The impact of degraded distractors on (non-degraded) target identification

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Abstract

In this series of experiments, based on Biederman's Recognition by Components theory, we postulate that corners (vertices) of objects are crucial in programming and execution of goal-directed action. We used a distractor interference paradigm to present line drawings of letters (M and W) with distractors (also M and W) which were either nondegraded or degraded (corners, that is, corners, or line segments missing). Degraded distractors caused less interference overall (reduced response times and errors) than nondegraded distractors, when these were presented peripherally or at fixation (Experiments 1 and 2). When presented at fixation, however, distractors with corners missing caused greater interference than distractors with line segments missing. This was pattern not replicated with non-identical, non-mirror reversed stimuli (H and E). We speculate that corners are critical in determining the extent of distractor interference. When missing from view, and given sufficient attentional resources, and structural similarity they may be reconstructed by the visuomotor system to aid performance to the target.

Distractor interference paradigms have yielded crucial information about the ability of the visuomotor system to select and inhibit non-relevant information on goal-directed actions (for example, Eriksen & Eriksen, 1974; Lavie & Tsal, 1994; Stroop, 1935). More recently, however, the complexity of the interaction between attention, cognitive and environmental factors has been emphasised. Distractor interference may be modulated by spatial, temporal and cognitive properties of the task. For example, high perceptual load (increased task demands) is associated with reduced interference (Lavie, 1995), as is a temporal separation between distractor and target (Kahneman, Treisman & Burkell, 1983; Watson & Humphreys, 1997) and the peripheral (compared with foveal) presentation of distractors (Beck & Lavie, 2005). This is consistent with evidence that component features of visual objects such as colour, orientation, and direction of motion can be selected as well as inhibited differentially for attentional processing (for example, Fanini, Nobre & Chelazzi, 2006).

In this series of studies, we focus on component features of stimuli, that is, line segments and corners. Using a distractor interference paradigm, we ask whether the visuomotor system is differentially sensitive to specific components features of irrelevant stimuli in the environment.

In object recognition feature binding into shapes is an important early-stage process (Biederman, 1987; Biederman & Cooper, 1991). The next issue to consider, then, is which components of an object are important and influence responses to targets? In the case of distractors, we argue that the information inherent in such components is processed early and automatically by the visuomotor system, and thus impacts on actions to targets.

Biederman's Recognition by Components model (RBC; for example, Biederman, 1987) describes an initial edge extraction stage in which luminance, texture and colour are processed (though see Palmeri & Gauthier, 2004, for a recent review of models of object recognition). In the subsequent stage of this model the object is parsed into separate regions, based on points of deep concavity, with each approximating one of about 36 geons (simple components). Importantly, however, concurrently at this stage of object recognition, non-accidental properties of objects are detected, such as collinearity and symmetry (Biederman, 1987). These properties place constraints on the subsequent processing and identification of components, and therefore the identification of the entire object. Biederman (1987) outlined five principles of "non-accidentness": collinearity, curvilinearity, symmetry, parallel curves, and vertices or co-termination, with co-termination, or vertices, providing information that can serve to distinguish the geons. In particular, Biederman and Blickle (unpublished data; see Biederman, 1987) manipulated contours (vertices versus midsegments) deleted form line drawings of common objects such cups. They also manipulated the duration of stimulus exposure (100, 200 or 750ms), and proportion of contour removed (25%, 45% or 65%). An interaction was evident, such that at the briefest exposure and greatest proportion of deletion removal of vertices led to higher identification error rates than midsegment removal. With lower proportion of deletion and higher exposure, conversely, identification was not affected to the same extent, although there was an advantage in naming for midsegment removal. Biederman speculated that vertices may be important as diagnostic image features for object components.

Furthermore, Biederman (1987) did, in fact, speculate about attentional resources being directed to component features of objects. He considered two possibilities: either attributes of the components act as independent features and are processed automatically without attentional resources, or some attentional processing is required to compile them from their individual-edge attributes (Biederman, 1987). In the context of distractor interference, therefore, if specific component features (such as the "non-accidental properties" described by Biederman) of the distractor are processed automatically, requiring no little or no attention, perhaps these features are primarily responsible for interference. In contrast, if attentional processing is required, manipulation of attentional resources should alter the impact of the component features.

The importance of nonaccidental properties has been highlighted recently in electrophysiological studies in primates. Based on the work by Ungerleider and Mishkin (1982), it is widely accepted that the inferotemporal cortex (IT) is intrinsically involved in object recognition. In particular, area TE appears to be involved in processing of complex shapes, although there are important projection from this area to other brain sites such as the prefrontal cortex, superior temporal sulcus and perirhinal cortex (see Tanaka, 1996 and Palmeri & Gauthier, 2004, for reviews). Relevant to the concept of nonaccidental properties, however, Biederman and colleagues (Vogels, Biederman, Bar & Lorincz, 2001) showed that in the IT there are neurones that are responsive to changes in these features, that is, changes in geons. Thus, there is both behavioural and neurophysiological evidence for the importance of corners in object recognition.

The basis of the following two experiments is the postulation that vertices (corners) of lines are primarily responsible for the phenomenon of visual distractor interference. We test this by removing either corners or segments of lines of stimuli (the letters M and W). We show that, in speeded responses to targets, the visuomotor system is differentially sensitive to component features of distractors, when they are presented at fixation and are structurally simple.

Experiment 1

Non-accidental properties such as corners are detected early in object processing and object identification (Biederman, 1987). If they are also crucial to and the planning of action, then their absence should be associated with attenuated interference in goal-directed actions. In Experiment 1, we examined the impact of degraded compared with non-degraded distractors (M and W) on goal-directed responses to targets (also M and W).

The stimuli were chosen because they are from the same category. Moreover, they are identical but inverted, therefore controlling for complexity and within-item structural variability. Differences have been reported for recognition of objects in living compared to non-living categories, in both neurological patients (Warrington & McCarthy, 1983) and healthy participants (Laws, Humber, Ramsey & McCarthy, 1995). Although these differences have been attributed to the organisation of the semantic system, it has become clear that they are more adequately explained by greater within-item structural variability for non-living items (for example, Laws & Neve, 1999). This is an important point to consider in the context of object recognition and object components, and one that has received support in recent findings: In the case of fragmented objects, it appears that recognition of artefacts (non-living objects) is more affected by degradation (fragmentation) than natural objects (Gerlach, Law & Paulson, 2006). Importantly, however, Gerlach et al (2006) showed that the neural substrate for both fragmented and non-fragmented object is the same, with activation of the region from inferior occipital gyri to the middle part of the fusiform gyri for both nondegraded outline of drawings and fragmented drawings.

Two degradation conditions were implemented: corners-missing (all corners removed) and line segments-missing (line segments between corners removed). Degradation was achieved by superimposing opaque rectangles on the stimuli, such that the summation of the two degraded stimuli added to one non-degraded stimulus and the amount of visual information was comparable kept constant between the two degradation conditions.

Consistent with previous work, we expected that distractors, particularly those associated with responses incongruent to the target, would cause interference (slowed response times and reduced accuracy to targets). We also expected that, overall, the impact of degraded distractors would be attenuated compared with non-degraded distractors. Consistent with Biederman's (1987) and Biederman and Cooper's (1991) speculations regarding the importance of vertices, we expected that degraded distractors with corners would cause greater interference than degraded distractors without corners.

Method

Participants

Thirteen participants (5 males, 8 females; age range 23-40 years, M = 28.5 SD = 4.5) were drawn from the participant pool of undergraduate psychology students of the University of Melbourne and completed the experiment for course credit, or were friends or associates of the experimenters. All participants gave informed consent, were right-handed, had no known neurological disturbances and had normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiment was run using the DmDX/DMASTR software developed at Monash University and the University of Arizona by K.I. Forster and J.C. Forster. An IBM compatible computer attached to a VGA colour monitor (set to 1024 x 768 pixels) presented the stimuli and recorded the latency and accuracy of responses. The latency of responses (reaction time, RT) was collected to the nearest millisecond (ms).

The experimental display is shown in Figure 1. A single target letter, either an outline block capital M or an outline block capital W, appeared at the centre of the computer screen. Under certain trial conditions the target appeared alone or with a single distractor letter (M or W; as a complete, nondegraded letter outline, or as a degraded outline with corner segments missing or line segments missing). The distractor, which appeared 20mm left or right of centre, was either congruent (M or W with W) or incongruent to the target (M with W or vice-versa). Ms and Ws were presented as bitmaps (22 X 33 pixels), with the W being formed by inverting the M. Degraded stimuli were formed by removing corners or lines segments, creating degraded distractors with exactly the same number of pixels remaining. The deleted segments (either corners or lines) were arranged such that if a corners-missing distractor was overlaid with a lines-missing distractor, a nondegraded letter would be formed. These procedures ensured that complexity and amount of visual information of degraded distractor stimuli were equal across both degraded distractor conditions.

Procedure

Data were collected in a sound attenuated and darkened laboratory. Participants read a plain language statement and then read the instructions and signed the consent form. Participants sat facing the computer screen with their head placed in an adjustable chin rest. The distance to the computer screen was 57cm and the body midline was aligned with the centre of the computer screen.

Participants were instructed to respond to the target letter as quickly as possible without compromising accuracy, and to ignore the distractor, by pressing the left or right shift keys with their left and right hands respectively. For half the experimental blocks participants used their left hand to respond to the target M, and their right hand to respond to the target W. Hand-to-letter correspondence was counterbalanced for the remaining half of the experimental blocks.

The paradigm consisted of four distractor presentation conditions. These were Target Alone, Nondegraded Distractor, Corners Missing and Line Segments Missing (see fig 1)**.** For all conditions each trial commenced with a large central fixation point (55 pixels diameter) that appeared for 300ms. This was replaced by a small central fixation point (13 pixels diameter) for 200ms, which was then followed by a blank screen, which remained on for a randomly varied interval (95-200ms).

In the Target Alone condition, following the blank screen the target subsequently appeared alone at fixation for 750ms. In the Nondegraded Distractor, Conjunctions Missing and Line Segments Missing conditions, following the blank screen interval, the central target and peripheral distractor appeared simultaneously for 750ms. The end of each trial was taken as either the time of response or 2000ms after the target offset.

This study consisted of 7 conditions in total, involving manipulations of distractor form (Target Alone, Nondegraded Distractors, Corners Missing and Line Segments Missing) and congruence (Congruent and Incongruent). These were presented in six separate blocks and were counterbalanced across all participants (that is, ABCDEF, BCDEFA, CDEFAB and so on). The order of trials according to distractor presence, form and congruence was also randomised within each block of trials. A practice block consisting of a representative sample of 40 practice trials preceded each experimental block. Within each of experimental block 10 trials of Target Alone and 20 trials of each of the other six conditions were presented, resulting in 130 trials per block for a total of 780 trials.

Insert Fig. 1 about here

The following responses were considered errors: trials on which no response was made (defined as a response not made by a temporal interval of 2,000 ms), a response of less than 150ms (anticipation), and responses using the incorrect hand.

Design and Data Analysis

Using pairwise comparisons, performance (reaction times and errors) for trials with a distractor was compared with trials in which the target was presented alone to demonstrate distractor interference. Thereafter, Target Alone trials were not included in the analysis. A 2 x 3 repeated measures ANOVA with Huyhn-Feldt correction was conducted for reaction time and errors. The first within-subjects factor was Distractor Congruence (Congruent, Incongruent) and the second factor was Distractor Form (Nondegraded, Line Segments Missing, Corners Missing; Target Alone omitted). Pairwise comparisons (with Bonferroni correction) were used to investigate any significant differences.

Results and Discussion

Reaction Times

Figure 2A shows mean reaction times for Experiment 1. Pairwise comparisons showed that reaction times were significantly faster for the Target Alone compared with Nondegraded Distractors, Corners Missing and Line Segments Missing (t_{12}= 6.784, p< 0.0001, t_{12}= 2.260, p< 0.05 and t_{12}= 2.559, p< 0.05 respectively).

Two-way repeated measures ANOVA showed a significant main effects of Distractor Form (F(2,24)= 46.793, p< 0.0001). The main effect of Congruence was also significant (F(1,12)= 5.813, p< 0.05), such that, averaged across Distractor Form, congruent distractors were associated with faster RTs than incongruent distractors . A significant interaction of distractor form and congruence was also shown (F(2,24)= 3.628, p= 0.05).

Insert Fig. 2 about here

Collapsed over congruent and incongruent trials, RTs for Nondegraded distractors were significantly slower than both Corners Missing (t_{12}= 7.460, p< 0.0001) and Line Segments Missing (t_{12}= 8.177, p< 0.0001) distractors. RTs for the Corners Missing and Line Segments Missing conditions did not differ (t_{12}= 0.564, p> 0.5).

Reaction Times were also faster for congruent compared with incongruent distractors in the Nondegraded distractor condition (t_{12}= 3.101, p< 0.01). There was no difference between reaction times for congruent versus incongruent Corners Missing distractors (t_{12}= 0.87, p> 0.05) and Line Segments Missing (t_{12}= 0.163, p> 0.05) conditions.

Errors

Errors due to anticipatory responses (less than 150 ms) or no response (2000 ms elapsed) together were less than 1% of all trials and were excluded from further examination. Errors due to incorrect hand use were included in the inspection of the accuracy data (see fig. 2B). Pairwise comparisons showed that significantly fewer errors were made for the Target Alone compared with Nondegraded Distractors, Corners Missing and Line Segments Missing (t_{12}= 8.902, p< 0.0001, t_{12}= 6.402, p< 0.0001 and t_{12}= 4.981, p< 0.0001 respectively).

A two-way repeated measures ANOVA showed significant main effects of Distractor Form (F(2,24)= 4.341, p< 0.05).The main effect of Congruence was also significant (F(1,12)= 16.524, p< 0.01), such that , averaged across Distractor Form, congruent distractors were associated with fewer errors than incongruent distractors. A significant interaction of Distractor Form and Congruence was also shown (F(2,24)= 10.291, p< 0.01).

Collapsed over congruent and incongruent trials, significantly more errors were made for Nondegraded distractors compared with both Corners Missing (t_{12}= 2.781, p< 0.05) and Line Segments Missing (t_{12}= 2.331, p< 0.05) distractors. Errors for the Corners Missing and Line Segments Missing conditions did not differ (t_{12}= 0.181, p> 0.05).

Significantly fewer errors were made for congruent compared with incongruent Nondegraded distractors (t_{12}= 5.834, p< 0.001). There was no difference between errors for congruent versus incongruent Corners Missing distractors (t_{12}= 0.00, p> 0.05)) and Line Segments Missing (t_{12}= 0.503, p> 0.05) conditions.

In summary, both the response time and error analyses indicate that, although degraded distractors caused less interference than nondegraded distractors, there was no difference between the two types of degraded distractors. Consistent with previous work, nondegraded incongruent distractors caused greater interference than congruent distractors. The findings thus far would suggest that neither line segments not corners (vertices) as component distractor features have a specific impact on responses to the target. Rather, it would appear that the attenuated but still significant interference is more reasonable attributable to the fact that the amount of visual information belonging to the distractor has been reduced. Note that both corners-missing and line segments-missing distractors were degraded to the same extent, and that the associated interference was comparable.

It is possible, however, that these component features require attentional processing to be compiled (Biederman, 1987). If so, making attentional resources available to degraded distractors should enhance the interference associated with them. This issue is addressed in Experiment 2.

EXPERIMENT 2

In Experiment 1, although degraded distractors caused attenuated interference relative to non-degraded distractors, no difference was evident between the types of degraded distractors, Corners Missing and Line Segments Missing. While these findings indicate that component features of distractors are unlikely to be processed automatically, it is not clear from the above paradigm whether directed attentional resources can enhance the processing of these non-accidental properties / components, over other (presumably 'accidental') object parts.

One possibility for this is that distractors always appeared in the periphery, where relatively fewer attentional resources are directed (Eriksen & St James, 1986).

Indeed, Beck and Lavie (2005) and Kritikos, McNeil and Pavlis (submitted) have shown that distractors presented at fixation caused greater interference (slower response times and reduced accuracy) than distractors presented at periphery.

In Experiment 2, we present distractors at fixation as well as periphery, and show that increased attentional resources at fixation can enhance processing of components of distractors, modulating interference.

Method

Participants

Sixteen participants (2 males, 14 females; age range 19-31 years, M= 24.3 SD= 4.1) who were students of Victoria University, or friends or associates of the investigators completed Experiment 2. Participation was voluntary and participants were paid AUD10 for their time. All participants fulfilled the previously outlined selection criteria.

Apparatus, Stimuli and Procedure

The apparatus, stimuli and procedure for this experiment were identical in set-up to those used in Experiment 1, with the following alterations.

In addition to the target at fixation/distractors at periphery conditions described in Experiment 1, half the trials in Experiment 2 contained targets presented peripherally with distractors at the fixation point. That is, when the target appeared in the centre, the distractor appeared randomly and equiprobably at either the left or right of the target (distractor at periphery). When the target appeared to the left or right of centre, the distractor appeared in the centre of the screen (distractor at fixation).

This study consisted of 14 conditions in total, 7 for each of the distractor location positions (Fixation and Periphery), involving manipulations of distractor form (Target Alone, Nondegraded, Corners Missing and Line Segments Missing) and congruence (Congruent and Incongruent).

The experiment was presented as four separate blocks, which were counterbalanced across all participants (that is, ABCD, BCDA, and so on). The order of trials according to distractor positions (left or right of centre or at fixation) and congruence was also randomised within each block of trials. Instructions to participants and response-hand counterbalancing were the same as in the previous experiments. A practice block consisting of a representative sample of 40 practice trials preceded each experimental block. Within each of the four experimental blocks 10 trials of each condition were presented, resulting in 140 trials per block for a total of 560 trials.

Design and Data Analysis

Using pairwise comparisons, performance (reaction times and errors) for trials with a distractor was compared with trials in which the target was presented alone to demonstrate distractor interference. Thereafter, Target Alone trials were not included in the analysis. A 2 x 3 x 2 repeated measures ANOVA with Huynh-Feldt correction was conducted for reaction time and errors. The first within-subjects factor was Distractor Location (Fixation, Periphery), the second within-subjects factor was Distractor Form (Nondegraded, Line Segments Missing, Corners Missing; Target Alone omitted) and the third factor was Distractor Congruence (Congruent, Incongruent). Two-way repeated measures ANOVAs and pairwise comparisons (with Bonferroni correction) were used to investigate any significant comparisons.

Results and Discussion

Reaction Times

Pairwise comparisons between the two Target Alone presentations (for Distractors at Fixation compared with Periphery) showed that when the target appeared in periphery (Distractor at fixation) response times were significantly slower compared with presentation at fixation (Distractor at periphery) (t_{15}=10.317, *p*< 0.0001, see Figure 3).

Moreover, for the Distractor at fixation condition, response times for Target Alone (at periphery) were significantly faster compared with a Nondegraded, Corners Missing or Lines Missing distractor (t_{15}=7.925, *p*<0.001; t_{15}=5.672, *p*<0.001 and t_{15}=3.136, *p*<0.01 respectively; see Figure 3), indicating interference in speeded responses due to the presence of distractors.

Similarly, for the Distractor at periphery condition, response times Target Alone (at periphery) were significantly faster compared with a Nondegraded and Lines Missing distractor (t_{15}=6.601, *p*<0.001 and t_{15}=2.356 *p*<0.05 respectively; see Figure 3), while the comparison between target alone and Corners Missing distractor showed a trend towards significance (t_{15}=1.961, *p*=0.069), also indicating interference in goal-directed responses due to the presence of distractors.

A three-way repeated measures ANOVA revealed a significant main effect of Distractor Location (F(1,15)= 106.846, *p* < 0.0001), such that, averaged over form and congruence, distractors at fixation were associated with significantly slower response times than distractors at periphery. There was also a significant main effect of form (F(2,30)= 61.182, *p* < 0.0001. Finally, there was main effect of Congruence (F(1,15)= 18.490, *p* = 0.001), such that, averaged over Location and Form, incongruent distractors caused slower response times than congruent distractors. There were also significant interactions of Distractor Location and Distractor Form ($F(2,30)= 18.128$, $p < 0.0001$), Distractor Location and Congruence ($F(1,15)= 24.646$, $p < 0.0001$) and a three-way interaction of Distractor Location, Distractor Form and Congruence ($F(2,30)= 8.637$, $p = 0.001$). The Distractor Form and Congruence interaction was not significant ($F(2,30)= 2.144$, $p > 0.05$).

Two-way repeated measures ANOVA for the Distractor at fixation conditions showed significant main effects of Distractor Form ($F(2,30)= 46.383$, $p< 0.0001$) and Congruence ($F(1,15)= 29.285$, $p< 0.0001$). A significant interaction of Distractor Form and Congruence was also shown ($F(2,30)= 6.145$, $p< 0.01$).

Insert Fig. 3 about here

Collapsed over congruent and incongruent trials, RTs for Nondegraded distractors at fixation were significantly faster than Corners Missing ($t_{15}= 6.210$, $p< 0.0001$) and Line Segments Missing ($t_{15}= 7.851$, $p< 0.0001$) distractors at fixation. RTs for the Corners Missing condition were significantly slower than for the Line Segments Missing condition ($t_{15}= 3.089$, $p< 0.01$).

Pairwise comparisons showed that reaction times were significantly faster for congruent compared to incongruent distractors in both the Nondegraded ($t_{15}= 4.325$, $p< 0.01$) and Corners Missing ($t_{15}= 5.997$, $p< 0.01$) conditions. There was no difference between reaction times for congruent versus incongruent Line Segments Missing distractors ($t_{15}= 1.689$, $p> 0.05$).

For the Distractor at periphery conditions, two-way repeated measures ANOVA showed a significant main effect of Distractor Form ($F(2,30)= 13.878$, $p< 0.0001$). There was no significant effect for Congruence ($F(1,15)= 2.001$, $p> 0.1$), nor was there a significant interaction of Distractor Form and Congruence ($F(2,30) = 2.398$, $p > 0.05$).

Pairwise comparisons indicated that for Distractors at periphery collapsed over congruent and incongruent trials, RTs for Nondegraded Distractors at periphery were significantly faster than Corners Missing ($t_{15} = 3.853$, $p < 0.01$) and Line Segments Missing ($t_{15} = 6.552$, $p < 0.0001$) distractors at fixation. RTs for the Corners Missing condition were not significantly different than the Line Segments Missing condition ($t_{15} = .277$, $p > 0.05$).

Errors

Errors due to anticipatory responses (less than 150 ms) or no response (2000 ms elapsed) together were less than 1% of all trials and were excluded from further examination. Errors due to incorrect hand use were included in the inspection of the accuracy data. The average standard deviation for errors, across all conditions, was 3.51. Errors ranged from 1.43 to 15% across all conditions (see table 1).

Pairwise comparisons between Target Alone for Distractors at Fixation vs Periphery showed a trend towards significance such that when the target was presented alone in the periphery errors were higher than when it was presented at fixation ($t15=1.980$, $p = 0.066$).

For the Distractor at fixation condition, errors for Target Alone (at periphery) were significantly lower compared with a Nondegraded distractor ($t_{15}=2.092$, $p<0.05$). There was no difference, however, for Target Alone compared with a Corners Missing or Lines Missing distractor (both $p> 0.5$). Similarly, for Distractors at periphery, there was no difference in errors for Target Alone (at fixation) compared with a Nondegraded, Corners Missing or Lines Missing distractor (all $p> 0.05$).

Insert Fig. 4 about here

A three-way repeated measures ANOVA revealed a significant main effect of Distractor Location ($F(1,15)= 28.1$, $p < 0.0001$), with participants making more errors when distractors were presented at fixation. There was a significant main effect of Congruence ($F(1,15)= 24.664$, $p < 0.0001$), such that participants made more errors with incongruent distractors. The Distractor Form main effect, however, was not significant ($F(1,19)= .278$, $p > 0.05$). There were significant interactions of Distractor Location and Distractor Form ($F(2,30)= 5.821$, $p < 0.05$) and Distractor Location and Congruence ($F(1,15)= 11.371$, $p < 0.05$). The Distractor Form and Congruence interaction ($F(2,30)= 1.874$, $p > 0.05$), and the three-way interaction of Distractor Location, Distractor Form and Congruence ($F(2,30)= 3.375$, $p> 0.05$) were not significant (see fig. 4).

A two-way repeated measures ANOVA for the Distractor at fixation conditions was conducted. There were significant main effects of Distractor Form ($F(2,30)= 4.578$, $p< 0.05$) and Congruence ($F(1,15)= .797$, $p= 0.001$). The interaction of Distractor Form and Congruence did not reach significance ($F(2,30)= 3.200$, $p> 0.05$)**.**

Collapsed over congruent and incongruent trials, pairwise comparisons revealed that there were significantly more errors made for Nondegraded distractors at fixation compared to Corners Missing distractors ($t_{19}= 2.611$, $p< 0.05$). The number of errors did not differ between Nondegraded distractors at fixation and Line Segments Missing distractors ($t_{19}= 1.856$, $p> 0.05$) or between Corners Missing distractors and Line Segments Missing distractors ($t_{19}= .891$, $p> 0.05$).

Pairwise comparisons showed that there were significantly fewer errors for congruent compared to incongruent distractors in both the Nondegraded ($t_{15}= 3.335$, *p*< 0.01) and Corners Missing (t_{15}= 3.565, *p*< 0.01) conditions. There was no difference in number of errors between congruent and incongruent Line Segments Missing distractors (t_{15}= 1.523, *p*> 0.05).

For the Distractor at periphery conditions, two-way repeated measures ANOVA showed a significant main effect of Distractor Form (F(2,30)= 5.102, *p*< 0.05) but not Congruence (F(1,15)= 1.963, *p*> 0.05). There was no significant interaction of Distractor Form and Congruence (F(2,30)= .594, *p*> 0.5)**.**

Pairwise comparisons collapsed over congruent and incongruent trials revealed that there were significantly more errors made for peripheral distractors with Corners Missing compared to both Nondegraded (t_{15}= 2.506, *p*< 0.05) and Line Segments Missing distractors (t_{15}= 2.515, *p*< 0.05). Number of errors did not differ between Nondegraded and Line Segments Missing distractors at periphery (t_{15}= .315, *p*> 0.05).

In summary, the findings of experiment 1 were replicated when distractors were presented peripherally: although incomplete distractors caused less interference than nondegraded distractors, there was no difference between the two types of degraded distractors. When distractors were presented at fixation, however, distractors with Corners Missing caused increased response times than distractors with line segments missing. In particular, the incongruent Corners Missing distractors caused significantly greater interference than congruent Corners Missing distractors. We attribute this difference to the improved processing of components of distractors when they are presented at the fovea.

EXPERIMENT 3

The findings of Experiment 2 indicate that, when presented at fixation, Corners Missing distractors which were incongruent to the (peripheral) target did cause more interference than lines-missing distractors. This may be because, at fixation, attentional resources are sufficient for reconstruction of corners. Alternatively, however, the pattern may be an artefact of the specific stimuli used[1]. In particular, both stimuli were in fact identical (one was the inverted version of the other), and they were symmetrical, making identification easier. In Experiment 3, we present distractors degraded and non-degraded at fixation, but use different stimuli (H and E). These stimuli were chosen to control for complexity: they contain the same number of corners, but are not mirror images of each other.

Method

Participants

12 participants (6 males, 6 females; age range 22 - 42 years, M = 31.7 years SD = 7.6 years) who were fiends or colleagues of the authors completed the experiment. All participants gave informed consent, were right-handed, had no known neurological disturbances and had normal or corrected-to-normal vision.

Apparatus and Stimuli

The experiment was run using the DmDX/DMASTR software. An IBM compatible computer attached to a VGA colour monitor (set to 1024 x 768 pixels) presented the stimuli and recorded the latency and accuracy of responses. The latency of responses (reaction time, RT) was collected to the nearest millisecond (ms).

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[1] We thank the anonymous reviewer for this suggestion.

A single target letter, either an outline block capital H or an outline block capital E, appeared in the left or right side of the computer screen. The target appeared alone or with a single distractor letter (H or E; as a complete, nondegraded letter outline, or as a degraded outline with corner segments missing or line segments missing). The target appeared 20mm left or right of centre, was either congruent (for example, H with H) or incongruent (for example, H with E) to the centrally located target. Hs and Es were presented as bitmaps (22 X 33 pixels). Stimuli were constructed as for Experiment 1.

Procedure

Data were collected in a sound attenuated and darkened laboratory. Participants read a plain language statement and then read the instructions and signed the consent form. Participants sat facing the computer screen with their head placed in an adjustable chin rest. The distance to the computer screen was 57cm and the body midline was aligned with the centre of the computer screen.

Participants were instructed to respond to the target letter as quickly as possible without compromising accuracy, and to ignore the distractor, by pressing the left or right shift keys with their left and right hands respectively. For half the experimental blocks participants used their left hand to respond to the target H, and their right hand to respond to the target E. Hand-to-letter correspondence was counterbalanced for the remaining half of the experimental blocks.

The paradigm consisted of four distractor presentation conditions. These were Target Alone, Nondegraded Distractor, Corners Missing and Line Segments Missing**.** For all conditions each trial commenced with a large central fixation point (55 pixels diameter) that appeared for 300ms. This was replaced by a small central fixation point

(13 pixels diameter) for 200ms, which was then followed by a blank screen, which remained on for a randomly varied interval (95-200ms).

In the Target Alone condition, following the blank screen the target subsequently appeared alone at periphery for 750ms. In the Nondegraded Distractor, Corners Missing and Line Segments Missing conditions, following the blank screen interval, the peripheral target and central distractor appeared simultaneously for 750ms. The end of each trial was taken as either the time of response or 2000ms after the target offset.

Trial type was randomised throughout each block. A practice block consisting of a representative sample of 40 practice trials preceded each block. Within each block, there were 10 trials of Target Alone and 10 trials of each of the other three conditions, resulting in 180 trials per block for a total of 360 trials. In the first block, half of the participants responded to H with right hand and E with the left, and the other half the reverse. This was counterbalanced for the second block.

The following responses were considered errors: trials on which no response was made (defined as a response not made by a temporal interval of 2,000 ms), a response of less than 150ms (anticipation), and responses using the incorrect hand.

Design and Data Analysis

Using pairwise comparisons, performance (reaction times and errors) for trials with a distractor was compared with trials in which the target was presented alone to demonstrate distractor interference. Thereafter, Target Alone trials were not included in the analysis. A 2 x 3 repeated measures ANOVA with Huyhn-Feldt correction was conducted for reaction time and errors. The first within-subjects factor was Distractor Congruence (Congruent, Incongruent) and the second factor was Distractor Form

(Nondegraded, Corners Missing, Missing; Line Segments). Pairwise comparisons (with Bonferroni correction) were used to investigate any significant differences.

Results and Discussion

Response times

Pairwise comparisons indicated that response times in the target Alone condition were fastest than each of non degraded congruent and incongruent, corners missing congruent and incongruent and line segments missing congruent and incongruent conditions (t_{11}=4.683, p<0.001; t_{11}=9.034, p<0.0001; t_{11}=4.404, p<0.001; t_{11}=7.637, p<0.0001; t_{11}=4.924, p<0.0001 and t_{11}=9.077, p<0.0001 respectively; see Figure 5a)

Insert Fig. 5 about here

There was a significant main effect for Congruence, such that responses to targets were slower in the presence of incongruent compared with congruent distractors ($F(1,11)= 21.144$, $p < 0.001$). There was also a significant main effect for Distractor Form ($F(1,2)= 12.086$, $p < 0.001$). Post-hoc comparisons indicated that responses were slower in the Nondegraded condition compared with the Corners missing condition and with the Line Segments missing condition (t_{11}=6343, p<0.0001 and t_{11}=2.957, p<0.01 respectively. Moreover, responses were slower in the line segments missing compared with the Corners missing condition (t_{11}=2.340, p<0.05).

The Congruence by Distractor Form interaction was also significant ($F(1,22)$= 17.624, $p < 0.0001$). Post-hoc comparisons showed that responses were slower in incongruent compared with congruent trials, for the Nondegraded condition (t_{11}=6.151, p<0.0001) but not the Corners Missing or Lines Missing conditions (t_{11}=1.989, p>0.05 and t_{11}=1.875, p>0.05 respectively).

Thus, the pattern of results of Experiment 2 was not replicated. In the Nondegraded distractor condition, responses were slower in the incongruent than congruent trials. Moreover, though not significant, the overall trend in the means was the same in the Corners Missing and Line Segments Missing conditions, in contrast to the finding of Experiment 2.

Errors

Pairwise comparisons indicated that errors were lower in the target alone condition compared with the Nondegraded incongruent and line Segments Missing incongruent conditions only (t_{11}=5.338, p<0.0001 and t_{11}=2.369, p<0.05 respectively; see Figure 5b). In all other conditions, the number of errors was comparable with target alone (p> 0.05). The average standard deviation for errors, across all conditions, was 0.7565 Errors ranged from 2.9 to 30.7% (see table 1).

There was a significant main effect for Congruence, such that errors to targets were higher in the presence of incongruent compared with congruent distractors ($F(1,11)$= 17.503, $p < 0.01$). The Distractor Form main effect was not significant ($p>0.05$), indicating that the number of errors were comparable across all distractor types. The Distractor Form X Congruence interaction was significant ($F(1,22)$= 3.913, $p < 0.05$). Post-hoc comparisons indicated that the number of errors was significantly higher in the incongruent compared with the congruent trials for the Nondegraded condition (t_{11}=5.376, p<0.0001) but not the Corners Missing or Line Segments missing conditions (p>0.05).

In summary, in this experiment, incongruent and non-mirror reversed distractors presented at fixation caused significantly greater interference than congruent distractors. Moreover, although degraded distractors caused less interference than

Nondegraded distractors, there was no difference between Corners and Line Segments Missing distractors. We speculate, therefore, that the visual system may be able to reconstruct the corners of (irrelevant) objects when these are presented at fixation, and therefore at the point of maximum attentional resource allocation. This ability, however, depends to a very great extent on the complexity of the stimuli.

General Discussion

In this series of experiments, we postulated that corners of visually presented stimuli are critical sub-component features of objects. We presented targets (Ms or Ws) accompanied by distractors (also Ms or Ws) which were non-degraded, or with either corners or line segments missing. In Experiment 1, distractors were either congruent or incongruent to the target, and were always presented peripherally. Although nondegraded distractors resulted in interference, degraded distractors resulted in significant but attenuated interference effects. There was no difference, however, between the two types of degraded distractors, that is, corners-missing and line segments-missing. In Experiment 2, distractors were presented either at fixation or peripherally. Overall, distractors at fixation resulted in greater interference than peripheral distractors. Again, degraded distractors resulted in attenuated but significant interference compared with non-degraded distractors. This time, however, corners-missing distractors caused significantly more interference than line segments -missing distractors. Finally, in Experiment 3, we generalised the paradigm to two different stimuli (H and E) but again presented distractors at fixation and targets peripherally. This time, there was no difference in performance between corners-missing and line segments-missing trials.

In all three experiments of this series, and consistent with the literature on distractor interference, distractors caused interference. This was the case whether they were degraded or non-degraded, symmetrical or asymmetrical (for example, M and M, H and H, or E and E). In other words, irrelevant information, regardless of its physical properties, always causes longer response times and reduced accuracy to the target. The pattern was exaggerated when distractors were incongruent to the target (M and W or H and E), and when distractors were presented at fixation and targets at periphery.

We argue that the circumstances under which, the visuomotor system is differentially sensitive to components of distractors in goal-directed action are very specific. The effect depends on two factors: first, the location of the distractors in the visual field, and thus presumably on the amount of attentional resources that may be allocated to them. Distractors at fixation receive more attentional resources and are processed more efficiently (Beck and Lavie, 2005; Eriksen & St James, 1986; Kritikos et al., in press). Consistent with this, performance (reaction time and accuracy) was better for targets presented alone at fixation, than at periphery; moreover, distractors had a greater impact when they were presented at fixation rather than periphery. Second, it depends on the complexity of the stimuli: we speculate that corners of distractors art fixation may be reconstructed if they are simple, for example symmetrical and identical to the targets (though mirror reversed).

In line with Biederman (1987), we speculated that corners are more important as ‘diagnostic features’ than line segments, because segmentation into geons and subsequently identification of the object is based on them. The evidence for this, however, is slight. If corners are such important features, the pattern of interference from degraded distractors at fixation is at first glance paradoxical. Distractors with line segments missing have existing corners which do not require reconstruction. Therefore, the interference exerted by line segments-missing distractors ought to be greater than corners-missing. Instead, when presented at fixation, corners-missing distractors caused greater interference than line segments missing. There was no difference in interference caused by the two types of degraded distractors when they were presented at periphery. Biederman and Cooper (1991) argued that corners cannot be restored by low-level processes. This reasoning, applied to this present paradigm, may explain the lack of differentiation between the two types of distractors when they were presented at periphery, with few attentional resources available. Biederman and Cooper (1991) thought it similarly unlikely that short- or long –range mechanisms for segment continuations could restore corners. They do speculate, however, that components may be activated from the partial information of the stimulus, thus specifying deleted features. Importantly, in Experiment 2, the stimuli were symmetrical so that reconstruction of components on one side may have "suggested" components on the other (Biederman & Cooper, 1991). Under these circumstances, and when sufficient attentional resources are available, we speculate that it is possible for the visuomotor system can reconstruct corners. It may even do so preferentially when the task involves speeded responses. This is supported by two findings. First, at fixation, corners-missing distractors caused greater interference in performance than line segments-missing distractors. Second, again at fixation, for both nondegraded and corners -missing distractors, the incongruent forms caused greater interference in performance than the congruent forms. There was no difference, however, between congruent and incongruent distractors for line segments-missing distractors. When targets and distractors are structurally distinct though equally simple, this reconstruction is not possible as the findings of Experiment 3 suggest. It remains to be seen whether these differences can be elicited with drawings of ecologically valid, real objects, rather than alphanumeric characters.

In summary, in this series of experiments we show that degraded distractors cause attenuated interference. Importantly, however, we show that under specific circumstances components of distractors and in particular corners have differential influence on speeded responses to targets. We argue that, given sufficient attentional resources and structural similarity, the visuomotor system may be able to reconstruct corners to aid in successful action.

The authors would like to thank Mr Mark Yates for his help in data collection and analysis.

Table 1: mean percent errors for each participant in Experiments 1, 2 and 3. (NB: participants differed across the three experiments)

Participant Number	Percent errors		
	Experiment 1	Experiment 2	Experiment 3
1	4.06	8.21	10.71
2	3.62	9.28	11.43
3	2.09	6.43	9.29
4	3.62	11.07	3.57
5	2.09	6.43	11.43
6	2.31	1.43	18.57
7	3.29	11.43	8.60
8	2.31	4.28	19.30
9	3.08	8.57	2.90
10	5.982	15.00	30.70
11	6.92	3.21	9.30
12	4.29	8.57	8.90
13	3.74	14.28	--
14	--	13.57	--
15	--	1.43	--
16	--	4.64	--

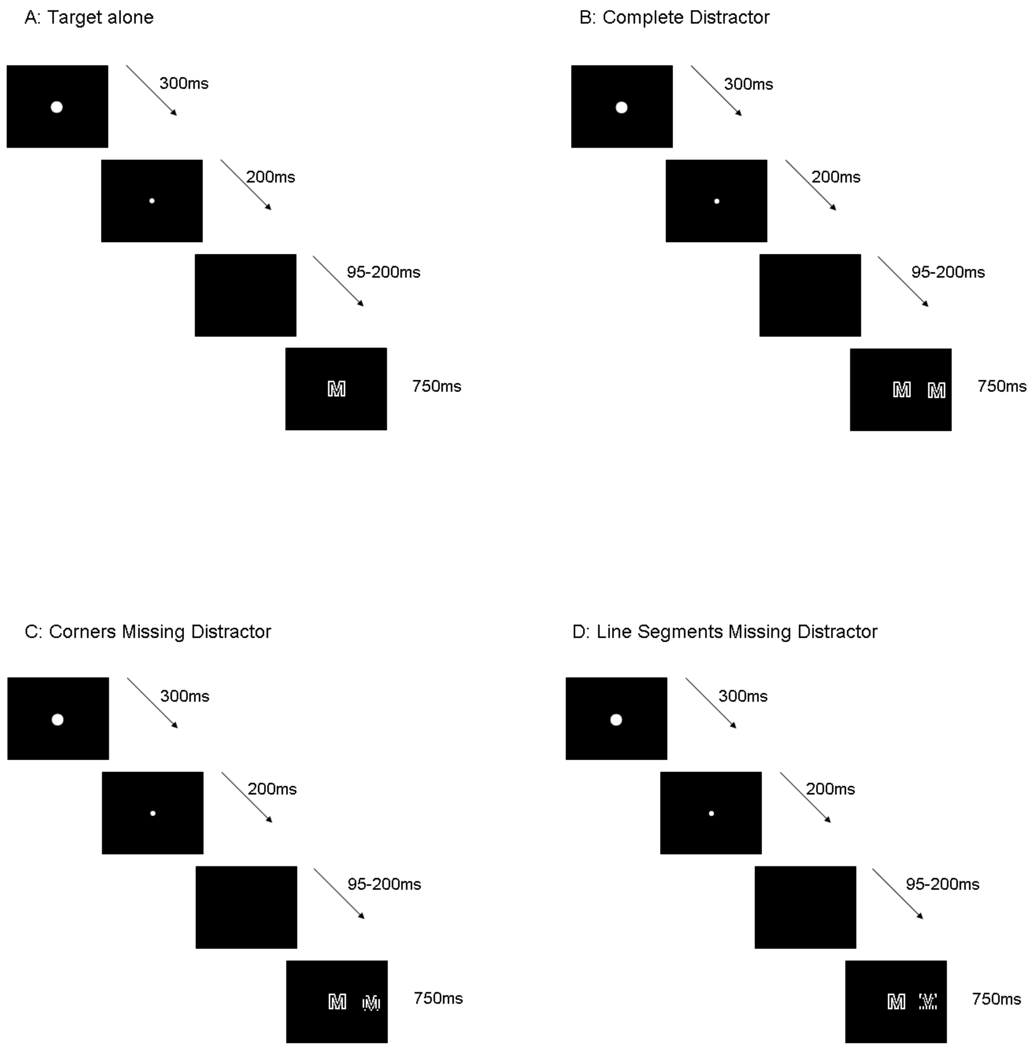

A: Target alone
300ms
200ms
95-200ms
750ms
B: Complete Distractor
300ms
200ms
95-200ms
750ms
C: Corners Missing Distractor
300ms
200ms
95-200ms
750ms
D: Line Segments Missing Distractor
300ms
200ms
95-200ms
750ms

Fig.1

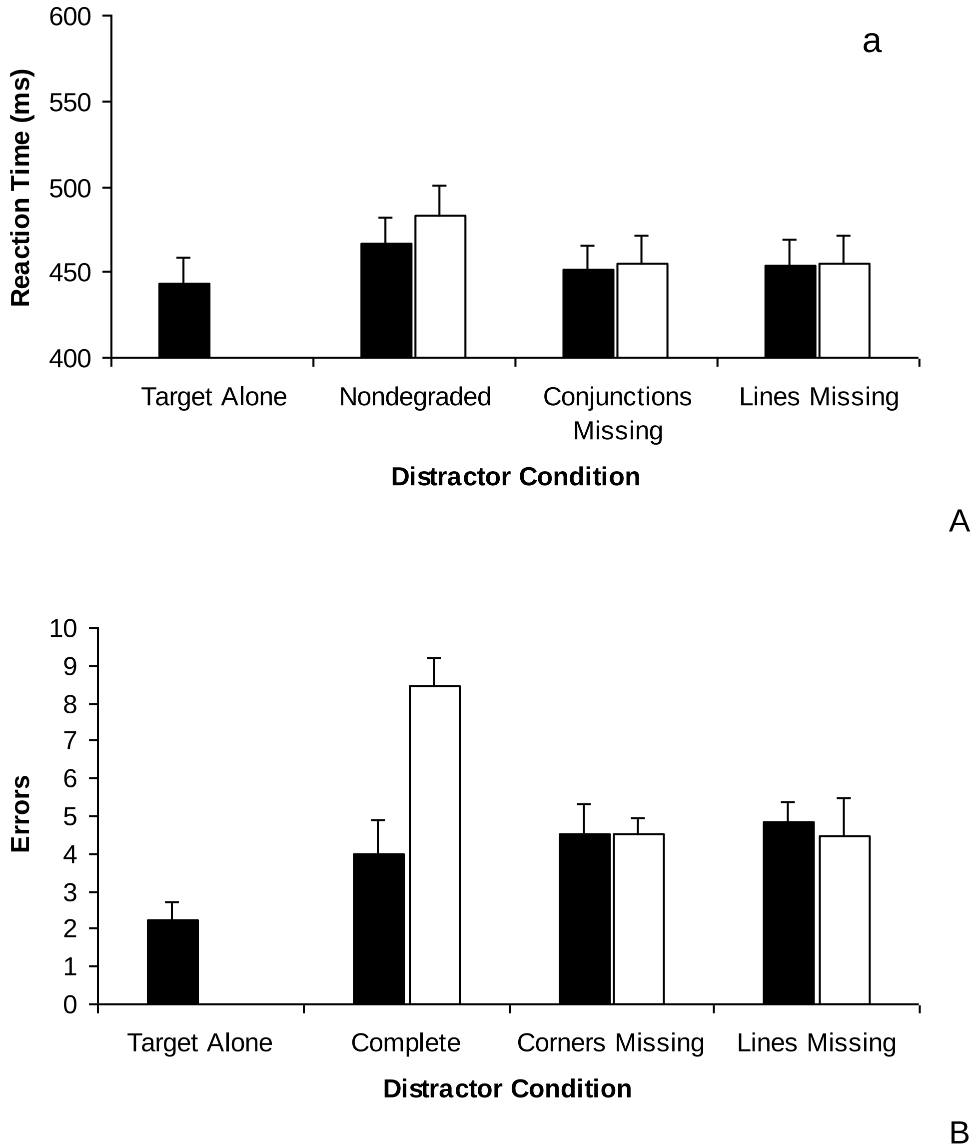

600
550
500
450
400
a
Reaction Time (ms)
Target Alone
Nondegraded
Conjunctions Missing
Lines Missing
Distractor Condition
A
10
9
8
7
6
5
4
3
2
1
0
Errors
Target Alone
Complete
Corners Missing
Lines Missing
Distractor Condition
B

Fig. 2

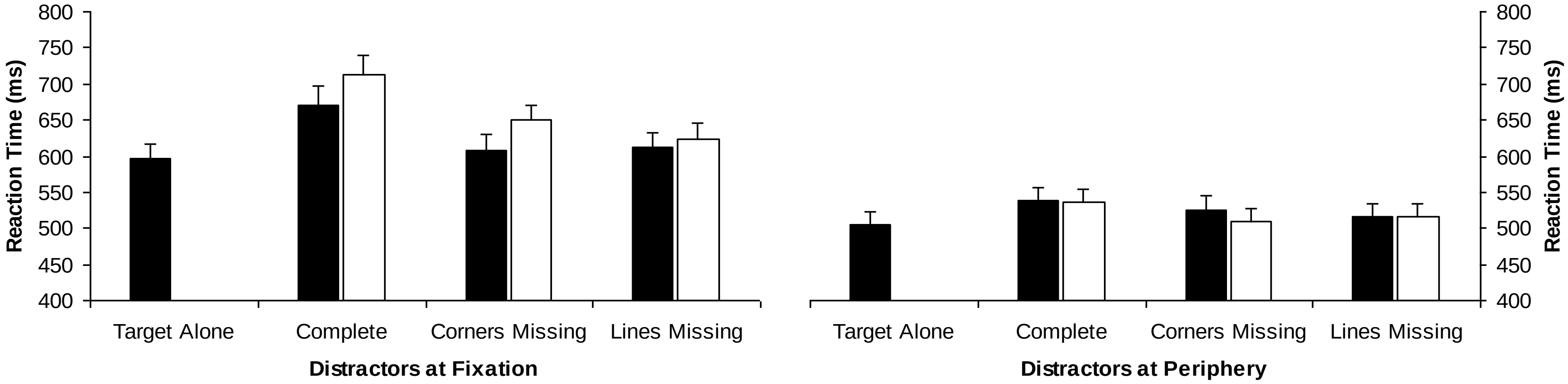

800
750
700
650
600
550
500
450
400
Reaction Time (ms)
Target Alone
Complete
Corners Missing
Lines Missing
Distractors at Fixation
Distractors at Periphery

Fig. 3

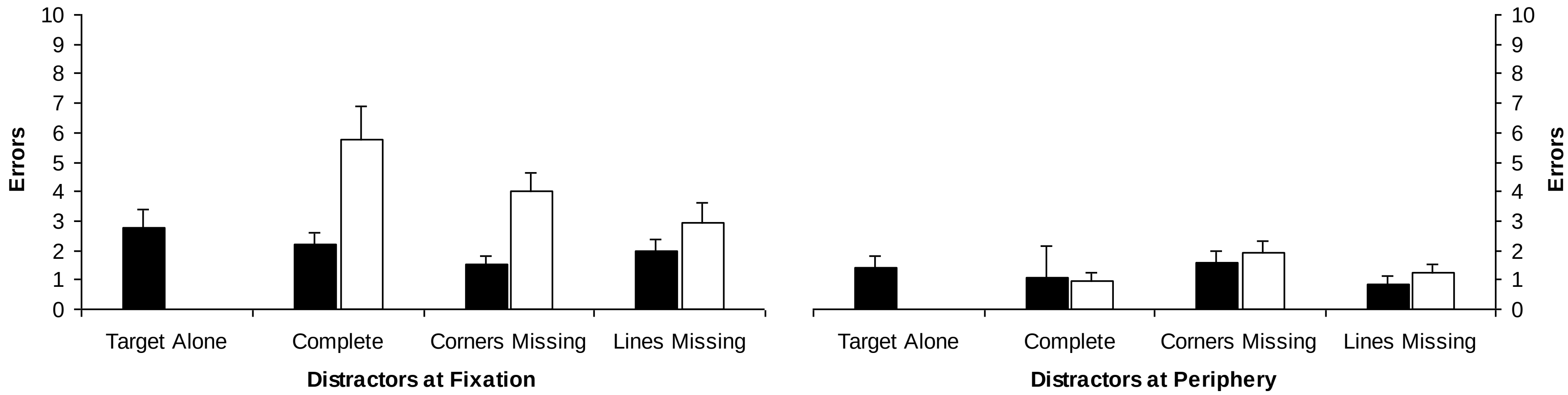
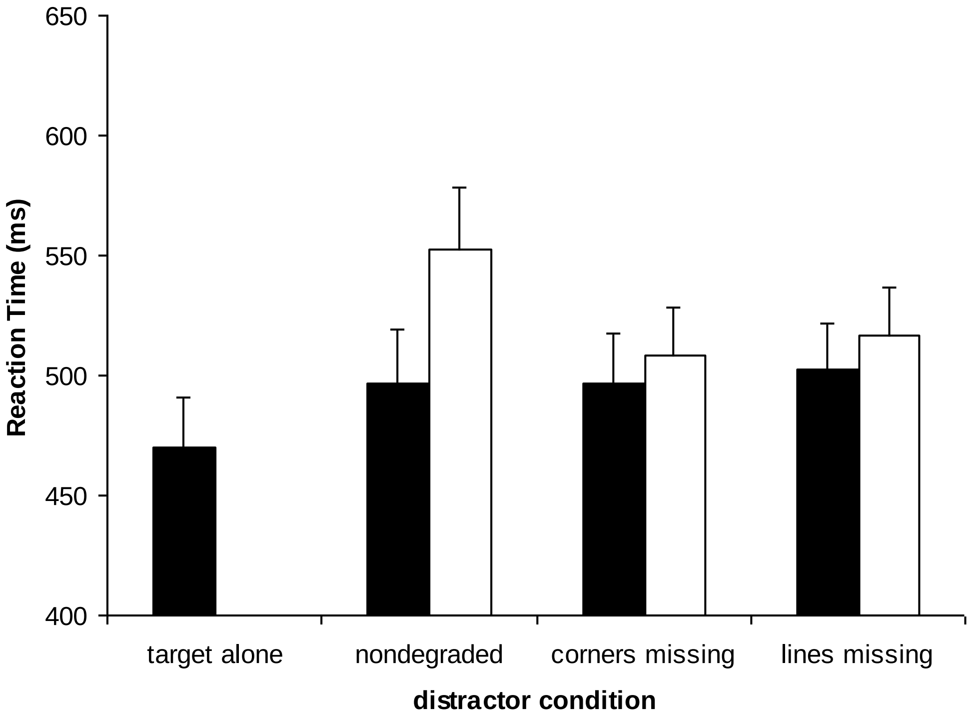
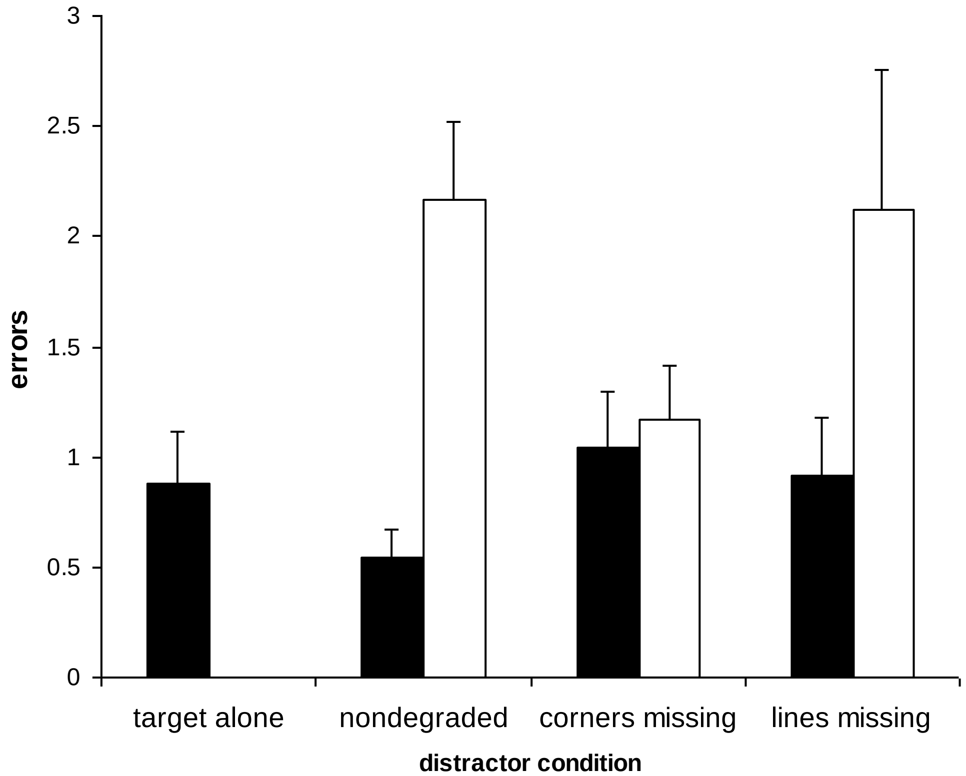

Errors
10
9
8
7
6
5
4
3
2
1
0
Target Alone
Complete
Corners Missing
Lines Missing
Distractors at Fixation
Target Alone
Complete
Corners Missing
Lines Missing
Distractors at Periphery
Errors

Fig. 4


650
600
550
500
450
400
Reaction Time (ms)
target alone
nondegraded
corners missing
lines missing
distractor condition

A


3
2.5
2
1.5
1
0.5
0
errors
target alone
nondegraded
corners missing
lines missing
distractor condition

B

Fig. 5

Figure Captions

Figure 1. Sample stimulus sequences for Experiment 1 and 2: (a) Target Alone (b) Nondegraded Distractor (c) Corners Missing Distractor (d) Line Segments Missing Distractor. Sample shows distractors at periphery.

Figure 2. Mean reaction times (panel A) and errors (panel B) for the Target Alone, Nondegraded Distractors, Corners Missing Distractors and Line Segments Missing Distractors in Experiment 1.

Figure 3. Mean reaction times for Distractors at Fixation (panel A) and Distractors at Periphery (panel B) for the Target Alone, Nondegraded Distractors, Corners Missing Distractors and Line Segments Missing Distractors in Experiment 2.

Figure 4. Mean errors for Distractors at Fixation (panel A) and Distractors at Periphery (panel B) for the Target Alone, Nondegraded Distractors, Corners Missing Distractors and Line Segments Missing Distractors in Experiment 2.

Figure 2. Mean reaction times (panel A) and errors (panel B) for the Target Alone, Nondegraded Distractors, Corners Missing Distractors and Line Segments Missing Distractors in Experiment 3.

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