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Object Trimming: When Masking Dots Alter Rather Than Replace Target Representations

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Five experiments demonstrate that when dots appear beside a briefly presented target object, and persist on view longer than the target, the flanked object is perceptually altered by the dots. Three methods are used to explore this *object trimming effect*. Experiments 1–3 assess participants' conscious reports of trimmed digits, Experiment 4 uses repetition priming to explore the target representation, and Experiment 5 examines the perception of apparent motion in trimmed targets. Results of all three methods indicate that object trimming is influenced by mechanisms of perceptual grouping that operate on target representations prior to conscious access. Separate contributions from visual crowding and backward masking are also identified. These results imply that common-onset masking does not always result from the target being substituted by the mask, but that target and mask can sometimes maintain separate mental representations.

When two objects appear simultaneously in nearby spatial locations, one only briefly and the other persisting for a longer period, the object that persists may replace the briefer stimulus in the consciousness of the observer (Di Lollo, Enns, & Rensink, 2000). Many experiments have identified variables that moderate this common-onset masking effect (Atchley, Grobe, & Fields, 2002; Di Lollo et al., 2000; Enns & Di Lollo, 1997; Jiang & Chun, 2001; Kahan & Mathis, 2002; Neill, Hutchison, & Graves, 2002), and results are broadly consistent with a theory of masking by *object substitution* in which reentrant processing of the visual system, when applied to a dynamic sequence of brief images, results in the updating of a single-object representation (Di Lollo et al., 2000; Enns, Lleras & Moore, in press). However, feedforward theories (Francis & Hermens, 2002; Neill et al., 2002) and two-object interference theories (Kahan & Lichtman, 2006) have also been proffered to explain these data. The present experiments explore a related perceptual effect, which we term *object trimming*, which promises to broaden the discussion by showing that common-onset masking is influenced by perceptual grouping mechanisms that sometimes allow target and mask representations to maintain separate identities.

Object Trimming

Although the spatial location of the dot pattern is clearly important for masking, the mask need not always surround the target to be effective (Jiang & Chun, 2001); four directly adjacent dots will also produce masking, especially if the four dots are perceived as moving from their original location to the adjacent location following target offset (Lleras & Moore, 2003). Likewise, Kahan and Mathis (2002) reported that two dots located to one side of the target produced masking, albeit reduced in magnitude relative to four-dot masking. In Kahan and Mathis' Experiment 3, a diamond missing either the left or right corner served as the target. A post-hoc analysis revealed masking only when the dots were located on the side opposite to the missing corner (i.e., adjacent to the target's edge); no masking was obtained when the dots appeared on the same side as the missing corner (i.e., adjacent to the target's blank side) (see Table 1)[1]. T1, Fn1

We refer to this effect as *object trimming* because when the dots were aligned near one corner of the diamond they seemed to shear it off, leaving the participant unable to distinguish a complete from a missing corner (see Figure 1). However, because target accuracy was scored as either only correct or incorrect, there was no way to more fully index participants' perception of the target in that study. Yet, the phenomenal appearance of the target implies that when only two rather than four dots are used as a mask, the dots may alter the representation of the target, but the mask may not substitute completely for the target in the consciousness of the participant, as proposed in object substitution theory (Di Lollo et al, 2000; Lleras & Moore, 2003; Moore & Lleras, 2003). Indeed, object trimming opens up the possibility that the processes of object updating also adhere to perceptual grouping principles, such that the representations of target and mask can remain distinct during object updating under some conditions, as proposed in the two-object interference theory of object substitution (see Kahan & Lichtman, 2006). F1

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[1] In Kahan and Mathis' (2002) Experiment 3, the target and mask could appear in one of four quadrants on the computer screen. In the unmasked condition, the dots appeared in a different quadrant from the target and were coded as being on either the same side of the missing corner (adjacent to blank) or the opposite side of the missing corner (adjacent to blank), had the target been presented in that quadrant.

Table 1
Kahan & Mathis' (2002) Experiment 3 Results

	Dot location		
Condition	Adjacent to edge		Adjacent to blank
Unmasked	.77		.81
Masked	.69		.79
Masking	.08*	>	.02ns

Note. Mean probability of reporting the target correctly, as a function of whether the target was masked or unmasked and whether the mask was on the opposite side of the missing corner (adjacent to blank) or on the same side of the missing corner (adjacent to edge).
* $p < .05$. ns $p > .05$.

Consistent with this possibility, we note that perceptual accounts reminiscent of what we are here calling object trimming were made long ago, but to our knowledge were never systematically pursued. Werner (1935), for example, described the phenomenological experience associated with seeing a brief dark disk followed in time by a dark half-ring in the same location as consisting of the disk nearest the half-ring being "absorbed" by the mask (p. 46). The remaining disk was described as appearing darker near the unbound side and increasingly light as one moved towards the half-ring side (see also Sherrick & Dember, 1970).

The present study focuses on the following questions: (1) Is the object trimming effect dissociable from object substitution masking, using a variety of different psychophysical methods (Experiments 1, 4, and 5); (2) Is object trimming influenced by the perceptual grouping of the dots, such that they interfere more with the target when their illusory edge lies in closer proximity to the edge of the target shape (Experiments 2 and 3); and (3) Is the internal representation of the target altered by the dots early enough in processing so that only their trimmed form is accessible to consciousness (Experiments 4 and 5)?

Experiment 1

In Experiments 1 through 3, we asked observers directly about the shape of a target when it was flanked by persisting dots. In Kahan and Mathis' (2002) experiment, this was not possible because observers' responses were simply scored as either correct or incorrect with reference to the actual target shape. Here, we used several different shapes that each formed digits, as shown in Figure 2, and were specifically designed so that when an observer gave an incorrect response to a target it was possible to infer how the masking dots had altered the shape's appearance. That is, if these digit shapes are trimmed by the dots in reliable ways, then observers should make predictable errors when reporting the shape of target digits. F2

Method

Participants. Eleven participants were recruited from an Introduction to Psychology class at the University of British Columbia. All of these individuals reported having normal or corrected-to-normal vision and received course credit for their participation.

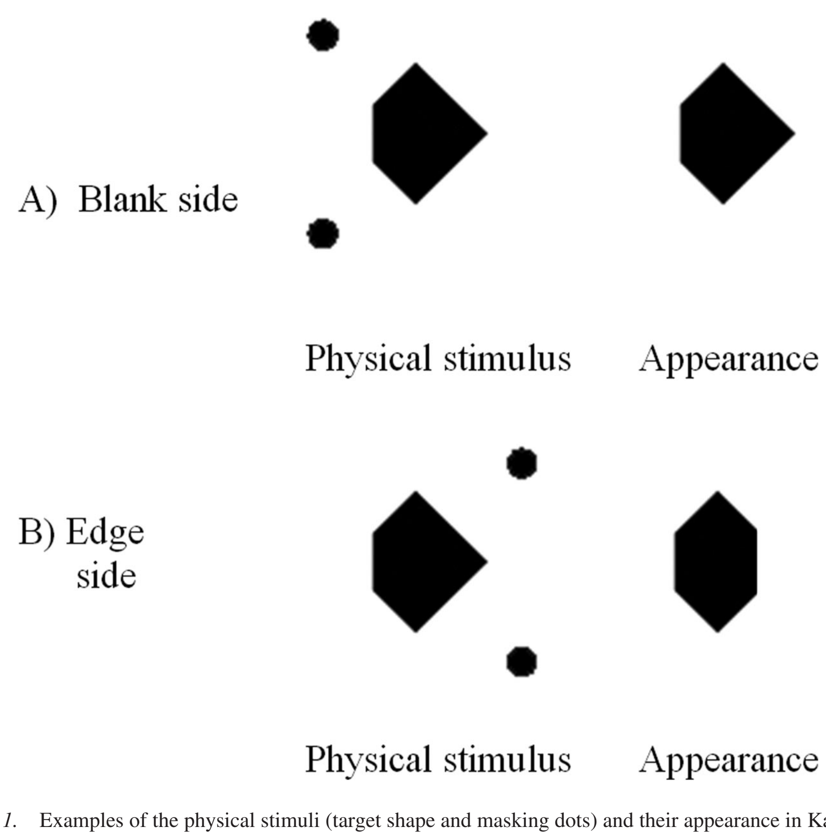

Figure 1. Examples of the physical stimuli (target shape and masking dots) and their appearance in Kahan and Mathis (2002).

Figure 2. Stimuli used in Experiment 1. The top row depicts the condition where dots flank an edge, while the bottom row depicts the condition where the dots flank a blank segment. If object trimming occurs and the dots perceptually trim the nearby edge, participant should see items in the top row similarly to the items below them in the bottom row.

Materials and procedures. Target stimuli consisted of the Arabic digits 5, 6, 8, and 9 shown in a clock font (Figure 2) and were always flanked by 2 dots located either to the upper right or lower left of the target; the dots measured .13° in diameter. The digits measured 1.04° in height and .73° in width and appeared in one of four randomly chosen quadrants, 5.71° from fixation; in the other three quadrants, a zero appeared. The dots appeared immediately adjacent to an edge on half of the trials (see top row of Figure 2), and on the other half of the trials the dots appeared adjacent to a blank area (see bottom row of Figure 2). Each digit was presented an equal number of times, and the dots appeared equally to the upper right or lower left of the target.

Before each trial, a fixation point (+) appeared for 1,000 ms. This fixation was replaced with the target display that included the target, flanking dots, and three distracting zeros, for 33 ms. On half of the trials, the dots had a delayed offset of 1,000 ms; and on the other trials, the dots terminated with the target. Participants were asked to indicate as accurately as possible what digit was shown on each trial. Participants made their responses using the 5, 6, 8, and 9 on the numeric keypad of the computer keyboard; the next trial began after a response was given. Response presentation and timing were controlled using E-Prime software in Experiments 1–4 (Schneider, Eschman, & Zuccolotto, 2002a, 2002b).

Participants completed 8 practice trials and 160 experimental trials. A self-paced break was given midway through the experiment. Each of the 8 stimuli depicted in Figure 2 appeared equally and in a fully randomized manner.

Results

Masking data. Common onset masking is typically assessed using one of two methods, using the nomenclature of Kahan and Mathis (2002). In the *briefly masked control* method, the masking dots either terminate with the target (simultaneous-offset condition) or remain visible beyond target offset (delayed-offset condition). Here, masking is indexed by the extent to which target accuracy is higher in the simultaneous-offset relative to the delayed-offset condition (e.g., Di Lollo et al. 2000, Experiments 3–5). Alternatively, masking can be measured using the *unmasked control* method (e.g., Enns & Di Lollo, 1997, Experiments 1 and 2). Here, the dots are either presented near the target (masked) or are not presented at all (unmasked), with masking indexed by the extent to which accuracy is higher in the unmasked relative to the masked condition. Object substitution masking has now been obtained in numerous experiments using both of these methodologies. In the current experiments, masking will be assessed using both of these methods (Experiments 1–3 use the briefly masked control method while Experiment 5b uses both methods).

Table 2 shows the mean probability of a correct response in each condition. T2 These data were submitted to a 2 (dots appeared adjacent to an edge or a blank area) × 2 (immediate or delayed offset of dots) repeated-measures analysis of variance (ANOVA). There was a significant main effect of dot location [$F(1, 10) = 39.25$, $p < .05$], indicating that participants were more accurate when the dots appeared adjacent to a blank side than when the dots appeared adjacent to an edge. There was also a main effect of offset duration [$F(1, 10) = 13.81$, $p < .05$], indicating that participants were more accurate in the immediate-relative to the delayed-offset conditions. More importantly though, there was an interaction [$F(1, 10) = 10.85$, $p < .05$]. Masking (immediate-offset accuracy greater than delayed-offset accuracy) only occurred when the dots appeared adjacent to an edge [$t(10) = 4.44$, $p < .05$]; no masking occurred when the dots appeared adjacent to a blank side [$t(10) = .78$, $p > .05$]. These data are consistent with a theory of object trimming and replicate the work of Kahan and Mathis (see Table 1) using a different methodology (Kahan and Mathis used diamond shapes as targets and assessed masking using the unmasked control method). The data further suggest that the dots interfere with perception of the target only when they appear adjacent to an edge.

Trimming data. To examine object trimming directly, we analyzed the errors of participants to see whether they selected a *trimmed response* (the identity of a digit after erasing the edge closest to the dots) at greater than chance levels (chance is .33 because there are three possible incorrect responses). For example, the trimmed response to the digit 8 flanked by dots in the upper right is 6; for the same 8 flanked by dots in the lower left, it is 9. The results showed participants did this in both the immediate-offset [$M = .73$; $t(10)=7.42$, $p < .05$] and delayed-offset [$M = .71$; $t(10) = 9.34$, $p < .05$] conditions. However, trimmed responses also did not differ in the immediate- and delayed-offset conditions ($p > .05$). This implies that object trimming is not confined to situations where the dots have a delayed offset, that is, to those conditions under which object substitution occurs.

We will return to this issue in the General Discussion. For now, we will simply point out that although many more errors were

Table 2
Mean Probability of Reporting the Target Correctly in Experiment 1 as a Function of the Dot Location (Adjacent to Edge or Adjacent to Blank) and Offset Duration (Immediate or Delayed)

	Dot location		
Offset duration	Adjacent to edge		Adjacent to blank
Immediate	.51		.78
Delayed	.34		.76
Masking	.17*	>	.02ns

Note. Masking is the difference in accuracy between the delayed and immediate offset conditions.
* $p < .05$. ns $p > .05$.

made in the delayed- versus immediate-offset conditions, making the total frequency of trimmed responses higher in the delayed condition as well, the conditional probability of making a trimmed response (as opposed to any other kind of error) was roughly equal in the delayed- and immediate-offset conditions.

Experiment 2

Experiment 1 demonstrates that dots located adjacent to a target can perceptually trim the neighboring portion of the target. This suggests that the dots may be grouped to form an illusory edge, and that it is this neighboring edge that interferes with target perception and is thus responsible for object trimming. If this hypothesis is correct, then object trimming might be reduced or even eliminated if the dots were perceptually organized so that their implied edge no longer shared a border with the target. To test this idea, we used an approach similar to that of Yantis and Nakama (1998), in which the dots appeared to group together along an edge that curved away from the target because of the addition of a small curved line
F3 with a bulge at its center (see Figure 3, right side). Note also that if object trimming is simply caused by the addition of noise, as in crowding or camouflage masking (Enns & Di Lollo, 2000), this manipulation should increase (rather then decrease) object trimming.

Method

Participants. Twenty-two participants were recruited from an Introduction to Psychology class at the University of British Columbia. All of these individuals reported having normal or corrected-to-normal vision and received course credit for their participation.

Materials and procedures. The materials and procedure were identical to Experiment 1 with the exceptions listed here. On half of the trials, the two dots were accompanied by a small curved line with a bulge at its center (see right-hand side of Figure 3), and on the other half of the trials the same two-dot displays that were used in Experiment 1 appeared (see left-hand side of Figure 3). Here too the dots appeared either adjacent to an edge or a blank side and were shown equally often to the lower left and upper right of the digits.

Participants completed 8 practice trials and 256 experimental trials. Self-paced breaks were given after every 64 trials. Each of the 16 stimuli depicted in Figure 3 appeared equally and in a fully randomized manner.

Results

T3 **Masking data.** Table 3 shows the mean probability of a correct response in each condition. These data were submitted to a

Figure 3. Stimuli used in Experiment 2. The stimuli depicted in the left-hand portion of the figure are identical with those used in Experiment 1. The stimuli depicted in the right-hand portion had curved segments added between the upper and lower dots. The top row depicts the condition where dots flank an edge, while the bottom row depicts the condition where the dots flank a blank segment.

Table 3
Mean Probability of Reporting the Target Correctly in Experiment 2 as a Function of the Dot Type (Two Dots or Dots With Curved Line) Dot Location (Adjacent to Edge or Adjacent to Blank), and Offset Duration (Immediate or Delayed)

		Dot location	
Dot type	Offset duration	Adjacent to edge	Adjacent to blank
Two dots			
	Immediate	.56	.80
	Delayed	.38	.76
	Masking	.18	.04
Dots with curved line			
	Immediate	.71	.48
	Delayed	.51	.37
	Masking	.20	.11

Note. Masking is the difference in accuracy between the delayed and immediate offset conditions.

2 (two dots vs. dots plus curve) × 2 (dots adjacent to an edge or a blank area) × 2 (immediate or delayed offset of dots) repeated-measures ANOVA. There were significant main effects of dot type [$F(1, 21) = 51.88$, $p < .05$], dot location [$F(1, 21) = 4.84$, $p < .05$], and offset duration [$F(1, 21) = 92.89$, $p < .05$]. These data indicate that participants were more accurate when the displays contained two dots ($M = .63$) relative to dots with curved lines ($M = .52$), the dots appeared adjacent to a blank ($M = .60$) relative to when the dots appeared adjacent to an edge ($M = .54$), and the dots terminated with the target ($M = .64$) relative to when the dots had a delayed offset ($M = .51$).

In addition to these main effects, there were two interactions. One was between type of dot and dot location [$F(1, 21) = 220.65$, $p < .05$] indicating that when two dots were used, accuracy was better when the dots appeared near a blank side ($M = .78$) than when the dots appeared near an edge ($M = .47$), but the opposite was true for dots appearing with a curved line. Here, accuracy was worse when the dots appeared near a blank side ($M = .43$) relative to when the dots appeared near an edge ($M = .61$). This interaction is reminiscent of the effects of lateral inhibitory mechanisms on the acuity of two edges at various distances from one another. When two edges are near one another (e.g., two dots flanking the target's edge) they can have mutually inhibiting effects on visibility, because they both compete for the same circuitry that is organized to enhance spatial differences. However, as the edges are moved apart (e.g., two dots accompanied by a curved segment which may move the illusory edge further from the target's edge), there comes a point where they are each mutually enhanced, because of their common suppression of the intervening region (Burns & Pritchard, 1971). In the present experiment, this may be occurring at the level of the virtual edge implied by the dots.

Finally, there was also an interaction between dot location and offset duration [$F(1, 21) = 12.93$, $p < .05$] indicating that masking (i.e., the difference in accuracy between the delayed and immediate offset conditions) was greater when the dots were adjacent to an edge (20% masking; $M = .64$ in the immediate-offset condition relative to $M = .44$ in the delayed-offset condition) than when the dots appeared adjacent to a blank side (7% masking; $M = .64$ in the immediate-offset condition relative to $M = .57$ in the delayed-offset condition). This interaction may reflect object trimming, which we next examine more closely.

Trimming data. We again analyzed the errors of participants to see whether they selected a *trimmed response* at greater than chance levels (.33). These data are shown in Table 4. Participants made trimmed responses at greater than chance levels in both the immediate-offset [$M = .78$; $t(21) = 14.32$, $p < .05$] and delayed-offset conditions [$M = .73$; $t(21) = 12.46$, $p < .05$] when there were only two dots. However, when the intervening curve was added to the displays, trimmed responses occurred at a rate no different from chance in both the immediate-offset [$M = .39$; $t(21) = 1.56$, $p > .05$] and the delayed-offset conditions [$M = .27$; $t(21) = 1.75$, $p > .05$]. In addition, trimmed responses were greater in the two-dots condition than the dots-with-curve condition, and this was true both when the dots had an immediate offset [$t(21) = 7.85$, $p < .05$] and when the dots had a delayed offset [$t(21) = 8.68$, $p < .05$]. These data indicate that perceptual grouping of the dots determines whether object trimming occurs. In particular, they suggest that the virtual edge implied by the two dots must share a border with the contour of the target in order for trimming to occur.

T4

Experiment 3

The curved segment that was added between the dots eliminated trimming in Experiment 2, but it is also possible that this somehow resulted from the addition of a third element to the display, rather than a displacement of the illusory contour near the target. To examine this possibility, the current experiment used three-dot displays, rather than two-dot displays. In experiment 3a, we arranged the three dots in a straight line (see left-hand portion of Figure 4); in Experiment 3b, we arranged the three dots in a triangle to imply a covering of a portion of the nearby target with the virtual triangle (see right-hand portion of Figure 4). If having three parts of the dot mask is what eliminated object trimming in Experiment 2, then trimming should be eliminated here as well. Alternatively, if a nearby contour is what causes trimming, then trimming should be obtained in both Experiments 3a and 3b, because the three dots in both cases implied an illusory edge that bordered a critical contour of the target digits.

F4

Table 4
Mean Probability of Reporting Trimmed Response Given an Error in Experiment 2 as a Function of the Dot Type (Two Dots or Dots With Curved Line) and Offset Duration (Immediate or Delayed)

	Dot type		
Offset duration	Two dots		Dots with curved line
Immediate	$.78^{*}$	>	$.39^{ns}$
Delayed	$.73^{*}$	>	$.27^{ns}$

* different from chance (.33), $p < .05$. ^{ns} not different from chance (.33), $p > .05$.

Figure 4. Stimuli used in Experiment 3. The stimuli depicted in the left-hand portion were displayed in Experiment 3a, while the stimuli depicted in the right-hand portion were displayed in Experiment 3b. The top row depicts the condition where dots flank an edge while the bottom row depicts the condition where the dots flank a blank segment.

Experiment 3a

Method.

Participants. Fourteen participants were recruited from an Introduction to Psychology class at the University of British Columbia. All of these individuals reported having normal or corrected-to-normal vision and received course credit for their participation.

Materials and procedures. The materials and procedures were identical with Experiment 1 with the exception that a third dot was inserted and aligned between the upper and lower dots (see left-hand portion of Figure 4).

Results.

Masking data. Table 5 shows the mean probability of a correct response in each condition. These data were submitted to a 2 (dots adjacent to an edge or a blank area) × 2 (immediate or delayed offset of dots) repeated-measures ANOVA. The only significant effect was the interaction [$F(1, 13) = 11.90$, $p < .05$], showing that masking was obtained only when the dots appeared adjacent to an edge [$t(13) = 3.81$, $p < .05$]. The opposite was found when the dots appeared adjacent to a blank side (e.g., the digit 6 flanked by dots in the upper right); here, participants were more accurate when the dots had a delayed relative to immediate offset [$t(13) = 2.21$, $p < .05$]. This latter effect might indicate that trimming, which we examine more directly below, made it unlikely people would erroneously perceive an edge at the blank location, thereby enhancing performance. T5

Trimming data. When errors were made, trimmed responses were given at greater than chance levels (.33) in both the immediate-offset condition [$M = .53$; $t(13) = 3.28$, $p < .05$] and the delayed-offset condition [$M = .56$; $t(13) = 5.23$, $p < .05$], and the difference between these conditions was not significant ($p > .05$).

Table 5
Mean Probability of Reporting the Target Correctly in Experiments 3a as a Function of the Dot Location (Adjacent to Edge or Adjacent to Blank) and Offset Duration (Immediate or Delayed)

	Dot location		
Offset duration	Adjacent to edge		Adjacent to blank
Immediate	.58		.49
Delayed	.46		.57
Masking	$.12^{*}$	>	$-.08^{*}$

Note. Masking is the difference in accuracy between the delayed and immediate offset conditions.
$^{*}p < .05$. $^{ns}p > .05$.

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Experiment 3b

Method.

Participants. Twelve participants were recruited from an Introduction to Psychology class at the University of British Columbia. All of these individuals reported having normal or corrected-to-normal vision and received course credit for their participation.

Materials and procedures. The materials and procedures were identical with Experiment 3a, with the exception that the three dots were now arranged in a triangular pattern (see right-hand portion of Figure 4).

Results.

T6 ***Masking data.*** Table 6 shows the mean probability of a correct response in each condition. A 2 $\times$ 2 repeated-measures ANOVA revealed a main effect of dot location [$F(1, 11) = 15.21, p < .05$] and a main effect of offset duration [$F(1, 11) = 10.85, p < .05$]. These main effects were qualified by an interaction [$F(1, 11) = 11.71, p < .05$]. As in previous experiments, masking (greater accuracy in the immediate-offset condition than in the delayed-offset condition) only occurred when the dots appeared adjacent to an edge [$t(11) = 4.30, p < .05$]; masking was not significant when the dots appeared adjacent to a blank side ($p > .05$).

Trimming data. When errors were made, trimmed responses were again given at greater than chance levels (.33) in both the immediate-offset condition [$M = .69$; $t(11) = 7.20, p < .05$] and delayed-offset condition [$M = .61$; $t(11) = 4.63, p < .05$], and this time trimming was significantly greater in the immediate-offset than in the delayed-offset conditions [$t(11) = 2.64, p < .05$]. Taken together, the results from Experiments 2, 3a, and 3b support the conclusion that it is the nearby illusory contour formed by the dots that is responsible for object trimming. The virtual contour implied by the dots must share the edge of the trimmed segment in order to be most effective. Object trimming was only eliminated when the contour was perceived as curving out away from the critical contour of the target.

Experiment 4

Experiment 4 was conducted to determine whether the internal representation of the target is altered by the dots relatively early in processing (before repetition priming occurs), or whether object trimming only arises at the time of conscious report. To examine this, we again presented participants with digits flanked by dots that persisted in time, but in this experiment we followed these displays with clearly visible targets. Participants were asked to respond to these targets as quickly and accurately as possible.

The prime and target displays used in this experiment are illustrated in Figure 5. The target displays consisted of either the digit 3 or 5, but these could be preceded by the prime digits 3, 5, or 9, with the flanking dots positioned as shown in Figure 5. Note that the flanking dots were arranged so that when the prime digit 9 was trimmed by persisting dots in the upper left, the resulting representation would look like the digit 3. Similarly, when it was flanked by persisting dots in the upper right, the resulting representation was the digit 5. F5

We expected to obtain repetition priming for target digits preceded by the same prime digits (i.e., target response time should be faster on congruent than on incongruent trials in the untrimmed condition). The key question was whether participants would also respond to the target digits 3 and 5 more quickly when preceded by a 9 trimmed to be congruent with the target (e.g., a 3 preceded by a 9 flanked by dots on the upper left) than when preceded by a 9 that is trimmed to be incongruent with the target (e.g., a 3 preceded by a 9 flanked by dots on the upper right). In addition, we also included trials where participants attempted to identify the masked primes to give us the opportunity to replicate the main findings of Experiments 1 though 3 using this method.

Method

Participants. Eleven participants were recruited from an Introduction to Psychology class at the University of British Columbia. All of these individuals reported having normal or corrected-to-normal vision and received course credit for their participation.

Materials and procedures. On each trial, participants were shown one of four different primes in a random order (a 3 flanked by dots in the upper left, a 5 flanked by dots in the upper right, a 9 flanked by dots in the upper left, or a 9 flanked by dots in the upper right) and one of two different targets (3 or 5). Primes, but not targets, were flanked by dots. This procedure resulted in 8 different combinations (4 primes $\times$ 2 targets) of four different types based on trimming condition (trimmed vs. untrimmed) and prime-target congruence (congruent vs. incongruent) (see Figure 5). On untrimmed trials, dots flanked a blank portion of the prime, whereas on trimmed trials dots flanked one of the prime's edges; half of the stimuli were of each of these types. In addition, on congruent trials the prime and target matched (e.g., 3 preceded by 3) or were trimmed to match (e.g., 3 preceded by 9 flanked by dots in the upper left), whereas on incongruent trials the prime and target mismatched (e.g., 3 preceded by 5) or were trimmed to mismatch (e.g., 3 preceded by 9 flanked by dots in the upper right); again, half of the stimuli were of each of these types.

As was the case in Experiments 1 though 3, each trial began with a fixation point (+) for 1,000 ms. This was followed by a randomly chosen prime digit in one of four quadrants for 33 ms; three distracting zeros appeared in the other three quadrants. Following prime offset, the dots remained on the screen for an additional 250 ms. After this, participants were shown a target display that remained on the screen until a response was given. The target was determined randomly; on half of the trials, the target was the words "First item?" written in 14-point courier new font, while on the other trials the target was the digit 3 or 5 written in the clock font used in

Table 6
Mean Probability of Reporting the Target Correctly in Experiments 3b as a Function of the Dot Location (Adjacent to Edge or Adjacent to Blank) and Offset Duration (Immediate or Delayed)

	Dot location		
Offset duration	Adjacent to edge		Adjacent to blank
Immediate	.46		.63
Delayed	.33		.63
Masking	.13*	>	.00ns

Note. Masking is the difference in accuracy between the delayed- and immediate-offset conditions.
* $p < .05$. ns $p > .05$.

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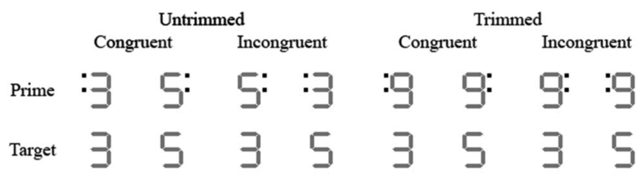

Figure 5. Prime-target stimuli used in Experiment 4 along with associated trimming and congruence conditions.

Experiments 1−3 (see Figure 5 for example stimuli). When the target was a digit, participants were instructed to identify it as quickly and accurately as possible using the 1 and 2 keys on the numeric keypad for 3 and 5, respectively. When the target was the question "First item?" participants were instructed to identify the prime as accurately as possible, also using the numeric keypad; here, participants used the 1, 2, and 3 keys for 3, 5, and 9 respectively. The next trial began after a response to the target was given. Participants completed 10 practice trials and 720 experimental trials. One-minute breaks were given after every 90 trials.

Results

We first report data from trials where participants attempted to identify the masked prime, in order to assess the degree of object trimming. We then report the speeded priming data, from trials where a digit appeared as the target.

Prime identification data. When dots flanked the prime display, participants were more accurate when the dots appeared adjacent to a blank section ($M = .86$) than when the dots appeared adjacent to an edge ($M = .16$) [$t(10) = 13.11, p < .05$]. This replicates the pattern of object trimming in Experiments 1 though 3, namely that target accuracy is reduced when the dots flanked a critical contour of the target. Trimmed responses were also made at a rate greater than expected by chance [$M = .82$; $t(10) = 13.30$, $p < .05$], also replicating this aspect of the Experiments 1 though 3.

Priming data. Geometric means of correct response times
F6 (RT) and mean response accuracy are shown in Figure 6. These data were analyzed with a 2 × 2 repeated-measures ANOVA. The RT data showed a main effect of trimming condition [untrimmed RT smaller than trimmed RT, $F(1, 10) = 14.67$, $p < .05$] and prime-target congruence [congruent RT smaller than incongruent RT, $F(1, 10) = 61.27$, $p < .05$]. This congruence effect was significant in both the untrimmed [154 ms, $t(10) = 6.95$, $p < .05$] and trimmed conditions [110-ms, $t(10) = 8.18$, $p < .05$]. However, these main effects were also qualified by a significant interaction [$F(1, 10) = 9.28$, $p < .05$], indicating that the congruence effect was larger in the untrimmed condition. We attribute the smaller congruence effect in the trimmed condition to the fact that the primes (aside from the location of the dots) were physically identical (i.e., the digit 9), making it likely that on those trials on which trimming was not complete, the prime was less effective. In any case, the 110-ms congruence effect that was obtained in the trimmed prime condition clearly indicates that trimming occurs on representations that are involved in repetition priming.

A similar analysis of the accuracy data (lower panel of Figure 6) only yielded a main effect of prime-target congruence [$F(1, 10) = 13.18$, $p < .05$]. Overall, participants were 11% more accurate in the congruent relative to the incongruent conditions, and this was true for both untrimmed and trimmed primes. Again, these data indicate that object trimming operates before repetition priming effects occur.

It is unclear if these same priming effects would have been obtained if our trimmed shapes were unavailable to conscious report. This could be done by pattern masking the prime locations after the prime-plus-dot displays. We note here though that because Cressman, Franks, Enns, & Chua (2007) have found that shapes which are unseen (because of masking) can have strong effects on motor priming and limb trajectories, we suspect that the same pattern of trimmed priming might also arise from unseen trimmed shapes.

Experiment 5

In Experiment 5, participants were asked to indicate their perception of motion in a bistable quartet (Ramachandran & Anstis, 1985; von Schiller, 1933 described in Koffka, 1935). In the standard bistable quartet, two stimuli are presented repetitively in successive recurrent frames. In the first frame, the objects appear in the upper-left and lower-right corners of an imaginary square; in the second frame, the objects appear in the upper-right and lower-left corners. Participants are asked to determine whether the objects are perceived as moving horizontally or vertically. Since apparent motion is influenced by similarity of form, such that same shaped items are seen as moving towards one another more readily than different shaped items (Oyama, Simizu, & Tozawa, 1999), we reasoned that a shape altered by object trimming might be able to influence the perceived direction of motion in a bistable quartet.

Experiment 5 was conducted in two parts. Experiment 5a assessed the internal representation of a trimmed shape indi-

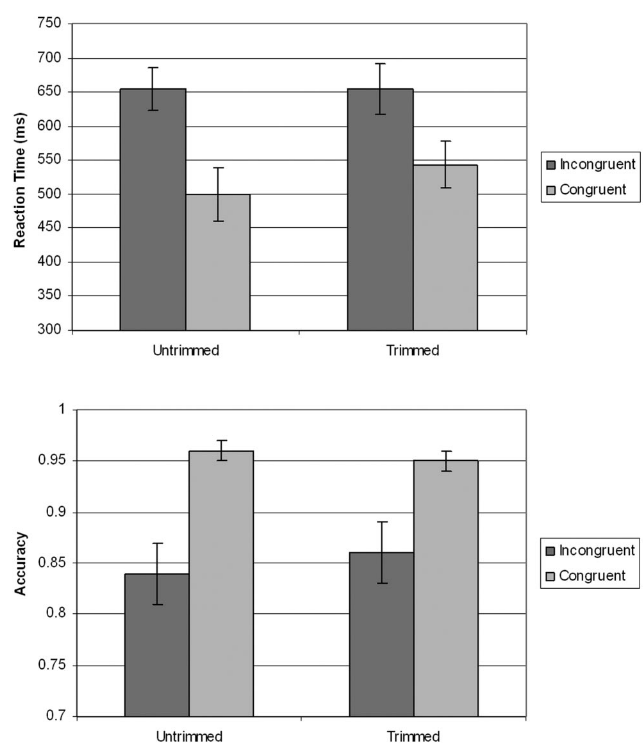

Figure 6. Mean geometric reaction times (top graph) and accuracy rates (bottom graph), responding to target digits in Experiment 4, as a function of trimming condition and prime-target congruence.

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rectly by testing whether it influenced the direction of apparent motion, using the sequence of four alternating frames shown in
F7 Figure 7. In frame 1, two diamonds were presented, with each diamond missing a corner. This was followed by a blank frame 2, which in turn was followed by frame 3, consisting of full diamonds flanked by dots. In frame 4, the full diamonds disappeared and only the dots remained (similar to the object-substitution masking procedure). This sequence was cycled five times. Two configurations were used that differed only in frame 1 (see Figure 7). In the *horizontal-trim* configuration, if the dots trimmed the nearby corner from the full diamonds, similarity of form would predict a greater likelihood of horizontal motion perception. In the *vertical-trim* configuration, similarity of form would predict more vertical motion.

Experiment 5b tested the perceived motion of the same shapes and display sequences but, in one case, removed the masking dots from the sequence, and in the other case, presented the masking dots only in the same frame as the target shapes (not in the subsequent frame). These two conditions therefore served as important controls for (1) the possible influence of the mere presence of the dots on the direction of motion, and (2) for the possible influence of simultaneous dots (rather than delayed dots) on the perceived direction of motion.

Experiment 5a

Method.

Participants. Twenty-seven people were recruited via the Internet. Participants were informed that the experiment examined visual perception, lasted approximately 15 min, and an explanation would be provided upon completion. Links to the experiment were posted on several science discussion forums. However, because we could not control aspects of the display with online testing, 18 additional participants were recruited from an Introduction to

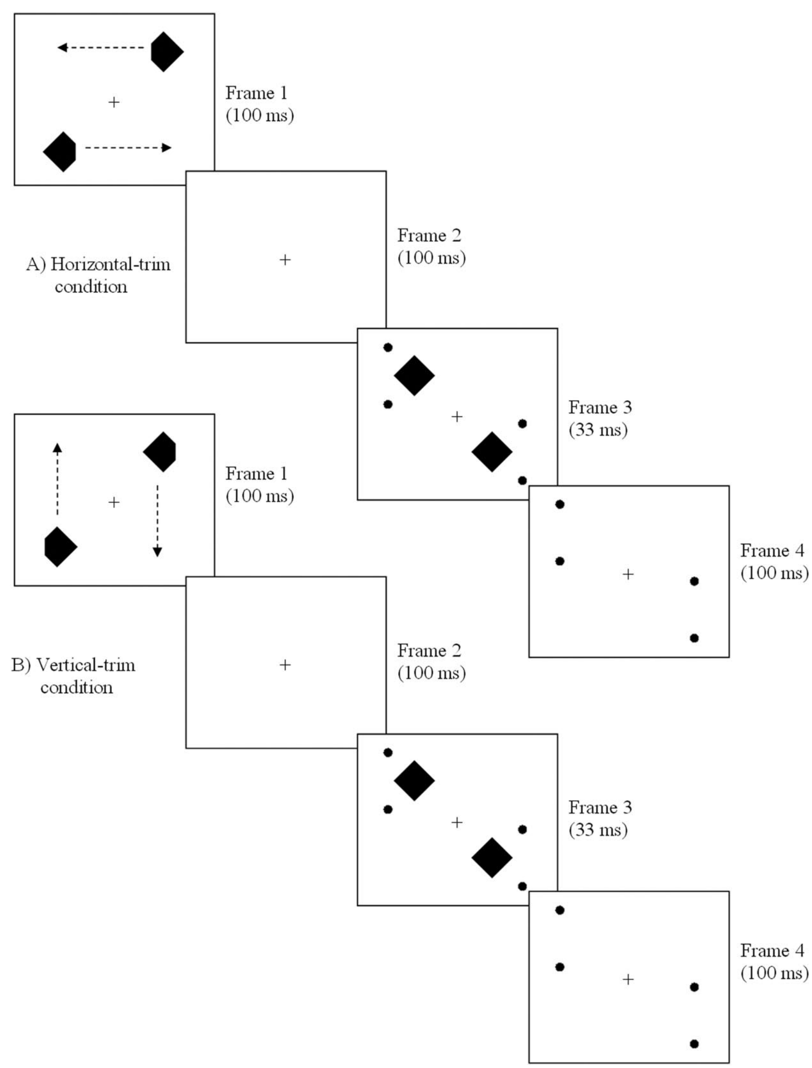

Figure 7. General sequence of events used in Experiment 5a. Object trimming should bias horizontal motion perception in (A) and vertical motion perception in (B). Perceived motion is depicted with dotted lines; these lines were not present in the display.

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Psychology class at Bates College. All of the individuals in this latter group reported having normal or corrected-to-normal vision and received course credit for their participation.

Materials and procedures. The experiment was programmed using Macromedia Authorware V.6.0 and was administered to the Internet sample through a Web browser; the laboratory-based sample participated in the experiment by way of an executable file loaded directly onto laboratory computers. Authorware software has been used successfully to replicate experimental laboratory-based findings with Web delivery (McGraw, Tew, & Williams, 2000; for a review of issues surrounding Web-based approaches to data collection, see Kraut et al., 2004). However, because the display resolution likely differed across participants in the Internet-based sample, and because we could not control the distance between the participant's eyes and the computer monitor in this sample, display sizes are reported in pixels rather than degree visual angle. We note however that because a repeated-measures design was used, and because stimuli were presented in a fully random manner, any differences in display size or irregularities in presentation durations affected each of the conditions equally for each participant. The laboratory-based sample completed the experiment on Dell Pentium IV 2GHz computers; the display resolution was set at 1024 $\times$ 768 pixels, and participants were seated approximately 60 cm away from the display.

The perceived direction of apparent motion in bistable displays has been reported to persist for several trials; for example, if horizontal motion is perceived on one trial, participants continue to perceive horizontal motion for several additional trials (Oyama et al., 1999). To reduce the likelihood that perception of motion would be unchanging, the horizontal distance between displays was manipulated. The diamonds were enclosed in an apparent rectangle that measured 159 pixels vertically and either 87, 107, 127, or 147 pixels horizontally. Pilot testing revealed that perceived motion was unequivocally horizontal in the closest condition (87 pixels), and unequivocally vertical in the farthest condition (147 pixels). Motion perception in the intermediate positions was ambiguous. Our hope was that by randomly intermixing all of these distances, participant perceptions would not be fixed and the two ambiguous displays would be malleable (a similar approach was used by Oyama et al., 1999). The diamond shapes measured 58 pixels horizontally and vertically; when a corner was missing, 11 pixels were cut from the width. The fixation measured 7 $\times$ 7 pixels and the masking dots 14 pixels in diameter. The dots were located 13 pixels from the edge of the diamond they flanked.

As shown in Figure 7, on every trial four sequentially presented displays/frames were repeated five times (i.e., the sequence was looped). In the first frame, which lasted 100 ms, two diamonds that were missing a corner were presented in either the upper left and lower right, or the upper right and lower left. This was replaced with a blank-screen frame for 100 ms, which in turn was replaced with a 33-ms frame containing two full diamonds located in the corners not previously occupied. These full diamonds were flanked by two small dots on their outer edges. The dots remained visible in the final display for 100 ms. In each of the four displays, a fixation (+) remained centered on the screen. Two configurations were used (see Figure 7). In the horizontal-trim condition the inner corners were missing in Frame 1, whereas the outer corners were missing in the vertical-trim condition. (The dotted arrows were added to Figure 7 for ease of exposition but were not presented in the actual experiment.) These predictions were only posited for the ambiguously perceived distances (107 and 127 pixels apart). At closest (87 pixels) and farthest (147 pixels) conditions, the trimming condition should not affect the perception of motion.

This created a 4 (horizontal distance) $\times$ 2 (horizontal trim vs. vertical trim), completely repeated-measures randomized design. Participants completed 160 randomly selected trials and made responses using the "h" and "v" keys for horizontal and vertical respectively, to indicate which direction motion they thought the display was moving.

Results. The mean probability of responding "vertical" in each experimental condition is given in the top portion of Table 7 (see "dots present" condition).[2] Results for both the Web-based (F_1) and laboratory-based (F_2) samples were analyzed using a 4 (distance) $\times$ 2 (trim condition) repeated-measures ANOVA. A main effect of distance [F_1 (3, 78) = 131.10, $p < .05$; F_2 (3, 51) = 548.56, $p < .05$] indicated that participants were more likely to see vertical motion as the horizontal distance increased, replicating the work of Oyama et al. (1999). More importantly, the predicted interaction between distance and trimming condition was obtained for both samples of participants [F_1 (3, 78) = 3.83, $p < .05$; F_2 (3, 51) = 2.83, $p < .05$]. Paired-sample *t*-tests indicated that when the displays were the closest (87 pixels), perception was unaffected by the trimming conditions [t_1 (26) = .46, $p > .05$; t_2 (17) = −.61, $p > .05$]; here, people chiefly perceived horizontal motion. Likewise, when the displays were the farthest apart (147 pixels), perception was unaffected by the trimming conditions [t_1 (26) = .67, $p > .05$; t_2 (17) = 1.63, $p > .05$]; here, people largely perceived vertical motion. As predicted, when the displays were ambiguous, trimming conditions affected motion perception. Perception of vertical motion was more probable in the "vertical-trim" relative to the "horizontal-trim" conditions, when the displays were horizontally separated by 107 pixels [t_1 (26) = 2.31, $p < .05$; t_2 (17) = 2.03, $p = .059$] and 127 pixels [t_1 (26) = 2.28, $p < .05$; t_2 (17) = 2.73, $p < .05$].

Experiment 5b

To control for the possibility that observers may have been biased to see vertical motion when the missing corners pointed outward (vertical-trim condition) and horizontal motion when the missing corners pointed inward (horizontal-trim condition; see Figure 7), we removed the dots from the sequence (i.e., we used the unmasked control method). We again used a laboratory-based sample as well as an Internet sample to assess this possibility.

To control for the possibility that the mere presence of the dots themselves (rather than their continued presence following the target shapes) influenced motion perception, other observers were shown the dots with the full diamond in Frame 3, but the dots did not persist into Frame 4 (i.e., we used the briefly masked control method). Only an Internet-based sample was tested here, simply because to date the results of every Web-based experiment we have conducted have perfectly mirrored those obtained in a laboratory setting.

Method.

Participants. Fifty-four people were recruited via the Internet as in Experiment 5a. Half of these were assigned to the unmasked

[2] The probability of responding "horizontal" can be computed by subtracting the numbers in Table 7 from 1.0.

Table 7
Mean Probability of Reporting Vertical Motion Perception in Experiment 5 as a Function of Masking Condition, Sample Type, Trim Condition, and Horizontal Distance

			Horizontal distance			
			Close		Far	
Masking condition	Sample	Trim condition	87 pixels	107 pixels	127 pixels	147 pixels
Dots present	Web	Vertical trim	.10	.23	.69	.83
		Horizontal trim	.12	.17	.62	.84
		Difference	$-.02^{ns}$	$.06^{*}$	$.07^{*}$	$-.01^{ns}$
	Lab	Vertical trim	.07	.29	.85	.97
		Horizontal trim	.08	.24	.78	.95
		Difference	$-.01^{ns}$	$.05^{*}$	$.07^{*}$	$.02^{ns}$
Unmasked	Web	Vertical trim	.12	.17	.59	.84
		Horizontal trim	.12	.18	.59	.81
		Difference	$.00^{ns}$	$-.01^{ns}$	$.00^{ns}$	$-.03^{ns}$
	Lab	Vertical trim	.17	.32	.87	.97
		Horizontal trim	.13	.36	.83	.96
		Difference	$.04^{ns}$	$-.04^{ns}$	$.04^{ns}$	$.01^{ns}$
Briefly masked	Web	Vertical trim	.21	.30	.63	.79
		Horizontal trim	.22	.29	.64	.79
		Difference	$-.01^{ns}$	$.01^{ns}$	$-.01^{ns}$	$.00^{ns}$

Note. Web = Internet; Lab = laboratory.
$^{*}p < .05$. $^{ns}p > .05$.

control group; the other half were assigned to the briefly masked control group. In addition, a sample of 18 participants was recruited from an Introduction to Psychology class at Bates College. All of the individuals in this laboratory-based sample reported having normal or corrected-to-normal vision and received course credit for their participation. The laboratory-based sample was assigned to the unmasked control version of the experiment. Participants in all groups were informed that the experiment examined visual perception, lasted approximately 15 min, and an explanation would be provided upon completion.

Materials and procedures. The materials and procedure were identical to Experiment 5a, with only a few minor alterations to Frames 3 and 4. For the unmasked control group, the flanking dots were removed from Frames 3 and 4. For the briefly masked control group, the dots remained visible in Frame 3 but were removed from Frame 4. Frames 3 and 4 were presented for the same lengths of time (33 and 100 ms, respectively) as had been done in Experiment 5a.

Results. The mean probability of responding "vertical" in each experimental condition is given in the middle (unmasked) and bottom (briefly masked) portions of Table 7. For the Internet-based sample, the data were submitted to a 4 (horizontal distance) × 2 (trim condition) × 2 (masking condition) mixed ANOVA (F_1), with horizontal distance and trim condition treated as within-subject variables and masking condition (unmasked vs. briefly masked) treated as a between-subject variable. For the laboratory-based sample, the data were submitted to a 4 (horizontal distance) × 2 (trim condition) repeated-measures ANOVA (F_2). The only effect that reached significance for both Internet and laboratory-based samples was a main effect of horizontal distance [F_1 (3, 156) = 133.98, $p < .05$; F_2 (3, 51) = 274.25, $p < .05$], indicating that vertical motion perception is more likely as the horizontal distance increases. The control data from Experiment 5b were then compared with the data from Experiment 5a; experiment was added as a between-subject factor. When this was done, there was a main effect of distance [F_1 (3, 237) = 226.92, $p < .05$; F_2 (3, 102) = 749.38, $p < .05$] and, more importantly, a three-way interaction between distance, trimming condition, and experiment [F_1 (3, 237) = 2.96, $p < .05$; F_2 (3, 102) = 3.67, $p < .05$]. The two-way interaction between trimming condition and distance was only found in Experiment 5a when the dots were presented in both Frames 3 and 4; this interaction was not present in Experiment 5b. These data clearly indicate that the results of Experiment 5a were a consequence of persisting dots trimming the nearby object.

General Discussion

The results of all five experiments are clear in indicating that two dots presented adjacent to a target shape, and persisting for a longer period, will perceptually trim that target in a way that is consistent with the presence of an illusory contour connecting the two dots. A target representation that is trimmed in this way will influence conscious reports of the target (Experiments 1–3)[3], speeded repetition priming (Experiment 4), and the perception of the direction of motion in a bistable quartet (Experiment 5). Figure 8 summarizes the results from each experiment. Examples of object trimming are available online at http://www.bates.edu/~tkahan/trimming/demo.htm Fn3 F8

In Experiment 1, we showed that two dots located adjacent to a target cause masking only when positioned alongside one of the target's edges; no masking was obtained when the dots flanked a blank area. Additionally, an analysis of the errors that were made in Experiment 1 showed that participants reported seeing a trimmed version of the correct digit when the dots flanked an edge at a rate much greater than would be expected by chance. In

[3] One interesting question for future work is whether trimmed shapes seen as fully trimmed or as graded reductions of themselves. Though we do not have any data that directly address this issue, it is the first author's phenomenological impression (after seeing many displays of this sort) that the dots cause a graded reduction in the clarity of the target's nearby edge. This impression matches that of Werner (1935).

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Experiment	Dot type	p (correct response) Edge	Blank	p (trimmed response | error)	Indirect effects
1		Masking	-----	Trimming	
2		Masking	-----	Trimming	
		Masking	Masking	-----	
3a		Masking	Enhancement	Trimming	
3b		Masking	-----	Trimming	
4				Trimming	Repetition priming
5					Motion perception

Figure 8. Summary of results from each experiment along with the dot type used. Masking effects (i.e., differences between simultaneous- and delayed-offset conditions) were computed by examining accuracy rates when the dots flanked an edge or blank segment. Cells labeled "masking" indicate that accuracy was lower when the dots had delayed relative to immediate offset, cells labeled "enhanced" indicate that accuracy was higher when the dots had delayed relative to immediate offset, and cells labeled "——" indicate that there was no difference in accuracy in these conditions. Trimming effects were computed by examining the probability of giving trimmed responses when errors were made. Cells labeled "trimming" indicate that trimmed responses were made at a rate greater than chance. Experiment 4 did not assess masking directly since delayed-offset but not simultaneous-offset conditions were used, and Experiment 5 did not assess masking or trimming directly. Indirect effects of the dots in Experiments 4 and 5 are depicted.

Experiment 2, we replicated the results from Experiment 1 and showed that although substantial masking is obtained when a curved segment is added to the display, object trimming is eliminated under these conditions, consistent with the operation of perceptual grouping mechanisms that segment the line connecting the dots away from the critical target contour. Experiments 3a and 3b demonstrated that trimming still occurs when a third item is added to the display, but one that does not promote the perception of a contour curving away from the target. Experiment 4 demonstrated that object trimming occurs relatively early in processing (before repetition priming operates) and is not limited to situations where participants must consciously report the trimmed item. Participants were faster and more accurate responding to the targets 3 and 5 when preceded by a 9 trimmed to match (e.g., the digit 9 flanked by dots in the upper-left and upper-right, respectively) than when preceded by a 9 not trimmed to match (e.g., the digit 9 flanked by dots in the upper-right and upper-left, respectively). Finally, in Experiment 5 dot frames were identical in the vertical-trim and horizontal-trim conditions (see Frames 3 & 4 in Figure 7), yet motion perception varied as a function of the arrangement of shapes in another frame (vertical vs. horizontal trim; see Frame 1 in Figure 7). These data also support an explanation where the dots trim the nearby corner from the diamond and the visual system tends to interpret their motion in the direction of similar forms.

Trimming in the Immediate- and Delayed-Offset Conditions

In Experiment 5, the perception of motion was only altered when the dots persisted beyond offset of the full diamonds (see Frame 4 of Figure 7). Motion perception was not altered when the dots were removed from the screen following the full diamond displays. However, in Experiments 1 though 3 we found that object trimming occurred in both the immediate-offset and delayed-offset conditions. This apparent discrepancy is easily reconciled with a closer examination of the conditions of the two types of experiment.

In Experiments 1 though 3, more errors were made when the dots persisted beyond target offset relative to when the dots terminated with the target, and this masking effect was only found when the dots flanked the target's edge (replicating Kahan & Mathis, 2002). An examination of participants' responses in both the immediate- and delayed-offset conditions indicated that participants made trimmed responses at a rate greater than expected by chance whenever errors were made, and that across Experiments 1 though 3 the conditional probability of making a trimmed response given an error was very similar (though sometimes slightly less) in the delayed-offset relative to the immediate-offset conditions. Importantly though, since more errors were made in the delayed-offset condition, similar conditional probabilities in the immediate- and delayed-offset conditions meant that a greater total number of trimmed responses were made in the delayed condition.

This is important to bear in mind because in the design of Experiment 5, motion perception is not expected to be biased in one direction or the other when the full diamonds are perceived correctly. Instead, the direction of motion perception is expected to be influenced only when the full diamonds are seen as trimmed versions of themselves. Since we could not separate those trials in Experiment 5 where the full diamonds were perceived correctly from those trials where the diamonds were perceived incorrectly (participants simply made horizontal or vertical judgments), and since the full diamonds should be seen incorrectly more often in the delayed-offset relative to the immediate-offset conditions, the overall rate of seeing the diamonds as being trimmed should be greater in the delayed-offset relative to the immediate-offset conditions (though the conditional rate of perceiving a trimmed representation given an error might conceivably still be roughly equivalent in the immediate- and delayed-offset conditions). Because of this, it is not entirely unexpected that motion perception was unaffected in the immediate-offset condition, in this condition it is likely that participants perceived the full diamonds correctly on many of the trials.

Masking and Trimming When the Dots Flank a Target's Central vs. Peripheral Edge

Jiang and Chun (2001) reported that a mask located adjacent to a target and flanking its central side (i.e., between the target object and fixation) will produce less object substitution masking than a mask that flanks the peripheral side of a target (i.e., on the side opposite the target relative to the fixation point). This asymmetric pattern of object substitution masking may reflect asymmetric inhibitory signals that are directed to areas surrounding the target (to prevent distraction) and which are stronger near the central relative to the peripheral sides. In a post-hoc analysis of each of the experiments reported here, we tested (a) whether we replicated this pattern of asymmetric object substitution masking, and (b) whether object trimming likewise varied with dot positioning.

In Experiment 1−4 (reported here with F and t values labeled with the subscript 1–4 respectively), we added dot positioning (central vs. peripheral) as a repeated measures variable to both the masking analyses (where the dependent variable was target accuracy) and the trimming analyses (where the dependent variable was the conditional probability of giving a trimmed responses when errors were made). In addition, in Experiment 4 we examined whether priming effects varied as a function of dot positioning (central vs. peripheral). In Experiment 5, we did not analyze dot positioning since the dots (when present) always flanked the target's peripheral edge in that experiment.

In terms of accuracy, there was a main effect of dot positioning which reached, or approached, significance in several experiments [F_2 (1,21) = 14.02, $p < .05$; F_{3A} (1, 13) = 3.64, $p = .079$; F_{3B} (1, 11) = 17.57, $p < .05$]. In each of these instances, accuracy was higher when the dots flanked the central relative to the peripheral F9 edge of the target (see Figure 9). This asymmetric pattern of accuracy is consistent with those reported by Jiang and Chun (2001). Interestingly, in several experiments there was also an interaction between dot positioning (central vs. peripheral) and dot location (dots adjacent to the target's edge vs. dots adjacent to a blank side) [F_1 (1,10) = 11.62, $p < .05$; F_2 (1,21) = 39.99, $p <$ F10 $.05$; F_{3B} (1, 11) = 10.39, $p < .05$] (see top portion of Figure 10). In each of these cases, whenever the dots flanked a blank side accuracy was greater when the dots were located centrally relative to peripherally [t_1 (10) = 2.27, $p < .05$; t_2 (21) = 5.81, $p < .05$; t_{3B} (11) = 4.32, $p < .05$], but the opposite was found when the dots flanked the target's intact edge [t_1 (10) = 2.93, $p < .05$; t_2 (21) = 2.89, $p < .05$; t_{3B} (11) = 1.15, $p > .05$]. One possible explanation for this is that masking and trimming effects are influenced by dot positioning in opposite ways. When the dots flank a blank side and there is nothing to trim, masking is greater

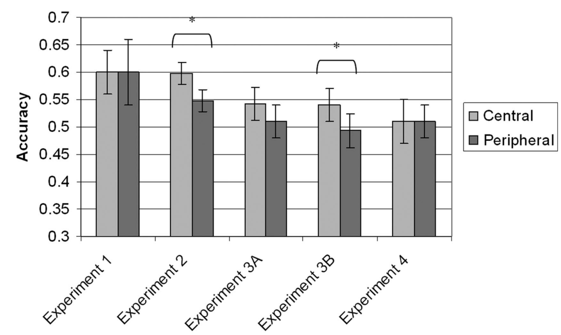

Figure 9. Accuracy rates in Experiment 1–4 as a function of whether the dots flanked the target's central or peripheral side.

when the dots are located peripherally relative to centrally, a result that replicates Jiang and Chun (2001). However, when the dots flank the target's edge, accuracy is lower when the dots are displayed centrally relative to peripherally as a consequence of greater object trimming in the former relative to the latter situation. To more directly assess the possibility that trimming is greater when the dots appear centrally, we turn our attention to analyses conducted on the conditional probability of giving trimmed responses when errors are made. These analyses yielded a main effect of dot positioning in the same experiments that had shown the interaction described previously [F_1 (1,10) = 7.35, $p < .05$; F_2 (1,17) = 13.76, $p < .05$; F_{3B} (1, 11) = 4.79, $p = .05$], and in each of these experiments whenever errors were made the probability of giving a trimmed response was greater when the dots flanked the target's central relative to peripheral edge (see bottom portion of Figure 10). Put simply, object trimming was larger when the dots flanked the target's central relative to peripheral edge. None of the effects of dot positioning reached significance in the priming analyses of Experiment 4. Taken together, these data indicate that dot positioning affects object substitution masking in different ways than object trimming; object substitution masking is larger when the dots appear peripherally, whereas object trimming is larger when the dots appear centrally. Future work may try to uncover why this is the case.

Mechanisms Responsible for Object Trimming: Crowding and Backward Masking

Object trimming was obtained in both the immediate- and delayed-offset conditions of Experiments 1−3. In the delayed-offset condition, it is possible to attribute these errors in target report to mechanisms of backward masking, as has generally been done for common-onset masking effects (Enns & Di Lollo, 2000; Di Lollo et al., 2000). However, in the immediate-offset condition, these errors cannot be attributed to any mechanisms associated with backward masking, since the dots terminated along with the targets. Instead, errors (and trimmed responses) in the immediate-offset condition are likely a consequence of perceptual crowding, where contours of the mask obscure the target through mechanisms of lateral inhibition. Taken together, this suggests that object trimming effects measured in the delayed-offset condition are likely a consequence of both types of mechanisms: crowding and backward masking. Object trimming that arises from crowding alone can be observed in the immediate-offset condition; object

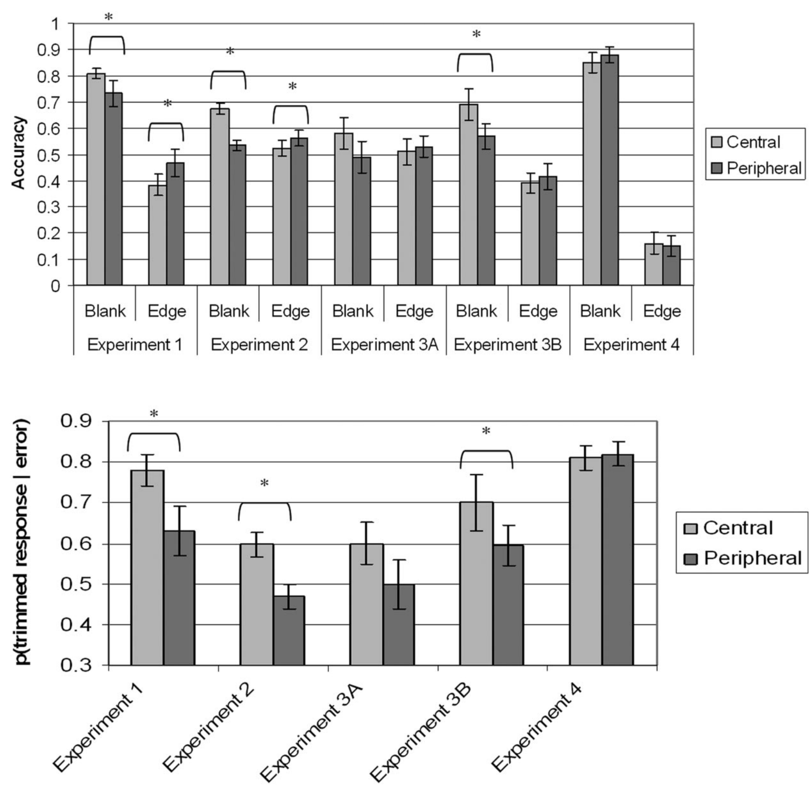

Figure 10. The top panel depicts accuracy rates in Experiment 1–4 as a function of dot location (adjacent to edge or adjacent to blank) and whether the dots flanked the target's central or peripheral side. The bottom panel depicts rates of making trimmed responses in Experiments 1–4 as a function of whether the dots flanked the target's central or peripheral side.

trimming arising from the combined effects of crowding and masking can be observed in the delayed-offset condition.[4] Fn4

If object trimming does reflect both crowding and backward masking, then object trimming may result from the same combination of mechanisms that lead to object-substitution masking. Object substitution masking has now been shown to reflect processes at both the image or featural level (Breitmeyer & Ogmen, 2000; Gellatly, Pilling, Cole & Skarratt, 2006) and at the object level (Lleras & Moore, 2003; Kahan & Lichtman, 2006). At the image level, visual contours of the mask may degrade nearby target information (i.e., perceptual crowding). At the object level, the target and mask might be represented in two unique and interfering object files (Kahan & Lichtman, 2006), or the target can be interpreted as morphing into the mask (i.e., as one object that is changing its appearance over time) [Lleras & Moore, 2003].

In the object substitution masking literature, recent evidence suggests that interference between two object files is partially (though not entirely) responsible for object-level masking, and as such may play a role in object trimming as well. To increase the probability that participants would represent the target and mask in separate object files, Kahan and Lichtman (2006) presented the stimuli in separate stereoscopic depth planes. Results from this experiment indicated that although object-substitution masking is robust when a four-dot mask appears in front of the target, no masking is found when the target appears in front of the mask (see also Lehmkuhle & Fox, 1980 for similar effects of depth on metacontrast masking). In subsequent experiments, Kahan and Lichtman presented the mask and target in separate spatial locations (in 2D space) to encourage the perception of unique object tokens; in these experiments, robust object-substitution masking was obtained when the four-dot mask moved to the location previously occupied by the target. Both of these findings support the conclusion that a dot mask, represented in a unique object token from the target (either because it is located in a different plane of view or because it started in a different location), can act as a mask because it occludes the representation of the target object. In the current experiments, this interpretation would suggest that that the two-dot mask was represented in a unique object file that *partially* obscured the target object, and as a consequence the target object's mental representation may have been altered (or trimmed).

Another mechanism, referred to as *object-mediated updating* (Moore & Lleras, 2005), has been shown to contribute to object-substitution masking and as such may also play a role in object

[4] We note that Francis and Hermens (2002) have made the argument that common-onset masking, like other forms of masking, may exclusively arise from feed-forward rather than reentrant mechanisms. By similar reasoning object trimming might solely reflect image-level mechanisms, which feed their output to higher level areas, rather than interactions between image-level and object-level mechanisms. However, even if this argument were correct, which we don't believe it is based on data that implicate reentrant and object-based processes in common-onset masking (e.g., Lleras & Moore, 2003), the trimming data reported here would not undermine the reentrant theory put forward by Di Lollo et al. (2000) since this theory explicitly posits *both* image-level and object-level contributions to masking.

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trimming. Here, participants perceive one object that changes over time; the target object becomes (or morphs into) the mask (Lleras & Moore, 2003; c.f. Enns, 2002). In a series of experiments, Lleras and Moore (2003) demonstrated that a dot-mask could degrade perception of a nearby target, as long as the spatiotemporal properties support the perception of the target moving to the mask location. In their Experiments 4 and 5, a dot-mask appeared adjacent to the target following target offset. As the interval between target and mask was lengthened, the perception of the target moving towards the mask decreased, and so too did masking. These data support the claim that object-substitution masking partially reflects object-mediated updating. However, this explanation cannot, unaltered, explain object trimming because perception of the target was not *eliminated* by the dot mask in the current experiments. As such, the object file that contained the target was not *completely* updated with information about the mask; somehow, a trimmed portion of the target remained. This suggests that object updating can occur separately for the representations of the target and the mask.

For some, a theory of object-mediated updating may have initially been appealing because it easily explains how one object can sometimes replace another object in consciousness. However, object trimming shows us that objects are not always replaced by other objects. Instead, objects can alter rather than replace mental representations; and this may, at first glance, make a theory of object-mediated updating seem less straightforward. We believe that this should not be considered a weakness though; instead, object trimming may help to make masking phenomenon more relevant to our general understanding of perception, rather than being viewed as some curiosity or a sideshow as it has often been studied and presented in textbooks. We live in a world where we see multiple objects that are sometimes presented in close spatial proximity, and our brains construct and maintain each of these objects in multiple object files. Object-mediated updating and object trimming may help us to better understand how we maintain multiple object representations and the circumstances that create distortions in perception.

Conclusion

Masking stimuli do not always render a target invisible but sometimes distort its perceived shape (see the shape-contrast effect reported by Suzuki & Cavanagh, 1998 and the feature-inheritance effect reported by Herzog & Kosch, 2001) or location (see illusory displacement effects reported by Sigman, Sackur, Del Cul, & Dehaene, 2008). Somewhat similarly, object trimming arises when a portion of an image that is presented only briefly, continues on view for a longer period, with the effect that it obscures some, but not all, of the original image. In this study, across five experiments, we have demonstrated that object trimming influences the conscious experience of briefly presented shapes, that it occurs relatively early in visual processing (being able to influence repetition priming and the direction of apparent motion), and it is caused by mechanisms associated with both crowding and backward masking. Though phenomenological reports of object trimming (Werner, 1935) and theoretical speculations about it (Kahan & Mathis, 2002) are not new, the current study is the first to provide concrete evidence for object trimming using three methods specifically designed to focus on the effect. We believe this is an important development, not only for gaining a more thorough understanding of crowding and masking effects, but also because object trimming may be useful as a tool for examining the nature of object representations and their parts (c.f., Feldman, 2003; whether some elements of an object can be trimmed while other elements cannot be trimmed as easily), as well as the mechanisms involved in the formation and maintenance of multiple object representations.

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