

Amodal Completion of Partly Occluded Surfaces: Is There a *Mosaic* Stage?

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Recent investigators have proposed that amodal completion is a sequential process requiring a preliminary *mosaic* stage. Results of 6 studies of the time course of completion processes show support for this mosaic-first view with pictorial displays, but not with displays involving occlusion specified by binocular parallax or when pictorial displays were observed monocularly. These results still do not rule out the mosaic-first view. A parallel model, however, can account more economically for the available data.

In our three-dimensional world of opaque surfaces, objects are continuously occluded. Yet, object recognition is generally successful and effortless. Phenomenological studies of amodal completion, which is the experience associated with surface parts that are not directly represented in any sensory modality (Michotte, Thinès, & Crabbé, 1967), rule out categorizing, memory, or imagination (Metzger, 1941; Kanizsa, 1985; Kanizsa & Gerbino, 1982). Early in processing, the perceptual representation of a partly occluded surface proves similar to that of a fully visible, complete surface (Behrman, Zemel, & Mozer, 1994; Bruno & Gerbino, 1987; Gerbino, 1981; Gerbino & Salmaso, 1987; Sekuler & Palmer, 1992). How is this achieved?

According to a widely held view, amodal completion is a two-stage sequential process (Rock, 1983; Sekuler & Palmer, 1992). In the first stage, a literal description of the visible part of an occluded surface (usually called *mosaic*) is produced. This initial two-dimensional representation is evaluated on the basis of constraints (spatial and otherwise). In the second stage, the occluded surface is completed. We call this the *mosaic-first view*. The mosaic-first view predicts a specific temporal asymmetry. The mosaic should be achieved first. After the mosaic is achieved, the system

should continue processing until it reaches the representation of the occluded surface as complete. This asymmetry renders the mosaic-first view empirically testable.

Sekuler and Palmer (1992) developed a primed matching paradigm for investigating the time course of amodal completion. They presented brief priming patterns followed by two simple shapes that had to be classified as same or different. Priming patterns included complete figures, truncated figures (called *mosaic primes*), or occluded figures having visible parts that were geometrically congruent with the truncated figures. Occluded primes yielded priming effects that were more similar to those of complete primes than mosaic primes. This is the familiar finding that the perceptual representation of amodally completed figures is similar to that of complete figures.

However, a similar effect of occluded and complete primes was found only at sufficiently long durations (Sekuler & Palmer, 1992). When the prime lasted for only 90 ms, the pattern was reversed and the occluded prime yielded priming effects that were more similar to those of the mosaic prime. This reversal is consistent with the notion of an initial mosaic. When processing is interrupted early, priming should come from the preliminary mosaic representation and should therefore favor matches of mosaic tests. Only when processing is allowed to proceed further should the system reach the completed representation that could then prime the complete tests. Thus, the duration effect found by Sekuler and Palmer is exactly what one would expect on the basis of the mosaic-first view.

Although the primed matching evidence is compelling, the mosaic-first view is difficult to relate to phenomenology. Several theorists have proposed that there are two modes of visual perception: the constancy and proximal modes (Rock, 1983; sometimes also called the visual "world" and the visual "field"; Gibson, 1950; see also Natsoulas, 1990). In the first mode, viewers are hypothesized to focus on distal properties of objects: their physical size, their layout in depth, and so on. In the second mode, they are hypothesized

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to focus on the act of seeing itself: how objects appear from a given vantage point and at a given point in time. Examples of proximal mode percepts have included the intensity of light as it is reflected from a given surface (technically called *brightness*; see Arend & Goldstein, 1987) and the visual angle subtended by a given surface (Epstein, 1963; Gilinsky, 1955; Rock & McDermott, 1964). Another example of a proximal mode percept is the mosaic interpretation of a partly occluded surface.

However, to see the world as a mosaic, one needs attentional effort and a certain attitude that improves with training. This feature of proximal viewing is problematic for the mosaic-first view. If the mosaic stage is achieved first, it must be available earlier than the completed representation. Yet, phenomenology suggests that experiencing the mosaic, although possible, is not easier or faster than experiencing amodal completion. One way out of this problem is to assume that the mosaic as the first stage in the completion process is not the same thing as the conscious "mosaic" in proximal mode perception. Testing this assumption, however, poses several other problems.

Although phenomenological reports can be rich, they typically do not provide quantitative information. Explicit matching studies can provide quantitative data on the conscious access to perceptual representations of occluded surfaces (Bruno & Gerbino, 1987; Gerbino & Salmaso, 1987). Primed matching studies can provide quantitative data on unconscious processing stages (Sekuler & Palmer, 1992). Even more objective approaches, however, have investigated only pictorial materials: line drawings. Line-drawing pictures of interposed surfaces differ from real-world occlusion in fundamental ways. When an observer moves in the environment, occluded surfaces undergo continuous transformations that reveal previously invisible parts (Gibson, 1979). Even for a static observer, there is always binocular parallax, that is, interocular differences in the visible parts of occluded surfaces (sometimes also called *half-occlusions*; see Anderson & Nakayama, 1994).

In typical matching studies of occlusion, observers are presented with line drawings under unconstrained viewing. Thus, these studies in fact present conflicting information. Although T junctions between edges specify interposition, binocular information specifies juxtaposition. Data on the role of occlusion constraints on the early solution to the aperture problem demonstrates directly that this kind of conflict can affect perceptual performance (Shimojo, Silverman, & Nakayama, 1989).

Rationale for Our Studies

We examined whether the pattern of data that seemingly supports the mosaic-first view can be generalized outside the pictorial domain. To make a reasonable compromise between outline figures and natural images, we investigated completion in displays involving binocular parallax. This has several advantages. For instance, stimuli can be limited to well-controlled stereograms, which are easy to generate on graphics workstations. Presentation of the test material needs not be spread over several frames, as would be

required to display motion information (see Wagemans & d'Ydewalle, 1988). The duration of the presentation can be controlled in a natural way. The most important advantage, however, is improved ecological validity. Although the displays are still simple, they do capture one essential feature of occlusion in natural conditions: Observers receive differential information about the occluded surface by comparing images projected to the two eyes.

To explore the role of binocular parallax in the microgenesis of completion as well as in the formation of related conscious perceptual experiences, we performed two sets of experiments. In the first set, we applied the primed matching paradigm of Sekuler and Palmer (1992) on pictorial displays and on equivalent displays in which occlusion was specified by binocular parallax. The rationale for this was to determine whether the evidence supporting the mosaic-first view would generalize to conditions that are more representative of natural occlusion. In the second set of studies, we used a version of the explicit matching paradigm used by Bruno and Gerbino (1987) and Gerbino and Salmaso (1987). In this paradigm, observers are briefly shown one pattern that is either complete or truncated. After having seen the pattern, observers have to perform a categorical match to a second pattern, which is occluded so that its visible part is congruent to the truncated pattern. Although a categorical match is always possible, matches on the basis of more primitive perceptual representations are also possible in this task. For instance, when observers see a complete shape first, they might match to the occluded shape by using an amodally completed representation of the occluded shape. Conversely, when they see a truncated shape first, they might match to the occluded shape on the basis of the mosaic representation of the occluded shape. Thus, by comparing these two kinds of matches, it is possible to obtain objective data on the speed and accuracy in achieving the corresponding perceptual experiences.

Experiment 1: Replication

As a first step, we performed a small-scale replication of Sekuler and Palmer's (1992) study by using exactly the same displays as they did. Given that their evidence for the mosaic-first view rested on a small change in the pattern of reaction times (RTs) as the stimulus onset asynchrony (SOA) was reduced, it was important to determine whether this change could be detected in an independent laboratory.

Method

Observers. All of us served as the observers in this study. We had normal stereoscopic vision, as tested using a random-dot stereogram, and normal or corrected-to-normal visual acuity.

Equipment. All stimuli were generated by a Silicon Graphics Indigo (Mountain View, CA) workstation and were displayed on a Silicon Graphics monitor. This monitor has a resolution of 1,280 × 1,024 pixels and 256 simultaneously displayable gray levels with a dynamic range of approximately 2 log units and a 60-Hz refresh rate under ordinary operating conditions. The RTs were measured by monitoring presses of two mouse buttons and by reading times off the workstation clock.

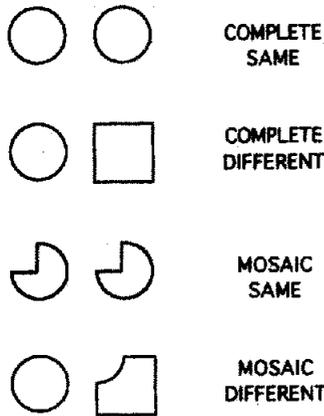


Figure 1. Test patterns in the first primed matching experiment. From "Perception of Partly Occluded Objects: A Microgenetic Analysis," by A. B. Sekuler and S. E. Palmer, 1992, *Journal of Experimental Psychology: General*, 121, p. 97. Reprinted by permission of the author.

Displays, priming paradigm, procedure, and design. The experimental design closely followed Experiment 2 of Sekuler and Palmer (1992). Two test shapes, a square and a circle, were crossed with two shape types, complete or mosaic (see Figure 1). The combination of these four types of test patterns with the two possible responses, same or different, and two possible positions, left or right, yielded 16 distinct test patterns. To keep our replication as close as possible to the original, we also included in our test patterns one "irrelevant" figure, which, according to Sekuler and Palmer, prevents apparent-motion effects from interfering with the matching paradigm. Given two possible irrelevant figures, again a square or a circle, we obtained 32 test patterns. We combined these with four possible primes: complete, occluded, mosaic, and none. (Examples of such primes are shown in Figure 2). Finally, the resulting 128 patterns were presented using an SOA of either 100 or 400 ms,¹ yielding a total set of 256 trials. To keep

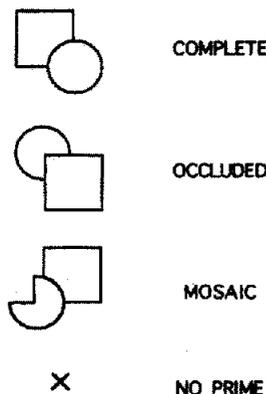


Figure 2. Examples of the types of priming patterns used in the first primed matching experiment. They were also exact replicas of those used by Sekuler and Palmer (1992). From "Perception of Partly Occluded Objects: A Microgenetic Analysis," by A. B. Sekuler and S. E. Palmer, 1992, *Journal of Experimental Psychology: General*, 121, p. 97. Reprinted by permission of the author.

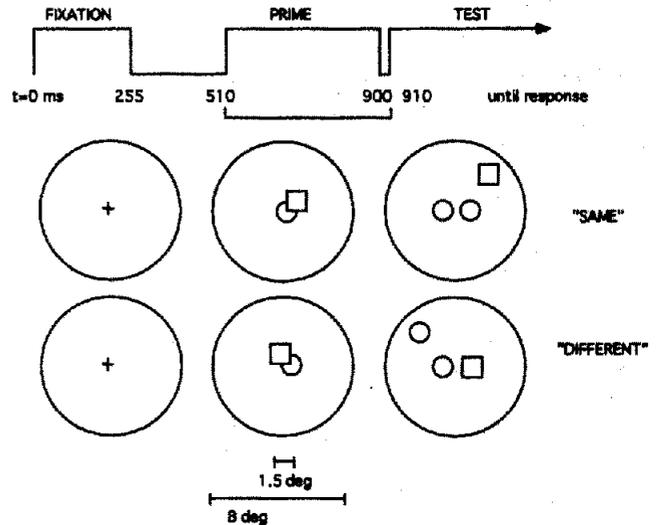


Figure 3. Examples of trials in the first primed matching experiment. The procedure was identical to that used by Sekuler and Palmer (1992). deg = degree.

the experiment to a manageable length, we decided to drop SOAs of 50 and 200 ms, which were included in the original study but yielded no evidence of other processing stages of interest. This modification was the first of two minor variations in the original design. The second minor variation involved our treatment of response errors, which Sekuler and Palmer eliminated altogether by having mistaken trials presented again after a fixed lag, until observers responded to all trials correctly. Although this approach has the advantage of ensuring equal observations in each cell of the design, it prevents one from checking possible speed-accuracy trade-offs. Thus, we found it more convenient to record all responses, check error rates, and then use the correct responses for later analyses. However, to compensate for possible reductions in the total amount of available data, each observer contributed four replications of the total stimulus set, yielding a total of 1,024 trials that were actually broken down into four completely randomized blocks. Viewing distance, visual angles subtended by the displays, and the experimental procedure were identical to those described by Sekuler and Palmer (1992). The sequence of events during each trial is summarized in Figure 3.

Analysis. We based our analysis on correct "same" responses. Before inferential analysis, however, we inspected the distributions of RTs and found substantial positive skews. To address this problem, we performed two corrections on the data: First, for each observer we obtained summary statistics of the correct "same" responses and excluded from the analysis all times greater than 2 SDs above the average. The number of excluded times was approximately 2% over all 3 observers. (Given that the distributions were skewed with a right-hand tail and that no time was shorter than 200 ms, no time shorter than the average was excluded.) Next, we performed a log transform on the remaining times. A combination of a log transform and correction for outliers

¹ Here and in the following experiments, stimulus onset asynchronies are rounded for clarity. Exact stimulus onset asynchronies used in the experiments were 595, 408, 204, 102, and 51 ms, corresponding to 34, 23, 11, 5, and 2 screen refreshes for the stimulus plus a 17-ms blank screen.

yields greater statistical power than simply averaging times within cells, and it provides equivalent protection against Type I errors (Bush, Hess, & Wolford, 1993). (For reasons to expect log-normal RT distributions, see Ulrich & Miller, 1993.) The log-transformed times were entered in a repeated measures analysis of variance (ANOVA). To make the results meaningful for readers, however, plotted data points are geometric averages of times rather than arithmetic averages.

Results

Combined averages over the 3 observers are plotted in Figure 4.² These proved 10 ms faster with the 400-ms SOA (486 ms) than with the 100-ms SOA (496 ms), a significant difference, $F(1, 2) = 123.5, p < .008$. Furthermore, at both SOAs observers were faster at matching mosaic test patterns when exposed to mosaic test patterns, whereas they were faster at matching complete primes when exposed to complete and occlusion primes. This crossover pattern yielded a significant Prime \times Test interaction, $F(3, 6) = 11.0, p < .007$. However, the extent of this crossover was much larger with the 400-ms SOA than with the 100-ms SOA, yielding a significant three-way interaction between prime, test pattern, and SOA, $F(3, 6) = 5.9, p < .031$. To check for speed-accuracy trade-offs, we also computed error rates for all cells in the design and replotted the data (see Figure 4) with error rate as the dependent variable. This replot showed essentially the same pattern as the RT data, suggesting that the

pattern of times does indeed reflect times required for certain processing operations, not merely changes in the balance between speed and accuracy.

Discussion

We first consider the results with the 400-ms SOA and then compare the means from the occlusion, complete, and mosaic primes with the no-prime means. When matching complete tests, complete primes and occlusion primes had the effect of speeding up the response relative to the no-prime trials, whereas mosaic primes remained as slow as the no-prime trials. When matching mosaic tests, this pattern reversed and mosaic primes speeded up responses, whereas complete primes and occlusion primes became as slow as the no-prime trials. Thus, as in the original study, we conclude that in these conditions the perceptual representation of the occluded surface is essentially identical to that of a complete surface after 400 ms.

Next, we discuss the results obtained with the 400- and 100-ms SOAs. With this shorter SOA, most differences relative to the no-prime trials reduced and the effect of the occlusion primes became more similar to that of the mosaic primes. This was similar to the pattern found by Sekuler and Palmer (1992). However, unlike the original data, the effect of the complete primes also became similar to that of the mosaic primes, and the overall effect of all three kinds of primes showed little difference relative to that of the no-prime trials. Although this pattern was not exactly identical to that observed by Sekuler and Palmer, it cannot be taken as a failure to replicate their results. The two-stage model makes no strong claim about the exact timing in completing each stage; it only predicts that the two stages will be achieved in time one after the other. Therefore, it is possible that averaging means at 100 ms masked individual differences in processing the two stages. In another experiment, Sekuler and Palmer reported that individual differences could be observed in the pattern of RTs with the 100-ms SOA. To check for this possibility, we inspected our individual patterns and found that of the 3 observers, 1 observer exhibited the same pattern both with the 400- and the 100-ms SOAs; one observer reversed it, with the occlusion prime becoming more similar to the mosaic prime with the 100-ms SOA; and 1 observer showed essentially no differences.

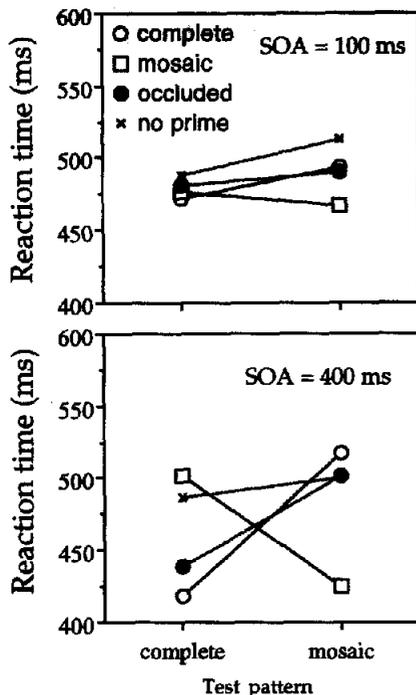


Figure 4. Response times as a function of stimulus onset asynchrony (SOA), type of prime, and type of test pattern in the first primed matching experiment. Data points are geometric means of reaction times. Standard errors are not plotted to avoid clutter. The omnibus within-subjects standard error was .013 (approximately 12 ms from the grand mean).

² An omnibus error term for a within-subjects design can be computed assuming sphericity (Loftus & Masson, 1994) by summing all error sums of squares and dividing by the sum of all corresponding degrees of freedom. In our analysis, because the resulting estimate was in log, not linear, units, care had to be taken to interpret the error term as a quantity to be added or subtracted from a mean, not as an absolute distance. In the present term, for instance, elevating 10 to the power of .013 would not yield a correct estimate size of error. Instead, the error can be understood as the limits of a 1-SEM confidence interval around a given treatment mean. For instance, if we interpret the estimate as a distance from the grand geometric mean, which in this case was 2.68 log ms (478 ms), the omnibus term sets the limits from 2.68 - .013 log ms (467 ms) to 2.68 + .013 log ms (490 ms).

Experiment 2: Comparing Pictorial Occlusion With Occlusion Involving Parallax

To assess the effect of parallax on completion, we compared priming effects in two conditions. In the first, the pictorial condition, the priming figures were presented so that both eyes of the observers saw exactly the same portion of each occluded surface. Given that this condition was comparable to that of the pictorial stimuli of Sekuler and Palmer (1992) and of our replication, here we expected to observe again the occlusion and SOA effects. In the second condition, the binocular parallax condition, the priming figures were presented so that each eye of the observers was exposed to a slightly different view of the occluded surfaces, thereby obtaining direct information concerning the fact that the surface continued behind the occluder. To obtain stereograms that were easy to fuse and generally not taxing for the viewer, we used displays that were different from those used in the previous experiments. Instead of line drawings of a square and a circle, we used pentagons and hexagons filled with different gray levels.

Method

Observers. Fourteen undergraduates of the University of Trieste volunteered to participate. All had normal stereoscopic vision, as tested using a random-dot stereogram, and normal or corrected-to-normal visual acuity.

Equipment. As in the previous experiment, all stimuli were generated by a Silicon Graphics Indigo workstation and displayed on a Silicon Graphics monitor. When in the stereo mode, this monitor has the capability of operating at a 120-Hz refresh rate. To control binocular inputs, we used a field-sequential stereo system. In this system, an emitter is used to broadcast an infrared signal to switch liquid crystal lenses on and off in exact synchronization with the image fields as they are displayed on the monitor at a rate of 60 Hz per eye. The lenses are mounted on glasses that are worn when observing the displays. RTs were measured by monitoring the presses of two mouse buttons and by reading times off the workstation clock.

Displays. We used filled surfaces presented in front of a $12^\circ \times 12^\circ$ white surround. The priming patterns, shown in Figure 5, always consisted of a combination of a large, dark-gray rectangle with a light-gray figure that could be either a five- or a six-sided regular polygon and that subtended 2.5° of visual angle. In the complete-prime displays, this figure appeared in front of the lower right corner of the larger square. In the occluded-prime displays, it appeared behind the lower right corner of the square (about 15% of the contour occluded). Finally, in the mosaic-prime displays, it appeared in front of the lower left corner of the square, which was then placed to the left rather than to the right of the larger white background. As in the previous studies, the mosaic primes actually consisted of polygons truncated so that they mimicked exactly the visible portion of the corresponding occluded surface. In the presence of binocular parallax, these priming patterns appeared as surfaces at different depth planes relative to the computer monitor. More precisely, the lighter gray prime was always made to appear on the same plane as the monitor (see Figure 6). However, depending on the type of priming pattern, the larger square appeared either about 10 cm in front of this plane (in the occluded primes) or about 10 cm behind this plane (the complete and mosaic primes). The amount of retinal disparity between the two images was set to 10 pixels. The test patterns, shown in Figure 7, consisted

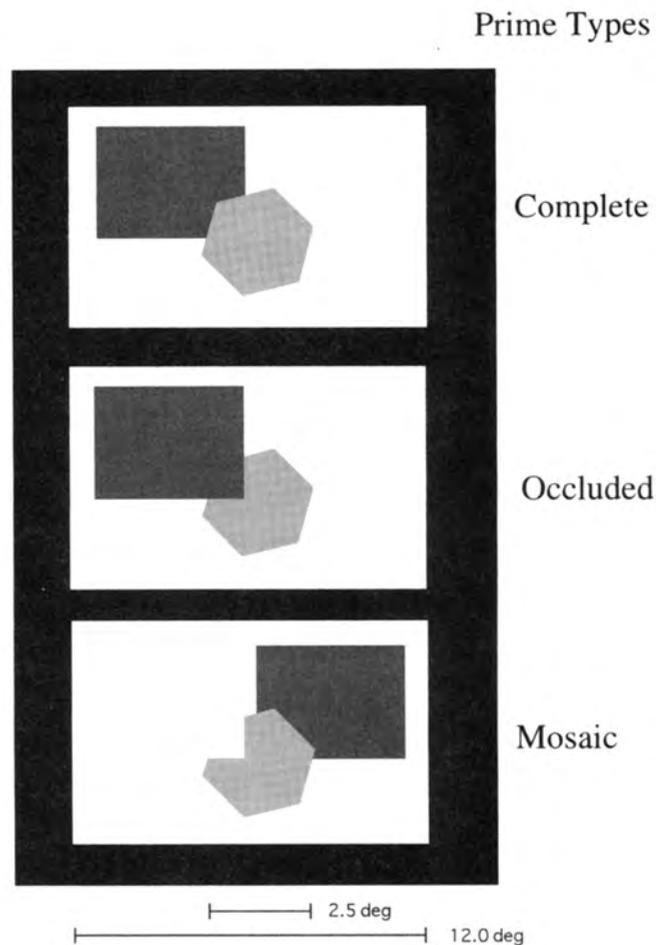


Figure 5. Examples of the types of priming patterns used in the second primed matching experiment. deg = degree.

of pairs of figures that could be hexagons or pentagons and could be either complete or truncated, as in the mosaic primes. Each of these figures subtended 2.5° of visual angle. One of them was presented at exactly the same position as the prime, whereas the other was presented to the left of the prime at a distance of 3° . Both test figures were presented on the same depth plane as the prime. Furthermore, hexagons and pentagons were presented in noncanonical orientations (slightly rotated so that no side was aligned with either the horizontal or vertical axes). This ensured that matching required some degree of careful inspection. In the "same" trials, mosaic primes in the parallax condition were geometrically congruent with either the right eye or the left eye view of the subsequent test figure, as determined by a computer-simulated coin toss before the presentation of the trial.

Design and procedure. The design and the experimental procedure were similar to those used in Experiment 1, with a few minor variations and the inclusion of a new independent variable, the mode of presentation that could be either pictorial or involving binocular parallax (see the previous section). First, to reduce the required number of trials, we omitted the no-prime condition. Second, to be completely sure that observers had sufficient time for completion to occur, we decided to compare SOAs of 100 and 600 ms. Thus, we included three types of prime (i.e., complete, mosaic, and occluded; see Figure 5) and crossed these with four types of

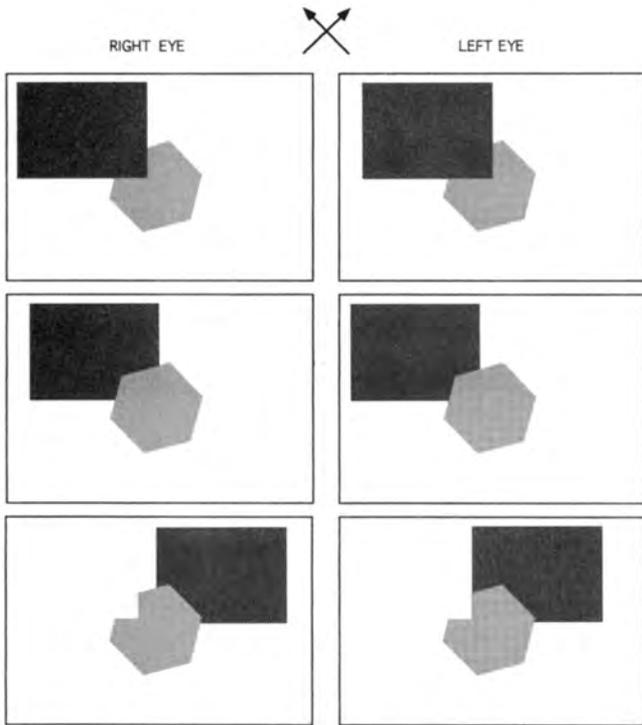


Figure 6. Stereo views of the parallax priming patterns in Experiment 2. They involved occlusion that was specified both by pictorial cues, such as T junctions, and by binocular parallax. The stereograms are designed to be cross-fused. The pictorial patterns were identical to those depicted here, except that the same portion of the occluded polygon was presented to both eyes. Thus, in these patterns the occluded polygon and the occluding square appeared on the same depth plane.

test patterns (i.e., complete same, complete different, mosaic same, and mosaic different; see Figure 7) and two values of SOA (100 and 600 ms), which yielded a total of 24 distinct trials that were presented in randomized order for 10 times in each experimental

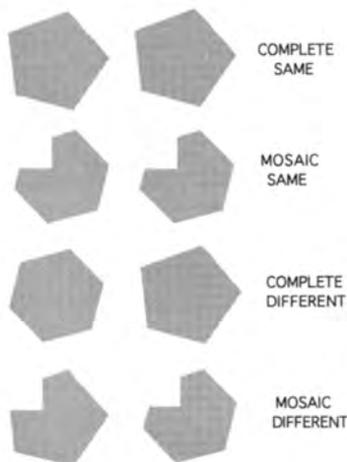


Figure 7. Examples of the types of test patterns used in the second primed matching experiment.

block. The sequence of events in each trial was similar to that of the previous experiment. First, a fixation cross appeared in the center of the screen for 255 ms. Next, the large white frame was presented for another 255 ms. This was followed by the priming pattern. The interstimulus interval (ISI) between the priming pattern and the test figures was 17 ms. The test figures remained on the screen until a response was produced. Each observer contributed two blocks, one consisting only of pictorial displays and the other of displays involving parallax. In both blocks, observers wore the stereo glasses even if those were not necessary for viewing the pictorial stimuli. The order of blocks was also randomized across observers. The experiment was run in a completely dark room, except for the light coming from the computer monitor. Before starting a block, each participant received an explanation of the task and performed a training session consisting of 10 trials drawn at random from those of the block to be performed; these were repeated until 90% accuracy was achieved.

Results

As in the previous experiment, the correct "same" responses were first normalized by performing a logarithmic transformation on RTs and by discarding all times larger than 2 SDs above the mean. Geometric averages were plotted as a function of test pattern, prime, and SOA for the pictorial and parallax conditions separately (see Figure 8). Log-transformed times were entered in an appropriate repeated measures ANOVA.

We found a large effect of the test pattern, indicating that observers were faster when matching complete tests (yielding a geometric average of 758 ms) than when matching

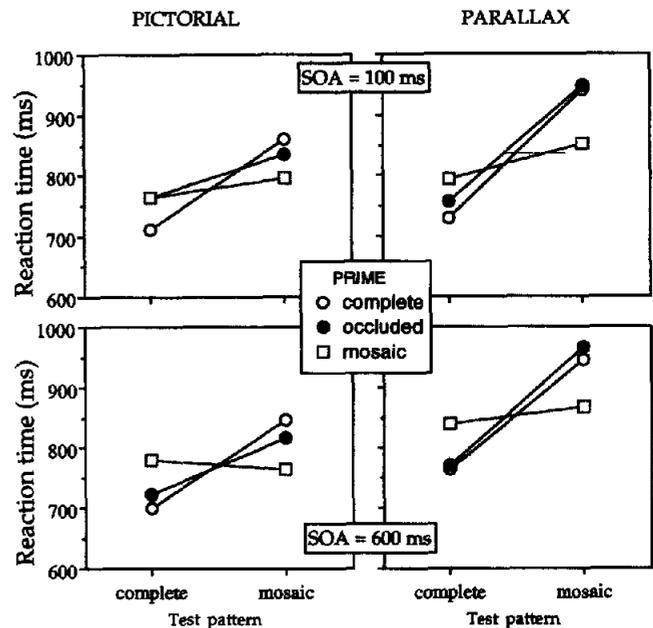


Figure 8. Response times as a function of stimulus onset asynchrony (SOA), type of prime, and type of test pattern in the pictorial (left) and parallax (right) conditions of the second primed matching experiment. Data points are geometric means of reaction times. The omnibus within-subjects standard error was .04 (approximately 64 ms).

mosaic tests (868 ms), $F(1, 13) = 36.8, p < .001$. This effect of the test pattern also interacted with the viewing mode, in that there was an 80-ms advantage of the complete over the mosaic tests in the pictorial displays, which almost doubled to 142 ms in the binocular displays, $F(1, 13) = 7.9, p < .015$. The test pattern also interacted with the type of prime, $F(2, 26) = 21.7, p < .001$, reflecting the fact that, on average, the observers were faster when matching complete tests after seeing complete (726 ms) or occluded (754 ms) primes than after seeing mosaic primes (794 ms), whereas this trend reversed when matching mosaic primes, which yielded faster times after mosaic primes (819 ms) than after complete (897 ms) or occluded (890 ms) ones.

We also found an interaction between the viewing mode (pictorial or parallax) and the SOA, $F(1, 13) = 8.9, p < .011$, indicating that parallax displays were 22 ms faster with the 100-ms SOA than with the 600-ms SOA, whereas pictorial displays were 17 ms slower with the 100-ms SOA. The latter two-way interaction has little relevance for the purpose of this study and is therefore not discussed further. Of greater interest here is the three-way interaction between the viewing mode, the test pattern, and the type of prime, which also was significant, $F(2, 26) = 3.9, p < .034$. The significance of this three-way interaction is indicative of a difference in pattern between the pictorial and the parallax displays. Readers can appreciate this difference by comparing the plots for the two viewing conditions in Figures 8 and 9. In the parallax condition, the 100- and 600-ms SOAs yielded essentially the same trends, with the complete and the occluded primes behaving similarly and clearly being different from the mosaic primes. Conversely, in the pictorial condition, the complete and occluded primes behaved similarly only with the 600-ms SOA. With the 100-ms SOA, all observed differences reduced and the data from the occluded prime became much more like those from the mosaic prime.

To test the significance of these differences, we computed a set of orthogonal contrasts. First, we compared mosaic primes with the occluded and the complete primes averaged. With the parallax displays, this comparison yielded a significant interaction for both the 600-ms SOA, $F(2, 26) = 18, p < .0004$, and the 100-ms SOA, $F(2, 26) = 10.4, p < .0001$, confirming that the occluded and complete primes were similar and differed from mosaic primes under these conditions. With the pictorial displays, however, the 600-ms SOA yielded a significant interaction, $F(2, 26) = 4.8, p < .017$, but the 100-ms SOA did not, $F(2, 26) = 2.1, p > .14$, as was found by Sekuler and Palmer (1992) in comparable conditions. Next, we compared complete primes against the average of occluded and mosaic primes. In this case, we found the opposite pattern of significant interactions. In pictorial conditions, the comparison now yielded a significant difference at 100 ms, $F(2, 26) = 3.5, p < .046$, but not at 600 ms, $F(2, 26) = 2.9, p > .07$, suggesting that the occluded prime had indeed an effect similar to that of the mosaic prime at the shorter SOA. In parallax conditions, none of these comparisons were significant: 600 ms, $F(2, 26) = 2.02, p < .14$, and 100 ms, $F(2, 26) = 2.04, p < .14$.

Discussion

The basic occlusion effect and the effect of SOA of Sekuler and Palmer (1992) were again replicated under the pictorial conditions. Under these conditions, the only differences between the present pattern and that of the previous experiment were a general increase in RT and an effect of the test. These differences are accounted for by the greater similarity and complexity of our two test figures. Of great interest, however, is that the pattern observed in the pictorial condition did not generalize to the parallax displays. With both the 600- and the 100-ms SOAs, occluded primes were similar to complete primes and different from the mosaic primes in the parallax displays. Thus, under these conditions it seemed that for most of our observers, the occluded surface was already represented similarly to a complete surface after 100 ms.

Experiment 3: Control

The results of the previous experiment might have been biased by a confounding variable. As described before, in Experiment 2 we used three types of priming figure. In the complete and occluded primes, a large dark rectangle appeared on the left part of the display area and a smaller gray figure was placed either partly in front or partly behind its lower left corner. In the mosaic primes, a large dark rectangle appeared on the right part of the display area and the gray figure was placed in front of its lower left corner. In all three types of primes, however, both test figures appeared on the left part of the display area. More precisely, the center test figure appeared in the same position as the prime gray figure, whereas the other test figure appeared to its left. As a consequence, in the mosaic-prime trials observers had to fixate to the upper right part first and then move their eyes to the left. This long saccade was not necessary in the complete-prime and occluded-prime trials because the test patterns appeared immediately below the larger dark rectangle. This unwanted difference between the mosaic and the other two types of primes might have lengthened all responses to such primes, or it might have encouraged observers to fixate on the test pattern area, causing the mosaic primes not to be foveated before the match.

To assess this potential confound, we performed Experiment 2 again, this time using test patterns that always appeared on the opposite side relative to the larger dark rectangle. Thus, in this new study, any prime could appear either on the left or on the right of the display area. The center test figure always appeared on the same position as the gray prime figure, but the second test figure always appeared on the opposite side relative to the larger gray rectangle. In this fashion, the required saccade from the prime to the test patterns was the same in all trials. Additionally, observers did not know in advance which part of the display area would contain the test pattern. This effectively prevented them from keeping their attention fixed on one part.

Another goal of this second study was to explore a larger range of SOAs. Because our main interest in Experiment 2

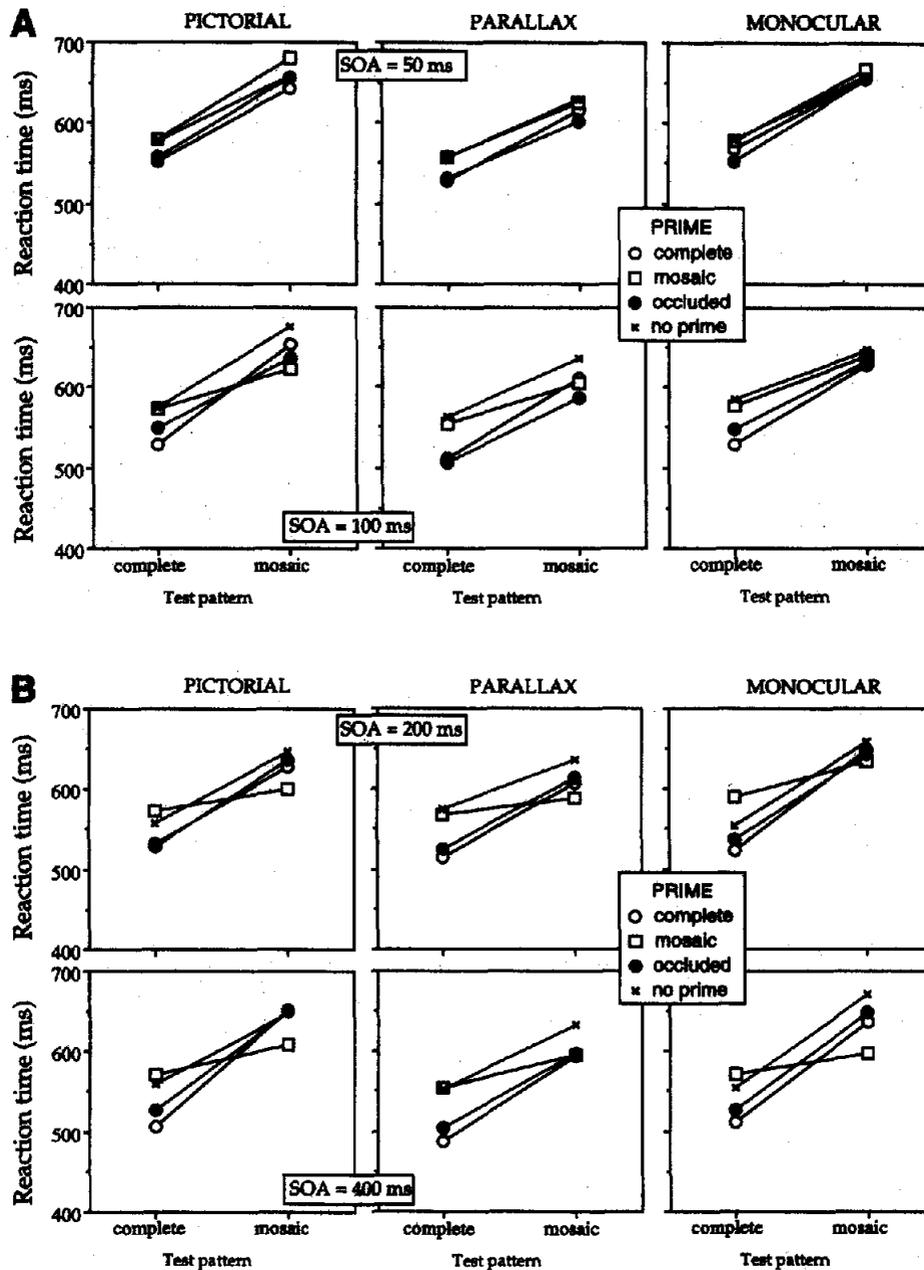


Figure 9. Response times as a function of stimulus onset asynchrony (SOA), type of prime, and type of test pattern in the pictorial (left), parallax (center), and monocular (right) conditions of the third primed matching experiment. Data points are geometric means of reaction times. Error bars are not plotted to avoid clutter. The omnibus within-subjects standard error was .009 (approximately 12 ms).

was to compare pictorial displays with displays containing binocular parallax, we used only two SOA values: 100 and 600 ms. Using these temporal regimes and pictorial displays, we found that the occluded primes behaved similarly to the mosaic primes at 100 ms and to the complete primes at 600 ms. This result was consistent with the speculation of an initial mosaic stage. Using the same temporal regimes and displays containing binocular parallax, however, we found

that occluded primes never behaved like the mosaic primes. Even at 100 ms, their pattern was almost identical to that of the complete primes. This result may be taken as evidence against an initial mosaic stage. An alternative explanation, however, could be that under binocular parallax conditions the two-stage process takes place much faster. Perhaps at 100 ms the mosaic stage has already given way to the beginning of the completion stage under these conditions. To

determine whether the alternative explanation is viable, we decided to add two more SOA values, 50 and 200 ms, and to reduce the longer SOA, which was 600 ms in the previous study, to 400 ms. Thus, our temporal regimes were now the same as those used by Sekuler and Palmer (1992). Finally, to ensure that our data were completely comparable to theirs, we reintroduced the no-prime condition.

Method

Observers. Two of us served as expert observers in this study. Both had normal stereoscopic vision, as tested using a random-dot stereogram, and normal visual acuity.

Equipment and displays. The equipment and displays were the same as those used in the previous experiment, with one exception. In this replication of Experiment 2, the priming patterns could appear either on the left or right of the large white frame and the test figures always appeared on the other side. Thus, two sets of primes and tests were used. In one set, the complete primes and the occluded primes appeared on the left side, the mosaic primes appeared on the right, and the test figures always appeared on the opposite side relative to the primes. In the other set, mirror-reversed versions of the complete and occluded primes were presented on the right, and mirror-reversed mosaic primes were presented on the left. Mirror-reversed tests were again presented on the opposite side relative to the corresponding primes.

Design and procedure. The design and experimental procedure were the same as those used in Experiment 2, except for three differences: First, we again added a no-prime condition consisting of a large X-shaped mark in the same position as the gray figure in the complete, occluded, and mosaic primes. Second, we added two more SOAs, 50 and 200 ms, and reduced the 600-ms SOA to 400 ms. Finally, we used only 2 expert observers, who contributed 10 blocks each in each condition (pictorial and parallax), randomized over successive days and totaling 20 measurements for each experimental display.

Results

Given that in this study we used only 2 observers who performed many blocks, in the analysis we used the blocks themselves as the random variable, whereas the observers were inserted as a between-blocks variable. Thus, the log-transformed times were entered into a 2 (observers) \times 2 (viewing conditions) \times 2 (test patterns) \times 4 (primes) \times 4 (durations) mixed-design ANOVA.

The geometric-average times are plotted in Figure 9 as a function of test pattern, prime, and SOA for the pictorial (first column) and parallax (second column) viewing conditions. These times are plotted jointly for the 2 observers on the basis of the observation that, although 1 of the 2 observers was generally faster, $F(1, 18) = 40.8, p < .001$, neither the five-way interaction between the observers and the four within-blocks variables, nor any of the four-way interactions, were significant, ($F_s < 1.9, p_s > .056$). This finding suggests that the 2 observers had essentially the same pattern despite an overall difference in speed and other minor differences that are discussed later. Both observers were faster (by 23 ms on average) when responding to parallax displays than when responding to pictorial displays, $F(1, 18) = 35.7, p < .001$, and both were slower when

responding to mosaic tests, $F(1, 18) = 867.5, p < .001$. Although the parallax advantage was almost equal for both observers, yielding a nonsignificant two-way interaction, $F(1, 18) = 2.7, p > .11$, the mosaic tests, disadvantage was larger for one of the observers, $F(1, 18) = 21.6, p < .001$. RTs differed as a function of the type of prime, yielding the slowest times in no-prime trials and faster times in the complete-prime trials, $F(3, 54) = 37, p < .001$. The advantage of the prime also interacted with the observers, $F(3, 54) = 10.1, p < .001$. Finally, times decreased as the SOA increased, $F(3, 54) = 7.7, p < .001$, but this effect was more marked for one of the observers than for the other, $F(3, 54) = 38.7, p < .001$. The three-way interaction between the observer, the prime, and the SOA also was reliable, $F(9, 162) = 3.836, p < .001$. In short, although there were individual differences in the effect of the priming patterns, mosaic tests, and prime duration, the overall pattern of the data was the same for both observers.

Of chief interest for the purposes of the present study is the three-way interaction between test patterns, primes, and SOA, which was significant, $F(9, 162) = 3.2, p < .01$. Separate ANOVAs on the two viewing conditions provided evidence for a change of priming effects as a function of test, prime, and SOA in the pictorial data, $F(9, 162) = 2, p < .03$, but not in the parallax data ($F < 1, p > .45$).

Discussion

The data from this control experiment were consistent with those of Experiment 2. As early as 200 ms, the occluded primes behaved essentially the same as the complete primes both in the pictorial and parallax conditions. Around 100 ms, however, the occluded primes seemed to be more similar to the mosaic primes in the pictorial condition, whereas they remained more similar to the complete primes in the parallax condition. Thus, we can rule out that the pattern of data observed in the previous experiment was due to the confounded asymmetry in the position of the primes. Around 50 ms, there was little evidence for any kind of priming effect. Thus, these results are generally not consistent with the speculation that the completion process may take place faster in the presence of binocular parallax. Given that the parallax trials did prove somewhat faster than the pictorial trials, however, the possibility remains that the mosaic stage occurred before the first 50 ms and that the lack of priming at 50 ms reflected an intermediate situation in which the mosaic was no longer available for priming but the completion stage was not yet ready. We discuss this later in the General Discussion section.

Experiment 4: Monocular Control

Another simple way to reduce information conflict under pictorial conditions is to observe pictures with only one eye. If the observed difference between pictorial and parallax displays are indeed attributable to such conflict, then observing the displays monocularly should yield the same results as our parallax display. This prediction was tested in a second control experiment.

Method

Observers. The same 2 expert observers who served in Experiment 3 participated in this study.

Equipment, displays, design, and procedure. These were the same as in the previous control experiment. The only difference was an opaque patch mounted over one of the lenses of the viewing glasses to attain monocular viewing.

Results

Combined geometric-average times are plotted in Figures 9A and 9B (third column) as a function of test pattern, prime, and SOA. As in the previous experiments, the analysis was based on correct log-transformed "same" responses. Again, the blocks were treated as the random variable and the 2 observers' data inserted as a between-blocks variable. As found in the previous experiment, neither the four-way interaction between observers, test patterns, primes, and SOA nor any of the three-way interactions were significant ($F_s < 1.6$, $p_s > .11$). Again, there was a disadvantage of mosaic test patterns, $F(1, 18) = 671$, $p < .001$, an ordering of the primes starting with the no-prime trials (slowest) and ending with the complete-prime trials (fastest), $F(3, 54) = 8.1$, $p < .001$, and an effect of the SOA, $F(3, 54) = 4.5$, $p < .001$. The effects of the prime and the SOA were larger for one observer, $F(3, 54) = 15$, $p < .001$, than for the other, $F(3, 54) = 12.8$, $p < .001$. Finally, there was a two-way interaction between the test pattern and the primes, $F(3, 54) = 4.5$, $p < .006$. No other effect, including the three-way interaction between test patterns, primes, and SOA, reached significance ($F_s < 1.2$, $p_s > .28$).

Discussion

The pattern of data was consistent with the proposal that pictorial completion is affected by the information conflict that is typical of pictorial viewing conditions. When this conflict was removed by viewing the displays monocularly, the pattern of times became more similar to the parallax pattern than to the pictorial pattern.

Experiment 5: Explicit Matching and Proximal Viewing

In natural vision, observers can experience occluded surfaces in two different ways: as complete and continuing behind the occluder or as a juxtaposed mosaic. The first is spontaneous and natural; the second requires training, conscious effort, and, for many observers, can be achieved only under reduction conditions. What is the relationship of these two kinds of perceptual experience to the hypothetical completion and mosaic stages?

To investigate this question, we performed an additional experiment using an explicit matching procedure. In this procedure, observers were briefly shown a first figure that could be either complete or truncated. After this had been switched off, they saw an occluded test figure. The test figure was occluded such that the visible part was geometrically congruent with the truncated figure, which was presented

first. Observers were instructed to match according to categorical identity. For instance, suppose that they saw a complete pentagon followed by an occluded pentagon. They were told that the correct response was "same" because the two figures both belonged to the category of pentagons. Instead, if the complete pentagon had been followed by an occluded hexagon, the correct response would have been "different."

In principle, this task can be performed simply by categorizing. However, more primitive representations are also available for matching. Specifically, when comparing the occluded figure with a complete figure, observers could also match them on the basis of the amodally completed representation of the occluded figure. Conversely, when matching the occluded figure to the truncated figure, they could match these figures using a mosaic representation. Previous research suggests that this may be what happens (Bruno & Gerbino, 1987; Gerbino & Salmasso, 1987).

In the following experiment, we modified the explicit matching procedure to accommodate displays that included binocular parallax. Again, we did this by controlling binocular inputs while observers performed the matching task. During the full length of the experiment, observers binocularly saw a large dark square in front of a white rectangular surface. In the parallax condition, the dark square was disparate relative to the white rectangle. Therefore, in this condition the square appeared at a definite distance in front of the white rectangle. In the pictorial condition, there was no disparity and the square appeared on the same plane as the rectangle.

Method

Observers. Eighteen members of the university community (15 students and the 3 of us) participated as observers. All observers had normal stereo vision, as verified using a random-dot stereogram, and normal or corrected-to-normal visual acuity.

Equipment, displays, and procedure. The equipment was the same as used in the previous experiments. Figure 10 shows examples of the displays and illustrates the procedure. The basic display consisted of a white field centered on the computer monitor, which had the peripheral part set to black. A large dark-gray square was placed on the upper left angle of this white field. In the first frame of each trial, a medium-gray surface was drawn on the upper right part of this field. This initial surface could be either complete or truncated, as illustrated in Figure 10. In the third frame of each trial, another medium-gray test surface was presented on the left part of the gray rectangle in such a way that it was partly occluded by the darker square. The initial and the test surfaces were one of three regular polygons (with five, six, and seven equal sides) presented in noncanonical orientation (i.e., with no side aligned with the horizontal or the vertical direction). The five- and six-sided polygons were the same as those used in Experiment 2. The whole arrangement subtended a visual angle of approximately 10° horizontally and 12° vertically.

Each trial consisted of three frames. After a warning tone, the initial figure appeared in the right part of the medium-gray rectangle. This initial figure lasted for 500 ms. Next, this figure was removed, but the rest of the display remained visible for an additional 250 ms. At this point, the test shape was presented behind the lower right angle of the occluding square. (This sequence did not produce an impression of apparent motion.) The

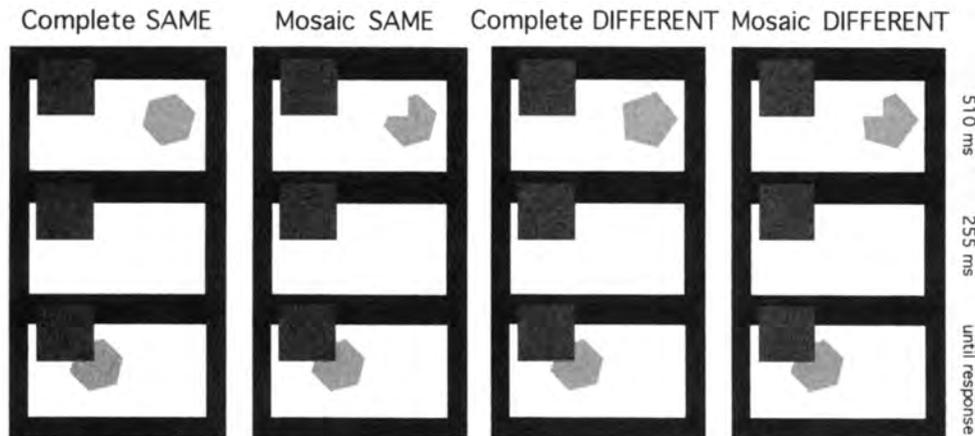


Figure 10. Examples of the four types of trials in the explicit matching experiment.

test shape remained visible until the observer produced a response by pressing either the left button of a mouse for the “same” response or the right button for the “different” response. At this point, the matching shape was removed and there was a fixed interval of 1 s. The complete experiment consisted of two separated blocks, 12 for each of the viewing conditions (pictorial or parallax). Each block consisted of randomizations of 10 repetitions for each of the 12 trials (120 trials per block total). In all blocks, observers wore the stereo glasses even if they were not necessary for viewing the pictorial stimuli. The experiment was run in a completely dark room, except for the light coming from the computer monitor.

Design. We manipulated two variables: whether the first figure corresponded to the completion (complete initial figures) or the mosaic representation (mosaic initial figures) and whether the conditions of observation included binocular parallax (such that the occluding square appeared on a nearer depth plane than the occluded shape) or not (such that binocular information conflicted with the pictorial interposition of the occluding and the occluded shape). As in the previous experiments, the disparity of the parallax displays corresponded to 10 pixels. In “same” trials, mosaic primes in the parallax condition were geometrically congruent with either the right eye or the left eye view of the subsequent matching shape,³ as determined by a computer-simulated coin toss before the presentation of the trial.

Complete and mosaic initial figures were randomized within each experimental block, whereas the viewing condition was manipulated between blocks. Block order was randomized across observers to balance training effects. A factorial combination of the two block types (i.e., pictorial or parallax) with the two prime types (i.e., complete or truncated) and the two test types (i.e., same as or different from the initial figure) yielded a total of 12 cells in the design, which were replicated for each of the three matching shapes, yielding a total of 24 distinct trials.

Results

As in the previous experiments, the analysis was based on correct “same” responses, which were log-transformed to compensate for the skew in the distributions of times. Again, our reported averages were geometric means, but all parametric analyses were performed on logarithms of RTs. Results are plotted in Figure 11A as a function of the viewing condition and the type of initial figure. In the pictorial

condition, observers were faster when matching to the mosaic initial figure (643 ms) than when matching to the complete one (655 ms). In the parallax condition, this pattern reversed. Observers were now faster when matching to the complete initial figure (603 ms) than when matching to the truncated one (687 ms). This interaction was significant, $F(1, 17) = 13.8, p < .002$. Planned comparisons demonstrated that the significance was attributable to the difference between the complete and mosaic initial figures in the parallax condition, $t(17) = -7.4, p < .001$, but not in the pictorial condition, $t(17) = 1.04, p > .2$. In addition, there was a monotonic increase of times as a function of the number of sides (614, 652, and 675 ms for five, six, and seven sides, respectively), yielding a significant effect of type of shape, $F(2, 34) = 8.5, p < .001$. We found no other significant difference between the parallax and pictorial conditions ($F_s < 4, p_s > .05$).

Discussion

These results confirm that there is a fundamental difference between pictorial occlusion and occlusion in conditions that include binocular parallax. In pictorial occlusion, matches made on the basis of the mosaic representation were slightly faster than matches made on the basis of amodal completion, but this trend was too weak to reach significance. In conditions that included binocular parallax, conversely, matches made on the basis of the completion representation were faster than those based on the mosaic by as much as 85 ms. Thus, in pictorial conditions, accessing the “mosaic” representation seemed to be as easy as accessing the completed representation. In parallax conditions, accessing the mosaic representation seemed to become harder, whereas accessing the completed one seemed to become easier.

³ Because of this manipulation, mosaic initial figures were exactly congruent with the occluded test figures presented to one eye and slightly different from the occluded test figures presented to the other eye. A control experiment, not reported here, demonstrated that this difference did not affect the pattern of results.

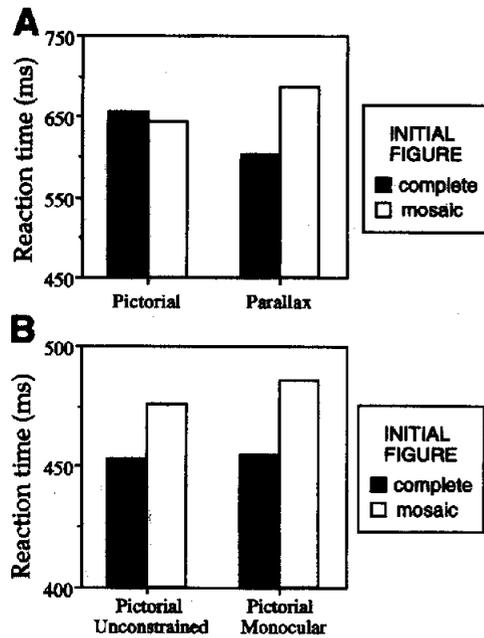


Figure 11. Response times as a function of viewing condition and type of initial figure in the explicit matching experiment (A) and control (B). Bars show geometric means of reaction times. In the explicit matching experiment, the omnibus within-subjects error term was .018 (approximately 25 ms). In the control experiment, it was .03 (approximately 60 ms).

When one considers the phenomenology of proximal viewing, these results are not surprising. In natural vision, becoming aware of one's retinal image requires attentional effort, presumably because one needs to ignore the sources of information specifying that the surface continues behind the occlusion. Therefore, it seems understandable that accessing the completed interpretation of a partly occluded surface could be easier than accessing the corresponding mosaic interpretation. In pictorial conditions, on the other hand, occlusion information is contradictory. Without additional assumptions, information from T junctions is equally compatible with surface interposition or a surface mosaic. Information from other sources, such as binocular parallax, is compatible only with a flat arrangement of juxtaposed surfaces. It comes as no surprise, then, that in pictorial conditions, accessing the mosaic interpretation would become easier than in parallax conditions.

Experiment 6: Monocular Control

If the pictorial displays of the previous experiment were affected by a conflict of information about occlusion, viewing the same displays monocularly should remove the conflict. As for the primed matching experiments, we therefore predicted that the pictorial times should become more similar to the parallax times if the pictorial displays are viewed monocularly.

Method

Observers. Two expert observers (2 of us) participated. They both had normal stereo vision, as verified using a random-dot stereogram, and normal or corrected-to-normal visual acuity.

Equipment, displays, procedure, and design. We tested two different viewing conditions for the pictorial displays of the previous experiment. In the pictorial unconstrained condition, observers wore the stereo glasses with both lenses uncovered. In the pictorial monocular condition, one of the lenses of the viewing glasses was covered with an opaque patch. Everything else was the same as in the previous experiment. Therefore, the design and analysis were similar to those used in the previous experiment.

Results

A preliminary inspection of the results demonstrated that the pattern was the same for the 2 observers. Joint geometric averages are plotted in Figure 11B as a function of the viewing condition and the type of initial figure. Observers were faster when matching to complete than to mosaic initial figures (454 vs. 481 ms) as well as under unconstrained rather than monocular viewing (465 vs. 471 ms). However, in the appropriate repeated measures ANOVA, none of these trends reached significance. In the unconstrained condition, observers were 23 ms faster when matching to the complete initial figure than when matching to the mosaic one. In the monocular condition, this difference increased to 31 ms, yielding a significant interaction, $F(1, 1) = 32,920, p < .004$. When tested individually in four orthogonal contrasts, all four differences between the interaction were significant, $ts(1) \geq 6.9, ps < .05$.

Discussion

Contrary to the previous experiment, we found a significant advantage of matches to complete initial figures over matches to mosaic initial figures. This suggests that access to the completed representation can be faster than access to the mosaic representation even with pictorial displays for trained observers. Most important, however, the advantage of matches to complete initial figures increased when the pictorial displays were observed monocularly. This result is consistent with the proposal that the processing of the pictorial displays can be slowed by information conflict. When the conflict was removed by observing the pictures with one eye, the difference between the complete and the mosaic initial figures was increased. At least for 2 trained observers, however, the effect of monocular viewing was not to speed up access to the completed representation but to inhibit access to the mosaic representation.

General Discussion

The results of these experiments provide evidence for three main conclusions. First, the SOA effect that is believed to support the mosaic-first view holds under pictorial conditions, but not in conditions involving binocular parallax. Second, conscious access to a completed or a "mosaic"

representation of an occluded surface can be strongly affected by the viewing conditions. When these are pictorial, accessing these two alternatives is almost as costly. When these include binocular parallax, however, accessing the mosaic requires more time than accessing the amodally completed surface. Third, the difference between the pictorial and the parallax conditions appears to be attributable to a conflict of information about the depth ordering of the involved surfaces. When this conflict is removed by monocular viewing, pictorial displays become similar to parallax displays.

Is the Mosaic-First View Ruled Out?

There are several ways to account for our data in the context of a mosaic-first sequential model. It could be assumed that an initial mosaic stage does occur in pictorial perception, but not in conditions that include binocular parallax. This assumption predicts that primed matching data will support the mosaic-first view only in pictorial displays, as found here. Additionally, it could be assumed that the initial mosaic stage is different from the mosaic percept under proximal viewing. This assumption dismisses the explicit matching data as being irrelevant to the issue of the initial mosaic stage. Finally, it could be argued that the completion process runs faster in the presence of more information for occlusion. According to this argument, parallax trials yield no evidence for a mosaic stage after 100 ms not because there is none but because in these conditions the mosaic has already given way to further processing at that point. None of these alternatives is economical, but Ramachandran (1985) warned that perceptual processes often adopt seemingly uneconomical solutions.

An Alternative Model

Although the mosaic-first view cannot be ruled out, an alternative model can explain the whole set of available data without an initial mosaic stage and more economically. Again consider the pattern of priming effects reported by Sekuler and Palmer (1992) and confirmed here for pictorial displays. At SOAs longer than 200 ms, occluded surfaces show priming effects that are practically identical to those of fully visible complete surfaces. At SOAs around 100 ms, on the other hand, occluded surfaces tend to show priming effects that are more similar to those of mosaic surfaces. In terms of the mosaic-first view, one would interpret these results as follows: At shorter durations of the prime, processing is stopped before the system reaches the second stage of the sequence. As a consequence, priming effects come from the output of the initial, mosaic stage.

Suppose, however, that the mosaic and completion representations are not sequential stages but are the output of two parallel processes that compete to gain access to consciousness. On the basis of phenomenology, one would predict that the completed output would win under ordinary conditions (i.e., uninterrupted processing and veridical information for depth). Under pictorial conditions, however, the displays are

fully compatible with a mosaic interpretation, whereas they contain conflicting information for the completed interpretation. Therefore, it may well be the case that amodal completion requires more time under these conditions. If this were the case, one would expect that interrupting processing early would leave the system in a situation in which the mosaic interpretation is fully available for priming but the completed interpretation is not. However, this would happen not because the mosaic is the first of two sequential stages but because the times required to produce the relevant representations are affected by the available occlusion information. We cannot presently determine whether the effect of pictorial occlusion is to facilitate access to the mosaic interpretation, as is suggested by the results of Experiment 6, or to facilitate access to the mosaic interpretation while also slowing access to the completed interpretation, as is suggested by the results of Experiment 5.

The view put forth in this article differs from the mosaic-stage concept in several ways: First, it proposes that the two kinds of perceptual representation are not produced in sequence but that they reflect the operation of two perceptual "modes" that are activated by task demands or perhaps are always active and operate in parallel. Second, it claims that both perceptual representations can be accessed consciously, albeit with differential degrees of attentional effort as a function again of task demands and viewing context. For instance, it is straightforward to predict that the mosaic mode would be the most easily activated when the stimulus displays lacks compelling depth information, as in pictorial stimuli, whereas it would require greater effort when some depth information is present.

If the alternative model is correct, amodal completion is not a two-stage process and there is no initial mosaic. Although this proposal has several strengths, as discussed in the previous section, it has one implication that may appear problematic. On the basis of what is known about the functional organization of the brain, visual early representations in the lateral geniculate nucleus and in V1 are retinotopic (see, e.g., Lennie, Trevarthen, Van Essen, & Wässle, 1990). However, retinotopic maps are not necessarily mosaics. There is no logical reason why such maps should not be thought of as a set of retinotopic edge descriptors that directly incorporate a classification of edges as occluded and occluding. This computational strategy has proved useful in several computational models of human vision (Grossberg, 1987, 1994; Grossberg & Mingolla, 1985) and of artificial vision (Chang, Chatterjee, & Kube, 1991; Geiger, Ladendorf, & Yuille, 1992; Thompson & Whillock, 1988; Toh & Forrest, 1990). In a study of the role of occlusion constraints in the solution of the aperture problem for motion, Shimojo et al. (1989) showed that the classification of edges as occluding or occluded precedes or at least influences the computation of the perceived direction of a moving edge. Similar findings have been reported concerning binocular processing and the correspondence problem (Nakayama & Shimojo, 1990; Shimojo & Nakayama, 1990). On the basis of these and other results, Anderson and Nakayama (1994) hypothesized neural struc-

tures that directly sense the lack of binocular correspondence at occluding contours, achieving an early classification of edges to be used in the 3-D representation generated by binocular viewing.

One implication of our results is that binocular parallax plays an important role in amodal completion. Because our aim was to address the mosaic-first view, not the role of parallax, this implication remained in the background. However, the role of parallax in constraining amodal completion is important and deserves further study. A potentially useful distinction is that between amodal *completion* and amodal *continuation* (Kanizsa, 1988; Minguzzi, 1987). Recall that parallax constrains the local direction of the occluded contour (with the additional assumption of a nonsingular viewpoint). This cannot specify the shape of the complete surface, only that the surface continues behind the occluder and is therefore not truncated. Perhaps the completion process should be understood as having a purely data-driven component plus a cognitive component. The data-driven component (amodal continuation) is impervious to cognitive influences and is responsible for the experience that the world is not a mosaic but an array of continuous surfaces at different depth planes. The cognitive component (completion proper) is responsible for people's greater willingness to accept certain kinds of completions and reject others. Thus, phenomenal continuation may be intimately linked with the analysis of occlusions in early perceptual processing, whereas phenomenal completion may require additional processing constraints, "between seeing and thinking" (Kanizsa, 1985).

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