

Memory for Structural Information Across Eye Movements

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Previous research has demonstrated that visual information is retained across eye movements at a more abstract level than at a point-by-point buffer. The results of 3 experiments, in which part-whole verification, same-different discrimination, and mental synthesis were used, show that one of the ways in which abstract visual information is represented is in the form of structural descriptions and that these structural descriptions are used in transsaccadic memory in the same manner as they are used in visual short-term memory. These results lend support to the idea that the memory store that retains information transsaccadically is in fact visual short-term memory (D. E. Irwin, 1991).

The visual world extends before us in all directions, but there are limitations on how much can be perceived at any one time. One limitation is due to acuity: The ability to perceive highly detailed information is reduced with an increase in distance away from the location in space at which the eyes are focused. To compensate for this loss of detail, the eyes move from point to point in space and can be directed to whichever object or region is currently of interest. The periods of time when the eyes are relatively still are called *fixations*, and the rapid, scanning eye movements between fixations are called *saccades*. A second limitation is the suppression of information during saccadic eye movements such that the information obtained from the world is largely confined to fixations (see Matin, 1974; Volkman, 1986, for reviews). Despite the discontinuity of receiving information in discrete chunks separated by saccades, the perception of the world is remarkably familiar and stable—familiar in the sense that when we look around a room, it does not appear to be filled with novel to-be-identified objects with each new fixation and stable in the sense that, despite the change in location of the objects with respect to us (e.g., on the retina when the eyes, head, or both move), their locations in space do not seem to change. These perceptions suggest that some information about objects is

retained from one eye fixation and may be invoked in the processing that occurs during the next eye fixation. The store in which this information is retained has been called *transsaccadic memory* (e.g., Irwin, 1991). The goals of our experiments were to examine in more detail the level of representation at which visual information is remembered in transsaccadic memory and to evaluate whether the use of such information across fixations is similar to its use within a fixation.

Integration of Abstract Visual Information

One early theory about the nature of visual information that survives across a saccade was the *spatiotopic fusion* hypothesis (Irwin, 1992a), which proposes that highly detailed point-by-point information from a single fixation is retained in a visual buffer onto which the contents of subsequent fixations are superimposed on the basis of spatiotopic coordinates (Breitmeyer, Kropfl, & Julesz, 1982; Davidson, Fox, & Dick, 1973; Jonides, Irwin, & Yantis, 1982; McConkie & Rayner, 1976; Wolf, Hauske, & Lupp, 1978, 1980). However, spatiotopic mapping of highly detailed information from consecutive fixations is now considered untenable for three reasons. First, there is considerable evidence that demonstrates poor performance on tasks that require fusion of detailed information presented in separate fixations (Bridgeman & Mayer, 1983; Irwin, Yantis, & Jonides, 1983; O'Regan & Levy-Schoen, 1983; Rayner & Pollatsek, 1983). Second, many methodological concerns have been raised with earlier studies that seemingly supported the spatiotopic fusion hypothesis (see Irwin, 1992a, for a review). Third, there are many failures to detect stimulus changes (such as color, location, and shape) that occur during a saccade (McConkie, 1991; see Irwin, 1992b, for a review).

This does not mean that no visual information is retained from one fixation to the next. Much evidence suggests that more abstract visual information does survive across a saccade and can affect processing during a subsequent fixation. For example, using a reading task, Rayner (1975) found that replacing a preview word with a visually similar target word that preserved both the overall shape of the word and the first two to three letters produced the same amount of facilitation as when the preview and target words were identical. Subsequent experiments showed that overall shape information was not critical because case changes (e.g., uppercase to lowercase)

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could be made between fixations with very little effect, thereby suggesting the use of a more abstract representation than specific letter features (McConkie & Zola, 1979; Rayner, McConkie, & Zola, 1980). In a conceptually similar task using a picture-naming paradigm, Pollatsek, Rayner, and Collins (1984) presented participants with a preview line drawing in one fixation and a to-be-named target line drawing in a subsequent fixation. A significant benefit was found when the preview was visually similar and conceptually dissimilar to the target (e.g., when the preview was a carrot and the target was a baseball bat). Additionally, significant facilitation was obtained both when the preview and target objects differed in size by as much as 10% (Pollatsek et al., 1984) and when the spatial location of the target object was shifted relative to the preview object's location (Pollatsek, Rayner, & Henderson, 1990), supporting the view that the visual information was abstract and not tied to a point-by-point spatiotopic representation (see Pollatsek & Rayner, 1992, for a review of this research). Similarly, research using other kinds of integration tasks has provided converging evidence for the retention of visual information from one fixation to the next in some relatively abstract visual form that represents structural or relational aspects of the stimulus and its components, that is, what it looks like, without the highly detailed point-by-point information (e.g., Irwin, 1991; Verfaillie, De Troy, & Rensbergen, 1994). However, the representational format of such abstract visual information remains undefined.

Where Is the Transsaccadic Information Represented?

If abstract visual information is not represented transsaccadically within a spatiotopic buffer, what memory store is used to retain it? More specifically, is this memory (conveniently referred to in this article and elsewhere [e.g., Irwin, 1991] as *transsaccadic memory*) separate from or the same as a store that is used within eye fixations? Visual memory has been divided into three components: sensory persistence, informational persistence, and visual short-term memory (Coltheart, 1980; Irwin, 1992b; Irwin & Yeomans, 1986). The within-fixation memory that is of most interest for the present purposes is visual short-term memory because the duration of sensory persistence expires after brief durations as measured from stimulus onset, much shorter than the typical eye fixation (Irwin, Brown, & Sun, 1988). Informational persistence has a relatively longer duration, lasting between 150 and 300 ms, as measured from stimulus offset (Irwin & Brown, 1987; Irwin & Yeomans, 1986). Within transsaccadic memory paradigms, in which a stimulus is erased and a new stimulus is displayed on elicitation of a saccade, informational persistence would operate well into the second eye fixation. Irwin (1992b) has speculated that informational persistence may play some role in the integration of information across eye movements. However, other properties of informational persistence (such as its susceptibility to masking) make it unlikely as a candidate for the abstract visual memory that is implicated by the eye movement studies reviewed above; therefore, the comparison between transsaccadic memory and visual short-term memory is focused on in this article. The possible transsaccadic role of

informational persistence is discussed in the General Discussion section.

For transsaccadic memory to be distinct from visual short-term memory, there should be evidence of an effect of an eye movement on the storage, retention, or retrieval of information that is not evident when the eyes remain stationary. Using a dot matrix comparison task, Irwin (1991) identified some of the properties of transsaccadic memory and compared them with the properties of visual short-term memory. Specifically, he varied the number of dots in the dot matrix (and hence its complexity) to determine the capacity of transsaccadic memory, and he systematically manipulated the delay between the presentation of the first dot matrix and the second dot matrix to determine its duration. His findings showed that transsaccadic memory was very similar to visual short-term memory: both are limited capacity and long lasting (up to 5,000 ms). These results show that participants could maintain a representation of the first dot matrix throughout a lengthy blank interval during which additional eye movements were possible. In addition, transsaccadic memory seems to have an abstract visual component like that of visual short-term memory. Participants could decide with good accuracy (about 70%) whether a dot pattern presented in one fixation matched a second dot pattern presented in a subsequent fixation, and changing the absolute location of the dot patterns in space from one fixation to the next did not disrupt accuracy. This suggests that visual information about the arrays was retained in a representation independent of absolute spatial information while preserving information about the relative positions of the elements of the display and information regarding the overall shape of the display. On the basis of these results, Irwin claimed that transsaccadic memory may in fact be the same as visual short-term memory.

If Irwin (1991) is right, then the following should hold true: First, the types of representations of abstract visual information that are known to be used in visual short-term memory should also be used transsaccadically. Second, these representations should be used equally well both within and across eye fixations. That is, there should be no consequence of programming and executing an eye movement on their quality or use. Note that issues of representation were not addressed by Irwin; even though he found similar duration and capacity properties between visual short-term memory and transsaccadic memory, information may be represented differently within and across eye fixations. An explicit test of the use in transsaccadic memory of a representational form known to be used in visual short-term memory is needed before concluding that the representation of information in the two memory stores is also similar and, more generally, that visual short-term memory is used to represent information across saccades (Irwin, 1991; Phillips, 1974). Because structural descriptions are central to many models of object recognition and represent how the component features of an object may be involved in its identification (e.g., Gottschaldt, 1926/1967; Hummel & Biederman, 1993; Marr & Nishihara, 1978; Neisser, 1967; S. Palmer, 1977; Reed, 1973; Sutherland, 1968; Ullman, 1984), we investigated this representational form.

Visual Information Represented as Structural Descriptions

One model of the relationship between the perception of a figure and the encoding of its parts was formulated by S. Palmer (1975, 1977, 1978). He proposed that the representation of an object was in the form of a hierarchy, in which the top level contained a central node corresponding to the whole or figural representation, and the subsequent lower levels contained nodes for specific parts and connections that specified the relations between the parts. As the hierarchy was traversed, there was an increasing decomposition of parts into further subparts. The representation that corresponded to a node in the hierarchy was referred to as a *structural unit* and was defined at a given level in the hierarchy by its value on global (Gestalt) properties such as proximity and connectedness and by its relation to other structural units.

An important property of the hierarchy was that its organization was selective. Only some elements of a figure would be formed together and represented as structural units; all possible orderings of elements were not considered. Therefore, a "good" part or set of elements was one for which a structural unit existed at some level within the figure's hierarchy, and a "bad" part was a set of elements for which no single structural unit existed, but in which segments were dispersed throughout the hierarchy. One consequence of such selectivity was that good parts would be identified more quickly and accurately than bad parts because a search through the hierarchy proceeded from the top node and worked downward so that intact structural units were accessed before individual elements of a unit. To use an example taken from Reed (1974), consider the Star of David shown in Figure 1. It seems much easier to detect the presence of a triangle in the figure than it does to detect a parallelogram, even though both are present. On the basis of Gestalt grouping principles (such as good continuation), the figure decomposes into two inverted triangles and not into a parallelogram and four smaller triangles.

Empirical evidence implicating the use of structural descriptions in visual short-term memory has come from a number of experimental paradigms, including part-whole verification (S. Palmer, 1977; Reed, 1974; Reed & Johnsen, 1975), same-different judgments (S. Palmer, 1978), and mental synthesis (Klatzky & Thompson, 1975; S. Palmer, 1977; Thompson & Klatzky, 1978). For example, S. Palmer (1977) explored the use of structural descriptions in a part verification task in which participants decided whether a part composed of three line segments was present in a whole composed of six line segments. He manipulated the "goodness" of the part as a structural unit of the figure by using three levels (high,

medium, and low) that were defined on the basis of Gestalt properties. For positive responses, both accuracy and response times were affected by goodness level: When the part corresponded to a good segmentation of the figure, responses were rapid and accurate; in contrast, when the part corresponded to a bad segmentation of the figure, responses were slow and less accurate. Such findings are supportive of the use of structural descriptions in visual short-term memory. Surprisingly, for negative responses, accuracy and response times were also affected by part goodness (although more weakly than for positive responses), despite the fact that the designation of a part as good or bad was arbitrary when the part was paired with a figure in which it was not present. S. Palmer attributed this to both the intrinsic properties of the to-be-verified parts (his good parts preserved connectedness) and to a covariation of goodness level and the number of segments in common between the parts and whole figures (sample stimuli can be seen in Figure 3).

S. Palmer (1978) also used a same-different verification task to show that the comparison of two figures was made on the basis of higher order structures of the figures rather than on their individual line segments. Specifically, there were triads of figures, consisting of a standard figure and two distractors: one that was structurally similar to the standard, and the other that was structurally dissimilar to the standard. He found that discrimination between the standard and the structurally similar distractor was more difficult, as measured by reaction time and error rate, than discrimination between the standard and the structurally dissimilar distractor, despite the fact that all of the figures in a triad shared five common line segments.

Finally, S. Palmer (1977) also used a mental synthesis task to investigate the use of structural units in visual short-term memory. He presented participants with two three-segment parts that varied in how good or natural they were as parts of a six-segment figure (high, medium, and low goodness). Participants were instructed to join mentally the parts to produce a single six-segment whole and then to compare the imagined whole figure with a presented whole figure. Response times for both synthesis and verification were recorded. Overall, the goodness of the parts affected both the synthesis times and verification response times, with the high goodness parts synthesized and verified more quickly than either the medium or low goodness parts, which did not differ significantly from each other. The fact that the goodness manipulation affected the verification latencies points toward the difficulty participants had in creating an integrated organized figure when given a bad set of parts and further supports the use of structural units as elements of perceptual organization (see also Klatzky & Thompson, 1975; Thompson & Klatzky, 1978).

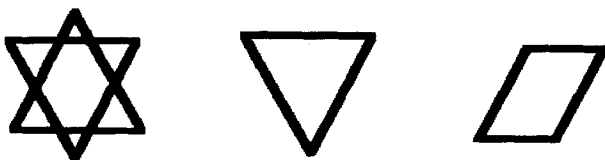


Figure 1. Star of David figure and an obvious part (the triangle) and a nonobvious part (the parallelogram).

On Structural Descriptions Mediating Integration

The research cited above provides strong evidence for the use of structural descriptions across a number of tasks in which successful performance requires the retention of information presented at Time1 for use in conjunction with information presented at Time2. Given that structural descriptions of figures and parts are retained in visual short-term memory for use in such tasks, it is reasonable to propose that structural

descriptions can also be retained in transsaccadic memory, and such a proposal is in accordance with the evidence for the retention of abstract visual information across fixations (e.g., Pollatsek et al., 1984). For example, Irwin (1991) found improved performance in his dot matrix same-different task with simple dot patterns relative to complex dot patterns, in which the complexity factor for these patterns had a structural dimension (Ichikawa, 1985). The fact that more structure was apparent in the simple pattern, and that performance with these simple patterns was improved, suggests the possible use of structural descriptions in transsaccadic memory.

In the current experiments, a part-whole verification task, a same-different discrimination task, and a mental synthesis task were used in an effort to provide converging evidence for the use of structural descriptions in transsaccadic memory. Depending on the task, the level of part goodness or the structural similarity between stimuli was varied. Eye movement and no-eye movement conditions were used in the first two experiments to permit a comparison of performance within and across fixations. Details and specific predictions about the transsaccadic use of structural descriptions for each task appear in the individual experiment descriptions that follow.

Experiment 1

In Experiment 1 we used a part-whole verification task to test whether structural descriptions are retained in transsaccadic memory. Specifically, the goodness of a part as a component of a figure, as defined by Gestalt properties such as connectedness and proximity, was varied to determine if that affected how quickly and accurately the part could be verified as occurring within a figure, when the part was presented in one eye fixation and the whole was presented in a subsequent eye fixation. Two eye movement conditions were used: one that preserved the spatial location of the part and the whole (*spatial overlap* condition) and the other that preserved the retinal location of the part and the whole (*retinal overlap* condition). In addition, two no-eye movement conditions were used to provide an estimate of within-fixation performance. In one condition, both retinal and spatial location were preserved (*retinal and spatial overlap* condition); in the other, neither retinal nor spatial location was preserved (*no-overlap* condition). These latter conditions were near replications of S. Palmer (1977), except that eye position was monitored so that trials on which saccades occurred could be detected and eliminated to produce a pure estimate of within-fixation memory performance.

If structural descriptions are used transsaccadically, then there should be a significant *goodness effect*, with good parts verified as present in a whole figure significantly faster and more accurately than bad parts. If structural descriptions are not used transsaccadically, then both speed and accuracy measures should be uninfluenced by the goodness manipulation. Such a finding is predicted by a segment-based approach, in which performance involves determining the overlap of individual line segments. This account predicts no effect of part goodness because the number of segments in common with the figure was kept constant across the good and bad

manipulation (see the *Stimuli* section for details). Thus, responses could be made on the basis of detecting that three segments overlap for the yes responses and detecting one or more discrepant segments for the no responses; these detections would be performed in the same manner for good and bad parts. J. Palmer and Ames (1992) found that participants could retain information about a line's length with enough precision that they could compare it accurately against a standard line, a task that seemingly requires quite literal visual information and could rely on a segment-based representation. If such representations are routinely used in transsaccadic memory, then no goodness effects should be found in Experiment 1.

Method

Participants

Twelve people from the University of Illinois community participated in Experiment 1. They were recruited by means of a sign-up sheet and were paid \$5 for each hour of their participation.

Stimuli

The stimuli were taken from the part-whole verification task of S. Palmer (1977, Experiment 3) and were constructed from the set of 16 component line segments illustrated in Figure 2. There were two sets of stimuli. (a) The *figure* set consisted of 10 six-segment figures, each of which was associated with two pairs of three-segment parts that were selected from all possible three-segment parts by using a measure that estimated the goodness of the segment as a part of the figure along Gestalt dimensions such as proximity and connectedness (details of this measure can be found in S. Palmer, 1977). Two levels of goodness (good and bad) were represented by the parts. (b) The *part* set consisted of 10 three-segment parts, each associated with two different figures for which the parts varied in goodness (good and bad). Positive trials were constructed by pairing each of the two parts with the appropriate figure for the figure set and by pairing each of the two figures with the appropriate part for the part set. Negative trials were constructed by pairing each part with a different figure for the figure set of stimuli and similarly pairing each figure with a different part for

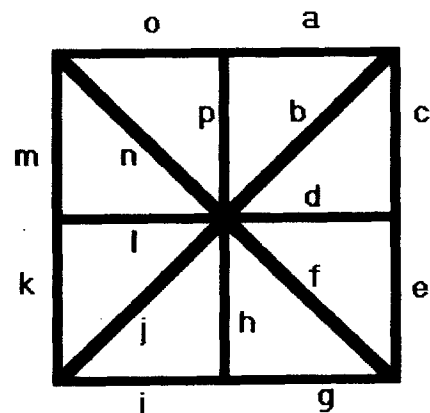


Figure 2. The matrix of 16 line segments from which the sets of stimuli for Experiments 1-3 were created. From "Hierarchical structure in perceptual representation," by S. E. Palmer, 1977, *Cognitive Psychology*, 9, p. 445 Copyright 1977 by Academic Press. Reprinted with permission.

the part set of stimuli. Goodness levels for the negative trials were defined as a function of the goodness of the parts when paired with the appropriate (correct) figures. Note that, as defined, these goodness levels are thus arbitrary for negative trials because parts are paired with a figure for which they are not parts.

Sample positive stimuli from the figure set appear in Figure 3A and from the part set in Figure 3B. The two sets of stimuli were used to balance any intrinsic properties associated with the parts or wholes because within each set the parts or whole remained constant across the goodness-level manipulation.

To verify the level of goodness of each stimulus set, we collected goodness ratings from 24 University of Illinois students. Students rated a given figure paired separately with a good and bad part for the figure set of stimuli and a given part paired with a figure for which it was a good or bad part for the part set of stimuli. Students rated 40 pairs for part goodness by using a scale with points ranging from 1 (*very bad part*) to 5 (*very good part*); identical parts and figures appeared on separate pages to prevent context effects. Analyses on these ratings and on all subsequent data were conducted with a significance level of $p < .05$, unless otherwise noted. Overall, the good parts ($M = 4.2$) received significantly higher ratings than the bad parts ($M = 2.4$), both by subjects, $F(1, 23) = 77.3, MSE = 1.1$, and by items, $F(1, 18) = 241.2, MSE = 0.139$. This pattern held for both the part set of stimuli ($M = 4.5$ for good parts and $M = 2.5$ for bad parts) and for the figure set of stimuli ($M = 3.9$ for the good parts and $M = 2.2$ for the bad parts), thereby verifying the validity of the good and bad part distinction in both sets of stimuli. We collapsed across the stimulus set variable in all subsequent analyses.

Design

On the basis of stimulus construction, there were four within-subject variables: level of goodness (good or bad), stimulus set (figure or part), response (yes or no), and stimulus pairs (10 sets), yielding 80 experimental trials. In addition, there was a within-subject blocking variable with four levels that defined the two eye movement conditions (retinal overlap and spatial overlap) and the two no-eye movement conditions (retinal and spatial overlap and no-overlap) that are referred to as *overlap* conditions.

Finally, there was a between-subjects variable called *order of presentation* that referred to whether participants received the part

followed by the whole (e.g., *part-then-whole* group) or the whole followed by the part (e.g., *whole-then-part* group). The use of structural descriptions can be observed with the whole-then-part order, in which a representation of the whole would be created and held in memory until the part is presented. If the part represents a structural unit of the whole, then verification should be fast and accurate. Similarly, for the part-then-whole order, a representation of the part would be created and held in memory until the whole is presented. If the structural description emerging from the perceptual organization of the whole contains that part represented as a single structural unit, then verification should be fast and accurate.

In all, each participant participated in four blocks of 80 trials each, yielding a total of 320 trials. Two of these blocks consisted of eye movement trials, and two consisted of no-eye movement trials. For all participants, the eye movement trials were conducted before the no-eye movement trials because the timing parameters of the saccades were needed to determine stimulus durations for the no-eye movement trials (see the *Procedure* section). Six participants were in the part-then-whole group, and 6 were in the whole-then-part group.

Apparatus

The stimuli were presented on a Nec MultiSync color monitor equipped with a P-22 phosphor. A refresh rate of 72 Hz¹ was used. The screen was covered with an FG Monitor Lens to reduce reflectance. Stimulus presentation and response collection were controlled by a Gateway2000 486 DX2-50 personal computer. Both parts and wholes were presented within the three-by-three dot matrices from which they were constructed (see Figure 2). Each matrix subtended 3.0° of visual angle both horizontally and vertically. The distance between the center and the left and right matrices was 2.0° between the closest edges. The span of the display from the left edge of the left matrix to the right edge of the right matrix was 13°. Stimuli were presented in dark gray on a light gray background.

For eye movement monitoring, an Applied Science Laboratory Model 210 scleral reflectance eye tracker was used that sampled the left eye every millisecond.

Participants made their responses by pressing hand-held switches. Participants held the yes switch in their dominant hand and the no switch in their nondominant hand. Response time was measured from the onset of the second figure to the response. The sequence of trials was self-paced. Participants used a bite bar throughout all sessions to help eliminate head movements.

Procedure

Each participant took part in a practice session and four experimental sessions.

Practice session. Participants participated in eight sets of six trials to familiarize themselves with the sequence of events in the eye movement and no-eye movement conditions. The practice session used a set of stimuli that did not appear in the experimental sessions.

Eye movement trials. In the first two experimental sessions, participants performed 40 trials in each of the eye movement conditions. The sequence of events constituting an eye movement trial for the retinal overlap condition is shown in Figure 4A; for the spatial overlap condition, the sequence is shown in Figure 4B. Each eye movement trial began with a calibration routine in which a series of three fixation points (+) appeared sequentially across the screen; the participant was instructed to fixate each point carefully. The first point appeared for 1,500 ms, 8° to the left of center (−8°), the second point at the

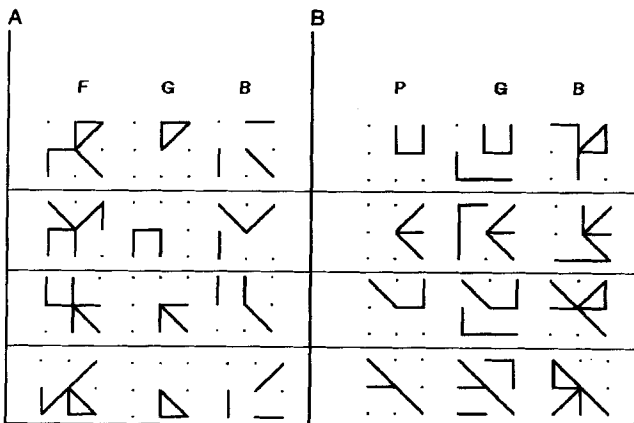


Figure 3. Sample parts and whole figures used in the part-whole verification task for Experiment 1. A and B in Figure 3 show, respectively, samples from the figure stimuli set and samples from the part stimuli set. F indicates figure; P indicates part; G indicates good parts or figures; B indicates bad parts or figures.

¹ The screen refresh rate adds some variability (range of 0 to 14 ms) to the duration of the screen displays; mean values are reported.

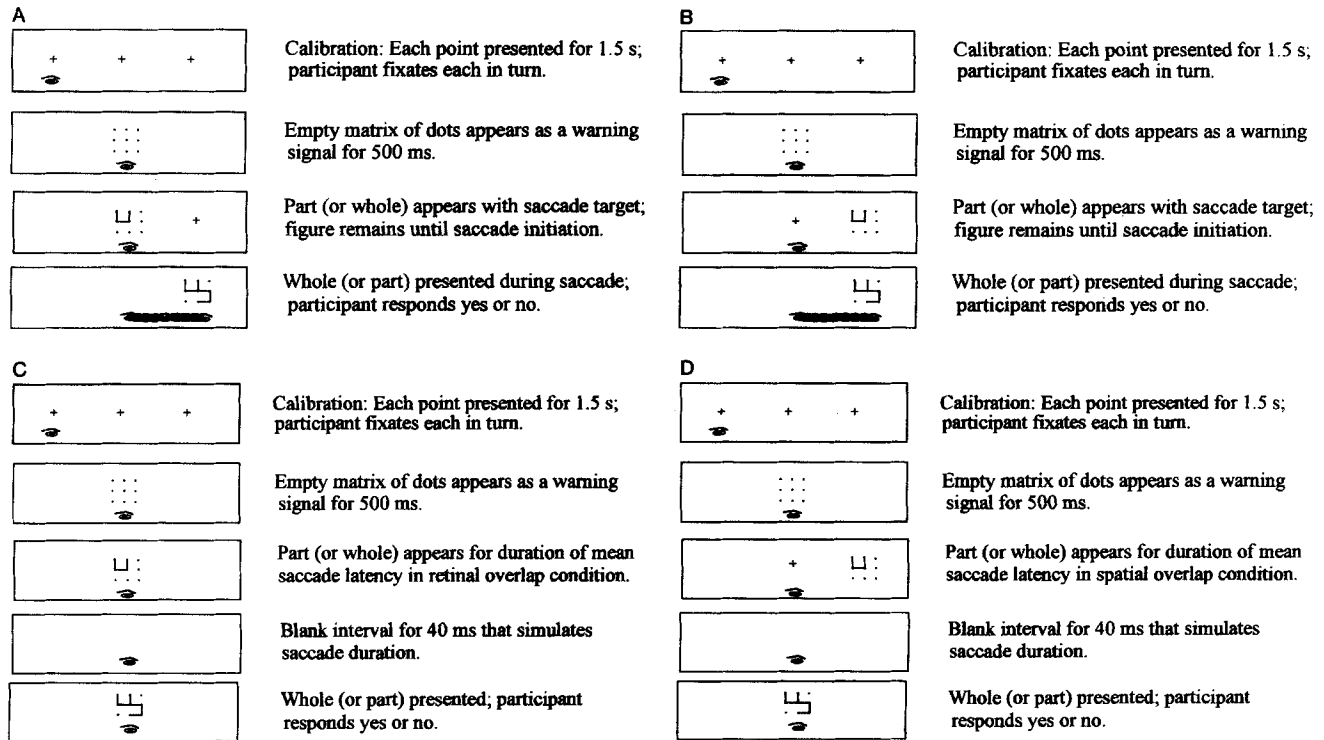


Figure 4. A, B, C, and D show, respectively, sequence of events for a retinal overlap eye movement trial, a spatial overlap for an eye movement trial, a retinal and spatial overlap for a no-eye movement trial, and a no-overlap no-eye movement trial.

center (0°), and the third point 8° to the right of center ($+8^\circ$). The average of the samples corresponding to the time interval from 900 to 1,000 ms for each calibration point was calculated, and these means were used to calibrate the output of the eye tracker with spatial position.

After a successful calibration, the participant moved his or her eyes to a central fixation point. After a 1,500 ms delay, an empty matrix of dots appeared 5° to the left or right periphery in the spatial overlap condition (see Figure 4B) or at fixation with a plus sign serving as the saccade target in the left or right periphery in the retinal overlap condition (see Figure 4A). After 500 ms, the first stimulus (either a part or a whole) appeared within the matrix. The participant was instructed to make an eye movement to the target in the periphery (either the part or the whole or the plus sign) once the first stimulus had been identified. The detection of the saccade was made on the basis of a change in eye position in the same direction that exceeded $0.05^\circ/\text{ms}$ for 3 consecutive milliseconds. On saccade detection, the second stimulus (either a whole or a part) was presented at the target location. Participants were instructed to decide as quickly but as accurately as possible whether the part was present in the whole.

For a trial to be considered acceptable, the following criteria had to be met. First, to ensure that participants were fixating on the initial figure, the starting fixation location had to be on the central matrix (a 3° span) in the retinal overlap condition and within $\pm 1.5^\circ$ of the central fixation point in the spatial overlap condition. Second, to ensure that participants had enough time to identify the first figure, but not an exceedingly long time, the saccade latency had to be greater than 100 ms and less than 1,000 ms. Third, the participants' eye movement had to land somewhere on the second figure (a 3° span). Fourth, saccade duration had to be greater than 25 ms and less than 80 ms. The maximum duration was arbitrarily set to flag trials in which saccadic

behavior was anomalous. The minimum duration was to ensure that participants perceived the two figures in separate eye fixations and was set on the basis of the response lag of the eye tracker (4–5 ms), the on-line calculation that a saccade has occurred (3 ms), and the vertical retrace delay (at most 14 ms).² Together, these criteria ensured that participants were viewing the first and second figures in separate fixations and thus required the retention of information from the first figure in transsaccadic memory. Finally, response times that exceeded 2.5 standard deviations from each condition mean were also excluded.

² To ensure that the first figure did not persist beyond this 14-ms retrace delay, we conducted the following shutter test with 6 participants. On 50 trials, a sample figure similar to the stimuli used in these experiments (a dark gray figure on a light gray background) was drawn onto a video page and displayed on the screen behind a closed shutter. On 50 different trials, no such figure was displayed. For all trials, the computer then switched to a blank video page, thereby erasing the stimulus (if present). After a 14-ms pause, the shutter opened, and the participant's task was to indicate whether the figure was displayed. Participants were told that the figure would be presented on half of the trials, and they were instructed to distribute their responses so that they indicated that the figure had been presented on roughly 50 of the trials. All participants reported that they did not see the figure at any time. Hit and false-alarm rates were calculated, and a d' measure was determined. Confirming participants' introspections, the mean d' was $-.08$, and the 95% confidence interval associated with this mean spanned zero ($-.02$ to $+.18$), thus indicating that sensitivity did not differ as a function of whether the figure was presented behind the shutter. We conclude that given our timing criteria, phosphor persistence did not contribute to performance.

In all, 68% of the trials were acceptable. Significantly more trials were acceptable in the spatial overlap condition ($M = 76\%$) than in the retinal overlap condition ($M = 59\%$), $t(11) = 4.1$ mostly because of the difficulty participants had with moving off of the foveally presented figure and in landing accurately on the saccade target (+) in the retinal overlap condition. This pattern was present for both orders of presentation.

No-eye movement trials. In the last two experimental sessions, participants performed 40 trials in each of the no-eye movement conditions. The sequence of trial events for the retinal and spatial overlap condition is shown in Figure 4C; for the no-overlap condition, the sequence is shown in Figure 4D. Participants' eyes were monitored so that trials in which eye movements were made could be excluded. Consequently, at the start of a no-eye movement trial, participants went through the same calibration routine used in the eye movement conditions. After a successful calibration, a center fixation point appeared, and participants were instructed to fixate this point throughout the remainder of the trial. The first stimulus (part or whole) was presented 5° to the left or right periphery in the no-overlap condition (see Figure 4D) or at fixation for the retinal and spatial overlap condition (see Figure 4C).

The timing parameters of the no-eye movement trials were yoked for each participant to the timing of events in the eye movement trials to ensure that the first stimuli were displayed for equivalent durations. Specifically, for the retinal and spatial overlap condition, the duration of the first stimulus was based on the mean saccade latency from the retinal overlap eye movement condition ($M = 555$ ms)³ because in both conditions, the first stimulus appeared foveally. For the no-overlap condition, the duration of the first stimulus was based on the mean saccade latency from the spatial overlap condition ($M = 468$ ms) because in both conditions, the first stimulus appeared peripherally. Next, a blank screen appeared for 42 ms, an interval meant to approximate the saccade duration in the eye movement trials, followed by the presentation of the second stimulus (whole or part) at the central fixation point. Participants were instructed to decide as quickly but as accurately as possible whether the part was present in the whole by pressing one of two hand-held switches. Response time was measured from the presentation of the second stimulus to the response. Because this method of timing included the saccade duration in the eye movement trials but not in the no-eye movement trials, the simulated saccade duration (42 ms) was added to the response times for the no-eye movement trials to facilitate comparisons between the eye movement and no-eye movement conditions.

For a trial to be considered acceptable, the following criteria had to be met. First, to ensure that participants were fixating on the initial figure, the starting fixation location had to be on the central matrix (a 3° span) in the retinal and spatial overlap condition and within $\pm 1.5^\circ$ from the central fixation point in the no-overlap condition. Second, the participant must have remained fixated at the center throughout the trial, without moving the eyes or blinking. Finally, response times that exceeded 2.5 standard deviations from each condition mean were excluded. In all, 77% of the trials were acceptable. There was no significant difference in the percentage of acceptable trials between the retinal and spatial overlap condition ($M = 78\%$) and the no-overlap condition ($M = 76\%$), $t(11) < 1.1$. There was no difference between overlap conditions for either order of presentation.

Results and Discussion

The results are presented as follows. Results for the yes and no trials are in separate sections. Within each section, a 4 (overlap conditions) \times 2 (part goodness) repeated measures analysis of variance (ANOVA) was calculated on both the error rates and response times. These analyses permitted both

an evaluation and a comparison of the use of structural descriptions across the eye movement and no-eye movement conditions. Significant effects that did not directly address the use of structural descriptions are not discussed. The response time data include only those acceptable trials for which the participant responded correctly.

Yes Response Trials

The mean error rates and response times for acceptable yes trials, broken down by overlap conditions and part goodness, are shown in Table 1.

Error rates. There was a significant main effect of part goodness, $F(1, 11) = 67.5$, $MSE = 214$, such that more errors were made in verifying bad parts ($M = 32.5$) than good parts ($M = 7.8$). In addition, there was a significant main effect of overlap conditions, $F(3, 33) = 5.3$, $MSE = 125.6$. A 95% confidence interval constructed to further explore this effect showed that a minimum difference of 10% was required for significance. Thus, there were significantly more errors in the spatial overlap eye movement condition ($M = 24\%$) than in the retinal and spatial overlap no-eye movement condition ($M = 13\%$). There was no interaction between overlap conditions and part goodness, $F(3, 33) = 1.5$, $MSE = 108.9$, $p > .20$. Thus, these error data support the conclusion that structural descriptions are used in similar ways within and across eye fixations.

Response times. There was a significant main effect of part goodness, $F(1, 11) = 57.5$, $MSE = 10,305$, a main effect of overlap conditions, $F(3, 33) = 18.6$, $MSE = 8,556$, and a significant interaction between overlap conditions and part goodness, $F(3, 33) = 3.6$, $MSE = 2,943$. A 95% confidence interval constructed to further explore this interaction showed that a minimum difference of 48.7 ms was required for significance. Thus, the goodness effect in the no-overlap no-eye movement condition ($M = 99$ ms) was significantly smaller than the goodness effects in the other three conditions, which did not differ from one another.

Do these differences indicate that the use of structural descriptions transsaccadically is not the same as the use of structural descriptions within a fixation? Two findings argue against such an idea. First, the size of the goodness effect did not differ between the retinal overlap eye movement condition ($M = 189$ ms) and the retinal and spatial overlap no-eye movement condition ($M = 185$ ms), indicating that neither any cost associated with the eye movement in the former condition nor any benefit associated with spatial overlap in the latter condition significantly affected the use of structural descriptions in these retinally similar conditions. Second, the significantly smaller goodness effect evident in the no-overlap condition differed not only from the eye movement conditions but also from the other no-eye movement condition, indicating

³ The saccade latencies observed in the experiments reported in this article are generally longer than the typical saccade latency of 200–250 ms obtained in other transsaccadic experiments. We attribute this to our instructions to the participants, which stressed the identification of the figure over speed of saccade initiation and explained that the duration of the first stimulus was under their control.

Table 1
Mean Response Times (RTs; in Milliseconds) and Error Rates (ERs; in Percentages) by Overlap Condition, Part Goodness, and Response for Experiment 1

Response	Part goodness				Goodness effect	
	Good		Bad		RT	ER
	RT	ER	RT	ER	RT	ER
Retinal overlap eye movement condition						
Yes	668	10	857	28	189	18
No	700	8	781	19	81	11
Spatial overlap eye movement condition						
Yes	641	10	795	37	154	27
No	686	5	733	12	47	7
Retinal and spatial overlap no-eye movement condition						
Yes	557	1	742	25	185	24
No	616	1	637	3	21	2
No-overlap no-eye movement condition						
Yes	591	10	690	40	99	30
No	624	5	654	7	30	2

that whatever process was responsible for the reduction of the goodness effect was not a factor that differentiated eye movement and no-eye movement conditions. Thus, for the most part, these data also support the similar use of structural descriptions within fixations and across eye movements.

No Response Trials

The mean error rates and response times for acceptable no trials, broken down by overlap conditions and part goodness, are shown in Table 1.

Error rates. On the basis of S. Palmer's (1977) results, there could be significant goodness effects for the no responses, even though the designation of good and bad parts is not necessarily meaningful with respect to the figure with which they are paired. Consistent with this, there was a marginally significant main effect of part goodness, $F(1, 11) = 3.6$, $MSE = 194$, $p = .09$, indicating the possible use of structural descriptions to verify that a part was not present in a whole figure. More errors were made for bad parts ($M = 10\%$) than for good parts ($M = 5\%$). In addition, there was a significant main effect of overlap conditions, $F(3, 33) = 7.9$, $MSE = 68.3$. A 95% confidence interval constructed to further explore this effect showed that a minimum difference of 7% was required for significance. Thus, there were more errors in the retinal overlap eye movement condition ($M = 14\%$) than in either the retinal and spatial overlap no-eye movement condition ($M = 2\%$) or the no-overlap no-eye movement condition ($M = 6\%$), suggesting that this eye movement condition was more difficult overall than the two no-eye movement conditions. Finally, there was no interaction between overlap conditions and part goodness, $F(3, 33) = 1.9$, $MSE = 61.9$, $p = .16$. Thus, like the data for the error rates for the yes responses, there is some support for the hypothesis that the use of structural descriptions across eye movements is similar to its use within eye movements.

Response times. There was significant main effect of part goodness, $F(1, 11) = 7.1$, $MSE = 6,757$, a significant main effect of overlap conditions, $F(3, 33) = 13.7$, $MSE = 10,817$, and a marginally significant interaction between overlap conditions and part goodness, $F(3, 33) = 2.7$, $MSE = 1,617$, $p = .06$. A 95% confidence interval constructed to further explore this interaction showed that a minimum difference of 36.1 ms was required for significance. Thus, the goodness effect in the retinal overlap eye movement condition ($M = 81$ ms) was significantly larger than the goodness effects in both the retinal and spatial overlap no-eye movement condition ($M = 21$ ms) and the no-overlap no-eye movement condition ($M = 30$ ms).

The results for the no responses provide some support for the use of structural descriptions transsaccadically. However, for both the error rates and the response times, there was little to no evidence of the use of structural descriptions in the no-eye movement conditions. This can be seen by comparing the sizes of the goodness effects in each of the no-eye movement conditions to the minimum values established by the confidence intervals (7% and 36.1 ms, respectively). One reason for this could be a lack of power. Consistent with the pattern found by S. Palmer (1977), the observed goodness effects over all overlap conditions for the no responses were smaller than the goodness effects found with the yes responses, both for error rates, $F(1, 11) = 18.7$, $MSE = 470.3$, and for response times, $F(1, 11) = 29.9$, $MSE = 10,152$. Moreover, the differences between good and bad parts in Experiment 1 were in the correct direction for goodness effects.

However, it may seem surprising to find goodness effects in the no responses at all because the goodness designation does not hold the same meaning for the pairing of a part and a figure in which it is not present; for these pairs, goodness was defined by the relation of the part and a figure in which it was present. It could be that some intrinsic properties of the parts themselves served to differentiate good and bad parts and that these are responsible for goodness effects in the negative trials. Indeed, the effects in the eye movement conditions replicated those found by S. Palmer (1977) and are similar to an effect appearing in the part-whole verification task of Ankrum and J. Palmer (1991, Experiment 6). S. Palmer (1977) attributed the effect to aspects of his stimulus sets, including the property of connectedness. More generally, a recent theory by S. Palmer and Rock (1994) on the role of connectedness in defining the initial segmentation of a figure into parts provides some support for this prediction.

In summary, the data from Experiment 1 suggested that participants can use structural descriptions transsaccadically, and the use of such representations does not differ in a systematic way from their use within a single fixation. Across both yes and no responses, for the error rates, there were no significant interactions between part goodness and overlap conditions. For the response times, there were significant interactions between part goodness and overlap conditions, but the nature of these interactions did not indicate systematic differences in the use of structural descriptions within and across fixations. These data also indicated that the visual information that is retained both within a fixation and across fixations is location independent because for the yes responses, there were no differences in the size of the goodness effects

among the two eye movement conditions that preserved either retinal or spatial location and the no-eye movement condition that preserved both retinal and spatial location. As such, these data are consistent with those of Irwin et al. (1990) and Pollatsek et al. (1990). Finally, it should be noted that, by necessity, the yoking of the timing parameters of the eye movement and no-eye movement trials required that their order remain fixed. As a consequence, any effects of practice on performance would predominantly be observed in the no-eye movement trials. However, overall, the pattern for the yes responses in the no-eye movement trials was similar to that observed by S. Palmer (1977), thus indicating that despite experience in the eye movement trials, participants were using a strategy similar to that used by S. Palmer's (1977) participants.

Experiment 2

We designed Experiment 2 to provide converging evidence for the use of structural descriptions within and across eye fixations by using a same-different discrimination task involving two whole figures. If a figure's structural description is retained in transsaccadic memory, then discriminating between it and a figure with a similar structural description should be more difficult than discriminating between it and a figure with a very different structural description. For structurally dissimilar figures, representations of the whole figures at the top node in the hierarchies may be deviant enough to generate a different response. However, for structurally similar figures, such discriminations cannot be made at the top level and a search must proceed at a lower level in the hierarchy where the figures are decomposed into parts. This search requires extra time. The discrimination is also more difficult because the similarity between the two figures at either the top or the part decomposition levels may be sufficiently high to trigger an erroneous same response, if the threshold for judging that two figures are the same is not high enough.

If structural descriptions are used in transsaccadic memory, then a *structural similarity* effect should be found, with significantly faster and more accurate different responses for structurally dissimilar stimuli than for structurally similar stimuli. Furthermore, if the use of structural descriptions in transsaccadic memory does not differ from their use in visual short-term memory, then equally large structural similarity effects should be observed in the corresponding eye movement and no-eye movement conditions.

If structural descriptions are not retained in transsaccadic memory, then the task should be equally difficult for both high and low structural similarity discriminations; thus, the response time measure should show no effect of structural similarity when an eye movement occurs between the presentation of the two figures. However, participants' accuracy may still be above chance if the decision can be made on the basis of some other code, such as responding on the basis of detecting a discrepant segment by using a comparison process that evaluates the overlap of individual line segments. This approach would predict no effect of structural similarity for the different trials because the figures and distractors all have five out of six line segments in common (see the *Stimuli* section for details).

Alternatively, a more holistic comparison approach could be

adopted that was not observed in Experiment 1 for two reasons. First, in that experiment, the parts did not fully preserve the overall shape of the whole figure (because they only had three line segments), so a holistic comparison strategy would not be effective. Second, the nature of the part-whole verification task encourages explicit decomposition and thereby discourages holistic stimulus processing. Recall that Irwin (1991) found that participants could accurately compare both simple and complex dot matrices across fixations. Because the complex matrices lacked an emergent structure (e.g., Ichikawa, 1985), the comparison process was presumably done on the basis of some other representation, perhaps embodying a more holistic or global approach. This approach would also predict an absence of a structural similarity effect.

With respect to the same trials, there should be no differences across conditions. Because the two figures are identical, a same response could be generated on the basis of comparing the whole figures at the topmost node of the hierarchy (S. Palmer, 1977) or the comparison could be done at the part decomposition level, given a high threshold for responding "same." In either case, both response times and accuracy rates should be constant across the different types of same trials (e.g., comparing the standard against itself, the high-similarity distractor against itself, and the low-similarity distractor against itself).

Method

Participants

Eleven people from the University of Illinois community participated in Experiment 2. All had participated in Experiment 1. They were paid \$5 for each hour of their participation.

Stimuli

The stimuli were figures consisting of six line segments and were based on the set of stimuli described by S. Palmer (1978) that were constructed from the matrix of 16 component line segments illustrated in Figure 2. A set of 10 figures labeled *standards* was created, and two distractor figures were formed from each standard by changing a single line segment. This resulted in 10 triads consisting of a standard and two distractors. For the high-similarity distractor, the line segment change did not alter the structural description of the standard at a given level in the hierarchy and generally preserved Gestalt properties such as connectedness and closedness. For the low-similarity distractor, the line segment change radically altered the standard's structural description so that Gestalt properties were not maintained between the standard and the low-similarity distractor. For a given standard, the same line segment was changed to create the two distractors, and the amount of change was equated in terms of orientation, location, and length of the changed segment. For example, for the sample stimuli in the top row of Figure 5, the middle vertical line segment of the standard was rotated 45° counterclockwise to create the high-similarity distractor and 45° clockwise to create the low-similarity distractor.

To verify the level of similarity of each distractor to its standard, we collected ratings from 24 University of Illinois students for each standard paired separately with its high- and low-similarity distractors. Students rated 20 pairs for similarity by using a scale with points ranging from 1 (*very dissimilar*) to 5 (*very similar*), with a given standard paired with one distractor appearing on a separate page from the standard paired with the other distractor to prevent context effects.

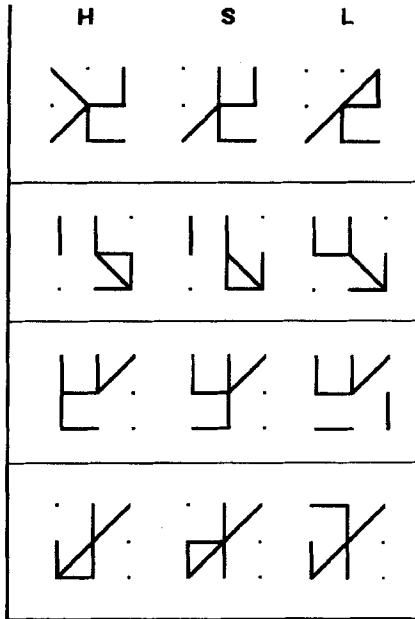


Figure 5. Sample stimuli used in the same-different task for Experiment 2. H indicates the high-similarity distractor; S indicates the standard figure; L indicates the low-similarity distractor.

The standard-high-distractor similarity pairs ($M = 3.6$) were rated as significantly more similar than the standard-low-distractor similarity pairs ($M = 2.6$), both by subjects, $t(23) = 8.3$, and by items, $t(9) = 6.0$, thereby verifying the validity of the high- and low-similarity distinction.

Design

There were three within-subject variables: response (same or different), pair type (4), and figures (10), yielding a total of 80 trials. The pair-type variable was nested within response and defined how the pairs of stimuli were constructed. More specifically, for different trials, pair type referred to pairing the standard with each of the distractors, yielding the following four types of pairs: a standard and high-similarity distractor with either the standard (SH) or the distractor (HS) presented first, and a standard and low-similarity distractor with either the standard (SL) or the distractor (LS) presented first. For same trials, pair type referred to whether the standard was compared against itself or a distractor was compared against itself. The levels were pairing a high-similarity distractor with itself (HH); a low-similarity distractor with itself (LL); and the standard against itself (SS). To have a fourth level for the same responses, we presented the SS comparison twice for each figure, following S. Palmer (1978).

Finally, as in Experiment 1, there was a within-subject blocking variable with four levels that defined the two eye movement conditions (retinal overlap and spatial overlap) and the two no-eye movement conditions (retinal and spatial overlap and no-overlap) that are the overlap conditions. In all, each participant took part in four blocks of 80 trials each, yielding 320 trials total. Two of these blocks were eye movement trials, and the other two blocks were no-eye movement trials. All participants performed eye movement trials before no-eye movement trials.

Procedure

The size of the displays was the same as in Experiment 1, and the same equipment from Experiment 1 was used. Each participant took

part in four experimental sessions, preceded by an initial practice session, for which the purpose was the same as in Experiment 1, using a set of stimuli that did not appear in the experimental sessions.

Eye movement trials. Participants performed 40 trials in each of the eye movement conditions. Briefly, each trial began with a calibration routine followed by the presentation of the first figure. In the retinal overlap condition, on initiation of a saccade, the first figure was removed and the second figure displayed immediately, as in Experiment 1 (see Figure 4A). In the spatial overlap condition, on initiation of the saccade, the first figure was removed and a 42-ms blank interval ensued before the presentation of the second figure.⁴ For the retinal overlap condition, response time was calculated from the onset of the saccade until the same or different response. In the spatial overlap condition, response time was calculated from the presentation of the second figure to the response. To facilitate comparisons between conditions, we added an estimated average saccade duration (42 ms) to the response times for this condition.

The criteria for considering a trial acceptable were the same as in Experiment 1. In all, 73% of the trials were acceptable. Significantly more trials were acceptable in the spatial overlap condition ($M = 88\%$) than in the retinal overlap condition ($M = 58\%$), $t(10) = 4.1$, mostly because of the difficulty participants had with moving off of the foveally presented figure and in landing accurately on the saccade target (+) in the retinal overlap condition.

No-eye movement trials. Participants performed 40 trials in each of the no-eye movement conditions. The sequences of trial events for the retinal and spatial overlap no-eye movement condition and for the no-overlap no-eye movement condition were the same as in Experiment 1 (refer to Figure 4C and 4D, respectively). Very briefly, each trial began with a calibration routine, after which participants maintained fixation at a center point for the remainder of the trial. The first stimulus was presented for a duration that was determined by the mean saccade latency obtained in the relevant eye movement condition. For the retinal and spatial overlap condition, the saccade latency from the retinal overlap condition ($M = 532$ ms) was used because the presentation of the first stimulus was foveal in each case. For the no-overlap condition, the saccade latency from the spatial overlap condition ($M = 463$ ms)⁵ was used, because the presentation of the first stimulus was peripheral in each case. A blank interval of 42 ms followed, after which the second part was presented at fixation. Response time was measured from the presentation of the second

⁴ The addition of a 42-ms blank interval between stimulus presentations was made because a sense of apparent motion was present during the saccade (i.e., saccadic suppression was not complete) without the delay. Because this motion was informative as to the correct response (e.g., a different trial), it was an artifact that had to be avoided. The results of an additional retinal overlap condition with a 42-ms blank interval did not differ from the results of the retinal overlap condition without the 42-ms blank interval that are reported in the text. In the eye movement conditions of Experiment 1 we did not use a blank interval, but apparent motion would not be informative in this experiment because the parts only had three line segments in common with the six segment figures. In addition, the most straightforward predictions for goodness effects in Experiment 1 were for the yes responses, trials in which apparent motion would not be present.

⁵ The mean saccade latency ($M = 463$ ms) used as the first figure duration in the no-overlap condition was actually taken from a spatial overlap condition in which the 42-ms blank interval between stimulus presentations was not included. This mean was calculated across acceptable and unacceptable trials after excluding trials for which the saccade latency was less than 100 ms. The corresponding mean saccade latency for the reported spatial overlap condition was 413 ms. These saccade latencies did not significantly differ, $t(10) = 1.8$, $p = .10$.

figure to the response. The simulated saccade duration (42 ms) was added to the response times to facilitate comparisons with the eye movement conditions.

The criteria for trial acceptability was the same as in Experiment 1. In all, 79% of the trials were acceptable. There was no significant difference in the percentage of acceptable trials between the retinal and spatial overlap condition ($M = 77\%$) and the no-overlap condition ($M = 81\%$), $t(10) < 1$.

Results and Discussion

The results are presented as follows. Results of a 4 (overlap conditions) \times 2 (part goodness) repeated measures ANOVA calculated on both error rates and response times for the different responses are presented first because these analyses permitted both an evaluation and a comparison of the use of structural descriptions across eye movement and no-eye movement conditions. Then, the results of the same responses are presented for completeness. Significant effects that did not directly address the use of structural descriptions are not discussed. The response time data include only those acceptable trials for which the participant responded correctly.

Different Responses

The mean error rates and response times for the different responses, broken down by overlap conditions and pair type (SH and SL), are shown in Table 2.

Error rates. There was a significant main effect of structural similarity, $F(1, 10) = 44.7$, $MSE = 31$, a significant main effect of overlap conditions, $F(3, 30) = 3.9$, $MSE = 70$, and a significant interaction between structural similarity and overlap conditions, $F(3, 30) = 3.5$, $MSE = 53$. A 95% confidence interval constructed to further explore this interaction showed that a minimum difference of 7% was required for significance. The structural similarity effect for the no-overlap no-eye movement condition ($M = 15\%$) differed significantly from the structural similarity effects in both the retinal and spatial overlap no-eye movement condition ($M = 1\%$) and the spatial overlap eye movement condition ($M = 6\%$). In addition, the

structural similarity effect in the retinal and spatial no-eye movement condition ($M = 1\%$) was significantly smaller than that in the retinal overlap eye movement condition ($M = 9\%$). In interpreting these differences, it is important to note that the two conditions that preserve spatial overlap (the spatial overlap eye movement condition and the retinal and spatial overlap no-eye movement condition) show little to no evidence of the use of structural descriptions because the structural similarity effects are smaller than the confidence interval. Thus, on the basis of the error data, the use of structural descriptions can only unambiguously be attributed to the retinal overlap eye movement ($M = 9\%$) and the no-overlap no-eye movement ($M = 15\%$) conditions. In these two conditions, the structural similarity effects were not significantly different.

Response times. For the response times, there was a significant main effect of structural similarity, $F(1, 10) = 22.8$, $MSE = 2,025$, a significant main effect of overlap conditions, $F(3, 30) = 6.6$, $MSE = 13,020$, and a marginally significant interaction between structural similarity and overlap conditions, $F(3, 30) = 2.2$, $MSE = 1,199$, $p > .10$. A 95% confidence interval constructed to further explore this interaction showed that a minimum difference of 32.5 ms was required to obtain significance. Thus, the size of the structural similarity effect was smaller in the retinal and spatial overlap no-eye movement condition ($M = 15$ ms) than in either the no-overlap no-eye movement condition ($M = 56$ ms) or the spatial overlap eye movement condition ($M = 66$ ms). Note that the size of the structural similarity effect in the retinal and spatial overlap no-eye movement condition is smaller than the confidence interval, thus providing no evidence for the use of structural descriptions in that condition. However, for the other three conditions, the size of the structural similarity effects exceeded the confidence interval; moreover, the structural similarity effects in these conditions did not differ significantly from one another. Thus, these findings provide some support for the hypothesis that the use of structural descriptions to retain information transsaccadically in the two eye movement conditions is similar to its use within a fixation in the no-overlap no-eye movement condition.

Same Responses

The mean error rates and response times for acceptable same trials, broken down by overlap conditions and pair type (SS, HH, and LL), are shown in Table 3.

Error rates. According to many different accounts (structural descriptions, wholistic comparison, and segment based), there should be no significant differences across pair types. A one-way ANOVA with pair type as a variable revealed no main effect of pair type (e.g., SS, HH, and LL) for the spatial overlap eye movement and no-overlap no-eye movement conditions ($F < 1$). For the retinal overlap eye movement condition and the retinal and spatial overlap no-eye movement condition, errors occurred only in two of the pair-type conditions. Analyses comparing these conditions revealed no significant differences due to pair type ($ts < 1.5$).

Table 2
Mean Response Times (RTs; in Milliseconds) and Error Rates (ERs; in Percentages) for Different Trials by Overlap Condition and Pair Type for Experiment 2

Overlap condition	Different pair type				Difference (H - L)	
	SH		SL		RT	ER
	RT	ER	RT	ER		
Eye movement conditions						
Retinal	696	11	650	2	46	9
Spatial	717	8	651	2	66	6
No-eye movement conditions						
Retinal and spatial	584	2	569	1	15	1
No overlap	646	18	590	3	56	15

Note. SH = trials comparing a standard against a high-similarity distractor, regardless of order of presentation; SL = trials comparing a standard against low-similarity distractor, regardless of order of presentation; H = high; L = low.

Table 3
Mean Response Times (RTs; in Milliseconds) and Error Rates (ERs; in Percentages) for Same Responses by Overlap Condition and Pair Type for Experiment 2

Overlap condition	Same pair type						Mean	
	SS		HH		LL			
	RT	ER	RT	ER	RT	ER	RT	ER
Eye movement conditions								
Retinal	638	1	644	9	646	0	643	3
Spatial	631	4	664	3	687	4	661	4
No-eye movement conditions								
Retinal and spatial	506	3	511	0	520	3	512	2
No overlap	580	4	586	9	601	4	589	6

Note. SS = trials comparing a standard against itself; HH = trials comparing a high-similarity distractor against itself; LL = trials comparing a low-similarity distractor against itself.

Response times. Similarly, a one-way ANOVA with pair type as a variable revealed no main effect of pair type on the response times, $F(2, 20) = 1.8, p > .19$.

The results of Experiment 2 demonstrate the use of structural descriptions when two figures are presented within the same fixation, as shown by significant structural similarity effects in the error rates and response times for the no-overlap condition. Structural descriptions were also used when the presentations of the two figures were interrupted by an eye movement, as demonstrated by a significant structural similarity effect in both the error rates and response times in the retinal overlap condition, and in the response times only in the spatial overlap condition. In addition, the size of the structural similarity effects did not significantly differ across the two eye movement conditions, despite the peripheral presentation of the first figure in the spatial overlap condition and the foveal presentation of the first figure in the retinal overlap condition. Moreover, comparing across similar retinal events, there were no significant differences in the response times in the size of the structural similarity effect between the spatial overlap condition and the no-overlap condition. This suggests that there was no detrimental effect of the saccade on the storage, retention, or retrieval of the structural descriptions in these conditions; structural descriptions were used in the same fashion transsaccadically as within a single eye fixation. These findings thus lend more credence to Irwin's (1991) claim that the memory that operates across eye movements may be the same as visual short-term memory. In addition, these data are consistent with the pattern found by Irwin et al. (1990), in which accuracy for a condition in which retinal and spatial location were preserved was significantly higher than accuracy for conditions with retinal overlap, spatial overlap, or no-overlap across stimulus presentations, and thus suggest that the encoding of visual information in the form of structural descriptions was location independent.

In contrast, for the retinal and spatial overlap no-eye movement condition, the nonsignificant structural similarity effects in both the response times and error rates might be attributed to the use of an alternative strategy that is sensitive to the maintenance of retinal and spatial information. Partici-

pants spontaneously offered that they found this condition the easiest and indicated that they could determine that two figures were different whenever they saw a line segment move. The perception of apparent motion is not surprising here because the timing parameters used in this condition are appropriate for creating an impression of motion (e.g., Anstis, 1980; Braddick, 1980). Therefore, it seems plausible that participants may have used apparent motion on some proportion of the trials, which significantly diminished or eliminated the structural similarity effect. This point is further addressed in the General Discussion section.

Experiment 3

In an effort to provide additional converging evidence for the transsaccadic use of structural descriptions, we used in Experiment 3 a mental synthesis task that explicitly required integration across a saccade. The basic task involved presenting a participant with one part in one fixation and a second part in another fixation that were to be mentally synthesized to form a single whole figure. The time required for this transsaccadic synthesis was recorded. When the participant indicated that the synthesis was complete, a whole figure was presented, and the participant indicated whether it matched the imagined synthesized figure. This verification time was also recorded.

As in Experiment 1, the goodness of a set of parts was varied to determine if it affected how quickly and accurately the two parts could be synthesized into a whole figure. If structural descriptions can be used in transsaccadic memory, as suggested by Experiments 1 and 2, then synthesizing a figure from a good set of parts should be faster and more accurate than synthesizing a figure from a bad set of parts. If structural descriptions are not used in transsaccadic memory, then there should be no goodness effect on the synthesis time because it should take about the same amount of time to synthesize a set of six line segments, regardless of whether they form sets of good or bad parts.

In addition, a significant goodness effect was expected in the verification times. Using a mental synthesis task, S. Palmer (1977) found that a figure made from a good set of parts was verified more quickly than a figure made from a bad set of parts. In a task requiring whole and part comparisons, Ankrum and J. Palmer (1991) found that comparisons of pairs of whole stimuli were made faster and more accurately than comparisons of pairs of parts and wholes. Thus, if the goodness effect operates on part synthesis such that a more complete image will be made for the good parts than for the bad parts (because the good parts are easier to synthesize), then verification of this more complete image against a second whole image should be faster than verification of a less complete image that may be represented only in terms of its parts (see also Thompson & Klatzky, 1978). Thus, a goodness effect in the same direction as that found in the synthesis response times may be found. Note that such a goodness effect would be consistent with the structural similarity effect found in Experiment 2, when two whole figures were compared. However, the underlying reason for the effects differs in the two experiments. In Experiment 2, a difference in structural similarity accounted for the effect. In Experiment 3, all distractors were structurally similar to the

figures emerging from the synthesized parts, as described below; therefore, any goodness effect would be attributable to a difference in the effectiveness of the mental synthesis. Ideally, if synthesis of the parts were complete before the presentation of the comparison figure, then there would be no effect of part goodness on the verification latencies.

Finally, only eye movement conditions were used in this experiment for the following reasons. First, because of the small size of the stimulus set (as indicated below), there was concern that learning of the parts and figures would occur across the overlap conditions. Because the no-eye movement trials were yoked to the eye movement trials, they would necessarily be run after participants had taken part in 128 eye movement trials, with 16 repetitions of each figure. Second, the durations of the eye movement trials were much longer in this experiment than in Experiments 1 and 2 because of the need to synthesize the parts into a whole and then make a verification decision; trials typically lasted between 2 and 4 s. For no-eye movement trials, participants would have to maintain constant fixation for this duration. Pilot data using such timing parameters for no-eye movement trials revealed that very few trials could be counted as acceptable as a result of participants' making small eye movements around the parts, making eye movements while attempting to synthesize, and blinking. Third, Experiments 1 and 2 showed few differences between eye movement and no-eye movement conditions in the use of structural descriptions, so it seemed less important to examine it in this experiment.

Method

Participants

Thirteen people from the University of Illinois community participated in Experiment 3, 11 of whom had participated in Experiments 1 and 2. They were paid \$5 for each hour of their participation. The data from 2 of these participants were not included because of a high number of unacceptable trials that led to missing data in some conditions.

Stimuli

The stimuli were based on the description of stimuli used in the mental synthesis task of S. Palmer (1977, Experiment 4). Sixteen connected figures with obvious organizations into two three-segment parts were constructed from the set of line segments illustrated in Figure 2 and were paired into eight sets, with the requirement that the figures in a pair have similar structures; thus, the figures in each pair were high-similarity distractors, using the terminology from Experiment 2. For each figure, two pairs of three-segment parts were identified. One pair corresponded to the obvious organization of the figure into parts and was referred to as the good set of parts. The second pair was referred to as the bad set of parts and was constructed by identifying two internally disconnected three-segment parts that differed from the organization represented by the good parts. The yes trials paired the parts with the figure from which they were identified. The no trials paired the parts of one figure with the other figure in the set. This resulted in each pair of parts and each figure being represented equally often in the yes and no trials. Sample parts and figures appear in Figure 6, in which each row illustrates a pair of figures that is structurally similar, with a segmentation of each figure into good and bad sets of parts.

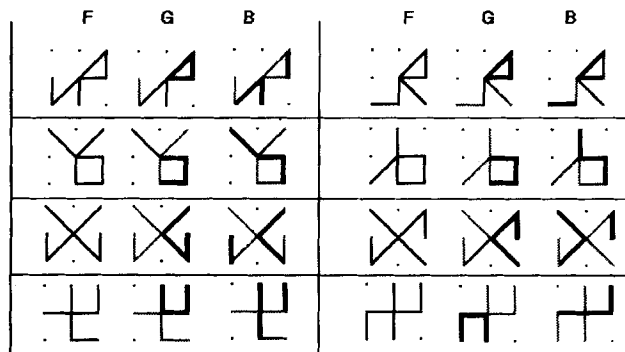


Figure 6. Sample paired stimuli used in the mental synthesis task in Experiment 3. For some trials, the parts were presented with the appropriate figure. For different trials, the parts were presented with the other figure in the paired set. The two three-segment parts are distinguished by dark and light lines. F indicates the figure; G indicates a set of good parts; B indicates a set of bad parts.

To verify the level of goodness of each set of parts, we collected ratings from 24 University of Illinois students. Students rated the goodness of the segmentation of 16 different figures paired separately with a good and a bad set of parts. The goodness of 32 such pairs was rated by using a scale with points ranging from 1 (*very bad segments*) to 5 (*very good segments*); identical sets of parts appeared on separate pages to prevent context effects. Overall, the good parts ($M = 4.0$) received significantly higher ratings than the bad parts ($M = 2.5$), both by subjects, $F(1, 23) = 42.7$, $MSE = 1.3$, and by items, $F(1, 14) = 15.9$, $MSE = 0.112$, thereby validating the classification of parts as good and bad.

Design

On the basis of the stimulus construction, there were three within-subject variables: level of goodness (good or bad), response (yes or no), and stimulus figures (16), yielding 64 experimental trials. In addition, there was a within-subject blocking variable that defined the two eye movement conditions (retinal overlap and spatial overlap) that are the overlap conditions. In all, each participant took part in two blocks of 64 trials each, yielding 128 trials total.

Procedure

The same display sizes and equipment were used as in Experiment 1. Participants took part in one experimental session, at the beginning of which they went through multiple sets of practice trials on stimuli that were not used in the experimental trials to familiarize themselves with the integration task.

For the experimental trials, the general sequence of events followed those used in Experiments 1 and 2 and is illustrated in Figure 7. Briefly, on successful calibration, the participant fixated a central fixation point. The first part was presented either foveally (in the retinal overlap condition; see Figure 7A) or peripherally (in the spatial overlap condition; see Figure 7B). After viewing the first part, the participant initiated an eye movement to the target in the periphery (either the part or the plus sign in the retinal overlap condition). On detection of the saccade, the first part was erased, and a blank screen was presented for 42 ms. The second part then appeared at the target location, and participants were instructed to mentally synthesize the two parts into a whole figure. They were told to maintain steady fixation during synthesis and to press either hand-held switch when the synthesis was complete. After this response, a blank interval of 500 ms

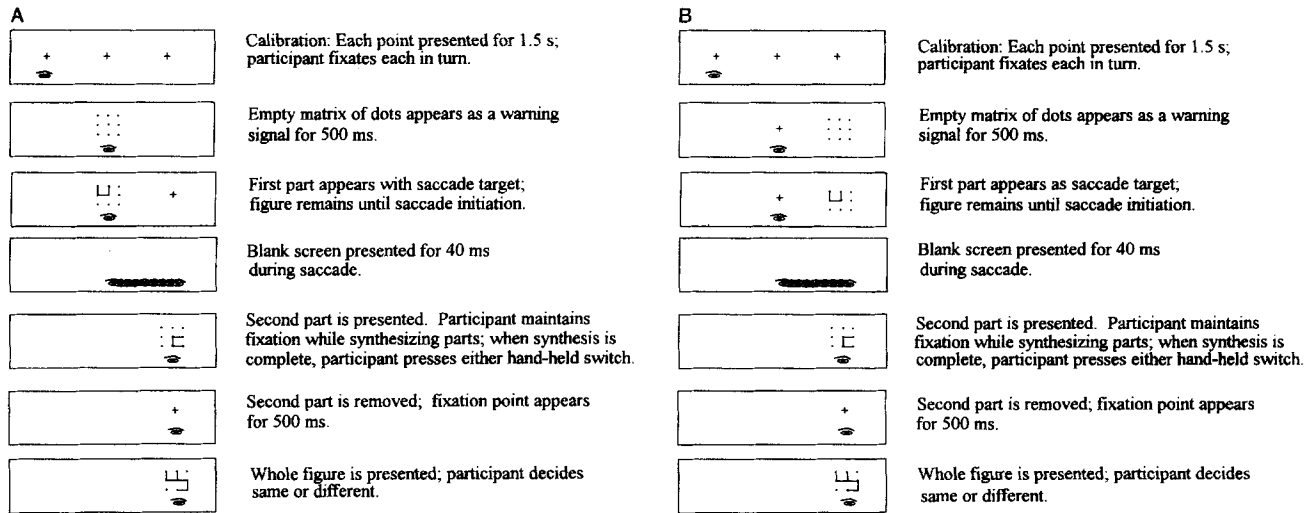


Figure 7. Sequence of events in Experiment 3. A and B show, respectively, a retinal overlap trial and a spatial overlap trial.

ensued with a fixation point, followed by the presentation of a whole figure. Participants were told to decide as quickly but as accurately as possible whether the figure was the same as the synthesized figure by pressing the appropriate hand-held switch.

The criteria for an acceptable trial were the same as in Experiments 1 and 2. Overall, 63% of the trials were considered acceptable. There were significantly more acceptable trials in the spatial overlap condition (76%) than in the retinal overlap condition (49%), $t(10) = 6.8$, mostly because of the greater difficulty participants had in removing their eyes from the foveally presented part and landing within 3° of the saccade target.

Results and Discussion

Results are presented as follows. First, results of a 2 (overlap conditions) \times 2 (level of goodness) repeated measures ANOVA conducted on the synthesis times are presented. Then, results from similar 2 \times 2 ANOVAs conducted on the error rates and response times for the yes and no responses are separately presented because these are the most relevant for evaluating the use of structural descriptions across fixations. Significant effects that did not directly address the use of structural descriptions are not discussed.

Synthesis Times

Mean synthesis times collapsed across response appear in Table 4, broken down by overlap conditions. Following S.

Table 4
Synthesis Time (in Milliseconds) by Overlap Condition and Part Goodness for Experiment 3

Overlap condition	Part goodness		Goodness effect
	Good	Bad	
Retinal	818	917	99
Spatial	818	832	14

Palmer (1977), we ignored type of responses (same or different) for these analyses because from the participant's perspective a trial could only be classified as same or different after synthesis was complete and the whole figure was presented for comparison.

There was no main effect of level of goodness, $F(1, 10) = 1.8$, $MSE = 19,904$, $p > .21$, although synthesis times for sets of good parts were faster ($M = 818$ ms) than for sets of bad parts ($M = 875$ ms). In addition, there was no main effect of overlap conditions and no interaction between overlap conditions and level of goodness ($F_s < 1$). There was a lot of variability in both the number of participants who showed a goodness effect in the synthesis times and in the sizes of the goodness effects. For the retinal overlap condition, 6 participants demonstrated a goodness effect, with a range of 36 to 790 ms. For the spatial overlap condition, 3 participants demonstrated a goodness effect, with a range of 10 to 426 ms. Finally, the mean synthesis times were surprisingly fast—S. Palmer's (1977) were on the order of 4 s. This suggests that either our participants did not follow instructions to synthesize completely the parts before responding or the sequential presentation of the two parts made the task more difficult, as compared with S. Palmer's task that used simultaneous presentation.⁶

Yes Verification Responses

Mean error rates and response times for yes trials for each overlap condition appear in Table 5.

Error rates. There was a main effect of level of goodness, $F(1, 10) = 8.7$, $MSE = 511$, such that verifying that a synthesized figure was the same as a presented figure was done significantly more accurately when the synthesized figure was constructed from a good set of parts ($M = 16\%$) than when it was constructed from a bad set of parts ($M = 37\%$), consistent

⁶ We thank Steve Palmer for raising this alternative.

Table 5
Mean Response Times (RTs; in Milliseconds) and Error Rates (ERs; in Percentages) by Overlap Condition, Part Goodness, and Response for Experiment 3

Response	Part goodness				Goodness effect	
	Good		Bad		RT	ER
	RT	ER	RT	ER		
Retinal overlap eye movement condition						
Yes	955	15	1,298	33	343	18
No	1,073	20	1,252	24	179	4
Spatial overlap eye movement condition						
Yes	901	17	1,240	40	339	23
No	1,090	30	1,164	36	74	6

with the use of structural descriptions. There was no main effect of overlap conditions and no interaction between overlap conditions and level of goodness ($F_s < 1$).

Response times. There was a significant main effect of level of goodness, $F(1, 10) = 17.7$, $MSE = 72,390$, with verifications involving figures synthesized from good parts performed significantly faster ($M = 928$ ms) than verifications involving figures synthesized from bad parts ($M = 1,269$ ms). There was no main effect of overlap conditions and no interaction between overlap conditions and level of goodness ($F_s < 1$).

No Verification Responses

Mean error rates and response times for no responses for each overlap condition appear in Table 5.

Error rates. There was no main effect of level of goodness ($F < 1$). There was a marginally significant effect of overlap conditions, $F(1, 10) = 3.3$, $MSE = 399.7$, $p = .10$, with more errors in the spatial overlap condition ($M = 33\%$) than in the retinal overlap condition ($M = 22\%$). There was no interaction between overlap conditions and level of goodness ($F < 1$).

Response times. There was a significant main effect of level of goodness, $F(1, 10) = 5.6$, $MSE = 31,621$, such that determining that the synthesized figure was different than the presented figure took significantly longer when the synthesized figure was constructed from bad parts ($M = 1,208$ ms) than when it was constructed from good parts ($M = 1,082$ ms). There was no main effect of overlap conditions ($F < 1$) and no interaction between overlap conditions and level of goodness, $F(1, 10) = 1.6$, $p > .23$, suggesting the use of structural descriptions as the basis of comparison in both the retinal overlap condition and the spatial overlap condition.

In combination, the data for the synthesis and verification latencies indicated that participants may not have followed directions to synthesize the parts into a complete whole before the presentation of the comparison figure. If they had, significant goodness effects would have been found in the synthesis latencies but not in the verification latencies. Instead, there was no significant effect of part goodness on the synthesis latencies, but there was a significant part goodness effect in the verification latencies. Alternatively, it could be that participants had a difficult time synthesizing the two parts because

they were sequentially presented rather than simultaneously presented. Nevertheless, the pattern of verification latencies replicated S. Palmer (1977), and coupled with the error rates, indicated the difficulty participants had in synthesizing the low goodness parts. One possible explanation for our results is the following. Ankrum and J. Palmer (1991) found that whole figure-whole figure comparisons were performed faster than part-whole comparisons. It could be that participants in our experiment were synthesizing the high goodness parts completely and the low goodness parts incompletely, thus leading to a faster whole-whole comparison in the former case and a slower part-whole comparison in the latter case (see also Thompson & Klatzky, 1978). Nevertheless, the fact that participants could perform this mental synthesis task with accuracy well-above chance indicates that a representation of the first part survived the saccade and, at some point, was compared in conjunction with the second part, either as a set of parts or as an imperfectly synthesized whole, against the presented figure. This is consistent with the findings of Experiment 1, in which a similar stimulus (a three-segment part) was successfully retained across an eye movement.

In terms of the synthesis latencies, these data do not discriminate between the possibility that participants could not integrate the parts into a coherent figure or the possibility that participants did not fully attempt integration before the presentation of the comparison figure. As noted earlier, the synthesis latencies for S. Palmer's (1977) participants were considerably longer than those observed here; nevertheless, his participants showed evidence of part goodness effects in the verification latencies. This suggests that integration of bad parts is quite difficult, even given long synthesis latencies.

General Discussion

Considerable evidence has shown that visual information is not stored across a saccade in a point-by-point fashion (e.g., Irwin, 1992a) but may be retained within a more abstract representation (e.g., Irwin, 1991; Irwin, 1992b; Pollatsek et al., 1990). Such an abstract representation could be a structural description (Gottschildt, 1926/1967; S. Palmer, 1977; Sutherland, 1968). In Experiments 1-3 we used different tasks and sets of stimuli with different properties to determine whether structural descriptions are a representational format that can be used to retain visual information transsaccadically. In Experiments 1 and 2 we used eye movement and no-eye movement conditions to compare the retention of visual information within a single fixation with the retention of visual information across an eye movement.

A part-whole verification task was used in Experiment 1 and showed significant effects of part goodness, in which good parts were believed to be selectively encoded as units within a structural description of the figure, and bad parts as individual segments dispersed through the hierarchy. The goodness effects were present in all conditions and were of comparable magnitude for the yes response times and errors for the two eye movement conditions and for the retinal and spatial overlap no-eye movement condition, suggesting both that structural descriptions could be used transsaccadically and that such transsaccadic use did not significantly differ from use

within a single eye fixation. For the no responses, there was some evidence for significant goodness effects in the eye movement conditions but not in the no-eye movement conditions.

The results from Experiment 2, in which we used a same-different discrimination task, were consistent with those from Experiment 1. For different responses, significant structural similarity effects were found in the response times and error rates for the eye movement conditions and for the no overlap no-eye movement condition. Moreover, there was no difference in the size of the structural similarity effect among the two eye movement conditions and the no-overlap no-eye movement condition, suggesting the use of a location-independent memory that operates both within and across fixations, which is consistent with the findings of Irwin et al. (1990).

Finally, in Experiment 3 we used a mental synthesis task that required explicit integration of information presented in separate eye fixations as a further test of the use of structural descriptions transsaccadically. Significant goodness effects were found in the verification latencies, consistent with the findings of S. Palmer (1977). However, surprisingly, there were no significant goodness effects in the synthesis latencies.

One conclusion that can be drawn from these experiments is that structural descriptions can be used to represent information transsaccadically. Given these findings, a logical next step would be to identify whether structural descriptions are involved in the transsaccadic retention of meaningful parts of meaningful stimuli, by using object parts, in the form of geons or generalized cones (see Biederman, 1987; Marr & Nishihara, 1978) that together form meaningful objects, and by using letter feature parts that form letter strings. It is possible that the difficulty that participants had with synthesizing the parts in Experiment 3 was due to the nonmeaningful nature of the stimuli. Better performance might be observed if a recognizable structure emerged from the set of meaningless (Thompson & Klatzky, 1978) or meaningful parts (Klatzky & Thompson, 1975). Alternatively, it could be the task demands rather than the nature of the stimuli that were responsible for the participants' failed performance. O'Regan and Levy-Schoen (1983) showed that participants could not fuse two sets of line segments that were transsaccadically presented to detect the meaningful letter strings that the parts formed. Perhaps the difficulty of the task was because it required the fusion of stimuli rather than a comparison of stimuli. Consistent with this, Irwin et al. (1983) found that participants could not fuse two halves of a dot matrix to detect the location of a missing dot, whereas Irwin (1991; see also Irwin et al., 1990) found that participants could compare two dot matrices transsaccadically to determine whether they were the same or different.

A second conclusion to be drawn from our results is that transsaccadic memory and visual short-term memory appear to use structural descriptions in much the same way. These findings lend support to the idea that there is nothing unique about transsaccadic memory; rather, the term is a convenient way to classify investigations of visual short-term memory as used across a saccade. What would be required to conclude that these memory stores are different? As suggested in the introduction, any consequence of executing an eye movement on the retention, storage, or retrieval of information could be grounds for concluding that a different memory store exists for

within-fixation and across-fixation processing, despite the similarity of more formal properties of the memory stores, such as their duration and capacity. A different conclusion could be that visual short-term memory and transsaccadic memory are the same, but that there is an effect of making a saccade on the way in which information is retained. The debate centers around the defining properties of a memory store and whether the representational format of information stored therein should be included as a parameter along with such properties as capacity and duration. The results of our experiments do not address this question because they consistently showed the absence of a difference between the two memory stores in the way that information was encoded, retained, or retrieved. Given Irwin's (1991) findings that such defining parameters of transsaccadic memory as its capacity and its duration are the same as for visual short-term memory, coupled with these findings that the representation of structured information is the same both within and across fixations, the conclusion that the memory stores are the same seems quite strong at this point.

Are Structural Descriptions Necessary?

An interesting finding from Experiment 2 was the nonsignificant structural similarity effect in the retinal and spatial overlap no-eye movement condition. This suggests the use of an alternative comparison strategy to structural descriptions. Both phenomenological experience and spontaneous comments by participants indicated that apparent motion was present in this condition and could be used to detect a difference between the two figures. Because both the low- and the high-similarity distractors had five out of six line segments in common with the standard figure, a comparison strategy that is based on the detection of a discrepant segment would operate similarly for either type of distractor; hence, no structural similarity effects in either the response times or error rates would be found. Such a strategy may also have been used in S. Palmer's (1978) same-different task. He had two conditions: one in which two figures were simultaneously presented side by side, and one in which the two figures were sequentially presented in the same spatial location. He found significant structural similarity effects with both types of presentation; however, the size of the structural similarity effect in the sequential presentation condition was significantly smaller (on the order of 50 ms) than the size of the structural similarity effect in the simultaneous presentation condition (on the order of 300 ms).

It is also possible that the lack of a goodness effect in the retinal and spatial overlap condition was not due to a strategy change per se but was based on the parallel processing of both low-level visual information and structural descriptions. According to this account, gross changes to the low-level information would be processed faster than changes in the structural description, and participants' responses in the retinal and spatial overlap condition could have been made on the basis of the detection of such a low-level change. Presumably such low-level information would not be available in the other overlap conditions.⁷

⁷ We thank Alexander Pollatsek for bringing this possibility to our attention.

In either case, these findings would indicate that the use of structural descriptions is not a necessary consequence of encoding and retaining a structured stimulus. Rather, under certain conditions, other strategies may be used that do not make use of the structure apparent in the stimulus. Indeed, other research has shown good retention of visual information without an identifiable structure, such as the complex dot matrices used by Irwin (1991). If so, what representational form is made use of, and where is such information retained?

Informational Persistence Within and Across Fixations

Isolated phenomena have appeared in the literature that indicate something special about conditions in which spatial overlap is maintained across an eye movement. For example, phenomenologically, a sense of apparent motion was present in the spatial overlap eye movement condition of the same-different discrimination task of Experiment 2. This was weaker than the sense of motion in the retinal and spatial overlap no-eye movement condition but was nonetheless salient. Similarly, Pollatsek et al. (1984) reported a looming effect of motion between two pictures that were presented in separate eye fixations when the pictures differed in size by more than 10%. In addition, Irwin (1992c) found a masking effect at his shortest interstimulus interval (40 ms) when a mask probe overlapped spatially with the location of a letter in a transsaccadic partial report task. Similarly, in a dot matrix comparison task, Irwin (1991) found an effect of pattern displacement in a spatial overlap eye movement condition with a 70-ms interstimulus interval (Experiment 2); however, this finding did not hold up in a more systematic replication (Experiment 3). Finally, McRae, Butler, and Popiel (1987) found evidence for spatiotopic masking and retinotopic masking in a full-report letter identification task.

What representational store could mediate the use of spatial information? As mentioned earlier, visual memory has been divided into sensory persistence, informational persistence, and visual short-term memory. The intent of these experiments has been to examine the use of a specific representational format in visual short-term memory and transsaccadic memory. However, it is possible that informational persistence could also be used within and across fixations, as suggested by Irwin (1992b). A relevant property of informational persistence is that it has a duration of between 150 and 300 ms after stimulus offset (Irwin & Yeomans, 1986; Irwin & Brown, 1987); given typical saccade durations of 40 ms, informational persistence from one fixation would still be available well into the start of a second fixation. Thus, under some conditions, informational persistence may operate either in place of or in addition to visual short-term memory. Further investigation of the use of informational persistence and its possible role in transsaccadic integration is planned.

Independence of Form and Position

The results of Experiments 1–3 suggest that structural descriptions are not necessarily encoded with respect to spatial or retinal location. The location independence of these representations is consistent with the speculations of a number of

investigators (e.g., Cave et al., 1994; Hummel & Biederman, 1992; Irwin, 1992b; Kosslyn, Flynn, Amsterdam, & Wang, 1990; Pollatsek et al., 1990). For example, in a recent model by Kosslyn et al. (1990), processing of visual information proceeds from a visual buffer to parallel encodings of object properties and spatial properties. The components of a stimulus are identified within the object properties module, and the relations between the components are represented within the spatial properties module, in the form of categorical relations. The relevance of such a model to the use of structural descriptions identified in these experiments is in the flexibility of the model to process a stimulus as a whole or as a set of multiple parts. The representation of the stimulus as a whole corresponds to the top node within a hierarchical description of the stimulus, and more holistic or global comparisons can be made at this level. The set of multiple parts and their relations and the mechanisms used to identify parts separately correspond to a decomposition of the stimulus into a hierarchical representation of the stimulus.

For the present, the current experiments provide important information about the extent and the form of visual information that is retained in transsaccadic memory. Evidence was found for the retention of abstract visual information in the form of structural descriptions both within and across fixations. As such, the results lend considerable support to the claim that transsaccadic memory may in fact be the same as visual short-term memory (Irwin, 1991).

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