

Surface Segmentation Cues Influence Negative Priming for Novel and Familiar Shapes

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In a series of experiments, a negative priming paradigm was used to determine how the visual system represents novel shapes under conditions of inattention. Observers in a shape-matching task viewed overlapping shapes with or without surface segmentation cues. Positive priming occurred with opaque and transparent surface-like shapes, whereas negative priming was found with outlined and transparent shapes that lacked surface segmentation cues. This effect generalized to familiar shapes. These results support the importance of segmentation cues in negative priming and suggest that, under otherwise identical conditions, surface segmentation processes can determine whether positive or negative priming occurs in an implicit memory task. Thus, selective attention for overlapping shapes may be best understood in relation to surface segmentation processes.

We live in a complex environment that contains an ever-changing array of differing objects. As organisms with limited processing capabilities, our perceptual analysis of this environment may be incomplete. It is traditionally assumed that attentional processes determine how much of our environment we come to understand (James, 1890). For example, attention strongly influences our ability to recognize visual objects. Observers of realistic scenes are often completely unaware of the disappearance or reappearance of an object if they are not directly attending to it (Rensink, O'Regan, & Clark, 1997). Moreover, our ability to detect a complex figure in a field of similar figures requires an attentional search (Treisman, 1988; Treisman & Gelade, 1980). Attention is also required for our perception of some moving objects (Cavanagh, 1991; Horowitz & Treisman, 1994). Finally, even when visual displays are simplified so that they contain only two or three forms, observers are still unable to describe unattended forms reliably (Mack & Rock, 1998; Rock, Linnett, Grant, & Mack, 1992).

Early Versus Late Selection Models of Attention

How and when attention directs information processing are topics of extensive debate. In early selection models of attention (e.g., Broadbent, 1958; Treisman & Gelade, 1980), information selection is based on simple, low-level object features. For exam-

ple, according to Broadbent's classic filter theory, a filter mechanism selects stimuli based on their physical properties. Selected items receive subsequent processing, whereas unselected items are filtered out and, as a result, are not processed. Consistent with this class of theories, observers are severely impaired in their ability to detect changes in unattended objects (Rensink et al., 1997). However, late selection models of attention (e.g., Deutsch & Deutsch, 1963; Duncan, 1984) propose that all objects in a scene are represented by the visual system and that attention modifies information processing only after object recognition. Thus, whereas early selection theories of attention posit that only attended objects are represented, late selection theories propose that unattended objects are also represented and identified (Keele & Neill, 1978).

Representation of Unattended Information

The interference paradigm has been widely used to investigate the level at which unattended information is processed. In the classic Stroop effect, observers are slower at naming a colored word when the color of the ink differs from the meaning of the word than when the ink color and word meaning are the same (Stroop, 1935). The Stroop effect, therefore, has been considered a classic example supporting late selection models of attention because it suggests that unattended information is identified and can subsequently interfere with performance. Numerous studies of selective attention also indicate that unattended information receives some kind of processing. For instance, unattended information concerning the location or properties of a stimulus can affect performance (B. A. Eriksen & Eriksen, 1974).

Early selection models of attention have offered a counterinterpretation of the above results by suggesting that interference effects actually indicate a breakdown of selective attention mechanisms (C. W. Eriksen & Rohrbaugh, 1970). According to this view, unattended objects have physical properties that force a disengagement of attention from the supposedly attended objects. In a number of studies, interference effects have been shown to disappear when attended and unattended objects have been made more physically distinct (B. A. Eriksen & Eriksen, 1974; Kahne-

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man & Henik, 1981). Given such findings, interference effects can be conceived of as a measure of how easily a distractor can be distinguished from a target rather than as a measure of the extent to which a distractor has been processed. Furthermore, interference effects occur during target processing, they do not easily address how distractor representations evolve and interact over time. Such limitations imply that a different paradigm may be needed to advance our understanding of selective attention. The negative priming paradigm has been offered as just such a tool (Neill, 1977; Tipper, 1985).

Negative Priming

Priming procedures are commonly used to examine selective attention. A conventional priming paradigm consists of a pair of displays. The initial, or prime, display is followed by a probe display. Observers are asked to respond to a stimulus or stimulus dimension in the probe display that has been repeated from the earlier prime display. When observers attend to an item in a prime display and then make a judgment about that same item in a subsequent probe display, the speed and accuracy of the judgment frequently improves (e.g., Neill, 1997; Dannenbring & Briand, 1982). Such facilitation is known as *positive priming*. *Negative priming* refers to a delayed responsiveness to ignored stimuli on their second presentation. Such slowing, relative to control items presented only once, can occur when an item is ignored on its initial presentation but then attended in a probe display. For example, Tipper (1985) presented observers with prime and probe displays consisting of overlapping figures of different colors. Observers were asked to name the green figure while ignoring the red figure. In the experimental trials, the ignored red figure in the prime display became the green, attended figure in the probe display. Under these conditions, naming latencies in the probe display increased. The fact that unattended stimuli can influence subsequent processing suggests that representations can be constructed under conditions of inattention (Tipper & Driver, 1988). Negative priming is a relatively robust effect that has been reported in a variety of tasks including picture naming (Allport, Tipper, & Chmiel, 1985), letter naming (Tipper & Cranston, 1985), target localization (Tipper, Brehaut, & Driver, 1990), Stroop tasks (Neill, 1977), and shape matching (DeSchepper & Treisman, 1996).

The negative priming paradigm is a particularly useful instrument in the investigation of attentional processes because it mimics our constant need to select relevant information and actions over irrelevant ones. Since naturalistic scenes usually contain many objects and each object may be associated with a different action, organisms are thought to use selective attention to direct their processing resources to whatever is relevant for the task at hand. Negative priming studies have suggested that a disruption of selective attention processes may be associated with suboptimal cognitive function. For example, negative priming effects have been shown to decrease in the elderly (Hasher, Stolzhus, Zacks, & Rypma, 1991; McDowd & Oseas-Kreger, 1991) and in children (Tipper, Bourque, Anderson, & Brehaut, 1989). Schizophrenic patients do not show negative priming effects (Hasher & Zacks, 1988), whereas patients with Alzheimer's disease show increased interference effects (Fisher, Freed, & Corkin, 1990; Spieler, Balota, & Faust, 1996). Such deficits suggest that the mechanisms

underlying negative priming may play a central role in human cognition.

Theories of Negative Priming

Two major classes of theories have been proposed to explain negative priming (Fox, 1995; May, Kane, & Hasher, 1995; Milliken, Joordens, Merikle, & Seiffert, 1998). The *episodic retrieval theory* suggests that negative priming is the result of a dual encoding of a repeated item as "to be ignored" in the prime and as "to be attended" in the probe (Allport et al., 1985; Logan, 1988; Neill, 1977). More specifically, when the critical item requires some judgment in a probe display, the most recent memory of that item from the prime display, along with its "to be ignored" tag, is automatically retrieved. This creates a situation of conflict and response competition that is thought to slow responsiveness (Neill, 1997; Neill & Valdes, 1992). This approach is based on the theory of automatization (Logan, 1988), which proposes that every time the visual system encounters a stimulus, it automatically retrieves the most recent memory of that stimulus. An important aspect of the episodic retrieval theory is its proposal that negative priming effects should depend on how successfully previous episodes can be retrieved (Fox & Fockert, 1998; Logan, 1988; Neill, 1997; Tulving, 1983).

The second class of theories, known as *distractor inhibition theories*, suggests that negative priming results from the inhibition of ignored stimuli in prime displays. This inhibition slows any subsequent responsiveness to the previously ignored item. More specifically, representations of both attended and unattended objects are constructed during the initial presentation of any visual scene. When an organism must respond to a particular object—the representations of the other—unattended items are inhibited so that the relevant information will not have to compete for processing with the irrelevant information (Neill & Westberry, 1987; Tipper, 1985; Tipper & Baylis, 1987). Thus, according to this view, inhibition takes place during selection and acts in a forward manner because the inhibition attached to the distractor in the prime display impairs the performance in a subsequent probe display (May et al., 1995).

This brief review illustrates that negative priming research has focused on the processes underlying selective attention. Such research has yielded important debates over the role of target activation, distractor inhibition, and episodic retrieval in negative priming, and hence, selective attention. Unfortunately, recent reviews suggest that current theories of inhibitory and memorial processes fail to explain all aspects of negative priming (Fox, 1995; May et al., 1995; Milliken et al., 1998).

The goal of the current set of experiments is to determine whether we might be able to gain some novel insight into the negative priming phenomenon by aiming studies in a different but complementary direction. By focusing on the inhibitory and memorial processes underlying negative priming, researchers have given little attention to the information available in the experimental displays themselves. As a result, experimental results have been compared across studies thought to tap the same processes but utilizing vastly different stimuli including novel and familiar shapes, numbers, single letters, letter strings, and words of differing sizes, forms, colors, luminances, durations, and locations. Thus, current studies cannot address the extent to which negative

priming might simply depend on the stimulus information available to an observer.

Surface Segmentation

What visual information might influence negative priming? Since negative priming is related to selective attention, information that the visual system normally uses to select and identify objects would seem a likely candidate. That is, human observers tend to see the physical world as being composed of surfaces and objects (Sajda & Finkel, 1995; Nakayama & He, 1995). To parse the continuous visual world into such discontinuous perceptual units, the visual system invokes surface segmentation mechanisms that depend on image cues such as occlusion, motion, and transparency (Braddick, 1993; Stoner & Albright, 1993). As a result of such segmentation mechanisms, observers can translate visual displays into a collection of surface-based representations (Nakayama & Shimojo, 1992; Nakayama, He, & Shimojo, 1995) or object files (Kahneman, Treisman, & Gibbs, 1992). This process is disrupted for visual scenes lacking surface segmentation cues (Bruno, Bertamini, & Domini, 1997). Simply put, the fewer the number of surface segmentation cues, the more difficult the segmentation. This would hold true for objects that must be selected or segmented from nonhomogeneous backgrounds as well as for objects that visually overlap with other objects.

How might this relate to negative priming? Let's consider tasks involving overlapping shapes (see, e.g., DeSchepper & Treisman, 1996; Tipper, 1985). In negative priming experiments, observers are asked to select a cued item and to make a judgment about it. To select that item, observers must segment it from the other items in the display. When image segmentation is difficult, because appropriate cues are missing or weak, observers may have trouble selecting the cued item because they cannot segment it from the other items in the display. As a result of this segmentation difficulty, a representation of each item may take longer to construct, retrieve, or compare with other representations. If, however, the segmentation process is easy, then object representations should be readily constructed and retrieved. To test this hypothesis, we examined priming for visual displays that either contained or lacked surface segmentation cues. In this way we hoped to determine whether the processes of selective attention and surface segmentation interact in the perception of visual objects.

To that end, we took advantage of previous negative priming studies in which superimposed line drawings, as illustrated in Figure 1, were used as stimuli (DeSchepper & Treisman, 1996; Rock & Gutman, 1981). Such displays lack salient occlusion, depth, and transparency cues. If the absence of surface segmentation cues disrupts some aspect of selective attention tasks, then these difficult-to-segment shapes may be negatively primed. This is exactly what Treisman and her colleagues found in an intriguing

Experiment 1

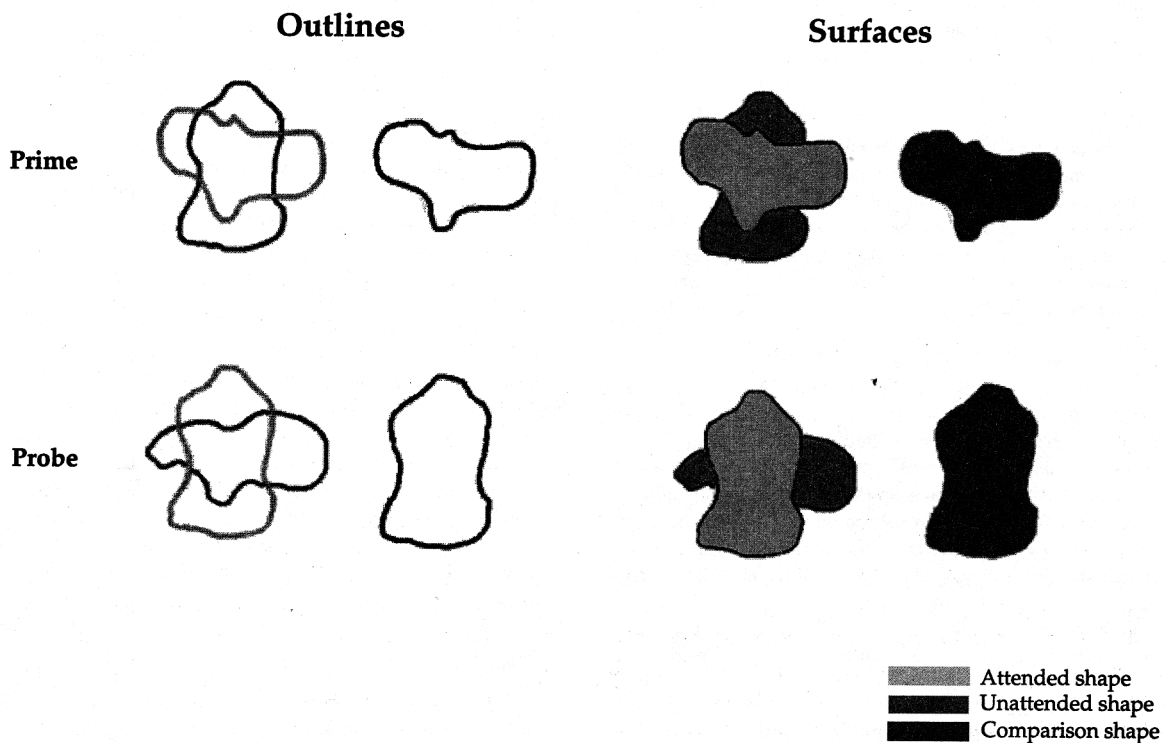


Figure 1. Sample stimuli used in Experiment 1 in the surface condition and the outline condition.

series of experiments (DeSchepper & Treisman, 1996; Treisman & DeSchepper, 1996; Zhang, Treisman, & Kulczycki, 1996). In one set of experiments, observers viewed superimposed, line drawn shapes of different colors, as illustrated in Figure 1. Observers were instructed to attend to and perform a matching task with the green and black shapes while ignoring the red shapes. Treisman and her colleagues found that observers performed the matching task more slowly with previously ignored stimuli than with control stimuli presented for the first time. On the basis of these results, DeSchepper and Treisman suggested that the distractors in the prime displays were suppressed and, as a result, slowed responsiveness upon their subsequent presentations.

Thus, a lack of surface segmentation cues is associated with negative priming in displays that consist of overlapping objects. This result holds true for both novel, nonsense objects (Treisman & DeSchepper, 1996) and for familiar, nameable objects (Tipper, 1985). However, if the lack of surface segmentation cues leads to negative priming, then the presence of surface segmentation cues should lead to positive priming. We tested this prediction in the following experiment. Because increasing evidence suggests that priming effects are determined by both encoding and retrieval processes (Neill, 1997; Wood & Milliken, 1998), surface segmentation cues were either present or absent in both prime and probe displays.

Experiment 1: Surface and Outline Shapes

A negative priming paradigm was used to examine whether surface segmentation cues play a role in tasks involving selective attention. To that end, a modified replication of DeSchepper and Treisman's (1996) negative priming experiment was conducted. The only manipulation was whether or not the overlapping shapes contained surface segmentation cues.

Method

Observers. Twenty-two Rutgers University undergraduates participated in this experiment for credit toward a class requirement. All observers reported that they had normal or corrected-to-normal visual acuity and color vision. Observers were naive to the hypothesis under investigation.

Apparatus. All stimuli were displayed on a Macintosh 21-in. (40 × 30 cm) RGB monitor with an 1,152 × 870 pixel resolution. A Macintosh Quadra 950 was used to control stimulus presentation and data collection. Observer responses were collected with a Macintosh keyboard. A chin rest was used to fix observers' viewing distance at 55 cm (21.6 in.) from the screen. This apparatus was used in all of the experiments reported here.

Stimuli. The stimuli consisted of 216 smoothly curved, closed two-dimensional shapes that were hand drawn. Seventy-two figures were used in the practice trials, and 144 were used in the experimental trials. These figures were rendered in Adobe Photoshop (Version 2.0.1) using an RGB palette. The figures differed in overall shape and were designed to be similar to those used in DeSchepper and Treisman (1996). The width as well as the height of each figure ranged between a minimum of 2.5 degrees of visual angle (DVA) and a maximum of 4.5 DVA.

Each trial consisted of a prime display followed by a probe display. Each display contained three figures as shown in Figure 1. Two overlapping figures were positioned on the left, and the third figure was on the right. The figure on the right was always black in color and had a 1.3-cd/m² luminance. The top figure on the left was always green with a 28.4-cd/m² luminance, whereas the bottom figure on the left was always red with a luminance of 16.9-cd/m². The background was an otherwise homoge-

neous 80.2-cd/m² white area having a 17.6 × 8.8 DVA rectangular shape. The center of the overlapping figures was positioned 9.6 DVA from the center of the black target figure.

There were two stimulus conditions. In the surface condition, all three figures were filled. The green shape always occluded the central portion of the red shape. As a result, the entire green shape was visible while only two sections of the partially occluded red shape were visible. The completion of this occluded shape always followed an "expected" or "typical" completion (Sekuler & Palmer, 1992). The green shape occluded approximately one third of the area of red shape. In the outline condition, the three shapes were shown in outline form as in DeSchepper and Treisman (1996). The width of the outline used in this condition subtended 9.4 min of visual angle. Thus, the shapes used in the prime and probe displays of the surface and outline conditions differed only in the presence or absence of occlusion cues.

Procedure. Observers were seated in front of the display monitor and were told that they would see some briefly presented figures. They were instructed to attend to the green and black figures and to ignore the red figures. Observers were asked to report as quickly and accurately as possible whether the green figure matched the shape of the black figure. Observers pressed one key on the keyboard when the green and black figures matched and a different key when these figures did not match. Reaction time and accuracy feedback were provided at the end of the practice trials but not during the experimental trials.

A negative priming paradigm (DeSchepper & Treisman, 1996) was used. Unbeknownst to the observer, there were two types of trials. During the "old" trials, one figure appeared in both the prime and probe displays. More precisely, as can be seen in Figure 1, the unattended, red figure in the prime became the attended, green figure in the probe display. During the "new" trials, the unattended, red figure from the prime had no relationship with the attended, green figure in the probe display. In both old and new trials, the red figure in the probe display was always novel. While observers performed the matching task during the prime and probe displays, reaction time and accuracy were only recorded for the probe displays.

Each observer completed one block of 32 experimental trials (that is, observers performed the matching task for 32 prime displays and 32 probe displays). Sixteen of these were old trials, and sixteen were new trials. In half of the prime and probe displays, the black figure matched the green figure. The other half of the displays contained a black figure that did not match the green figure. Thus, the correct response to one half of the prime displays and one half of the probe displays was "same," whereas the correct response to the other half of the displays was "different." A trial could consist of two "same" displays, two "different" displays, a "different" prime display followed by a "same" probe display, or finally a "same" prime display followed by a "different" probe display.

For the prime displays in the 16 new trials, the 8 "different" displays contained 3 novel figures and the 8 "same" displays contained 2 novel shapes (because the green and black shapes were the same). Thus, these prime displays were constructed from 40 figures [(3 × 8) + (2 × 8)]. The probe displays in the new trials and the prime displays in the old trials were each similarly constructed from 40 shapes. The 16 probe displays in the old trials were constructed from 24 novel shapes in the following manner: In the 8 "different" trials, the green shape had appeared as the red shape in the previous prime display. Thus, only two shapes were novel. In the 8 "same" displays, the green shape had also been presented in the previous prime trial as the red shape. Moreover, the green shape matched the black shape. Thus, since only one shape was novel in the "same" displays (8 × 1) and two shapes were novel in the "different" displays (8 × 2), these probe displays were constructed from 24 shapes.

Each trial began with the presentation of a white screen containing a central fixation point for 1.0 s. Then the prime display was presented for 1.5 s. This fixed duration insured that all observers observed each of the prime shapes for the same amount of time. The disappearance of the prime display was followed by a 300-ms duration white screen. The probe display

was then presented until the observer pressed a key (with a maximum duration of 3.0 s). This was immediately followed by the 1.0-s blank screen and then the next prime display.

According to a between-subjects design, half of the observers participated in the surface condition, whereas the other half of the observers participated in the outline condition. All observers completed one practice block containing 16 trials (that is, observers performed the matching task for 16 prime displays and 16 probe displays) before beginning the experimental trials. If an observer had a mean reaction time greater than 900 ms in the practice block, then the observer repeated the same block of practice trials until their reaction time fell below 900 ms. Different shapes were used in the practice and experimental trials. The order of trial presentation was randomized across observers.

Results

The amount of time needed for observers to report correctly whether the green and black figures matched or differed from each other was recorded across condition and trial type. Reaction time, or the amount of time from display onset to observers' key press, for correct responses was included in the analysis. Mean reaction times, corresponding standard deviations, error rates, and priming—or reaction time differences—are presented in Table 1. Specifically, negative priming was observed in the outline condition, whereas positive priming was observed in the surface condition.

To assess the effects of condition and the possible interactions, a $2 \times 2 \times 2$, mixed-model analysis of variance (ANOVA) with match type (same–different) and trial type (old–new) as the within-subjects variables and condition (surface–outline) as the between-subjects variable was used. As in all of the studies reported in this article, the alpha level was fixed at .05. This analysis revealed significant effects of condition, $F(1, 20) = 12.9$, $MSE = 78,171.2$, match type, $F(1, 20) = 39.9$, $MSE = 11,553.8$, and trial type, $F(1, 20) = 9.7$, $MSE = 3,017.2$. There was a significant interaction between trial type (old–new) and condition (surface–outline), $F(1, 20) = 43.6$, $MSE = 3,017.2$. However, no significant interaction was found between trial type (old–new) and match type (same–different), $F(1, 20) = .5$, $MSE = 4,372.8$, or between condition and match type, $F(1, 20) = .1$, $MSE = 11,553.8$.

To evaluate the priming effects within each condition, we performed individual two-tailed t tests to determine simply whether positive or negative priming occurred. Since the overall interaction between trial type and condition was significant, the t tests were also used to determine which groups showed significant priming effects. In the outline condition, observers correctly reported “same” matches for the old trials 155 ms slower, on average, than they reported “same” matches for the new trials. A paired t test revealed that this difference between the correct “same” responses to the new and old trials was significant, $t(10) = 6.717$. There was also a significant -73 -ms difference in reaction times for “different” responses to the two types of trials, $t(10) = 2.320$. Thus, significant negative priming was observed in the outline condition. In the surface condition, however, observers correctly reported “same” matches for old trials 61 ms faster, on average, than for new trials. A paired t test revealed that this reaction time difference between the “same” responses of the old and new trials was significant, $t(10) = -3.240$. Thus, significant positive priming was observed in the surface condition for the “same” responses. However, the 20-ms reaction time difference between the correct

“different” responses in the old and new trials in the surface condition was not significant, $t(10) = -0.716$. “Different” responses frequently yield weak or even nonexistent priming effects (Beller, 1971; Krueger, 1978; Neill, Lissner, & Beck, 1990).

Discussion

The results of the outline condition clearly replicate those of DeSchepper and Treisman (1996). That is, novel, outlined shapes are negatively primed under conditions of inattention. This further supports the hypothesis that negative priming requires neither preexisting representations nor semantic processes. Moreover, under otherwise identical conditions, positive priming was found with the same shapes when they were presented as filled surfaces in the surface condition. Since the displays used in these two conditions differed only in the presence of surface segmentation cues, the results of this experiment suggest that selective attention processes, as indexed by priming, can be substantially modulated by surface segmentation cues. Indeed, the results of this experiment imply that, at least in the perception of novel shapes, the processes underlying selective attention may be related to the processes of surface segmentation. Over 150 ms of negative priming was found in the outline condition, and 61 ms of positive priming was found in the surface condition. The magnitude of these effects, as well as that of their difference, supports the claim that shape perception may provide a particularly useful window into selective attention processes.

However, there are some important limitations to the current data. First, because we manipulated segmentation ease in the prime and probe displays simultaneously, the results of this experiment cannot be used to address whether the presence of segmentation cues in the prime or probe display is the critical factor. This important issue is directly addressed in Experiment 4. Another limitation to the current experiment, and indeed, to all of the experiments reported here, is their relationship to priming studies involving spatially overlapping words and letters. Whereas object representations are surface based (Nakayama et al., 1995; Nakayama & Shimojo, 1992), there is no obvious reason why words and letters should be represented as surfaces. Since the grouping processes used in the perception of letters and surfaces may differ in some fundamental ways, the current findings may not generalize outside the domain of object perception.

A final caveat is that the current study does not constitute a test between the inhibitory and episodic retrieval theories of negative priming because our results can be explained by either theory. According to inhibitory theories, ignored items are inhibited in prime displays, and the subsequent retrieval of such inhibited representations yields negative priming. Inhibition is thought to be particularly potent when target selection is difficult (e.g., Fox, 1994; Fuentes & Tudela, 1992; Ruthuff & Miller, 1995). In the present experiment, the presence of segmentation cues could have eased target selection and thereby decreased or eliminated the need for distractor inhibition in the prime. This might have led to positive priming. The absence of segmentation cues might create selection difficulty, increasing the need for inhibitory mechanisms, and thereby leading to negative priming.

According to episodic retrieval theories (e.g., Neill, 1997; Neill & Valdes, 1992), the absence of segmentation cues in the prime might cause observers to process distractor items very deeply or

Table 1
Priming Results for Experiments 1–5: Mean Reaction Times, Corresponding Standard Deviations, Priming Magnitudes, and Error Rates Broken Down by Stimulus Condition, Trial Type, and Correct Response or Match

Experiment	Condition	Trial	Match	Error rates (%)	Reaction times (ms)		
					<i>M</i>	<i>SD</i>	Priming
1	Outlines 1500 ms	Same	New	3.4	856	122	–155
			Old	12.5	1011	140	
		Different	New	12.5	1050	177	–73
			Old	13.6	1123	203	
	Surfaces 1500 ms	Same	New	4.5	759	126	+61
			Old	3.4	697	128	
		Different	New	9.1	875	181	+20
			Old	6.8	855	150	
2	Nontransparent 1500 ms	Same	New	10.2	776	101	–70
			Old	3.4	846	83	
		Different	New	5.7	900	88	–35
			Old	14.8	934	133	
	Transparent 1500 ms	Same	New	2.3	754	133	+100
			Old	3.4	655	113	
		Different	New	10.2	806	131	+33
			Old	8.0	772	137	
3	Outlines 1000 ms	Same	New	6.8	701	108	–59
			Old	20.5	760	100	
		Different	New	14.8	788	135	–26
			Old	18.2	813	177	
	Surfaces 1000 ms	Same	New	2.3	686	101	+92
			Old	2.3	594	55	
		Different	New	11.4	723	108	+19
			Old	11.4	704	85	
4	Surface cues in probe 1000 ms	Same	New	12.5	662	90	–61
			Old	18.2	724	151	
		Different	New	23.9	770	85	–79
			Old	22.7	849	94	
	Surface cues in prime 1000 ms	Same	New	21.6	916	120	+19
			Old	15.9	896	83	
		Different	New	19.3	892	154	+25
			Old	20.5	867	98	
5	Familiar outlines 1000 ms	Same	New	9.1	683	86	–78
			Old	10.2	761	112	
		Different	New	9.1	716	112	–66
			Old	12.5	783	167	
	Familiar surfaces 1000 ms	Same	New	0.0	591	77	+49
			Old	0.0	542	86	
		Different	New	3.4	650	122	+57
			Old	3.4	593	90	

Note. “Priming” indicates the magnitude and direction of the priming effects calculated as the mean reaction time from the “new” trials minus the mean reaction time from the “old” or repeated-shape trials. Error rates refer to the percentage of trials during which subjects made incorrect matching responses.

actively and hence, to attach a particularly influential “to be ignored” tag to these items. Such tags would slow processing whenever previously ignored items are retrieved during the probe displays. In this case, response slowing is thought to result from a response conflict created when the representation of the critical

item along with its “to be ignored” tag is automatically retrieved when the observer attends to this same item in the probe display. Conversely, distractor items might be only superficially processed in the presence of segmentation cues thereby rendering the “to be ignored” tag less influential. This would reduce response conflict,

and hence, negative priming, when these representations are retrieved during probe displays.

Experiment 2: Surface Transparency

In the previous experiment, occlusion cues were shown to influence shape priming. If surface segmentation processes play an important role in our ability to selectively attend to and represent shapes, then other salient surface segmentation cues should also influence priming. Since not all surfaces are opaque, the current study examined whether surface transparency influences object priming.

A surface is seen as a transparent when its luminance falls in between the luminances of the adjacent image regions and has boundaries that are consistent with the occlusion of another surface. X-junctions, formed at the intersection of overlapping surfaces, are thought to be an important cue to the interpretation of transparent surfaces (Watanabe & Cavanagh, 1993). Since transparency is related to surface luminance and occlusion, the visual system is thought to use transparency to facilitate surface segmentation (Nakayama, Shimojo, & Ramachandran, 1990).

Transparency manipulations allow us to address several issues. First, in the previous experiment, the entire unattended object was not visible in the prime display because the attended object occluded it. Filling-in processes were required before the unattended shape could be represented as a single shape. Since the critical shape was partially displayed in the prime and fully displayed in the probe, unusual perceptual (Srinivas, 1993; Zhang et al., 1996) and memorial (Neill, 1997) processes may have been tapped. Second, the results of Experiment 1 simply suggest that the presence of image segmentation cues, in general, is sufficient for the elimination of negative priming. It is more likely that available image cues must be consistent with the interpretation of surfaces before image segmentation processes are facilitated. Relatedly, in the outline condition of Experiment 1, the shapes satisfied the X-junction but not the luminance rules for transparency. Thus, these shapes may have been difficult for the visual system to interpret because they were neither opaque nor transparent. This interpretation difficulty may have caused the performance impairment in that condition. Manipulations of surface transparency allowed us to address these issues.

Method

Observers. Twenty-two observers participated in this experiment for credit toward fulfillment of a course requirement. All observers reported that they had normal or corrected-to-normal visual acuity and color vision. All observers were naive to the hypothesis under investigation, and none had participated in the previous experiment.

Stimuli. The stimuli consisted of a transformed version of the same set of 216 shapes used in the outline condition of Experiment 1. Adobe Photoshop (Version 2.0.1) software was used to create transparent and nontransparent versions of each pair of overlapping shapes. The black comparison shapes on the right of each display were identical to those used in Experiment 1.

Luminance values were measured with a Tektronix (Model J1803; Tektools Tektronix, Beaverton, OR) photometer. In both the transparent and nontransparent conditions of this experiment, the occluded surface was presented as a dark, 14.6-cd/m² homogeneous green. Both conditions also used the same white, 80.2-cd/m² background. As shown in Figure 2, the shapes from the two conditions differed only in the luminance values of the

occluding surface. The perception of transparency requires that the overlapping region of the occluding surface have a luminance value that is intermediate to the luminances of the occluded surface and the nonoverlapping regions of the occluding surface (Metelli, 1974). With this in mind, the luminance values of the occluding shapes were established. In the transparency condition, the two nonoverlapping regions of the occluding shape were both a 28.4-cd/m² light green, whereas the luminance of the overlapping region of the occluding shape was 20.2-cd/m². In the nontransparency condition, these two luminance values were simply reversed. That is, the overlapping region had a 28.4-cd/m² luminance value, whereas the two, nonoverlapping regions of the occluding shape both had a 20.2-cd/m² luminance. Thus, the luminance values of the light green, occluding surface in the transparency condition were consistent with the interpretation of a transparent surface (because the 20.2-cd/m² luminance of the overlapping region falls in between 28.4 and 14.6 cd/m²), whereas the luminance values in the nontransparency condition were not consistent with the interpretation of a transparent surface (because the 28.4-cd/m² luminance does not fall between 20.2 and 14.6 cd/m²). In all other respects, the shapes in the transparent and nontransparent conditions were identical.

Procedure. Observers were instructed to pay attention to the light green shape and the black shape and to ignore the dark green shape. Pilot studies showed that observers readily perceived the overlapping shapes as transparent in the transparent condition and nontransparent in the nontransparent condition. The same design and procedure used in Experiment 1 were used here.

Results

Reaction times for correct responses, error rates, and priming—or the reaction time difference between old and new trials—are presented in Table 1. A 2 × 2 × 2 mixed-model ANOVA with match type (same–different) and trial type (old–new) as the within-subjects variables and condition (transparent–nontransparent) as the between-subjects variable revealed significant effects of condition, $F(1, 20) = 7.0$, $MSE = 43,099.8$, and match type, $F(1, 20) = 39.5$, $MSE = 5,049.0$, but no significant effect of trial type, $F(1, 20) = .2$, $MSE = 4,675.6$. There was a significant interaction between trial type (old–new) and condition (transparent–nontransparent), $F(1, 20) = 16.6$, $MSE = 4,675.6$. There was no significant interaction between trial type (old–new) and match type (same–different), $F(1, 20) = .7$, $MSE = 1,811.5$, or between condition and match type, $F(1, 20) = .5$, $MSE = 5,049.0$.

Two-tailed *t* tests were performed to determine whether positive or negative priming occurred in each condition. Our ANOVA did not reveal a significant main effect of the trial type. However, there was a significant interaction between the trial type (old–new)—that is, the priming effects—and the condition. Therefore, *t* tests were used to define the presence or absence of priming effects in the four groups (same old vs. same new, different old vs. different new). In the transparent condition, a paired *t* test revealed a significant 100-ms difference between the “same” responses of the new and old trials, $t(10) = 5.34$ as well as a nonsignificant 33-ms difference for the “different” responses, $t(10) = 1.290$. In the nontransparent condition, paired *t* tests revealed a significant –70-ms difference between the “same” responses of the new and old trials, $t(10) = -2.770$, but a nonsignificant –35-ms difference between the two types of “different” responses, $t(10) = -1.310$. Thus, for “same” responses, significant positive priming was found in the transparent condition, whereas significant negative priming was found in the nontransparent condition.

Experiment 2

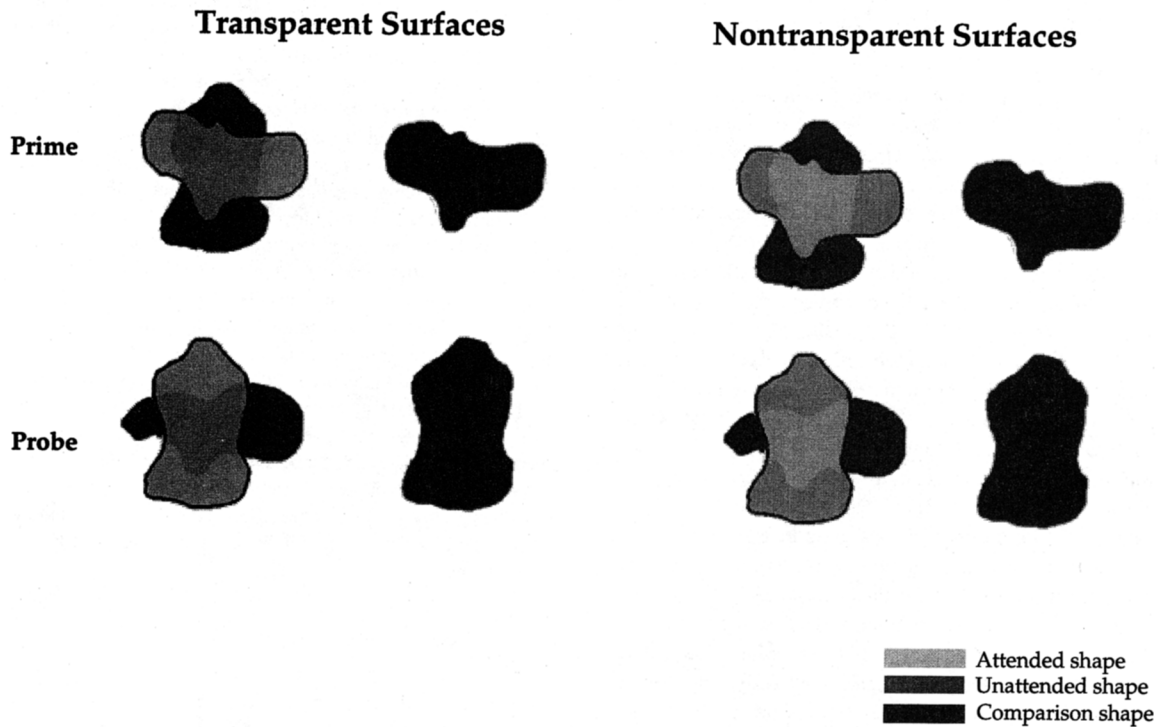


Figure 2. Stimuli for Experiment 2: transparent condition and nontransparent condition. Positive priming was found in the transparent condition, and negative priming was found for the same shapes in the nontransparent condition.

Discussion

The results of this experiment further support the hypothesis that surface segmentation cues play an important role in selective attention. To the extent that the visual system uses surface transparency to segment surfaces (Nakayama et al., 1990), transparent target surfaces should be easy to select and represent. The results of this study therefore support the association between easy segmentation and a reduction—or in this case a reversal—of negative priming. In the transparent condition, the overlapping shapes were presented in a manner consistent with the interpretation of one transparent surface occluding another surface. In the nontransparent condition, the luminance values of the displays made them inconsistent with such an interpretation. Transparency information was present in both types of displays. The only difference was what that information suggested. The large priming differences found under these conditions imply that the presence of segmentation information is not, in and of itself, responsible for the shift to positive priming in these experiments. Indeed, the nontransparent shapes contained numerous segmentation cues. Instead, segmentation cues must be consistent with the interpretation of coherent surfaces in order for overlapping shapes to be positively primed under our experimental conditions of inattention.

Because the target and distractor shapes in the two conditions differed only in the locations of the luminance values, the luminance contrasts of the two displays were identical. Moreover, the

X-junctions were identical in both conditions. Thus, local luminance differences and boundary differences cannot explain these results. Furthermore, because transparency renders the distractor shape fully visible, filling-in processes and form differences in the prime and in the probe displays cannot explain why priming switches from negative to positive when coherent surface segmentation cues are added to a display. Instead, the results of this experiment, when combined with those of Experiment 1, strongly suggest that surface segmentation cues can control the mechanisms underlying perceptual priming.

Experiment 3: Prime Duration Control

Previous studies of negative priming with novel shapes have involved shorter prime display durations than the ones used in the previous two experiments. For example, DeSchepper and Treisman (1996) did not use a fixed prime presentation duration. Instead, their prime displays were presented until observers responded with a mean response time latency of approximately 700 ms and an *SD* of roughly 150 ms. Moreover, naming latencies in Tipper's (1985) negative priming experiments averaged approximately 500 ms. In our Experiments 1 and 2, prime durations were fixed at 1.5 s: that is, for a duration two times longer than DeSchepper and Treisman (1996) and three times longer than Tipper (1985). Thus, one possible account of the previous results is that observers used the extra time to fully attend to both of the

overlapping shapes. As a result, observers may have attended to the supposedly ignored item. To overcome this interpretation difficulty, Experiment 1 was replicated with a prime display duration of 1.0 s.

Method

Observers. Twenty-two observers participated in this experiment for credit toward fulfillment of a course requirement. All observers reported that they had normal or corrected-to-normal visual acuity and color vision. All observers were naive to the hypothesis under investigation, and none had participated in either of the previous experiments.

Stimuli. The stimulus set and experimental procedure used in Experiment 1 were used in this experiment as well. The only change was that the prime duration was reduced by 500 ms. Pilot studies suggested that the use of prime durations shorter than 900 ms yielded significantly larger error rates than those found for Experiment 1. Thus, for purposes of comparison, a prime duration of 1.0 s was used.

Procedure. The same between-subjects procedure was followed, and observers again performed the same shape-matching task previously described. As before, observers completed at least 16 practice trials before beginning the experimental trials. Again, reaction time and accuracy were measured.

Results and Discussion

Reaction times for correct responses, error rates, and priming magnitudes are presented in Table 1. The same analyses used in Experiments 1 and 2 were used in this experiment as well. The $2 \times 2 \times 2$ ANOVA revealed significant effects of condition, $F(1, 20) = 4.4$, $MSE = 39,258.2$, and match type, $F(1, 20) = 16.4$, $MSE = 6,878.7$, but no significant effect of trial type, $F(1, 20) = .5$, $MSE = 2,090.0$. There was a significant interaction between trial type (old–new) and condition (outline–surface), $F(1, 20) = 25.1$, $MSE = 2090.0$. No significant interaction was found between trial type (old–new) and match type (same–different), $F(1, 20) = .7$, $MSE = 3,399.0$, or between condition and match type, $F(1, 20) = .0$, $MSE = 6,878.7$.

As discussed in Experiment 2, two-tailed t tests were used to define the presence or absence of priming effects in the four groups (same old vs. same new, different old vs. different new). In the surface condition, observers correctly responded “same” to old trials 92 ms faster than their correct “same” responses to new trials, $t(10) = 3.950$. The “different” responses differed by a nonsignificant 19 ms, $t(10) = 0.800$. In the outline condition, paired t tests revealed the opposite pattern; that is, observers responded 59 ms slower to old trials than to new trials with correct “same” responses, $t(10) = -5.35$. Once again, there was a nonsignificant –26-ms difference between the two types of “different” responses, $t(10) = -0.920$.

The results of this experiment, in which the prime duration was reduced by 500 ms, replicate those of Experiment 1, in which the prime duration was 1.5 s. As before, positive priming was found in the surface condition, whereas negative priming was found in the outline condition. This finding suggests that the results of Experiments 1 and 2 are robust and did not simply result from the use of extended prime durations. In any case, it is difficult to imagine why observers would have used the long prime durations in Experiment 1 to attend to the distractor shape in the surface condition but not in the outline condition.

Experiment 4: Selection or Retrieval?

In all of the previous experiments, surface segmentation cues were manipulated in both the probe and prime displays. As a result, it is not possible to determine when these cues exert their influence. This question is particularly important because the classic theories of negative priming make different predictions.

Distractor inhibition theories suggest that, because inhibitory mechanisms are activated during the prime display, the information available in the prime makes a significantly larger contribution to negative priming than does probe information (e.g., Tipper, 1985). It follows that inhibitory theories predict that surface segmentation cues in the prime will be the major determinant of negative priming. Conversely, episodic retrieval theories focus on how distractors are encoded in the prime trials as well as on how targets cue memory retrieval in the probe trials (e.g., Neill & Valdes, 1992). Since processing during both the prime and probe displays is important, retrieval theories predict that surface segmentation cues in the probe and the prime should contribute to negative priming effects. Finally, other studies have reported that manipulations in either the prime or probe display can impact negative priming as long as the selection state and task demands remain constant (e.g., Houghton & Tipper, 1994; Milliken et al., 1994; Tipper, Weaver, & Houghton, 1994).

To determine when surface segmentation cues influence negative priming, and presumably selective attention, a modified version of Experiment 3 was carried out in which either the prime or the probe, but not both, contained surface segmentation cues. Thus, in one condition, the prime displays contained outlined shapes, and the probe displays contained filled or surface-like versions of the same shapes. This was reversed in the other condition. One caveat to this approach is that, unlike in the other studies reported here, the prime and probe shapes differ as to whether they contain surface segmentation cues. Such a similarity decrease may result in decreased priming magnitudes (Fox & Fockert, 1998; Neill, 1997).

Method

Observers. Twenty-two observers participated in this experiment for credit toward fulfillment of a course requirement. All observers reported that they had normal or corrected-to-normal visual acuity and color vision. All observers were naive to the hypothesis under investigation, and none had participated in any of the previous experiments.

Stimuli. There were two stimulus conditions. The shapes in both conditions were identical to those used in Experiments 1 and 3. As indicated in Figure 3, surface segmentation cues were presented in either the prime display or the probe display but not in both. Thus, in the surface-cues-in-prime condition, observers viewed the surface condition shapes in the prime displays and the corresponding outline condition shapes in the probe displays. In the surface-cues-in-probe condition, observers viewed outline condition shapes in the prime and surface condition shapes in the probe.

Procedure. The same between-subjects procedure was followed, and observers again performed the same shape-matching task previously described. We used 1.0-s prime display durations as in Experiment 3. As before, reaction times and the percentage of correct responses were recorded.

Results

Reaction times for correct responses, error rates, and priming magnitude are presented in Table 1. A $2 \times 2 \times 2$ ANOVA

Experiment 4

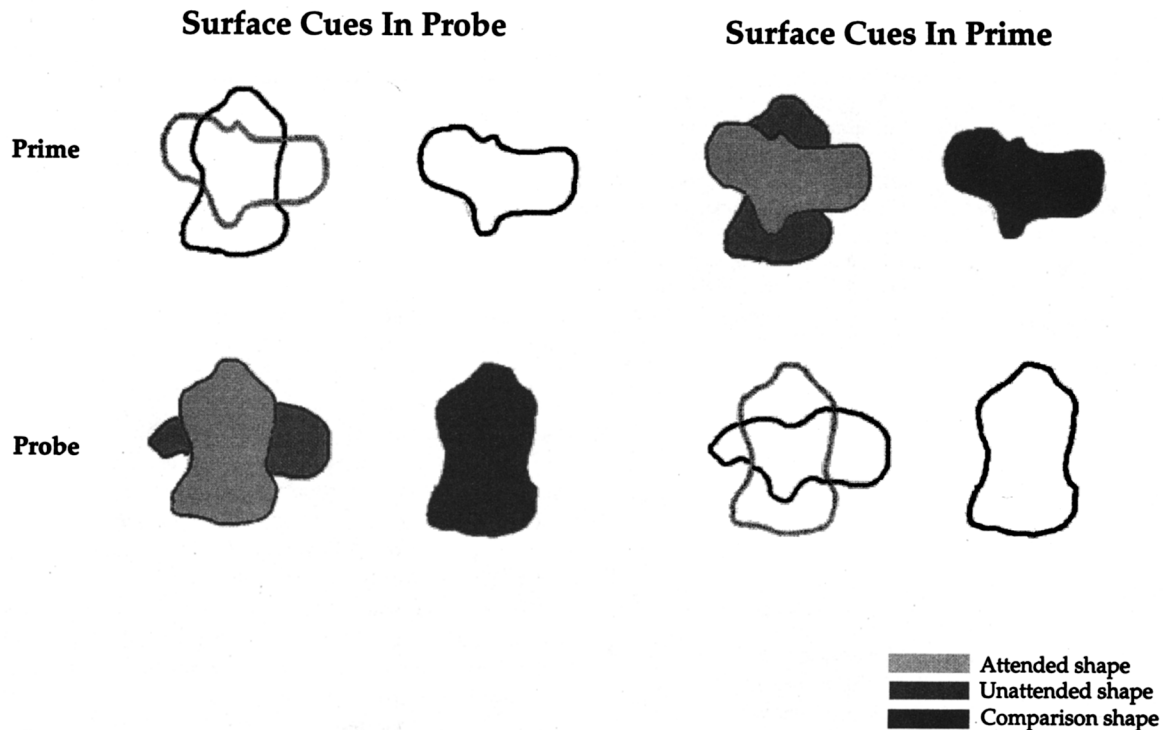


Figure 3. Stimuli for Experiment 4. In the surface-cues-in-probe condition, prime displays contained outline shapes, and probe displays contained surface-like versions of the corresponding shapes. This was reversed in the surface-cues-in-prime condition.

revealed significant effects of condition, $F(1, 20) = 13.5$, $MSE = 32,723.0$, and match type, $F(1, 20) = 6.4$, $MSE = 6,850.5$, but no significant effect of trial type, $F(1, 20) = 2.3$, $MSE = 5,422.8$. The only significant interaction was between trial type (old–new) and condition (surface-cues-in-prime/surface-cues-in-probe), $F(1, 20) = 8.7$, $MSE = 5,422.8$.

Individual t tests were performed to identify any priming effects in the two conditions. In the surface-cues-in-prime condition, a paired t test revealed a nonsignificant 19-ms difference between the “same” responses of the old and new trials, $t(10) = .530$. When the correct response in this condition was “different,” the reaction times to these two trial types differed by a nonsignificant 25 ms, $t(10) = .660$. In the surface-cues-in-probe condition, paired t tests revealed a significant difference of -61 ms between the “same” responses to the old and new trials, $t(10) = -2.480$, and a significant -79 -ms difference between the “different” responses, $t(10) = -3.090$. Thus, no significant priming was found in the surface-cues-in-prime condition, whereas significant negative priming was found in the surface-cues-in-probe condition.

Discussion

There are three main results to this experiment. First, significant negative priming was found when prime displays contained outlined shapes. Second, no significant priming was found when the

probe displays contained outlined shapes. Finally, the error rates for both conditions in this experiment were double, or even greater, than the error rates in Experiments 1 and 3. The implications of each of these findings are discussed in turn below.

Previous research has shown that manipulations of selection ease in prime displays significantly modify negative priming (Fox, 1994; Fuentes & Tudela, 1992; Ruthruff & Miller, 1995). To the extent that a lack of surface segmentation cues in the prime displays rendered target selection difficult, the current results are consistent with the hypothesis that selection ease in the prime is an important determinant of negative priming. However, if the presence or absence of surface segmentation cues influences the depth of distractor processing in the prime display, then the current results can also be explained by episodic-retrieval theories.

No significant priming was found in the surface-cues-in-prime condition. In this condition, the prime displays contained the surface-like shapes, and the probe displays contained outline versions of the same shapes. At first glance, this result may seem at odds with previous findings that information in probe displays also contributes to negative priming (Lowe, 1979; Milliken et al., 1998; Moore, 1994; Neill, Terry, & Valdes, 1994; Neill & Valdes, 1992; Tipper & Cranston, 1985). However, the current finding can be interpreted in light of recent reports that perceptual priming may be asymmetric. That is, simple or low-level versions of a stimulus

can prime more complex or higher level renditions of the same stimulus. However, priming does not occur in the reverse direction. That is, no priming is found when more complex renditions of a stimulus are presented in the prime display, whereas less complex versions of the same stimulus appear in the probe display. This priming asymmetry has been found for low- and high-spatial-frequency faces (Oliva & Schyns, 1997; Schyns & Oliva, 1994; 1999), silhouettes and shaded objects (Hayward, Tarr, & Corderoy, 1998), fragmented outlines, continuous outlines, luminance contours, and subjective contours (Loula & Shiffrar, 1997).

This asymmetry can be interpreted in terms of a slightly modified episodic-retrieval theory that allows for an asymmetric similarity space. Research from several different domains supports the proposal that perceptual similarity space is asymmetric such that an Object X can be more similar to Object Y than Y is to X (e.g., Deregowski & McGeorge, 1998; Ortony, Vondruska, Foss, & Jones, 1985; Tversky, 1988). Such asymmetry is most likely to occur when more is known about one item than is known about the other (Tversky, 1988). In the current study, the surface-like shapes contain more information than do the outline shapes. Thus, according to the episodic-retrieval theory, if an outline version of a shape is more similar to the surface version of that same shape than *visa versa*, then one would predict the priming asymmetry that was found in this experiment.

Since distractor inhibition theories focus almost exclusively on perceptual and encoding conditions during prime displays, this class of theories cannot explain the lack of significant priming in the surface-cues-in-prime condition. Target selection was easy in the prime displays because surface segmentation cues were present. Under these conditions, distractor inhibition theories predict the same positive priming found in the surface conditions of Experiments 1 and 3. Yet, no significant priming was found.

Finally, the high error rates in this experiment, relative to those from Experiments 1 and 3, also support one of the key premises of the episodic-retrieval theory. That is, the target in the probe display functions as a retrieval cue for the ignored distractor from the prime display only when the two are sufficiently similar (e.g., Neill, 1997). In Experiments 1 and 3, these critical shapes were either both surfaces or both outlines. Under these conditions, the error rates for the same–new trials in the surface and outline conditions of Experiment 3, for example, were 2% and 7%, respectively. However, in this experiment, the critical shapes differed in the prime and probe displays. More specifically, in one display the critical shape appeared as an outline figure lacking surface segmentation cues, whereas in the other display it was shown as a surface. Under these conditions, the error rates for the surface-cues-in-prime trials were 19% for the “same” matches and 20% for the “different” matches. For the surface-cues-in-probe trials, the error rates were 15% for the “same” matches and 23% for the “different” matches. This substantial performance decrement with decreasing prime–probe similarity supports aspects of the episodic-retrieval theory. More specifically, the episodic-retrieval theory predicts that as the similarity between the critical item in the prime and the probe displays decreases, priming will diminish and be more error prone as a result of a problematic and weakened match between the encoding and the retrieval conditions (Neill, 1997). Importantly, because distractor inhibition theories do not address prime–probe similarity (Fox & Fockert, 1998), these theories predict that the error rates in Experiment 4 should have

replicated those from the previous experiments. Clearly, this was not the case.

Taken together, the results of this experiment indicate that manipulations of surface segmentation cues in prime and probe displays can have differential effects on negative priming. When considered along with the results of Experiments 1 and 3, the current results clearly suggest that overlapping shapes will be negatively primed when prime displays lack surface segmentation cues. From Experiments 1 and 3, we know that positive priming results when both prime and probe displays contain surface segmentation cues. However, the results of this experiment indicate a lack of significant priming when surface cues only appear in the prime display. This result could be understood in terms of an episodic-retrieval theory that allows for an asymmetric similarity space.

Experiment 5: Familiar Shapes

Does the existence of prior shape representations override or reduce the importance of surface segmentation cues in selective attention tasks? The results of the previous studies indicate that surface segmentation cues can determine whether the representations of ignored shapes are positively or negatively primed. To the extent that negative priming tasks tap selective attention processes, these results strongly support the role of surface segmentation cues in determining performance in perceptual priming tasks. However, this critical role of low-level surface cues may be restricted to the attentional selection or retrieval of novel, nonnameable shapes. If so, then such cues may not play an important role in the perception and representation of familiar shapes.

Additionally, recent work suggests that negative priming may depend on the repeated presentation of ignored items (Strayer & Grison, 1999). To explain the significant negative priming found by DeSchepper and Treisman (1996), Strayer and Grison (1999) suggested that novel, unfamiliar shapes might be easily confused with one another, thereby leading to the apparent repetition of at least some of DeSchepper and Treisman’s shapes. Negative priming may have resulted from this apparent repetition. The present study was designed to address both this and the previous concern by determining whether the role of surface segmentation cues in negative priming paradigms generalizes to familiar shapes.

To that end, a replication of Experiment 3 was conducted in which the unfamiliar shapes were replaced with a standardized set of familiar figures (Snodgrass & Vanderwart, 1980), previously used by Tipper and his colleagues in negative priming experiments (Tipper, 1985; Tipper & Driver, 1988). In Tipper and Driver’s (1988) experiments, observers viewed overlapping outline drawings of common objects and were asked to name a green object while ignoring a red object. Naming latencies were longer for objects that had been previously ignored. Since familiar objects have preexisting representations, these representations may have negated the role of segmentation cues. In other words, familiar objects may be easy to segment even in the absence of surface segmentation cues. This raises the question of whether overlapping, familiar shapes will be positively, instead of negatively, primed when they are displayed with surface segmentation cues.

To address this question, the outlined stimuli used by Tipper and Driver (1988) were converted to surface-based stimuli. The matching paradigm previously used was used again, as indicated in

Figure 4. If segmentation cues play any important role in the representation of familiar as well as novel objects, then positive priming should occur in the surface condition, whereas negative priming should occur in the outline condition. However, if negative priming is found in both conditions, then it can be concluded that the role of surface segmentation cues is strictly limited to novel shapes.

Method

Observers. Twenty-two observers participated in this experiment for credit toward fulfillment of a course requirement. All observers reported that they had normal or corrected-to-normal visual acuity and color vision. All observers were naive to the hypothesis under investigation, and none had participated in any of the previous experiments.

Stimuli. The stimuli consisted of 108 shapes selected from the classic set of Snodgrass figures (Snodgrass & Vanderwart, 1980). Thirty-six figures were used in the practice trials, and 72 were used in the experimental trials. As in all of the previous experiments, two overlapping red and green shapes were positioned on the left, and one dark comparison shape was positioned on the right of each display. The lateral locations of the shapes relative to the fixation point were identical to those used in all of the previous experiments. The range of the width and height of each shape as well as the outline width were the same as that of the previous experiments. The degree of overlap between the red and green shapes was roughly the same as in the previous experiments. In the surface condition, the shapes were filled, and a thin black line was used to indicate the internal

structure of each shape, such as the strings of a guitar or the near edge of a table top. In the outline condition, outline versions of these shapes were used as in Tipper (1985). The luminance values of the red and green objects were the same as those used in the previous experiments.

Procedure. As in all of the previous experiments, observers were instructed to report, with a button press, whether the green figure on the left matched the comparison figure on the right. Observers were asked to ignore the red figure. Prime duration was fixed at 1 s. In a between-subjects design, half of the observers completed the outline condition, whereas the other half completed the surface condition. Accuracy and reaction times were recorded. As before, all figures were displayed only once except for the critical item in old trials, which was shown twice (once in the prime and once in the subsequent probe display).

Results

Reaction times for correct responses, error rates, and priming magnitude are presented in Table 1. A $2 \times 2 \times 2$ ANOVA revealed significant effects of condition, $F(1, 20) = 17.4$, $MSE = 25,453.4$, and match type, $F(1, 20) = 7.7$, $MSE = 4,881.6$, but no significant effect of trial type, $F(1, 20) = .2$, $MSE = 9,013.2$. The only significant interaction was between trial type (old–new) and condition (outlines–surfaces), $F(1, 20) = 9.5$, $MSE = 9,013.2$.

Individual *t* tests were performed to identify the priming effects in each condition. In the surface condition, a paired *t* test revealed

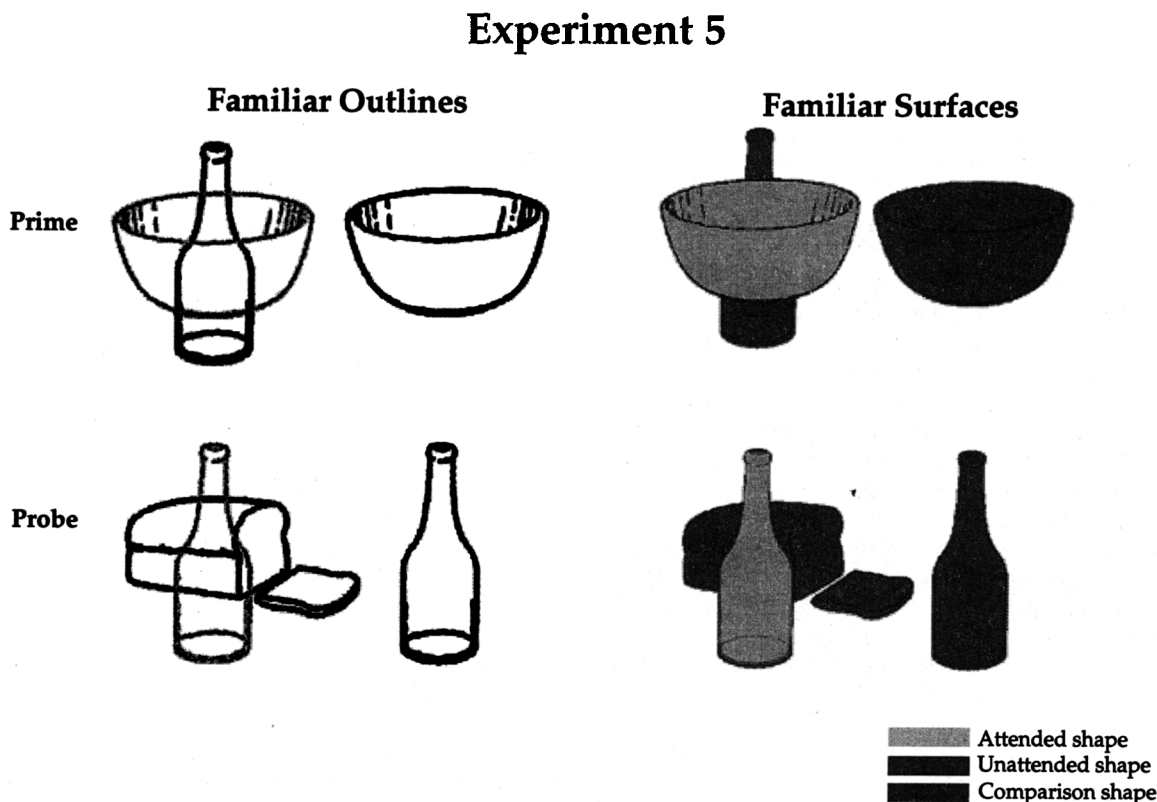


Figure 4. Sample stimuli from Experiment 5. In the familiar outlines condition, Snodgrass figures were used in the same shape-matching task that was used in our previous experiments. In the familiar surfaces condition, these same shapes were rendered opaque surfaces.

a significant 49-ms difference between the “same” responses of the old and the new trials, $t(10) = 2.780$. The “different” responses in the new and old trials differed by a nonsignificant 57 ms, $t(10) = 1.460$. In the outline condition, paired t tests revealed a significant difference of -78 ms between the “same” responses of the old and new trials, $t(10) = -3.140$, but a nonsignificant -66 -ms difference between the two types of different responses, $t(10) = -1.040$.

Discussion

The results of this experiment replicate those of Experiment 1. More specifically, when observers selectively attended to one of two overlapping outline shapes, negative priming occurred. However, when these same familiar shapes were presented as opaque surfaces, matching judgments were positively primed. This pattern of results further supports the hypothesis that surface segmentation cues can determine whether shape judgments are slowed under conditions of inattention. When considered along with the results of Experiments 1, 2, and 3, the results of the current experiment suggest that the existence of prior representations does not override the powerful effects of surface segmentation processes in selective attention tasks.

Recent studies have suggested that negative priming depends on the degree of similarity between prime objects as well as on the number of times an ignored object is shown. More specifically, Strayer and Grison (1999) found no negative priming when unfamiliar shapes were ignored only once but significant negative priming when the same shapes were repeatedly presented as distractors. On the basis of these findings, Strayer and Grison (1999) suggested that the negative priming effects reported by DeSchepper and Treisman (1996) may have reflected the inhibition of one or a small number of prototype shapes because the novel shapes used in their experiments may have appeared to be very similar. Thus, negative priming in the case of novel objects or words may be an artifact of familiarity (Malley & Strayer, 1995; Strayer & Grison, 1999). Such conclusions are particularly important because they pose a serious challenge to episodic-retrieval theories, which predict that ignoring an item once should be sufficient for negative priming (Neill et al., 1994). The results of the current experiment directly challenge such familiarity based explanations of DeSchepper and Treisman’s (1996) negative priming studies. Because the Snodgrass figures are familiar and distinct, they are not readily confusable. Moreover, as in all of the previous experiments, all of the figures used in this experiment were displayed in only one prime–probe trial. Thus, familiarity based theories of negative priming predict that no negative priming should have been found in the current experiment. Yet, significant priming, the sign of which corresponded to presence or absence of surface segmentation cues, was found. Thus, stimulus repetition or distractor similarity is not necessary for the occurrence of negative priming.

General Discussion

Physical environments generally contain an abundance of objects. Since our attentional capacities are limited (James, 1890), at any point in time we must ignore all but a few of these objects. The goal of this series of studies was to gain some understanding of the

process of selective attention as it relates to objects. The results of a series of priming experiments suggest that the process of selective attention for shapes may not be fully understood independently of surface segmentation processes. More specifically, in Experiment 1, a modified replication of DeSchepper and Treisman’s (1996) negative priming paradigm was undertaken in which observers matched a previously ignored or a new shape with a comparison shape. The target shape was always presented as overlapping with the ignored distractor shape. When the target and distractor were displayed as outlines, shape matches were negatively primed. However, when the same shapes were presented as opaque surfaces, positive priming was found. The same pattern of results was found in Experiment 3 when the duration of prime displays was reduced by 500 ms.

Surface transparency was manipulated in Experiment 2. When shapes were presented as transparent surfaces, positive priming resulted. When the luminance values of these shapes were subtly modified so that they were no longer consistent with the perception of transparent surfaces, shape matching was negatively primed. The results of Experiment 5 indicate that this effect of surface segmentation cues is not limited to novel shapes. When outline versions of the Snodgrass figures (Snodgrass & Vanderwart, 1980) were used in the same DeSchepper and Treisman (1996) shape matching task, previously ignored shapes were negatively primed. Conversely, when the same nameable figures were displayed as surfaces, positive priming was found. Finally, the results of Experiment 4, when compared with those of Experiment 3, indicate that a lack of surface segmentation cues in prime displays results in negative priming. Probe display analyses also contribute to negative priming effects because a decrease in the similarity between prime and probe items can eliminate priming effects in an asymmetric manner. Specifically, when outline shapes were presented in prime displays—whereas surface-like versions of the corresponding shapes were presented in the probe displays—negative priming resulted. However, when the presentation order was reversed, such that surface-like shapes were presented before the corresponding outline shapes, no significant priming was found. Such results suggest that perceptual priming may be asymmetric (Loula & Shiffrar, 1997).

The results of Experiments 1, 2, 3, and 5 can be explained by both distractor inhibition and episodic-retrieval theories of negative priming. For example, the repeated association between a lack of surface segmentation cues in the prime displays and negative priming can be understood in terms of selection ease (Fox, 1994; Fuentes & Tudela, 1992; Ruthruff & Miller, 1995; Treisman & DeSchepper, 1996). When target items in prime displays are difficult to select, because of an absence of surface segmentation cues, distractor items may be inhibited. This inhibition might lead to negative priming. The presence of surface segmentation cues might enhance selection ease, thereby eliminating the need for inhibitory mechanisms and yielding positive priming. According to episodic-retrieval theories, the presence of surface segmentation cues might create a situation in which observers can easily perform their matching task without deeply processing the distractor items. Under these conditions, response conflict during subsequent probe displays (in which the previously ignored distractor items are re-presented as the target item) would be substantially decreased. Negative priming would increase whenever response conflict in-

creased as a result of the automatic retrieval of deeply processed distractor items.

However, the results of Experiment 4 are clearly best explained by episodic-retrieval theories of negative priming. First, when the similarity between the prime and probe displays was decreased, substantial increases in error rates were found. This result is fully consistent with the premise of episodic-retrieval theories that negative priming effects depend on how successfully previous episodes can be retrieved (e.g., Neill, 1997). Moreover, this result cannot be explained by distractor inhibition theories because they do not take into consideration the contextual similarity between the prime and probe displays (Fox & Fockert, 1998). Second, the priming asymmetry found in Experiment 4 can only be explained by a slightly modified version of the episodic-retrieval theory. Research from other areas suggests that perceptual similarity space is asymmetric (e.g., Tversky, 1988). The priming asymmetry from Experiment 4 can be explained by an episodic-retrieval theory that allows for asymmetric similarity spaces. Once again, it is far from obvious how distractor inhibition theories could be modified so as to predict this priming asymmetry because these theories do not address issues of retrieval. Thus, when concerned together, the results of the current series of experiments are best captured by episodic-retrieval theories of negative priming.

Importantly however, the goal of the current series of experiments was not to create a decisive test between the distractor inhibition and episodic-retrieval theories of negative priming. Instead, the primary focus of these studies was to determine whether simple manipulations of visual information can influence selective attention. This focus is important because theories of negative priming are frequently tested with studies using very different stimuli. In the current series of experiments, stimulus shape, spatiotemporal parameters, experimental task, and subject selection state (as evidenced by the results of Experiment 4) were all held strictly constant. In this light, the results of these studies most strongly support the hypothesis that surface segmentation cues play a fundamental role in negative priming and, presumably, in selective attention for shapes. Indeed, given theories that object recognition and image segmentation processes cannot be understood as isolated processing modules (Peterson & Gibson, 1993, 1994; Peterson, Harvey, & Weidenbacher, 1991), the current results do suggest that the mechanisms underlying selective attention and surface segmentation may be tightly interconnected.

Our results and conclusions are limited in at least two major ways. First, many priming studies involve text-based stimuli. Because there is no obvious reason why letters and numbers should be represented as surfaces, the grouping processes used in the perception of letters and surfaces may differ in fundamental ways. Thus, the current results may not extend beyond the perception of visual objects. Secondly, negative priming is not restricted to tasks in which a target item must be selected or segmented from one or more distractors (Milliken et al., 1998; Wood & Milliken, 1998). Indeed, it is entirely possible that there are several different ways to trigger negative priming effects. Thus, our conclusions may only extend to selection tasks involving the visual perception of multiple objects or possibly to individual objects presented against heterogeneous backgrounds.

The current results also have implications for other, neurophysiologically based models of selective attention. Recent imaging and single-cell recording studies have suggested that when multiple

stimuli are presented within the same visual display, the cortical representation of each stimulus competes with the representation of the other stimuli in an inhibitory or suppressive manner (Kastner, De Weered, Desimone, & Ungerleider, 1998; Reynolds, Chelazzi, & Desimone, 1999). The results of the current study clearly suggest that this need not always be the case. The positive priming results illustrate that multiple objects can interact in a facilitatory manner. Furthermore, the current results suggest that the processes underlying selective attention are more complex than neurophysiological models imply because these processes depend upon otherwise subtle surface segmentation cues.

In conclusion, the current results suggest that the implied costs to perceptual processing suggested by the negative priming paradigm may not normally apply to the analysis of realistic visual scenes. Physical objects have surface qualities that make them relatively easy to segment. In the current studies, the presence of such cues led to positive priming. Thus, under realistic conditions, ignoring an object may not slow its subsequent analysis.

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