changes to a scene even when they freely explored the scene for changes that could occur over a wide range of features, parts and whole objects.

A secondary finding was that change detection was more difficult for drawings than for pictures and for part deletions and insertions as compared to changes in color or object orientation. Large age-related differences were observed in the detection of deleted parts and in the detection of color changes, but less so for changes in object orientation. This is consistent with a reduced sensitivity in younger participants to the details of objects (i.e. specific colors and parts), but not a similar reduction in sensitivity to the orientation of whole objects.

The testing of change detection in school-age children was intended to bolster the understanding of the development of the exploratory mode of visual selectivity, as change detection represents a unique combination of controlled (conscious) processing in combination with the absence of a well-specified goal or task to accomplish. Humans often simply need to learn more about their environment, especially when it is new, before they are able to form more specific goals. Some aspects of a scene are processed preferentially, even when a person explores an unfamiliar environment, with no other goal than to gain new information (see review by Egeth & Yantis, 1997). The change detection task, in which change can occur in any of a potentially large number of ways, is one way to begin to tap into this unique mode of selectivity. The evidence from the present study seems to reveal the relatively greater sensitivity of younger observers to overall meaning of an object with respect to themselves (object orientation) than to the particular details of an object (color, missing parts).

This particular pattern of sensitivity is consistent with the reverse-hierarchy theory of visual experience (Hochstein & Ahissar, 2002), in which the ordering of our conscious experience is inverted with respect to the ordering of the lower-level visual operations that give rise to these conscious experiences. For example, in order to register an entire object, the visual system must first process the image through a number of stages that include spatially localized and highly specialized parallel operations that analyze the edges and colors of the object. In contrast, conscious experience begins with whole objects and their meanings, and the specific details of these objects are only attended to much later (Navon, 1977). The present findings that the largest age-related differences in sensitivity to the most detailed changes are consistent with this theoretical position, and suggest that the visual experience of children and adults is most similar at the whole object level. This hypothesis clearly warrants further research.

Of course, the particular version of the change detection task used in this study has its limitations. One, the images we tested in no way mimicked the rich visual environments that humans tend to explore on a daily basis. Two, the possible types of changes that could occur and that were repeated often in different pictures were highly restricted. Yet, the finding of age differences, despite these severe limitations in generality to everyday environments and in the restricted nature of the task participants performed, bodes well for further research in this area. These limitations suggest that testing in more realistic environments and over a larger range of possible change types will reveal even more striking age-related differences in visual selectivity. Moreover, these findings suggest that this method is appropriate for addressing such questions as the 'entry level' of detail with which a scene is viewed, and which objects are of central as opposed to peripheral interest to a viewer, without asking them any direct questions that might alter their spontaneous approach to a scene.

A final limitation to note concerns our interpretation of the differential rate of development in sensitivity to details versus whole objects. Caution is advised here because the factors that were associated with the slowest developmental rate were also the same factors that adult participants found most difficult. This indicates that our developmental interpretation cannot be fully distinguished in these data from the possibility that children simply show the slowest rates of development for those tasks that were most difficult. Although this distinction was previously sorted out in other attentional tasks (e.g. Burack *et al.*, 2000; Enns, 1993), so that task difficulty does not account for the relative rate of development in all cases, it still needs to be considered in the study of age differences in change detection.

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Instruction to printer	*Textual mark*	*Marginal mark*
Leave unchanged	• • • under matter to remain	Stet
Insert in text the matter indicated in the margin		New matter followed by
Delete	through matter to be deleted	
Delete and close up	through matter to be deleted	
Substitute character or substitute part of one or more word(s)	/ through letter or through word	New letter or new word
Change to italics	— under matter to be changed	
Change to capitals	under matter to be changed	
Change to small capitals	under matter to be changed	
Change to bold type	under matter to be changed	
Change to bold italic	under matter to be changed	
Change to lower case	Encircle matter to be changed	
Change italic to upright type	(As above)	
Insert 'superior' character	/ through character or where required	under character e.g.
Insert 'inferior' character	(As above)	over character e.g.
Insert full stop	(As above)	
Insert comma	(As above)	,
Insert single quotation marks	(As above)	and/or
Insert double quotation marks	(As above)	and/or
Insert hyphen	(As above)	
Start new paragraph		
No new paragraph		
Transpose		
Close up	linking letters	
Insert space between letters	between letters affected	#
Insert space between words	between words affected	#
Reduce space between letters	between letters affected	
Reduce space between words	between words affected	