

**MOTION ENHANCES OR REDUCES TARGET VISIBILITY, DEPENDING
ON PREDICTION AND POSTDICTION OF SHAPE**

by

Peter Jordan Lenkic

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Abstract

Motion masking refers to the finding that objects are less visible when they appear as part of an apparent motion sequence than when they appear for the same duration in isolation. Against this backdrop of generally impaired visibility, there are reports of a relative visibility benefit when a target on the motion path is spatiotemporally predictable versus when it is unpredictable. The present study investigates whether prediction based on the shape of the originating stimulus in the motion sequence, and postdiction based on the terminating shape, is an aid to the visibility of a target in motion. In Experiment 1 these factors are examined separately for originating and terminating stimuli; in Experiment 2 they are examined in combination. The results show that both factors influence target discriminability in an additive way, suggesting that the processes of prediction and postdiction have independent influences on visibility. Experiment 3 examines the same display sequences with a different psychophysical task (i.e., detection) in an effort to reconcile the present findings with previous contradictory results. The upshot is that in contrast to the results for discrimination, target detection is influenced little by these factors. Experiments 4 and 5 examine the discrimination of a fine shape detail of the target, in contrast to the crude discrimination of target orientation in Experiments 1 and 2. This design also eliminates the opportunity for decision-biases to influence the results. The results show that predictable motion has a strong positive influence on target shape discrimination, to the extent that it makes a backward-masked target even more visible than when it appears in isolation. These findings are related to the empirical literature on visual masking and interpreted within the theoretical framework of object updating.

Preface

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Table of Contents

Abstract.....	ii
Preface.....	iii
Table of Contents	iv
List of Figures.....	vi
Acknowledgements	vii
Dedication	viii
Introduction.....	1
Chapter 1: Baseline Shape Discrimination and Controls for Shape Effects	8
1.1 Method	9
1.1.1 Participants.....	9
1.1.2 Stimuli and Materials	9
1.1.3 Procedure	10
1.1.4 Analysis.....	12
1.2 Results.....	12
1.3 Discussion	14
Chapter 2: Discrimination With Both Origin and Terminus	16
2.1 Method	17
2.1.1 Participants.....	17
2.1.2 Stimuli, Materials and Procedure.....	17
2.2 Analysis and Results	19
2.3 Discussion	21

Chapter 3: Target Detection	24
3.1 Method.....	25
3.1.1 Participants.....	25
3.1.2 Stimuli, Materials and Procedure.....	25
3.1.3 Analysis.....	26
3.2 Results.....	27
3.3 Discussion	28
Chapter 4: Baseline Local Contour Discrimination and Controls.....	30
4.1 Method.....	31
4.1.1 Participants.....	31
4.1.2 Stimuli, Materials and Procedure.....	31
4.1.3 Analysis.....	32
4.2 Results.....	32
4.3 Discussion	34
Chapter 5: Discrimination of Local Contour with Both Origin and Terminus.....	36
5.1 Method.....	36
5.1.1 Participants.....	36
5.1.2 Stimuli, Materials and Procedure.....	36
5.2 Analysis and Results	37
5.3 Discussion	40
General Discussion.....	42
Notes.....	48
References.....	49

List of Figures

Figure 1: Spatial Layout of Stimuli in Experiment 1	10
Figure 2: Results of Experiment 1	13
Figure 3: Spatial Layout and Timing in Experiment 2	18
Figure 4: Results of Experiment 2	20
Figure 5: Results of Experiment 3	27
Figure 6: Results of Experiment 4	33
Figure 7: Results of Experiment 5	38

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Dedication

To Lisa

INTRODUCTION

When two stimuli are presented in close spatiotemporal proximity we experience a single object in motion. This is known as apparent motion, with the first and second stimuli termed the origin and the terminus of the motion, respectively. Despite its transparency to the viewer, this experience is only achieved by the visual system after it has solved a number of computational problems. For instance, in order to see apparent motion from a succession of still displays, the human visual system has to overcome problems of image correspondence (Ramachandran and Anstis, 1986), motion blur (Burr, 1980; DiLollo and Hogben, 1985), the perception of relative spatial position of each of the elements (Nijhawan, 1994; Krekelberg and Lappe, 2000; Eagleman and Sejnowski, 2000), and visual masking of one stimulus by the other (Breitmeyer and Ogmen, 2006; Breitmeyer and Ogmen, 2000; Enns and Di Lollo, 2000). Because of motion blur and masking, for instance, one could reasonably predict that it should be more difficult to perceive a stimulus which is part of an object in motion as opposed to a static stimulus of similar duration and spatial extent. Nevertheless, moving objects have been found to be *more* visible than predictions based on motion blur in the image (Burr, 1980; Hogben and DiLollo, 1985). This suggests that the visual system is somehow able to compensate for such problems. In the present paper, we will examine how visual identification and detection can be sometimes impaired and at other times enhanced by the relations between stimuli making up an object in an apparent motion sequence.

Functional brain imaging studies provide hints that the illusory motion token during apparent motion may be represented by activity in the primary visual cortical (V1) areas to which the token's spatial position retinotopically corresponds. In other words, neural activity is able to be filled-in based on the timing and positioning of the inducing elements. For example, Muckli, Kohler, Kriegeskorte, and Singer (2005) found that an apparent motion condition, in which the apparent motion-inducers were presented several times in alternation, produced a significant blood-oxygenation-level-dependent (BOLD) response in certain V1 areas. The authors argue that the V1 areas of activation correspond to the area in visual space between the origin and terminus stimuli, since these areas were not active when the origin

and terminus were presented alone but did show significant activity compared to baseline under a real motion condition. The fact that non-retinotopically stimulated areas of V1 can show activity, according to these and other researchers, is likely due to feedback input into V1 originating from the hMT+ cortex (Sterzer, Haynes, and Rees, 2006), although Yantis and Nakama (1998) and other researchers (Jancke et al., 2004; Stettler et al., 2002) note that horizontal connections could also be implicated, particularly in cases where the motion-inducing stimuli are not widely separated. Moreover, this apparent motion-induced V1 activity is closely coupled with a subject's perception of apparent motion, as indicated by subjective reports of experienced motion while viewing a bistable quartet motion display (Muckli et al., 2005, Experiment 3). Other neuroimaging studies of apparent motion have produced similar results (Sterzer et al., 2006; but see Liu et al., 2004).

In contrast to these recent imaging studies, it is notable that early behavioural studies failed to support the idea that the experience of motion from a rapid succession of static stimuli is filled in to resemble real motion. Kolers (1963), for instance, presented subjects with two vertical bars as horizontal apparent motion-inducers, with a target of shorter length and dimmer luminance presented between them. He found no effect of apparent motion on target detection rates, and concluded that the filling-in experience from apparent motion does not interfere with the perception of the target stimulus presented within the apparent motion path (see also Attneave and Block, 1974). However, a couple studies along these lines have since examined this question (Schwiedrzik et al., 2007; Yantis and Nakama, 1998), and Kolers' (1963) conclusions have been called into question. Yantis and Nakama (1998) have found that when subjects were induced by an occluder to perceive 3-4.5 cycles of vertical as opposed to horizontal motion from a quartet motion display, they were subsequently significantly slower to correctly identify a target letter when it was presented within the vertical compared to the (potential) horizontal apparent motion path. Crucially, because the stimulus array was bistable, these interference effects are isolable to the subjective percept of motion as opposed to physical display properties. Expanding upon these findings, Schwiedrzik, Alink, Kohler, Singer, and Muckli (2007) presented 6 to 12 cycles of vertical

apparent motion (9 on average) after which they presented a target within the motion path. In addition, some trials consisted of origin and terminus only, which served as controls for interference due to spatial proximity (i.e., masking controls). They found that the miss rate for detection was significantly higher for targets at positions and delays within the apparent motion path compared to origin and terminus only controls, thus corroborating a robust interference effect of motion-inducing stimuli on perception of a target stimulus within the motion path. In fact, Yantis and Nakama (1998) termed the general paradigm ‘motion masking’ in reference to this interfering effect.

However, in addition to general motion masking, Schwiedrzik and colleagues (2007) also found significant differences in miss rates for the target when it was presented within the apparent motion path at the three different positions and two different delays used; importantly, when appearance of the target coincided with the expected trace of motion (based on the timing of and distance between the inducers), detection was significantly higher. For instance, detection rates were high for targets presented both with the short delay and at the position closest to the origin, whereas detection was lower for targets presented with the long delay at that same position. Owing to these fine-grained differences within the motion path found by Schwiedrzik and colleagues (2007), target visibility may therefore depend crucially on its predictability based on its timing and position relative to the motion-inducing stimuli.

The role of prediction has been gaining importance in recent theories of how both visual masking and apparent motion are experienced (Nijhawan, 1994; Enns and Lleras, 2008, Mathewson, Fabiani, Gratton, Beck and Lleras, 2010), including displays of motion (Roach, McGraw and Johnston, 2011). For instance, Roach, McGraw, and Johnston (2011) presented pairs of inducer stimuli to the left or right of central fixation, which moved up or down at a frequency of 5 Hz. The researchers presented a target Gabor stimulus in the path of one of these inducers, and manipulated its timing so that the target appeared either at the end of the inducer’s motion or at the beginning. Furthermore, these researchers manipulated the target’s presentation so that it was either in phase with the inducer, or out of phase, by varying degrees. Subjects were simply instructed to report whether the target was presented to the left or right of

fixation. The results of this experiment were that the target's detection threshold was no different from that of a target presented in isolation when spatial phases matched, but only when the inducer's motion lead into the target's appearance. In this case, target visibility was highest when it was in phase with the inducer, in which case it was no different from solitary target, and the detection threshold increased incrementally as the phase became increasingly out of synch. On the contrary, when the inducer's motion led away from the target's appearance, visibility of the target was consistently lower than that of a solitary target, and was not modulated by the congruency of temporal phase between the inducer and target. According to these researchers, such findings suggest that target visibility can be enhanced when it is predictable from the temporal phase of the inducer.

It is an open question, though, whether the predictability found in motion masking for Schwiedrzik et al.'s study (2007) pertains solely to spatiotemporal coincidence with the motion trace, or whether the shape of the target is an integral part of the prediction. In other words, is the prediction only space-time specific or is it also shape specific? In their general discussion, Schwiedrzik et al. (2007) discuss the possibility that the dissimilarity between motion-inducing and target stimuli identity might have played a role in the general interfering effects found by Yantis and Nakama (1998). In that study, the motion inducing stimuli were bright green circles, whereas a dim blue "E" or "S" was presented as the target letter. In experiment 4, Yantis and Nakama (1998) used a low luminance green Landolt C, which was smaller than the inducers (34 compared to 52 min visual angle in diameter), and found that discrimination of the location of the gap in this target was required significantly higher luminance levels for equivalent accuracy levels when it was presented within the motion path compared to the non-motion path. In contrast to Yantis and Nakama (1998), Experiments 1-3, Schwiedrzik et al. (2007) used identically shaped squares both as their inducing and target stimuli, although the target was of dimmer luminance. To our knowledge, the relation between the form of the inducing and target stimulus has not yet been explicitly manipulated in the same study of motion masking, so that the target and inducers were either identical (as in Schwiedrzik et al., 2007 and Yantis and Nakama, 1998, Experiment 4), or distinct

(as in Yantis and Nakama, 1998, Experiments 1-3). A systematic study of shape congruence should indicate whether the motion trace enables a prediction not only of when and where a stimulus will appear, but also what its shape will be.

It is also important to bear in mind that prediction, or forward-going expectations of what will momentarily be, are only part of what occurs in dynamic visual displays. Postdiction, or backward-going interpretations of what was just presented, have also been found to influence the perception of a target image in multi-stimuli displays (Eagleman and Sejnowski, 2000; Di Lollo, Enns, and Rensink, 2000; Lleras and Moore, 2003; see also Kolers and Pomerantz, 1971; Kolers and von Grunau, 1976). A possible mechanism for postdictive influence is updating at the object-level of representations, or simply *object updating* (Enns, Lleras and Moore, 2009) although other mechanisms for postdiction have been proposed (e.g., Krekelberg and Lappe, 1999, 2000; Roulston, Self and Zeki, 2006). Moore, Mordkoff and Enns (2007) suggest that when images can be interpreted as corresponding to the same object in motion, a process of impletion occurs by which the single object appears to change smoothly, or at least less abruptly, despite large differences between physical images of which the motion is composed. In brief, currently sampled information can change active (existing) representations of information recently sampled, which is a postdictive process. Such impletion may help make sense of an otherwise confusing sequence of events (Moore, Mordkoff and Enns, 2007), but at the same time it incurs a cost. The cost is that highly dissimilar target images may be ‘overwritten’ and rendered less visible or invisible when the subsequent image, perceived as belonging to the same object, alters the perception of the target image by this impletion process (e.g., Di Lollo, Enns and Rensink, 2000; Lleras and Moore, 2003; Moore and Lleras, 2005). Pertinent to this point, Kawabe (2011) reported that size judgments of a leading bar were significantly influenced by the size of a trailing bar, when the two stimuli were arranged to produce the perception of apparent motion. When the trailing bar was shorter, subjects were more likely to perceive its origin stimulus as shorter than a bar of identical size followed by a larger bar. This implies that similar postdictive processes may influence the visibility of the target item in studies of motion masking.

To sum up, similarity or dissimilarity between images has been suggested to influence, in both the forward and backward direction, the visibility of targets in dynamic multi-stimuli displays. In the case of ‘motion masking,’ however, the similarity between successive images has not been explicitly manipulated in order to determine whether content might be part of the predictions which are thought to influence how perceptible the target is. Furthermore, the influence of the origin and the terminus has not been differentiated in this type of task.

In the present study we aim to (1) determine whether the perceptibility of a target image is subject to both predictive processes and postdictive processes with regard to shape, and if so to (2) evaluate the cost in visibility of a non-predictable or non-postdictable target relative to a similar target presented by itself. If both processes are at work, other important questions can then be asked: (3) Is the magnitude of one direction of influence greater than the other? (4) Do these processes interact in an additive or synergistic way? (5) How is one process changed when the potential for the other process is either available or not, or in short, is impletion influenced by the potential for prediction, or vice versa?

In order to address these questions, we designed a task in which the effects of the origin and the terminus on one’s ability to perceive the target can be evaluated independently and jointly. We did this by varying the congruence between inducing and target shapes. To anticipate the upcoming experimental goals, in Experiment 1 we separately evaluated predictive and postdictive processes by presenting the target with only an origin or a terminus and varying the shape congruence between target and inducer. We assessed the visibility of the target by measuring how accurately observers could report its shape. We had a separate condition in which the target was presented by itself to evaluate the cost of shape incongruence on the visibility of the target. Experiment 2 examined predictive and postdictive processes jointly by presenting both origin and terminus stimuli with the target, while independently manipulating each one’s congruence with the target. This allowed us to assess whether the cost in target visibility of predictive and postdictive incongruence measured separately was comparable in character to the cost of having both incongruent at the same time, i.e., to evaluate whether these processes interacted additively or

synergistically. It also allowed us to evaluate how terminus presence influenced the potential origin congruence effect in Experiment 1, and how origin presence influenced the potential terminus congruence effect. Experiment 3 arose from the results of the previous experiment, and attempted to replicate Experiment 2 but with a task of detection rather than discrimination, in an attempt to explain inconsistencies between the results of Experiment 2 and the results of prior motion masking studies. Experiments 4 and 5 replicated the design of Experiments 1 and 2 with a task of notch discrimination instead of orientation discrimination, in order both to extend those results to perception of local instead of global contour and to definitively circumvent any potential problems of the prior results being attributable to processes of decision-making rather than perception.

CHAPTER 1: BASELINE SHAPE DISCRIMINATION AND CONTROLS FOR SHAPE EFFECTS

We first conducted a baseline experiment in order to compare the accuracy of target discrimination for a target shape in an apparent motion sequence with accuracy for a single target presented for the same duration. Three conditions were compared: origin and target (OT), target and terminus (TT), and solitary target (T). On OT trials, one stimulus preceded the target, whereas on TT trials, one stimulus followed the target, with the target and non-target stimuli spatially and temporally arranged on these trials to induce the perception of apparent motion (see Figure 1). In the OT and TT conditions, the two stimuli either had the same shape (overall orientation) or the opposite shape (orthogonal orientation).

Three other independent variables were manipulated in addition to shape congruence, but these were designed to elicit optimal measures of target visibility, rather than being of primary theoretical importance. One, to ensure that target visibility would not always be at ceiling, a backward pattern mask was presented immediately after the target and in the same spatial position on half of the trials was presented immediately after the target, and in the same spatial position, on half of the trials (Breitmeyer and Ogmen, 2006). Two, the spatial proximity between stimuli in the OT and TT conditions was varied in two steps, to examine the role of contour contiguity in target visibility (Breitmeyer and Ogmen, 2006). Three, spatial uncertainty about the target location was maintained by presenting displays randomly to the right or left of fixation. Object updating effects, including object substitution masking, have been found to be larger when spatial attention is distributed (Enns and Di Lollo, 1997; Enns and Di Lollo, 2000).

1.1 Method

1.1.1 Participants

15 students from the University of British Columbia participated in Experiment 1. Each person received \$10 (CAD) or class credit for their participation. Participants had normal or corrected-to-normal vision. All gave informed consent and were treated according to UBC ethical guidelines.

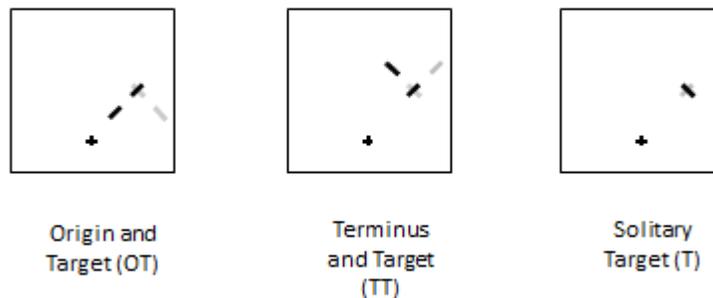
1.1.2 Stimuli and Materials

Stimuli were presented on an LCD monitor set to a refresh rate of 60-Hz. The origin, target, and terminus were all rectangular bar stimuli with dimensions $2.5^{\circ} \times 1^{\circ}$. Each stimulus bar slanted either 45 degrees or 135 degrees from vertical, such that multiple stimuli in the display could either have the same orientation or a perpendicular orientation relationship. Stimuli were presented on a white background. Mask stimuli were isoluminant with the bar stimuli, and consisted of 6 different patterns made up of two slightly off-vertical and two slightly off-horizontal bars whose average dimensions were $2^{\circ} \times 0.3^{\circ}$, and of two diagonal bars, slightly off the 45 degree or 135 degree angle with the vertical, whose average dimensions were $2.5^{\circ} \times 0.3^{\circ}$ (see Figure 3b for an example mask). The fixation cross was 5.5° down from the center of the screen.¹

The OT condition did not have a terminus stimulus, while the TT condition did not have an origin stimulus; in these two conditions, in addition to mask presence, proximity and congruence between the target and nontarget stimuli were manipulated. The origin or terminus stimulus was spatially contiguous with the target on close proximity trials, and was separated by a gap of 4° on far proximity trials. In contrast, in the T condition, there was neither an origin nor terminus stimulus; thus mask presence was the only real manipulation for these trials, while proximity and congruence were dummy-coded (see below in Procedure). Examples of the spatial layout for the OT, TT, and T conditions are shown in Figure 1. Hemifield location of stimuli was also randomized: the left hemifield condition was the mirror image of the right hemifield condition along the (nominal) vertical midline of the screen. Although motion

direction and hemifield were randomized, the target was always the same center-to-center distance from the fixation cross (10.5°)- though either to its left or right- regardless of these and all other manipulations.

Figure 1: Spatial Layout of Stimuli in Experiment 1. Examples of the spatial layout for the three conditions (Origin and Target, Target and Terminus, and solitary Target) in Experiment 1 (see Procedure for the timing of stimuli presentation). The sequence of motion is proceeding from bottom to top and the stimuli are in the separated rather than contiguous proximity condition (for the OT and TT conditions). Other possible positions for stimuli in these conditions are shaded in gray. The subject's task was to report the orientation of the mid-screen target bar as having a back or forward slant.



1.1.3 Procedure

Subjects were seated approximately 57 cm from the monitor. Subjects were instructed to maintain their gaze on the fixation cross and to “use their peripheral vision” to view the target stimulus, which they were told would be the stimulus mid-way between the top and bottom of the screen on either the left or right side. They were then allowed 10 practice trials at a slowed display rate and with feedback on each trial (“correct” or “incorrect”) to ensure they understood the goal of the task.

Each trial began with a variable onset interval (from 1400 to 2200 ms, in steps of 200 ms). At this point, the sequence of events depended on whether the trial was in the OT, TT, or T condition, and whether the mask was present or absent. On OT trials, the origin was presented for 100 ms, followed by the 33ms duration target alone in mask absent trials, or the target and then a 33 ms ISI and a 33ms duration mask for mask present trials. On TT trials, the target was presented for 33 ms, then there was either a blank interval of 66 ms (mask absent conditions) or a 33 ms blank interval and then a 33 ms duration mask (mask present conditions), and finally the terminus was presented for 100 ms. For T trials, the target was presented for 33 ms, and on mask present trials this was followed by a blank interval of 33 ms and finally a mask for 33ms. After these sequences, the subject had to register their response by pressing one of two keys corresponding to the two possible target orientations. Subjects were told to make a response reasonably quickly, and to register a response even when they were not completely certain as to the target's identity. After the response was registered, the trial ended with a visual feedback message indicating whether their response was "correct" or "incorrect".

The design was counterbalanced among 4 factors in the following way: 2 target orientation (back-slanting or forward-slanting diagonal bar) x 2 congruence x 2 mask presence x 2 proximity x 3 condition (OT, TT, and T). Congruence and proximity were dummy-coded for the T trials, such that a value for these variables was recorded, though the display was identical regardless of the value. Consequently these values were collapsed across for the purpose of analysis of the T condition. Hemifield (left or right) and motion direction (up or down) were random from trial to trial and were also collapsed for subsequent analyses. There were 768 trials altogether, which were divided into 8 blocks of 96 trials each, with self-paced breaks between blocks. Every block of trials contained a random permutation of two repetitions of each combination of target orientation, congruence, mask presence, proximity, and condition, (2 repetitions x 2 x 2 x 2 x 2 x 3= 96 trials).

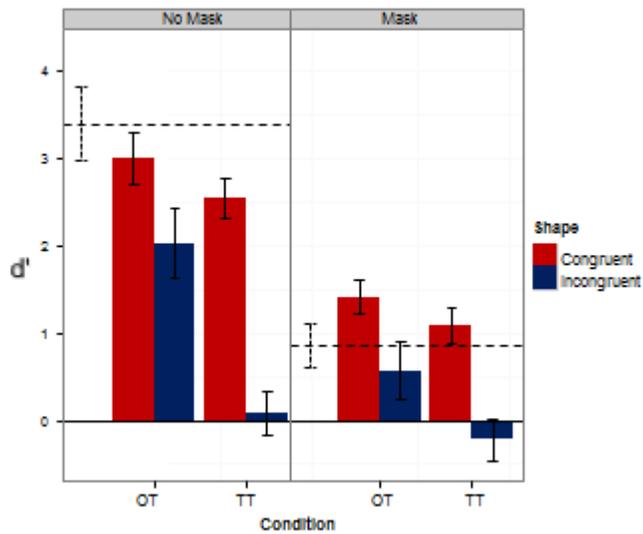
1.1.4 Analysis

Hit and false-alarm rates were arbitrarily defined as the proportion of left-slanting target reports to a left- and right-slanting target, respectively, for each combination of condition, congruence, mask, and proximity factors, and for each subject. From these hit and false-alarm rates, d' values for each combination were calculated according to the formula $d' = z(pH) - z(pFA)$. Since proportions of 0 or 100 cause d' to take on a value of infinity, hit or false alarm rates with these values were replaced with values of 0.01 and 0.99, respectively (Macmillan and Creelman, 1991), which, in effect, placed an absolute ceiling value of approximately 4.46 for d' .

1.2 Results

The OT and TT conditions were entered into a 4-way ANOVA with condition (OT or TT), congruence, mask and proximity as the factors. Recall that congruency and proximity were dummy-coded for the T condition, thus we excluded that condition from this ANOVA in order to evaluate the effects of these factors on target visibility in the remaining two conditions. There were significant main effects of condition (d' origin=1.73 vs. terminus=.85, $F_{(1,14)}=26.58$), congruence ($F_{(1,14)}=23.67$), mask ($F_{(1,14)}=34.86$), and proximity ($F_{(1,14)}=15.33$, $p=.0036$). In addition, the two-way condition x congruence ($F_{(1,14)}=6.13$, $P=.027$), condition x mask ($F_{(1,14)}=6.59$), and congruence x proximity ($F_{(1,14)}=33.48$) interactions, as well as the three-way condition x congruence x mask ($F_{(1,14)}=13.73$) and congruence x mask x proximity ($F_{(1,14)}=6.35$, $p=.025$) interactions were significant. To further evaluate the condition x congruence interaction, simple main effects of congruence were calculated for both levels of the condition factor. This revealed that the orientation-congruence effect was significant for both the origin and target condition ($F_{(1,14)}=12.10$, $p=.0037$) and the target and terminus condition ($F_{(1,14)}=48.71$, $p=.0000065$), despite the difference in magnitude between these effects. Thus, the interaction between condition and congruence indicates that the congruency effect is greater in magnitude for the TT conditions than the OT conditions (see Figure 2).

Figure 2: Results of Experiment 1. Visibility of the target (d' +/- SE) in the Origin and Target (OT) and Target and Terminus (TT) conditions is depicted by the bars, and in the solitary Target (T) condition by the dashed lines. The left panel shows conditions in which the backward mask was absent, and the right panel shows mask present conditions. The shapes of the target bar and the non-target bar in the OT and TT conditions were congruent or incongruent.



To compare the visibility of targets in the OT and TT conditions with the visibility of solitary targets, 8 contrasts were conducted that compared target visibility in, for example, OT with congruent orientation and mask absent to the average of the T mask absent congruent and T mask absent incongruent conditions (since congruency in the latter conditions was a dummy-coding, their average was calculated for purposes of the contrast; the values of these averages are represented by the dashed lines in Figure 2, for mask absent and mask present conditions). Error terms were calculated for each of these contrasts, and the Bonferonni-adjustment was applied for the eight contrasts, which resulted in a .00625 alpha-level for significance per comparison. When the mask was absent (Figure 2, left panel), these contrasts showed that the OT incongruent ($F_{(1,14)}=27.00, p=.0001$), TT congruent ($F_{(1,14)}=12.95, p=.0029$), and TT incongruent ($F_{(1,14)}=121.97, p<.0001$) conditions were significantly less visible than the

T condition baseline, though the OT congruent condition was statistically equally visible ($F_{(1, 14)}=6.41$, $p=.024$). When the mask was present (Figure 2, right panel), only the TT incongruent condition ($F_{(1, 14)}=23.75$, $p=.0002$) was significantly less visible than the corresponding T condition baseline, with OT congruent ($F_{(1, 14)}=7.02$, $p=.019$), OT incongruent ($F_{(1, 14)}=1.16$, $p=.30$), and TT congruent ($F_{(1, 14)}=0.62$, $p=.44$) conditions each showing no difference from this baseline.

1.3 Discussion

Target visibility, as indexed by d' , was compared in three conditions: a solitary target condition (T), an origin and target condition (OT), and a target and terminus condition (TT). The first finding of note was the strong effect of shape congruence in both the OT and TT conditions: target visibility was higher when the target and non-target shape were congruent than when they were incongruent. This is consistent with the tenets of object updating (Enns, Lleras and Moore, 2009), which proposes that human vision is biased to process a spatiotemporal sequence of stimuli as the same object translating in space-time. However, based on this experiment alone, we cannot rule out the possibility that these results were influenced by decision-making as well as by perceptual processes. For instance, when viewers see an inducing stimulus relatively clearly, they may be biased to respond to a question about uncertain target visibility in a way that is consistent with the inducing stimulus. So if they see a left-leaning inducing shape, they may be more likely to respond that the target was left-leaning as well. This would tend to inflate congruent d -primes and underestimate incongruent d -primes. We will return to this issue in Experiments 4 and 5.

A second finding was that the influence of shape congruence was greater in the TT condition, which corresponds to the conventional conditions of backward masking, than it was in the OT condition, which corresponds to the conventional conditions of forward masking. These results are thus completely consistent with what has previously been reported for forward and backward masking of shape (Breitmeyer and Ogmen, 2006). But there may be other factors at work as well. For example, the greater

visibility in the OT compared to the TT conditions could be due to the temporal warning provided by the origin, in effect providing a signal that an upcoming important event is about to occur and thus permitting the subject to tune his or her attention to events in the period of time immediately following the origin stimulus.

A third finding was that in both the no-masking and masking conditions, congruent inducing shapes led to target visibility that was equal to or approximated target visibility under solitary stimulus conditions (T). However, incongruent inducing shapes significantly reduced target visibility below this baseline, consistent with previous reports of motion masking (Yantis and Nakama, 1998; Schwiedrzik et al., 2007).

Regardless of the ambiguity surrounding their interpretation, these three findings now provide us with the appropriate baseline conditions for examining the question of primary interest in this study: how do predictive and postdictive processes combine to influence the visibility of a target stimulus in an apparent motion sequence?

CHAPTER 2: DISCRIMINATION WITH BOTH ORIGIN AND TERMINUS

Given that shape congruence effects were observed for the OT and TT conditions in Experiment 1, we now turn to several questions concerning how the predictive and postdictive influences may combine in motion sequences in which a target shape is preceded and followed by another shape. For instance, do the predictive and postdictive processes interact in an additive way, such that they each combine together as independent influences? Or are they synergistic, such that their influence on a target in motion is greater than the sum of the individual influences? Finally, does the influence of the originating stimulus observed in Experiment 1 only occur when there is no terminal stimulus; and, analogously, is the influence of the terminal stimulus only observed when there is no originating stimulus?

Subjects in this experiment were given the task of discriminating target orientation, in a motion masking paradigm in which the congruence between origin and target shape and target and terminus shape were independently varied. In other words, the origin and target and the target and terminus were either aligned in orientation or misaligned such that they were perpendicular. Examples of the spatial layout of the four motion conditions, namely origin and terminus congruent (OTC), origin congruent (OC), terminus congruent (TC), and neither congruent (NC), are shown in Figure 3. The mask and proximity manipulations were the same as in Experiment 1.

Incidentally, in addition to analyzing the interaction of predictive and postdictive processes, the present experiment permitted a between-subjects comparison with the data from Experiment 1, allowed a comparison between target visibility when both origin and terminus were present (Experiment 2) with its visibility when only one (OT or TT) or neither (T) were present (Experiment 2)

2.1 Method

2.1.1 Participants

15 different students from the University of British Columbia participated in Experiment 2. Each person was given \$10 or class credit for their participation. Participants had normal or corrected-to-normal vision. All gave informed consent and were treated according to UBC ethical guidelines.

2.1.2 Stimuli, Materials and Procedure

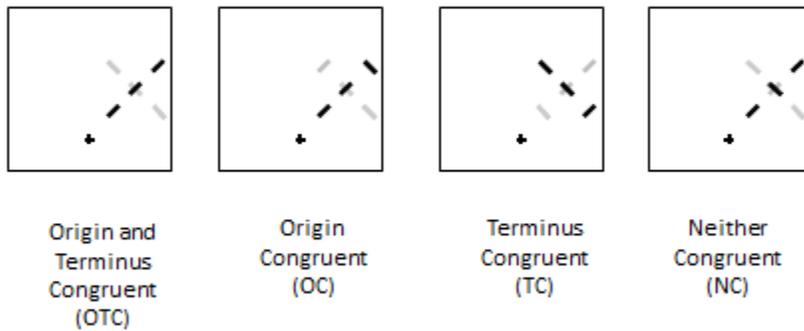
The set-up and stimuli were the same as for Experiment 1. An example of the spatial layout for the four motion conditions is shown in Figure 3a.

The procedure was the same as in Experiment 1 prior to the trial onset. After the variable delay interval, the origin was presented for 100 ms; this was followed by the 33ms duration target, then either an interstimulus interval of 66 ms (mask absent conditions) or a 33 ms ISI and a 33ms duration mask (mask present conditions). Finally, the terminus was presented for 100 ms, after which the subject had to register their response as in Experiment 1, at which point feedback appeared. An example of the timing for one trial is shown in Figure 3b.

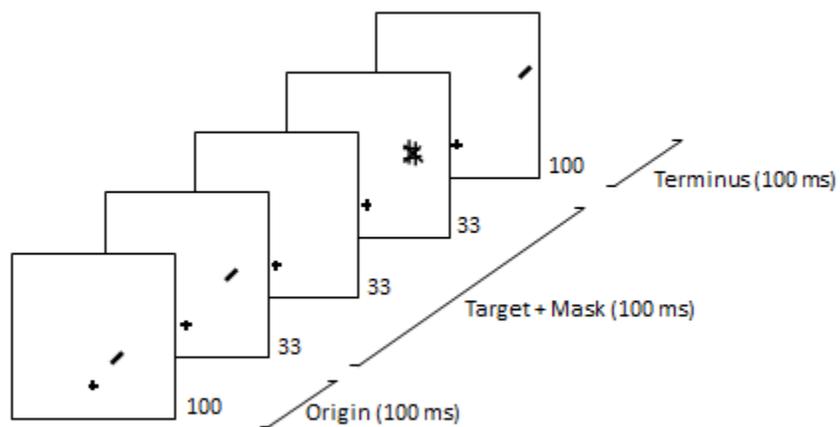
The design was counterbalanced among the following factors: 2 target orientation (back-slanting or forward-slanting diagonal bar) x 2 origin-target shape congruence x 2 target-terminus shape congruence x 2 mask presence x 2 proximity (close or far) x 2 motion direction (up or down). Hemifield (left or right) was random from trial to trial. There were 768 trials altogether, which were divided into 6 blocks of 128 trials each, and every block contained a random permutation of 2 repetitions of each combination of target orientation, origin-target shape congruence, target-terminus shape congruence, mask presence, proximity, and motion direction (2 repetitions x 2 x 2 x 2 x 2 x 2 x 2 = 128 trials).

Figure 3: Spatial Layout and Timing in Experiment 2. (A) Examples of the spatial layout for the four motion conditions in Experiment 2. In these examples, motion is occurring in the upward direction, and the stimuli are in the separated rather than contiguous proximity condition. The subject's task is to discriminate the orientation of the target (middle) bar. Other possible positions for these stimuli are shaded in gray. (B) The timing of stimuli presentation in Experiment 2 (depicted here with mask present).

A



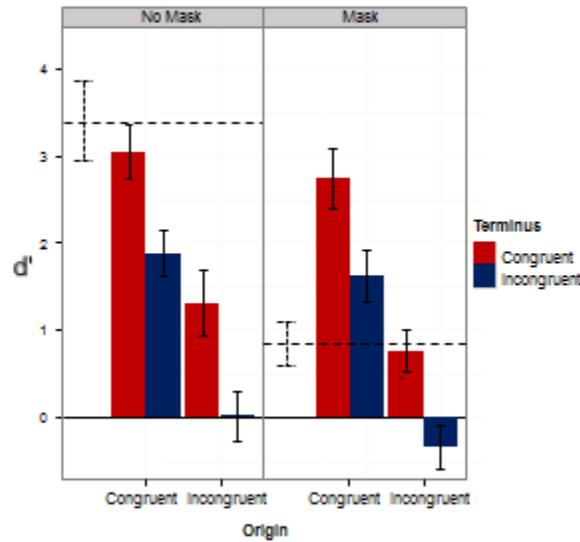
B



2.2 Analysis and Results

The hit and false alarm rates to the left-slanting and right-slanting target orientation, respectively, were used to calculate d' values. The value of the solitary target condition is shown as a dashed line in Figure 4, with standard errors indicated. In order to compare the visibility of the solitary target with that of the congruent motion target and the incongruent motion target, two two-way between-within ANOVAs were conducted. The first had a between-subjects factor of condition (T, from Experiment 1, or OTC, from Experiment 2) and a within-subjects factor of mask presence; the second ANOVA had a between-subjects factor of condition (T, from Experiment 1, or NC, from Experiment 2) and a within-subjects factor of mask presence. The first ANOVA showed significant effects of mask ($F_{(1,28)}=79.63$) and of condition ($F_{(1,28)}=5.41, p=.027$), which were modulated by a significant interaction of mask x condition ($F_{(1,28)}=37.38$). The simple main effect followup to this interaction reveals that the OTC condition is equal in visibility to the T condition when the mask is absent ($d'=3.13$ vs. $3.26, F_{(1,28)}=.28$), but much greater in visibility when the mask is present ($d'=2.68$ vs. $.81, F_{(1,28)}=65.95$). When the simple main effects are conducted along different levels of condition, mask presence has an insignificant effect on the target for the OTC conditions ($F_{(1,28)}=3.95$), but significantly reduces target visibility in the T conditions ($F_{(1,28)}=113.06$). Similarly, the second ANOVA showed significant effects of mask ($F_{(1,28)}=83.62$), condition ($F_{(1,28)}=43.11$), and mask x condition ($F_{(1,28)}=43.68$). The simple main effect followups to this interaction show that the target is significantly less visible in the NC condition than the T condition, both when the mask is absent ($d'=-.0094$ vs. $3.26, F_{(1,28)}=220.98$) and present ($d'=-.40$ vs. $.81, F_{(1,28)}=30.46$). When the simple main effect of mask presence is calculated at levels of condition, the mask presence has no significant effect on target visibility in the NC conditions ($F_{(1,28)}=3.21$), but the mask significantly reduces target visibility when it is present in the T conditions ($F_{(1,28)}=124.09$).

Figure 4: Results of Experiment 2. Visibility of the target bar (d' +/- SE) as a function of the four motion conditions (Origin and Terminus Congruent, Origin Congruent, Terminus Congruent, and None Congruent). Mask absent and present conditions are shown in the left and right panel, respectively. The dashed lines indicate visibility for solitary targets (d' +/- SE) without and with a backward mask, based on data from Experiment 1.



To evaluate whether the effect could be due solely to the influence of shape similarity between origin and target or between target and terminus, the motion conditions were re-coded so that instead of OTC, OC, TC, and NC conditions, they were categorized along two orthogonal dimensions: origin-target congruence and target-terminus congruence. A 2 origin-target congruence x 2 target-terminus congruence x 2 mask presence x 2 proximity within-subjects ANOVA was conducted. There were significant main effects of origin-target congruence ($F_{(1,14)}=55.77$), target-terminus congruence ($F_{(1,14)}=27.97$), and mask presence ($F_{(1,14)}=20.38$). There was furthermore a significant two-way interaction of origin-target congruence x proximity ($F_{(1,14)}=5.68$, $p=.032$), such that the congruence effect was compressed or narrowed under the harder to see close proximity conditions compared to the far proximity conditions. There was no significant interaction between origin-target congruence and

terminus target congruence ($F_{(1,14)}=.26$), and the interactions of these two factors with the mask factor, proximity factor, and both factors were all not significant (all p values $> .24$).

Dunn-Bonferroni contrasts with the Bonferroni correction were conducted in order to determine whether the differences between pairs of the four motion conditions were significant. The target was significantly more visible in the OTC condition than the TC ($F_{(1,14)}=11.68$) and NC conditions ($F_{(1,14)}=36.85$), but not the OC condition ($F_{(1,14)}=5.25$). The OC produced higher target visibility than the NC condition ($F_{(1,14)}=14.29$), though the TC and NC conditions showed equal target visibility ($F_{(1,14)}=7.04$); and finally, the OC was equivalent to the TC condition in target visibility ($F_{(1,14)}=1.27$). Because there was no interaction between the origin-target congruence, target-terminus congruence, and mask and proximity factors, the effects congruence effects observed might not depend on whether baseline conditions of stimuli render the target relatively highly visible (e.g., mask absent and far proximity) or less visible (e.g., mask present and close proximity). To confirm the generality of congruence effects across mask and proximity conditions, Bonferroni-corrected contrasts between OTC and NC conditions under the four masking and proximity conditions were conducted. These contrasts show that d' is significantly greater for OTC compared to NC motion conditions for all four combinations of masking and proximity (mask present and close proximity, d' : 2.73 vs. -.39, $F_{(1,14)}=302.87$; mask present and far proximity, d' : 2.79 vs. -0.40, $F_{(1,14)}=316.61$; mask absent and close proximity, d' : 3.17 vs. .015, $F_{(1,14)}=309.70$; mask absent and far proximity, d' : 3.18 vs. -.039, $F_{(1,14)}=322.39$).

2.3 Discussion

In this experiment, the motion-masking paradigm of Schwiederzik et al. (1998) and others was modified so that the orientation of the target was either congruent or incongruent in shape with both the origin and the terminus. This allowed us to evaluate whether these congruencies had effects on target visibility, and if so, whether the effects were independent or interacted.

The results showed that target visibility was greatly dependent on how its shape was related to both the origin and the terminus. The effects of origin-target congruence and target-terminus congruence are both significant: congruence appears to increase the visibility of the target. However, these factors do not appear to interact, either with each other or the other factors of mask or proximity. In other words, there is no evidence from the results of this experiment of synergy between congruence with the target of the origin and the terminus.

The results of the comparison between solitary target discrimination (in Experiment 1) and discrimination of a target within the OTC and NC conditions, both with and without a mask, revealed two interesting results. First, we found that a backward-masked target was more discriminable within the path of orientation-congruent motion than when it was presented by itself. This finding shows that motion-inducing stimuli can enhance target visibility even when the target is followed by an effective spatially overlapping mask. This finding also implies that ‘motion masking’ may not be an accurate term for generalizing the effects of target visibility when it is presented along the motion path. Conversely, when the target was presented within the motion path of orientation-*incongruent* stimuli, its visibility remained below that of a target presented without motion-inducing stimuli, under both the mask and no-mask conditions. This means, in effect, that the orientation-incongruent motion condition resulted in greater masking than when a backward mask was presented following a solitary target. This shows that when there is an incongruity in orientation, the motion-inducing stimuli can have as great an effect in reducing target discriminability as a strong spatially overlapping backward mask.

Second, whereas the mask had significant effects on the solitary target by acting to reduce its visibility when present, the effect of the mask was much reduced on the OTC and NC conditions. The target remained highly visible in the OTC condition regardless of the mask’s presence or absence, and the target showed low visibility in the NC condition despite changes in mask presence. It appears therefore that the backward mask is not as effective, provided that the target is embedded within the spatial path of a single moving stimulus. A target shape in motion therefore renders the target less vulnerable to

backward masking. The most important determinant of target visibility, at least among the factors manipulated in the present experiment, is the shape congruence between the target and the inducing stimuli. The implications of this will be taken up again discussed in the general discussion.

CHAPTER 3: TARGET DETECTION

One outstanding question is why Kolers (1963) failed to find evidence of motion masking, whereas Yantis and Nakama (1998) and Schwiedrzik and colleagues (2007) found motion masking effects. Yantis and Nakama (1998) have argued that the quality of motion is an important factor; specifically, Kolers (1963) only used one cycle of motion, whereas the later researchers used multiple cycles of motion, allowing for a stronger motion percept, before presenting the target. However, an alternative explanation for the absence of a motion masking effect may be found in the particular content for report used. In general, detection measures are more sensitive than measures of discrimination of shape or luminance (Fehrer and Raab, 1962; Taylor and McClosky, 1990, 1996; Klotz and Neumann, 1999; Vorberg et al., 2003). More pertinent to the present discussion, object updating in tasks which show object substitution masking has been shown to vary in magnitude depending on the measure used (Pilling and Gellatly, 2009; Gellatly, Pilling, Cole and Skarratt, 2006). For instance, Gellatly and colleagues (2006, Experiment 1) displayed a target diamond with one side missing, sometimes followed by a stimulus capable of producing masking and other times followed by a stimulus which would not produce masking, and had subjects report either the location of the gap (contour discrimination) or whether the target was present or absent (detection) on a given trial. These researchers found a significant interaction between task and masking condition. Specifically, the masking magnitude was high for the task of shape discrimination, whereas it was much smaller when subjects attempted to merely detect the target. This might explain why Kolers (1963), using a detection measure, originally failed to find a motion masking effect using only one cycle; one can speculate that a discrimination measure, which has been shown by Gellatly et al. (2006) to be more sensitive to object updating, might produce a significant motion masking effect with the use of a single cycle of motion. To circumvent this ambiguity, we ran an experiment with a single motion cycle, as before, but in which the measure of target perception was detection of target presence or absence rather than discrimination of target shape.

In keeping with the findings of Gellatly et al. (2006), we therefore hypothesize that the magnitude of motion masking across experiments will depend on the particular measure used. Experiment 2 has demonstrated a robust effect of motion masking, in that the perception of the target, as determined by shape reports, was significantly influenced by motion conditions. However, it can't be ruled out that minute differences in the physical stimuli used can account for the motion masking observed here, but not with Kolars (1963). In order to explicitly evaluate the importance of criterion content for motion masking, we conducted a third experiment in which the stimuli and conditions (motion conditions, mask presence, and proximity manipulations) were identical to those used in Experiment 2, with the following exception: on only half of the trials the target bar was present, and the subjects' task was now to report on the presence or absence of the target.

3.1 Method

3.1.1 Participants

15 different people were recruited from UBC's class credit pool, and were given credit or \$10 for participating. All had normal or corrected-to-normal vision, and were treated according to UBC ethical guidelines.

3.1.2 Stimuli, Materials and Procedure

The stimuli were kept the same as in Experiments 1 and 2. The spatial layout was exactly the same as in Experiment 2, with the exception that there was no target stimulus on target absent conditions.

The procedure was the same as previous experiments with the following exceptions. Subjects were told to report on the presence or absence of a target bar in the middle of the motion sequence. Each trial began with a variable onset interval (from 1400 to 2200 ms, in steps of 200 ms). Then the origin was presented for 100ms, followed by either a 33 ms duration target (target present conditions) or a 33 ms blank interval, after which both conditions had a 33 ms blank interval. Then there was either a 33 ms

duration mask (mask present conditions), or another 33 ms blank interval, which was finally followed by a 100ms duration terminus. After these sequences, the subject had to register their response by pressing one of two keys corresponding to the target present or absent conditions.

The design was 2 target orientation (back-slanting or forward-slating diagonal bar) x 2 origin-target congruence x 2 target-terminus congruence x 2 mask presence x 2 proximity x 2 target presence (present or absent). Target orientation, origin-target congruence, and target-terminus congruence were dummy-coded for the target absent trials. Hemifield (left or right) and motion direction (up or down) were random from trial to trial, as with Experiment 1, and were collapsed for subsequent analyses. There were 768 trials altogether, which were divided into 6 blocks of 128 trials each, with self-paced breaks between blocks. Every block of trials contained a random permutation of 2 repetitions of each combination of target orientation, origin-target congruence, target-terminus congruence, mask presence, proximity, and target presence (2 repetitions x 2 x 2 x 2 x 2 x 2 x 2 = 128 trials).

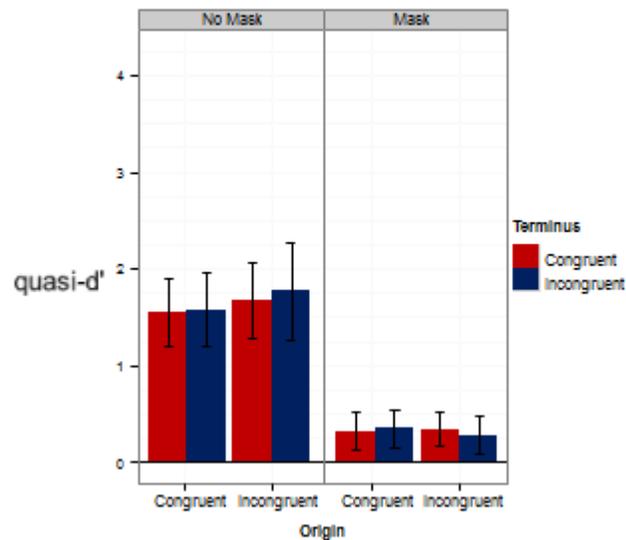
3.1.3 Analysis

The analysis for this Experiment was different from that of Experiment 1 and 2, because in the target absent cases, the orientation between the motion-inducing stimuli and the “target” is not defined, and hence was dummy-coded, as mentioned in the Procedure. Therefore, although there was no problem in calculated hit rates for the four motion conditions, the false alarm rates could not be uniquely calculated for all four of the motion conditions described in Experiment 1. To accommodate this, quasi- d' values were calculated. This involved using the same false alarm rate for the congruent and incongruent motion conditions- the case where the origin and the terminus stimuli are aligned- and unique false alarm rates for the origin-“target” congruent and terminus-“target” congruent conditions. In short, the OTC and NC conditions were perceptually identical when the target was absent, and so false alarm rates were pooled across these two conditions. From these hit and false-alarm rates, quasi- d' values for each combination were calculated as above, according to the formula $d' = z(pH) - z(pFA)$.

3.2 Results

To evaluate whether any effect could be due solely to the influence of shape similarity between origin and target or between target and terminus, the motion conditions were re-coded so that they were categorized along two orthogonal dimensions: origin-target congruence and target-terminus congruence (see Figure 5). A 2 origin-target congruence x 2 target-terminus congruence x 2 mask presence x 2 proximity within-subjects ANOVA was conducted, with quasi-d' as the dependent variable. There were significant main effects of mask presence ($F_{(1,14)}=58.84$) and proximity ($F_{(1,14)}=12.81, p=.0030$).

Figure 5: Results of Experiment 3. Detection performance (quasi-d' +/- SE) as a function of the four motion conditions (Origin and Terminus Congruent, Origin Congruent, Terminus Congruent, and Neither Congruent). The left and right panels show unmasked and mask conditions, respectively.



Since there were no significant congruence effects, nor interactions of congruence effects with mask or proximity factors, it appears that there is no evidence that congruence between target and inducer

shape influences target visibility as assessed by a measure of detection. To emphasize the non-significance of the congruence manipulations with the detection measure in contrast to the significance found in Experiment 2 with the discrimination measure, analogous Bonferroni-adjusted contrasts were conducted comparing target visibility in the four different congruence conditions. All of these six comparisons produced F-values of less than one (all $F_{(1,14)}$ values $< .28$).

3.3 Discussion

A hypothesis was proposed for the discrepancy between the results of Kolars' (1963) study (in which there was no change in target detectability when presented within the path of apparent motion inducer) and the results of Experiment 2 of the present study (in which target visibility was found to be enhanced or reduced within the apparent motion path compared to solitary presentation). Namely, the difference in criterion for target report was suggested to influence the observer's state of mind, such that non-target influences should have less of an influence on detectability of target than its discriminability. To test this hypothesis, we varied the motion conditions so that the orientation of the target was either aligned or misaligned with the origin and the terminus stimulus, as in Experiment 2, but for this experiment the target was present on only half of the trials, and the subjects' task was to merely detect the target's presence rather than identify it. A measure of sensitivity, quasi-d' was calculated which compensated for the redundancy of certain motion conditions when the target was absent. The results of the ANOVA evaluating congruence effects suggest that these manipulations did not affect target visibility in this detection task.

Planned Dunn-Bonferroni comparisons between congruent and incongruent motion conditions showed no significant effects of the different motion conditions on target detection, once the significance criterion was adjusted for multiple comparisons. This sharply contrasts with the large effects found in the Dunn-Bonferroni contrasts in Experiment 1, and suggests that the relationship between target orientation and motion-inducer orientation does not strongly affect the degree of motion masking, at least as assessed

by a measure of target detection rather than shape discrimination. Additionally, because the stimuli and motion conditions were as closely matched as possible to those used in Experiment 2, the alternative explanation that large effects found in that experiment were due to nuanced stimuli or display differences from Kolars (1963) can be more readily discounted.

CHAPTER 4: BASELINE LOCAL CONTOUR DISCRIMINATION AND CONTROLS

To bolster the case that the capacity to identify the target stimulus is enhanced in the congruent motion conditions, another two experiments were conducted, which closely mirrored the structure of Experiments 1 and 2. In Experiments 4 and 5 we used a measure for which thorny issues regarding context-induced bias on d' values are not an issue: specifically, the target bar (but not motion-inducing bars) had a notch present on either its left or right side, with equal probability. The subjects' task in the following two experiments was to report the location of the notch on the target bar.

Again, the congruence between origin and target and between target and terminus were independently varied, and mask presence and proximity were also manipulated. Thus, these experiments can be viewed as test of whether the results of Experiments 1 and 2 extend to the case where local contour judgments index perceptibility of the target, while at the same time circumventing potential decision-based biases in responding. Furthermore, these tasks can be viewed as more similar to prior studies on dynamic display target visibility; specifically, many researchers have used contour judgments for example, as to whether the gap in a Landolt C is on its left or right side, or whether a diamond is missing its corner on the left or right side (e.g., Enns and Di Lollo, 1997, 2000; Lleras and Moore 2003, Experiment 4).

In Experiment 4, as in Experiment 1, there were three conditions (T, OT, and TT). Again, the mask was present in half of all trials, and orientation congruence and proximity were manipulated in OT and TT conditions.

4.1 Method

4.1.1 Participants

A new set of 15 subjects were recruited for this experiment, using the UBC student credit pool. All of these individuals had normal or corrected-to-normal vision. Participants were treated according to UBC ethical guidelines, and were given course credit or \$10 for their participation.

4.1.2 Stimuli, Materials and Procedure

The stimuli for this Experiment were the same as that of Experiment 1, with the exception that the target bar had a semicircular notch of 0.4^0 radius dimension located on either its left or right length, positioned midway along the length. Thus the notch was on the left or right side of the target bar independent of its slant, with equal probability of each notch location (left or right) for a given trial.

The procedure for this experiment was equivalent to that of Experiment 1, but with the additional factor of target notch location incorporated into the design. Again there were three conditions- solitary Target, Origin and Target (OT), and Target and Terminus (TT)- and the timing of the presentations were the same as in Experiment 1. After these sequences, however, the subject had to register their response by pressing one of two keys corresponding to left and right target notch locations.

The design was 2 target orientation (back-slanting or forward-slating diagonal bar) x 2 congruence x 2 mask presence x 2 proximity x 2 notch location x 3 condition (solitary Target, Origin and Target, and Target and Terminus). Congruence and proximity were dummy-coded for the solitary Target trials. Hemifield and motion direction were random from trial to trial, as with Experiment 1, and were collapsed for subsequent analyses. There were 768 trials altogether, which were divided into 8 blocks of 96 trials each, with self-paced breaks between blocks. Every block of trials contained a random permutation of each combination of target orientation, congruence, mask presence, proximity, target notch location, and condition ($2 \times 2 \times 2 \times 2 \times 2 \times 3 = 96$ trials).

4.1.3 Analysis

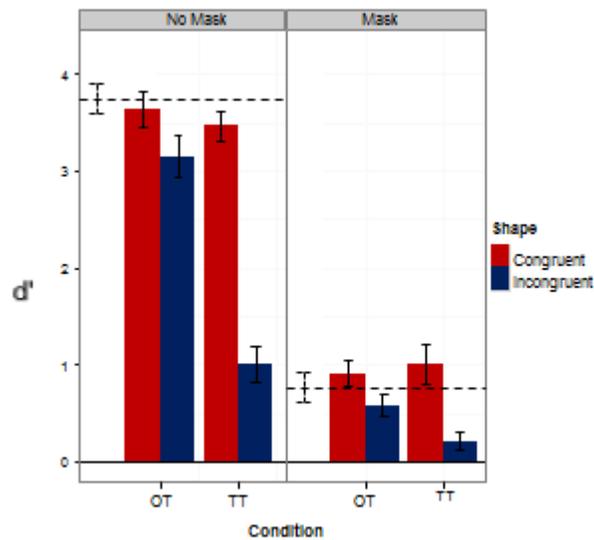
Hit and false-alarm rates were arbitrarily defined as the proportion of left-notch target reports to a left- and right-notch target, respectively, for each combination of motion condition, mask condition, and proximity condition, and for each subject. As in previous experiments, d' values for each combination were calculated according to the formula $d' = z(pH) - z(pFA)$. It should be noted that this measure is more immune to decision-based biases from the non-target inducing stimuli, since these stimuli did not have a notch.

4.2 Results

A 4-way ANOVA with condition (OT or TT), congruency, mask, and proximity was conducted, and the solitary target condition was excluded in order to evaluate the effect of congruency and proximity on target visibility (see Figure 6, excluding dashed lines). There were significant main effects of condition ($F_{(1,14)}=19.17, p=.00063$), congruency ($F_{(1,14)}=105.26$), mask ($F_{(1,14)}=369.07$), and proximity ($F_{(1,14)}=6.52, p=.023$). In addition, the two-way condition x congruency ($F_{(1,14)}=65.40$), condition x proximity ($F_{(1,14)}=9.50, p=.0081$), condition x mask ($F_{(1,14)}=17.28, p=.00097$), mask x congruency ($F_{(1,14)}=59.57$), and mask x proximity ($F_{(1,14)}=5.03, p=.042$) interactions, as well as the three-way condition x congruency x mask ($F_{(1,14)}=18.09, p=.00080$) and congruency x mask x proximity ($F_{(1,14)}=5.37, p=.036$) interactions were significant. All other interactions were not significant ($ps > .094$). The simple main effect follow-ups to the condition x congruency interaction indicate that the orientation-congruent target was significantly more visible than the orientation-incongruent target in both the OT condition ($F_{(1,14)}=15.08, p=.0017$) and the TT condition ($F_{(1,14)}=234.70$), although this congruency effect was much weaker in the OT condition. The smaller congruency effect for the origin conditions may indicate a temporal warning effect from having the inducer precede the target, although the fact that the congruency effect was significant suggests that object-updating may also influence target visibility in the origin inducer conditions. The higher-order interaction of condition and congruency with mask indicates

that the mask condition compresses the large congruence effect of the TT condition much more so than smaller congruence effect of the OT condition. Similarly, the interaction of congruence with both mask and proximity denotes an asymmetrical compressing of the congruence effect under the most difficult condition (mask present and close proximity).

Figure 6: Results of Experiment 4. Visibility of target's local contour (d' +/- SE) is depicted by bars for the Origin and Target (OT) and Target and Terminus (TT) conditions, and by dashed lines for solitary Target (T) condition. Unmasked and masked conditions are shown in the left and right panels, respectively. The shapes of the target bar and non-target bar in the OT and TT conditions were congruent or incongruent.



In order to determine whether the visibility in these conditions represented an enhancement or decrement relative to the solitary target condition, further comparisons were made. Specifically, the visibility of the target in the Origin and Target and the Target and Terminus conditions was compared to its visibility in the equivalent (mask present or absent) solitary Target condition. In all, eight contrasts were conducted, comparing target visibility in, for example, the congruent OT with mask absent condition

to the average of the mask absent T congruent and incongruent conditions (since congruency was dummy-coded, the average was calculated for purposes of the contrasts; these values are indicated by the dashed line for mask absent and present conditions, in Figure 6). Contrast-specific error terms were calculated, and the Bonferroni-adjusted correction for the eight comparison resulted in a .00625 alpha-level cut-off for significance. When the mask was absent (Figure 6, left panel), the OT incongruent ($F_{(1, 14)}=16.53$, $p=.0012$) and TT incongruent ($F_{(1, 14)}= 190.86$, $p<.0001$) conditions both showed reduced target visibility relative to the solitary target baseline, whereas there was no difference from baseline target visibility for the OT congruent ($F_{(1, 14)}= 2.36$, $p=.15$) and TT congruent ($F_{(1, 14)}=7.94$, $p=.014$) conditions. When the mask was present (Figure 6, right panel), only the TT incongruent condition had a significantly less visible target than the corresponding solitary target baseline ($F_{(1, 14)}=21.15$, $p=.0004$), with no visibility differences for the OT congruent ($F_{(1, 14)}=0.55$, $p=.47$), OT incongruent ($F_{(1, 14)}=1.13$, $p=.31$), and TT congruent ($F_{(1, 14)}= 3.67$, $p=.076$) conditions. These results suggest that origin or terminus only conditions only have an impairing effect on target visibility relative to solitary target conditions.

4.3 Discussion

Three conditions (solitary Target, Origin and Target and Target and Terminus) were tested in this Experiment, which was analogous to Experiment 1 but with a notch on the target as the feature of report for observers. This measure eliminates the potential for decision-based processes which weigh heavily the features of non-target stimuli in the observer's report of the target. There were significant effects of the orientation congruence between target and origin and target and terminus with this measure, providing support that the processes of prediction and postdiction do indeed influence target visibility in multi-stimuli displays.

The TT condition showed stronger orientation-congruence effects on target visibility than did the OT condition. The explanations provided for the similar finding in Experiment 1 apply here as well. Namely, the incongruent OT condition produced discriminability scores which did not drop off much

from performance in the congruent OT condition, which may be attributable to the advanced warning that the origin provides the target which is not possible for the TT conditions. Furthermore, forward masking has generally been found to produce weaker effects than backward masking.

The solitary target condition allowed us to fix a baseline on target visibility when the non-target motion inducing stimuli were absent. When each of the OT and TT conditions were compared to the target, and mask presence was equated, it was found that the solitary target was equal to or greater in visibility than the target when it was presented with an inducer. Thus, to the extent that the addition of a single inducer to the target had any effect on local contour identification, this effect was detrimental.

CHAPTER 5: DISCRIMINATION OF LOCAL CONTOUR WITH BOTH ORIGIN AND TERMINUS

In Experiment 5, as in Experiment 2, the congruence between origin and target and between target and terminus were independently manipulated to produce four motion conditions (OTC, OC, TC, and NC). The subject's task, however, was to identify the local contour of the target (i.e., its notch location) rather than its global orientation.

5.1 Method

5.1.1 Participants

15 different people were recruited for the UBC class credit pool. All had normal or corrected-to-normal vision. Each was given credit or \$10 for their participation, and was treated according to UBC ethical guidelines.

5.1.2 Stimuli, Materials and Procedure

The stimuli for this Experiment were the same as that of Experiment 1, with the exception that the target bar had a 0.4° radius semicircular notch located on either its left or right side independent of the slant of the target, with equal probability of each notch location for a given trial.

The procedure for this experiment was the same as Experiment 2, with the following exceptions. Subjects were told to report on the location of the notch on the target bar in the middle of the motion sequence. After the motion sequences, the subject had to register their response by pressing one of two keys corresponding to left notch or right notch on the target.

The design was 2 target orientation (back-slanting or forward-slating diagonal bar) x 2 origin-target congruence x 2 target-terminus congruence x 2 mask presence x 2 proximity x 2 target presence (present or absent). Target orientation, origin-target congruence, and target-terminus congruence were dummy-coded for the target absent trials. Hemifield (left or right) and motion direction (up or down)

were random from trial to trial, as with Experiment 2, and were collapsed for subsequent analyses. There were 768 trials altogether, which were divided into 6 blocks of 128 trials each, with self-paced breaks between blocks. Every block of trials contained a random permutation of 2 repetitions of each combination of target orientation, origin-target congruence, target-terminus congruence, mask presence, proximity, and target notch location (left or right), (2 repetitions x 2 x 2 x 2 x 2 x 2 x 2= 128 trials).

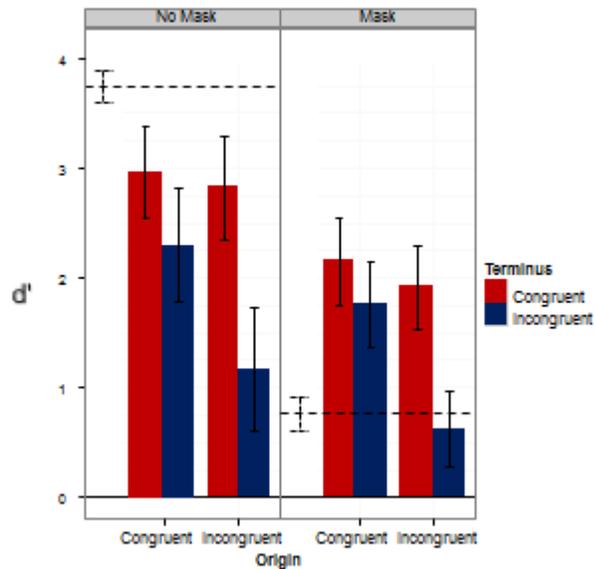
5.2 Analysis and Results

The hit and false alarm rates to the left and right target notches, respectively, were used to calculate d' values used in the following analyses. The value of the solitary target condition is shown as a dashed line in Figure 7, with standard errors indicated.

In order to assess independently the influence of the origin-target and target-terminus congruence effects, the motion conditions were re-coded so that they were categorized along two orthogonal dimensions: origin-target congruence and target-terminus congruence. A 2 origin-target congruence x 2 target-terminus congruence x 2 mask presence x 2 proximity within-subjects ANOVA was conducted. There were significant main effects of origin-target congruence ($F_{(1,14)}=32.28, p=.000057$), target-terminus congruence ($F_{(1,14)}=40.19, p=.000018$), and mask presence ($F_{(1,14)}=92.73$) on d' values. Additionally, d' values showed significant two-way interactions of origin-target congruence x target-terminus congruence ($F_{(1,14)}=27.97, p=.00011$), and the four-way interaction of origin-terminus congruence x target-terminus congruence x mask presence x proximity was significant ($F_{(1,14)}=5.87, p=.030$). The four-way interaction results from the finding that although the two-way interaction of origin-target congruence x target-terminus congruence was significant in all combinations of mask and proximity conditions (all p values $< .039$), the mask present and far proximity condition in particular produced a much stronger interaction between the congruence factors ($F_{(1,14)}=44.98, p=.0000099$) than did any of the other three mask and proximity conditions (mask present and close proximity: $F_{(1,14)}=5.25,$

$p=.038$; mask absent and far proximity: $F_{(1, 14)}=7.75, p=.015$; and mask absent and close proximity: $F_{(1, 14)}=8.04, p=.013$).

Figure 7: Results of Experiment 5. Visibility of target's local contour (d' +/- SE) as a function of motion condition (Origin and Terminus Congruent, Origin Congruent, Terminus Congruent, and Neither Congruent), for both mask absent and mask present trials. The dashed lines indicate visibility (d' +/- SE) for the local contour of solitary targets without and with a mask, based on data from Experiment 4.



Dunn-Bonferroni contrasts with the Bonferroni correction were conducted to compare visibility among the four motion conditions (6 contrasts, therefore the F-value cutoff for significance was 9.42). These contrasts reveal that the OTC condition produces significantly greater target visibility than the NC condition ($d'=2.59$ vs. $.91, F_{(1, 14)}=43.41$), but is not different from the OC ($d'=2.59$ vs. $2.05, F_{(1, 14)}=4.49$) and TC ($d'=2.59$ vs. $2.40, F_{(1, 14)}=.56$) conditions; the TC condition shows greater target visibility than the NC ($F_{(1, 14)}=34.15$) but not OC ($F_{(1, 14)}=1.88$) condition; and the OC condition shows greater visibility than

the NC condition ($F_{(1, 14)}=19.99$). These findings reveal that motion condition can significantly affect the visibility of the target. To further show that this is the case regardless of the particular combination of mask and proximity manipulation, Bonferroni-adjusted contrasts were conducted comparing target visibility in the OTC and NC conditions for all four combinations of masking and proximity conditions (mask present and close proximity, d' : 2.25 vs. .68, $F_{(1, 14)}= 210.07$; mask present and far proximity, d' : 2.11 vs. .59, $F_{(1,14)}=196.90$; mask absent and close proximity, d' : 2.82 vs. 1.10, $F_{(1, 14)}=252.13$; mask absent and far proximity, d' : 3.18 vs. 1.28, $F_{(1, 14)}= 307.66$).

Two two-way between-within ANOVAs were conducted to assess how target notch discriminability within motion paths compared to visibility of solitary target notch discriminability. The first ANOVA had a between-subjects factor of condition (OTC condition, from Experiment 5, or solitary target, from Experiment 4) and a within-subjects factor of mask presence; the second ANOVA had a between-subjects factor of condition (NC condition, from Experiment 5, or solitary target, from Experiment 4) and a within-subjects factor of mask presence. The first showed a significant effect of mask ($F_{(1,28)}=407.18$) and a significant interaction of mask x condition ($F_{(1, 28)}=89.25$). Followup comparisons for this interaction indicate that the OTC condition is less visible than the T condition when a mask is absent ($d'=2.85$ vs. 3.75, $F_{(1, 28)}=39.45$), but more visible when a mask is present ($d'=1.77$ vs. .76, $F_{(1, 28)}=50.11$). When the simple main effect is analyzed the other way, the mask's presence has a much greater effect for the T condition ($F_{(1, 28)}=438.85$) than the OTC condition ($F_{(1, 28)}=57.58$) which remains relatively high in visibility regardless of mask presence. The second ANOVA showed significant effects of mask ($F_{(1,28)}=330.88$), condition ($F_{(1,28)}=38.11$), and mask x condition ($F_{(1,28)}=142.79$). The simple main effect followups to this interaction indicate that the NC condition is significantly less visible than the T condition when the mask is absent ($d'=1.30$ vs. 3.75, $F_{(1, 28)}=306.50$), but is no different in visibility when the mask is present ($d'=.68$ vs. .76, $F_{(1, 28)}=.37$). The other way of breaking down the simple main effect shows that compared to the much greater effect of the mask on the T conditions ($F_{(1,$

$_{28}) = 454.19$), the mask has a significant but smaller effect on the target in the NC conditions ($F_{(1, 28)} = 19.47, p = .0001$), which remains on the lower side of the visibility range regardless of mask presence.

5.3 Discussion

In order to test whether the orientation congruence effects found in Experiment 2 apply with local contour judgments and in the absence of potential for inducer influenced response bias, all stimuli and conditions were the same as in that experiment, with the sole exception that the target had a notch on its left or right side. Subjects in the present experiment were told to report on the location of the notch on the target bar. The results of the analysis testing the origin-target congruence effect and target-terminus congruence effect show that both of these effects are significant, again implicating predictive and postdictive processes in the visibility of the target stimulus in dynamic displays. Furthermore, these two effects interacted, such that the benefit in terms of target visibility of having both origin and terminus congruent with the target is greater than the benefits of each when added separately. This synergy was absent in the bar orientation task of Experiment 2. This discrepancy will be discussed further in the general discussion.

Comparisons among the congruence conditions further corroborate the orientation-congruency effect of origin and terminus stimuli on target visibility, in this case assessed by discrimination of a local target notch. Summed up generally, these comparisons show that target congruent conditions, whether from the origin, terminus, or both (OC, TC, or OTC), produce higher visibility than the case where no inducer is congruent (NC). Furthermore, although the origin-congruence and terminus congruence factors interacted with mask and proximity factors, in all combinations of mask and proximity it was found that the OTC condition was higher in target discriminability than NC condition. This suggests that the advantage in target visibility produced by congruent inducers generalizes to different base conditions of target visibility. The results once again suggest that motion *masking*, i.e., the *reduction* in target

discriminability when placed in the path of motion produced by inducing stimuli, is more likely to occur when the target is incongruent in orientation to the motion-inducing stimuli.

Comparisons of target discriminability within the motion path and in isolation reveal some interesting findings. In the OTC motion condition, the target is less visible than the solitary target with no mask. However, when the targets in these conditions are followed by a backward mask, the OTC condition produces higher target visibility than the solitary condition. This reiterates the previous finding that multi-stimuli displays can under some circumstances actually enhance observers' capacity to perceive a target stimulus. What appears to matter in the present experiment is the relation between target and inducers in terms of shape. Thus, when both relations are incongruent (NC condition), the target is less visible than a solitary target without a mask, and only equally visible with a backward mask.

Furthermore, the motion conditions used here have the effect of moderating the efficacy of the backward mask. Whereas there are very large and highly significant differences in solitary target visibility when a mask is present versus absent, in both the OTC and NC conditions the difference in target visibility as mask presence is varied is much smaller in magnitude, albeit still significant in both cases. Taken in tandem, these results suggest that the effect of congruent motion inducers is to enhance target visibility significantly above baseline performance when a mask is present, and that the effect of incongruent motion-inducers is to reduce its visibility significantly below baseline performance when a mask is absent, and thus the relation between motion inducers and an embedded target in terms of shape can have significant influences on that target's visibility; conversely, however, the visibility of the target within the path of motion is not as greatly affected by the presence or absence of a backward mask.

GENERAL DISCUSSION

In five experiments, we have shown that a briefly presented target stimulus can vary a great deal in visibility, depending on its relationship to the shapes of the motion inducers that surround it. In these experiments, we held the temporal and spatial relationship among stimuli constant, while we varied the target shape to be either congruent or incongruent in its shape with the other stimuli in the motion sequence. The results showed that both the origin and the terminus shape had an influence on target visibility, and we hypothesized that this occurred through processes of prediction (for the origin) and postdiction (for the terminus). However, the most important result was that these processes exerted a synergistic effect, such that when either of the inducing shapes was congruent with the target, target visibility was very high and when both of them were incongruent, such that a false expectation was created, target visibility was very low.

Another very important finding, observed in Experiment 2 and 5, was that motion does not always interfere or inhibit the observer's capacity to distinguish a target's identity. On the contrary, under what should otherwise be difficult to perceive conditions (i.e., when the target is followed by a backward mask), predictive and postdictive processes based on the local motion context can operate together to make a target stimulus more visible than it is when presented with the mask in isolation. Thus, it cannot be assumed that motion masking is the inevitable consequence for target visibility in a motion sequence. Although this may be the conclusion reached by Yantis and Nakama (1998) and other researchers, the present results show that motion masking is only one possible consequence on target visibility. Yantis and Nakama's (1998) theoretical speculation that target visibility is influenced by the relationship between the content of stimulus events involved in this paradigm, over and above simple temporal and spatial attentional tuning, is what has been demonstrated in the present experiments.

Consider also Schwiedrzik and colleagues (2007). While these authors reported that the spatial and temporal coincidence of the target with the trace of inducer's motion can make the target less

susceptible to motion masking effects due to anticipation of the target's location and time of appearance, the present experiments extend this notion by showing that the prediction based on motion also involves anticipation of target shape.

Are these shape predictions primarily based on the origin or the terminus? Perhaps because of Schwiedrzik et al.'s (2007) findings showing temporal and spatial anticipation based on motion, one could reason that visibility benefits or motion in the present experiments are due primarily to origin-based effects. Indeed, in Experiments 1 and 4, the target remained relatively highly visible when only preceded by an origin which was incongruent in shape, whereas the target was much less visible when only followed by an incongruent terminus. However, with the spatial and temporal layout identical prior to the terminus, target visibility was nonetheless significantly altered when the terminus was either identical or dissimilar in shape to the target: specifically, the terminus congruent (TC) condition in Experiment 5 was significantly greater in target visibility than the neither congruent (NC) condition (though the corresponding comparison in Experiment 2 showed equal visibility). Furthermore, when the target and terminus were presented alone, shape-based congruency produced high target visibility compared with shape-based incongruency, as shown in Experiments 1 and 4. Taken in tandem, these findings suggest that shape-based postdiction, and not just prediction, influences the visibility of a target presented within a motion path. We believe that the postdictive processes shown in these experiments are attributable to the impletion mechanism described by Moore, Mordkoff and Enns (2007), which fall under the theoretical framework of object updating.

An outstanding question asked by Yantis and Nakama (1998) is why Kolers (1963) failed to find an effect of motion masking on target visibility. Taken together, Experiments 2 and 3 suggest the possibility that Kolers' (1963) failure to find motion masking effects was not solely due to his use of only a single motion cycle as opposed to multiple motion cycles, as suggested by Yantis and Nakama (1998). We contend instead that Kolers (1963) was only likely to find small effects of motion masking, if any, because he used a measure for which only small object substitution effects have been found (Pilling and

Gellatly, 2006), and also because, unlike Schwiedrzik et al. (2007), he did not vary the timing and positioning of the target within the motion path. First, Schwiedrzik and colleagues (2007) have recently shown that when a target coincides with the trace of motion produced by identically shaped inducers, as in Kolers (1963), detectability does not differ from that of the same target in isolation. Second, prior studies have found that measures of identification as opposed to coarse target localization are dissociable in dynamic displays. For instance, reaction time to preceding but unseen stimulus suggests that the capacity for detection of the prime precedes its identification in masking studies (Fehrer and Raab, 1962; Taylor and McClosky, 1990 & 1996; Klotz and Neumann, 1999; Vorberg et al., 2003). Using the same stimuli and display parameters, but varying the state of mind of the observer by requiring them to either identify or merely detect the target stimulus can produce different patterns of target visibility. Thus, in Experiment 3 of the present study, detection rates did not differ when the spatiotemporal layout of inducers and target remained constant but orientation congruence was varied. However, Experiment 2, which was closely matched in display parameters to Experiment 3, produced large variations in target *discriminability* to this same manipulation. Moreover, because a target within the path of identically shaped motion inducers is actually easier to perceive than a solitary target when both targets are masked, we reason that if Kolers (1963) had asked his participants to make a contour discrimination rather than detection report, target visibility in his motion condition would be enhanced relative to his baseline (solitary target) condition if both targets were dim enough. Considering the distinction between measures found by Gellatly et al. (2006) and other researchers, as well as in the results of the present experiments, it is likely generally the case that contextual (non-target) stimuli have less of influence on target detection than identification measures.

Contextual or non-target stimuli in the present experiment include the motion inducing stimuli as well as the mask. Whereas only the mask had an effect on target detectability (Experiment 3), both the inducers as well the mask had an effect on target discriminability (e.g., Experiments 2 and 5). One of the more interesting findings from the latter experiments is that cluttering the display with more non-target

stimuli does not necessarily have an interfering effect of on target discriminability (i.e., the motion enhancement effect). The results of Experiments 2 and 5 further show an interesting relationship between the motion inducers and the mask. Specifically, whereas masking is quite effective when only the target and mask are presented, when spatially and temporally bracketed by motion inducing stimuli, the masking effect is significant though much attenuated. Thus, when a target is presented within the path of shape congruent motion inducers, its visibility remains relatively high regardless of whether a mask is present or absent. Conversely, when presented within the path of incongruent motion inducers, the target remains relatively low in visibility regardless of mask presence. These results hint at the possibility that masking, as traditionally studied, is effective primarily in idiosyncratic cases where a target image is presented in isolation rather than as part of a motion sequence which comprises other, non-target images. One speculation we will advance here is that the motion inducer influences and masking influences reported in the present experiments are able to interact and influence or moderate each other through the common neural underpinning of recurrent activity.

There is evidence that the neural basis for the postdictive impletion process which is described in theories of object updating and thought to underlie masking effects (Moore, Mordkoff and Enns, 2007) relates to feedback or recurrent activity. It has long been suggested that recurrent processes might be implicated in visual perception, based on anatomical evidence of the abundance of cortico-cortical connections which project backwards as well as forward within the hierarchy of the visual system (Bullier et al., 1988; Felleman and Van Essen, 1991; Zeki, 1993). More recently, it has been theorized that when resonance is achieved between feedforward and recurrent neural processing upon the presentation of a brief duration stimulus, a stable and conscious percept of that stimulus emerges, and on this account, processing of a subsequently presented mask is thought to disrupt resonance from recurrent processing of the target stimulus, thus rendering the target less visible or invisible (Lamme and Roelfsema, 2000; Di Lollo, Enns and Rensink, 2000; Breitmeyer and Ogmen, 2006; but for another account, see e.g., Bachmann, 1984, 1997). Recent evidence for this view comes from neurophysiological (Fahrenfort,

Scholte, and Lamme, 2007) and Transcranial Magnetic Stimulation (TMS; Hirose et al., 2005, 2007; Ro et al., 2003) studies (but see also Macknik and Martinez-Conde, 2007). For instance, Hirose et al. (2007; see also Hirose et al., 2005), applied a TMS pulse to the MT/MT+ area in their subjects and found that the locally applied TMS pulse disrupted masking and led to target recovery. Recall that feedback activity from the MT cortex is also involved in apparent motion perception, and it might be the neural mechanism by which perception of the target in motion masking displays is filled in from stimulation by the origin and terminus stimulus (Sterzer, Haynes and Rees, 2006; Muckli et al., 2005; Liu, Slotnick and Yantis, 2004). Thus a similar cortical area is critically involved in both masking and apparent motion perception, and when activity in this area is disrupted, the perceptual experiences of both are eliminated or reduced. It is not clear, however, that the recurrent filling-in required for the perception of apparent motion is related to the recurrent processing thought to be required for conscious perception of a briefly presented stimulus. Further work is needed to determine how the human MT cortical area subserves both motion perception and masking, and whether and how recurrent cortical processes involving this area might interact such that a motion sequence is able to attenuate the magnitude of backward masking, as was found in the present experiments².

In addition to this speculation though, a few things still remain unclear. First, although a number of the analyses from the bar discrimination task (Experiment 2) were corroborated by the local discrimination task (Experiment 5), some discrepancies emerged. For one, predictive and postdictive processes appeared to interact in the latter experiment, but not the former. Second, whereas both origin and terminus had to be congruent with the target in order to raise its visibility above baseline in Experiment 2, only one had to be congruent to produce the same effect in Experiment 5 (although they both had to be present, since the single inducer conditions of Experiment 4 did not show significant motion enhancement under masking conditions). One possibility is that these differences arose from discriminating the local versus global contour of a target stimulus, although it is not immediately clear why this would be the case. Another possibility is that the potential for decision-based rather than

perception based processes in the bar discrimination task were at play in producing these differences.

Future studies should allow for the possibility to evaluate whether differences in the effects observed here are primarily due to the discrimination of global versus local shape.

NOTES

¹ The fixation cross was located towards the bottom of the screen for reasons pertinent to a separate line of research questions which will not be discussed in the present study.

² It's important to note, though, that the pattern masking as used in this experiment is thought to be only partially attributable to impletion or object updating processes. Interference at an earlier, precortical neural locus arising from the processing of a masking stimulus which spatially overlaps with the target, of the kind used in the present experiments, is also possible (this has been called "integration masking", Breitmeyer and Ogmen, 2006; and camouflage, Enns, 2004).

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