This document contains the supplementary appendix and auxiliary analyses for the following paper:

Alvarez, G. A., & Scholl, B. J. (in press). How does attention select and track spatially extended objects?: New effects of attentional concentration and amplification. *Journal of Experimental Psychology: General*.

Supplementary Appendix: Auxiliary Analyses

[Alvarez & Scholl, 2005, *JEP:General*]

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The four experiments in this paper provided an extremely rich data set for exploratory analyses, and we have thus analyzed the probe detection data from each experiment in several other ways, both to rule out potential confounds, and to explore the effects of new variables. In each case below we present the data from Experiment 1 in detail along with an explanatory figure, and we then provide the equivalent information for each of the other experiments in a table and associated figures.

For each analysis the data were divided in various ways, with the divisions selected to cover as wide a range as possible on each variable while still providing enough data within each cell to conduct the analysis. These divisions were selected based on Experiment 1, and for simplicity we used the same divisions for each analysis in each experiment. However, because of differences in probe probability and tracking accuracy across experiments, some of the cells for Experiments 2-4 were empty or had a small number of trials. To address this problem, in some cases we ran an additional analysis that included a greater number of probe trials, which increased the power of these analyses. Specifically, rather than using the strict criterion of perfect tracking accuracy, we used a more liberal criterion in which all target probes that were presented on a target line that was selected at the end of the trial were included in the analysis. For example, if only 2 of 3 targets were tracked the original analysis would exclude all probes from this trial, but the additional analysis would include target probes for the 2 tracked targets and exclude target probes only for the 1 target that was not tracked. Similarly, all distractor probes that were presented on a distractor line that was not selected at the end of the trial were included in the analysis. All of the results reported in the following tables and figures are based on the strict tracking criterion, and cases in which an additional analysis was run with the more liberal criterion are marked within the table with an accompanying note on the results of this analysis.

To foreshadow the results of these auxiliary analyses, we find that the observed effects of attentional concentration and amplification cannot be explained by appeal to either probe-position velocity or probe eccentricity, in any of the experiments. We do, however, discover three auxiliary results that seem theoretically interesting. First, we find that both target and distractor probes are detected better when other targets and distractors are closer. Second, we find that in some cases attentional concentration increases for targets when the probed target lines are intersecting more distractor lines. Finally, we find that recent changes in the length of a line — i.e. growing or shrinking, beyond the actual line length at the moment of the probe — can affect probe detection.

VELOCITY EFFECTS

In Experiment 1 the average velocity of endpoint probes was 3.9°/s, whereas the average velocity of center probes was 2.7°/s. It is possible that this difference in speed makes endpoint probes more perceptually difficult to detect, regardless of the distribution of attention within the lines. To rule out this potential confound we determined the speed that each probe position was moving from 215 ms prior to the probe appearance to its offset. Center and endpoint probes were then matched for velocity by binning them into Slow, Medium, and Fast categories, corresponding to less than 2.5°/s, 2.5-4°/s, and greater than 4°/s, respectively. Figure A.1 shows that endpoint probes and center probes were well matched for velocity within each velocity group.

The results of this analysis show that there is no effect of probe position velocity on probe detection miss rate and that the difference between center and endpoint miss rates is observed at each velocity for target probes and distractor probes. Figure A.2 shows probe detection miss rates for both targets and distractors. A 2 x 2 x 3 ANOVA was run on miss rates with object (target vs. distractor), location (center vs.

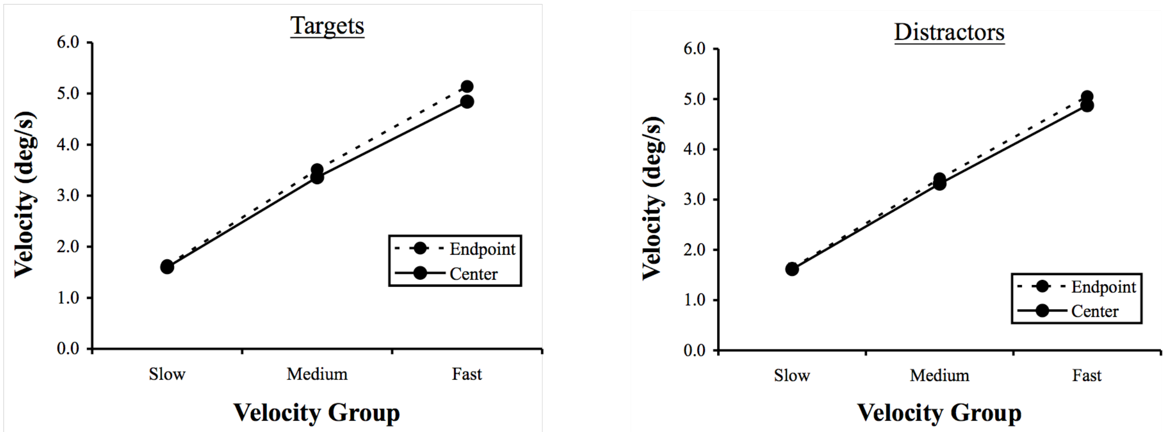

Figure A.1. ***Mean velocity for each velocity group in Experiment 1***. The trials were binned into groups based on the velocity of the probe position (from 215 ms prior until the offset of the probe). Endpoint and center probes within each group were well matched for velocity. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

endpoint), and velocity (Slow, Medium, and Fast) as factors. Miss rates were higher for distractor probes than target probes (main effect of object, $F(1,8) = 19.0$, $MSE = 443$, $p = .002$, $\eta_p^2 = .71$). Miss rates for endpoint probes were higher than for center probes (main effect of location, $F(1,8) = 44.70$, $MSE = 316$, $p < .001$, $\eta_p^2 = .85$). However, there was no effect of velocity on miss rates ($F(2,16) < 1$) and, critically, none of the interactions were significant (all *F*s less than 1). Thus, the effect of probe location (center vs. endpoint) does not interact significantly with velocity (location x velocity, $F(2,16) < 1$).

The equivalent data for Experiments 2 through 4 are presented in Table A.1 and Figures A.3-A.8, and similar data for the long near center and short endpoint results of Experiment 4 are presented in Table A.1 and Figures A.9-A.11. The results for these experiments are the same as those for Experiment 1 with one important exception: The target/distractor difference was not significant in Experiment 3. However, this lack of significance appears to be due to the relatively noisy data resulting from the lower tracking accuracy and smaller number of probes included in the analysis of Experiment 3. When the more liberal criterion for including probes was used, the target distractor difference was robust (p = .001). Most importantly, the effect of probe location (center vs. endpoint) did not interact significantly with velocity in any of these experiments. Thus, we conclude that the attentional concentration effect in each experiment is the result of the probe position within the object, rather than the rate at which the probe position was moving just prior to or during the presentation of the probe.

ECCENTRICITY EFFECTS

Observers in our experiments were not given any special instructions concerning fixation, but the displays did include small boxes at their centers, which some observers may have fixated. (We and others have noted that observers do not saccade to each object in turn during MOT, and that it seems easier to fixate centrally than to fixate only one of the targets, for example. This was our reason for including a fixation box in the displays.) In this analysis we hypothesize that observers fixated the center of the display, and then ask whether eccentricity differences could account for the observed attentional concentration effect. In Experiment 1 the average eccentricity of endpoint probes was about 13.9° from the fixation point, whereas the average eccentricity of center probes was about 9.7°. Thus, it is possible that the difference between center and endpoint miss rates reflects a difference in retinal eccentricity rather than attentional concentration or amplification. To rule out this potential confound we determined the distance of the onset position of each probe from fixation. Center and endpoint probes were then matched for eccentricity by binning them into Very Near, Near, Far, and Very Far categories corresponding to 0°-7.8°, 7.8°-12.4°, 12.4°-16.7°, and greater than 16.7° eccentricity, respectively. Figure A.12 shows that endpoint probes and center probes were well matched for eccentricity within each eccentricity group.

The results of this analysis show that probe miss rates increase with eccentricity, but the difference between center and endpoint miss rates is observed at each eccentricity for targets. For distractors, the center versus endpoint difference occurs at near positions,

Table A.1. ***Velocity Analyses for Each Experiment***. The first analysis for Experiment 4 (4_1) is on endpoint vs. center probes, and the second (4_2) is on short endpoint vs. long near center probes. These analyses employed the same duration threshold and velocity bins as described in the text for Experiment 1.

	Experiment				
Analysis Category	1	2	3	4_1	4_2
Average Endpoint Probe Velocity (°/s)	3.9	3.9	3.9	4.0	4.0
Average Center Probe Velocity (°/s)	2.7	2.7	2.8	2.8	2.8
Average Velocity for Each Bin (°/s)	Fig. A.1	Fig. A.3	Fig. A.5	Fig. A.7	Fig. A.9
Probe Miss Rate for Each Bin (%)	Fig. A.2	Fig. A.4	Fig. A.6	Fig. A.8	Fig. A.11
Main Effect of Object					
F	19.1	21.1	1.07	34.6	18.4
Degrees of Freedom	(1,8)	(1,5)	(1,8)	(1,9)	(1,5)
MSE	443	224	466	476	487
p	.002	.006	.331[a]	<.001	.008
η_p^2	.71	.81	.12	.79	.79
Main Effect of Location					
F	44.7	88.4	17.9	30.7	30.6
Degrees of Freedom	(1,8)	(1,5)	(1,8)	(1,9)	(1,5)
MSE	316	138	457	429	294
p	<.001	<.001	.003	<.001	.003
η_p^2	.85	.95	.69	.77	.86
Main Effect of Velocity					
F	< 1	<1	2.77	<1	<1
Degrees of Freedom	(2,16)	(2,10)	(2,16)	(2,18)	(1,5)[b]
MSE	384	800	466	113	341
p	.990	.445	.092	.725	.700
η_p^2	<.00	.15	.26	.04	.03
Interaction (Location x Velocity)					
F	< 1	<1	<1	1.2	2.6
Degrees of Freedom	(2,16)	(2,10)	(2,16)	(2,18)	(1,5)
MSE	279	756	292	153	54
p	.801	.701	.424	.336	.169
η_p^2	.03	.07	.10	.11	.34

a. The main effect of object was significant when the more liberal criterion for tracking accuracy was used to increase the number of probes included in this analysis as described in the text ($F(1,9) = 20.5$, $MSE = 121$, $p = .001$, $\eta_p^2 = .70$).
b. The number of long near center and short endpoint probes was too small to include the fastest velocity in this analysis

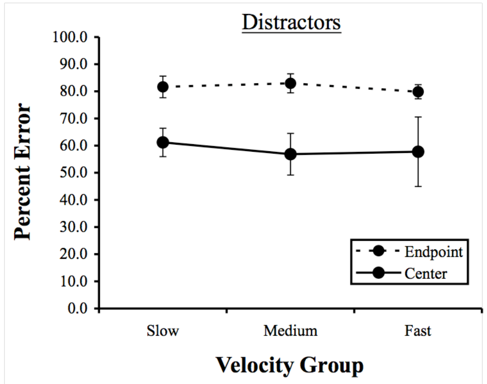

Figure A.2. ***Probe detection performance for each velocity group in Experiment 1***. There was no overall effect of the velocity at which the probe position moved, and the difference between center and endpoint miss rates was constant across the range of velocities for both targets and distractors. Thus, even when the velocities of center and endpoint probes are matched, there is an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

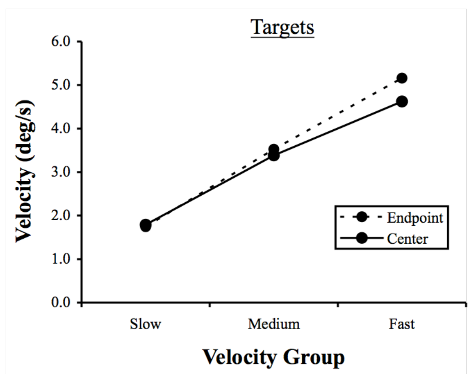

Figure A.3. ***Mean velocity for each velocity group in Experiment 2***. The trials were binned into groups based on the velocity of the probe position (from 215 ms prior until the offset of the probe). Endpoint and center probes within each group were well matched for velocity. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

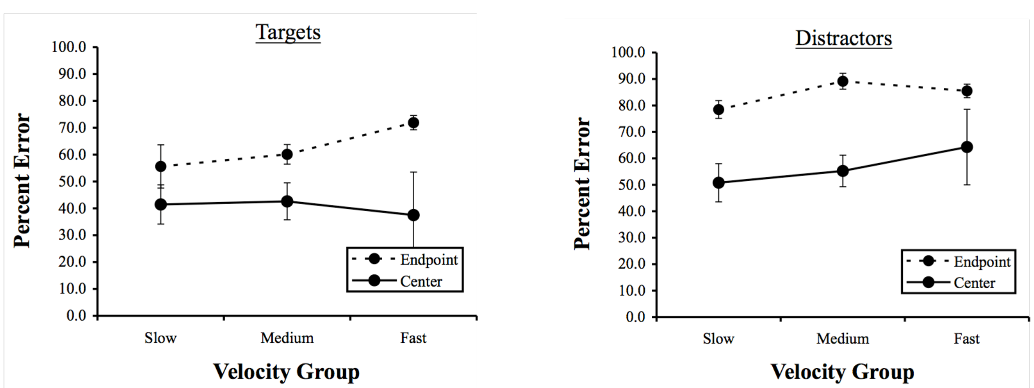

Figure A.4. ***Probe detection performance for each velocity group in Experiment 2***. There was no overall effect of the velocity at which the probe position moved, and the difference between center and endpoint miss rates was constant across the range of velocities for both targets and distractors. Thus, even when the velocities of center and endpoint probes are matched, there is an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

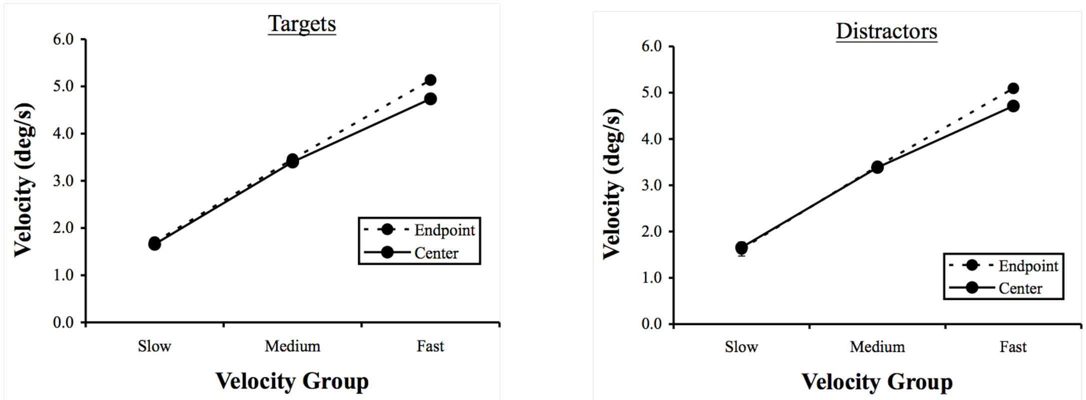

Figure A.5. ***Mean velocity for each velocity group in Experiment 3***. The trials were binned into groups based on the velocity of the probe position (from 215 ms prior until the offset of the probe). Endpoint and center probes within each group were well matched for velocity. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

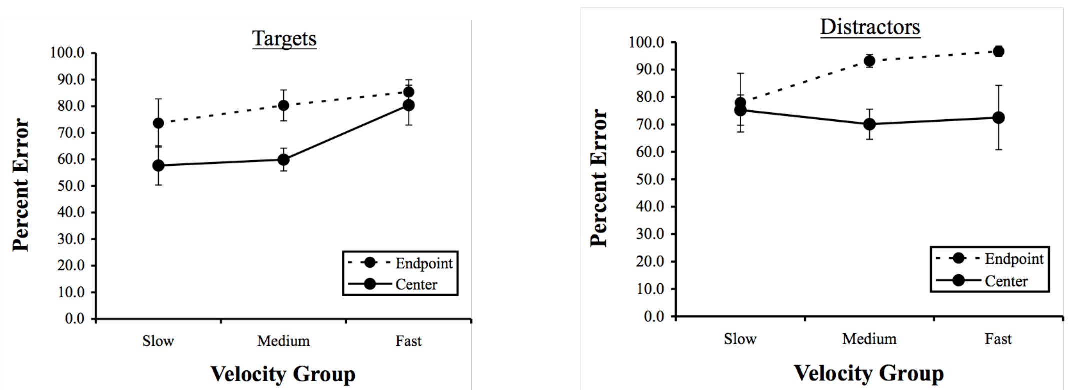

Figure A.6. ***Probe detection performance for each velocity group in Experiment 3***. There was no overall effect of the velocity at which the probe position moved. The difference between center and endpoint probes was less consistent across velocity groups than in the other experiments. However, overall the difference between center and endpoint probes was significant even when the velocities of center and endpoint probes are matched, there is an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

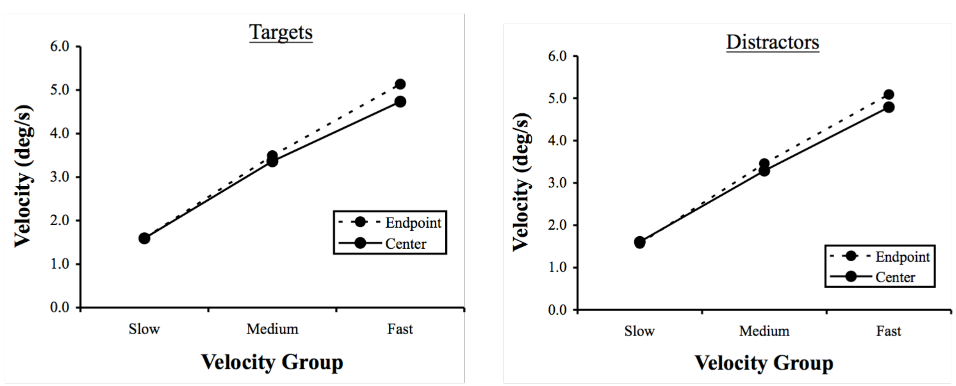

Figure A.7. ***Mean velocity for each velocity group in Experiment 4 (center vs. endpoint analysis)***. The trials were binned into groups based on the velocity of the probe position (from 215 ms prior until the offset of the probe). Endpoint and center probes within each group were well matched for velocity. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

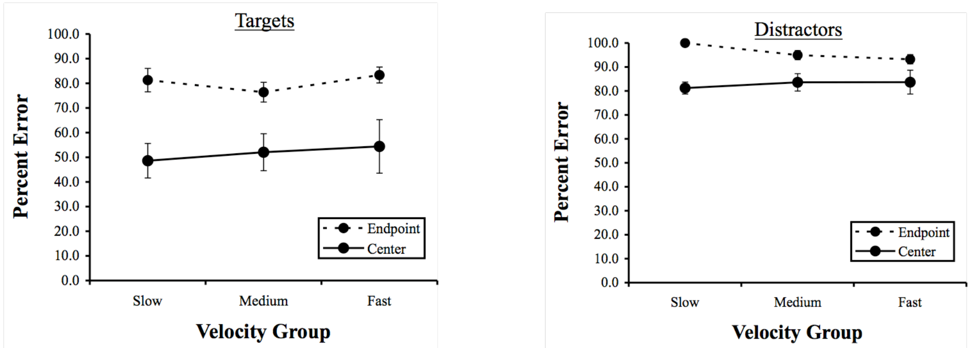

Figure A.8. ***Probe detection performance for each velocity group in Experiment 4 (center vs. endpoint analysis)***. There was no overall effect of the velocity at which the probe position moved, and the difference between center and endpoint miss rates was constant across the range of velocities for both targets and distractors. Thus, even when the velocities of center and endpoint probes are matched, there is an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

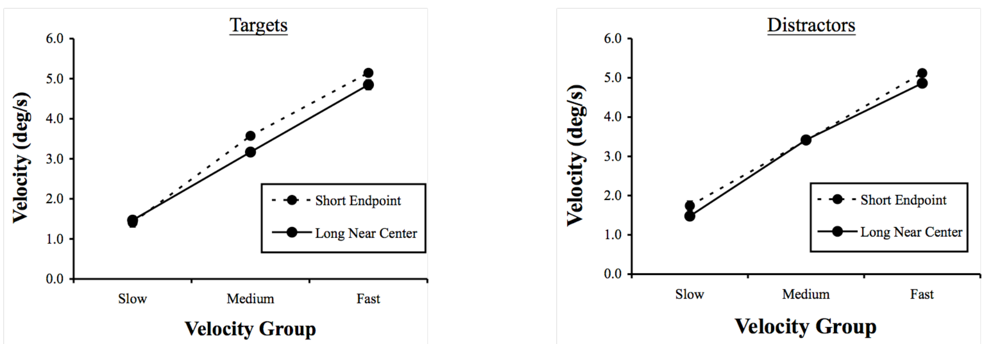

Figure A.9. ***Mean velocity for each velocity group in Experiment 4 (long near center vs. short endpoint analysis)***. The trials were binned into groups based on the velocity of the probe position (from 215 ms prior until the offset of the probe). Short endpoint and long near center probes within each group were well matched for velocity. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

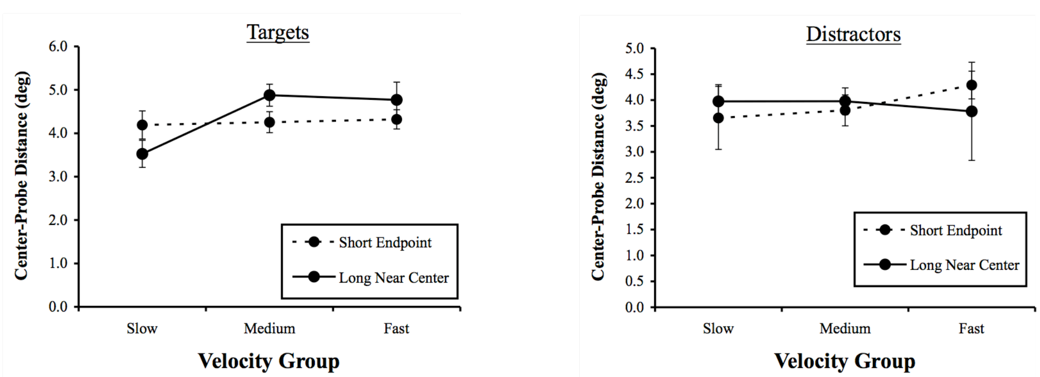

Figure 10. ***Mean center-probe distance for each velocity group in Experiment 4 (long near center vs. short endpoint analysis)***. Short endpoint and long near center probes within each group remained well matched for distance between the center of the line and the probe after binning into velocity groups. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

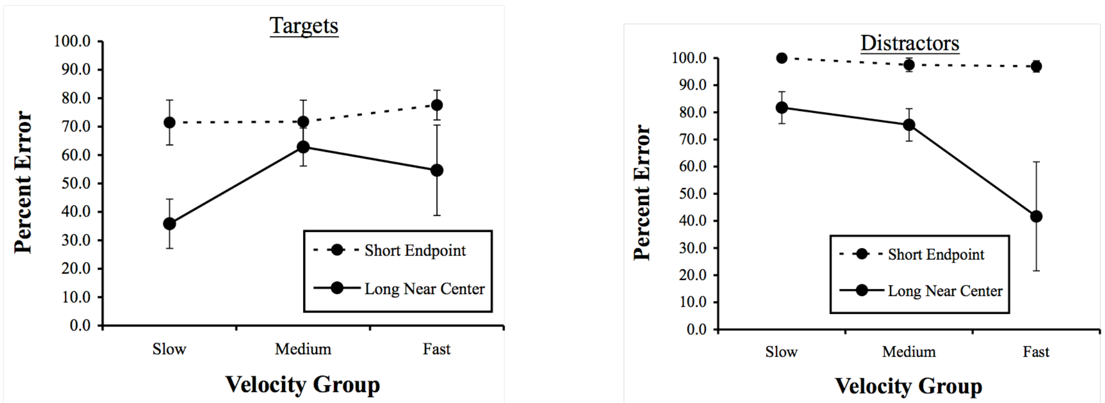

Figure 11. ***Probe detection performance for each velocity group in Experiment 4 (long near center vs. short endpoint analysis).*** There was no overall effect of the velocity at which the probe position moved, and the difference between long near center and short endpoint miss rates was present across the range of velocities for both targets and distractors. Thus, even when the velocities of long near center and short endpoint probes are matched, there is an object relative attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

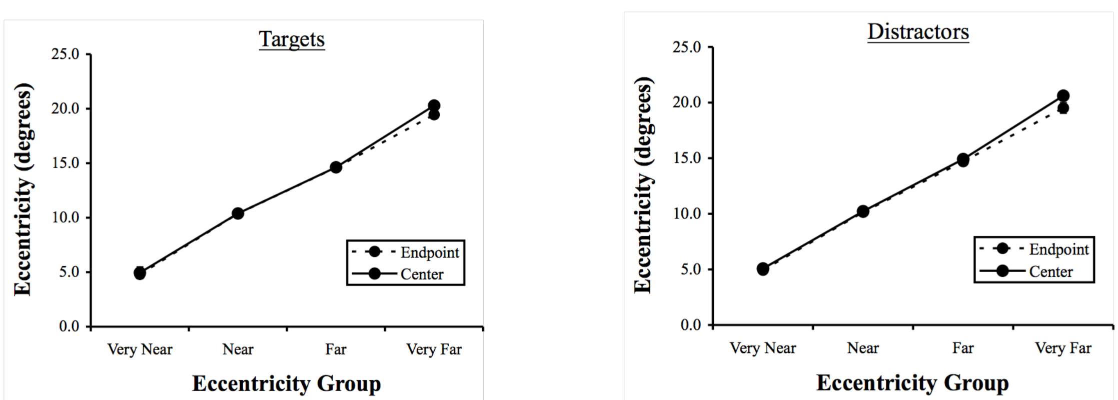

Figure 12. ***Mean Eccentricity for each eccentricity group in Experiment 1***. The trials were binned into groups based on the distance from fixation to the probe onset position. Endpoint and center probes within each group were well matched for distance from fixation. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

but is reduced at far positions (possibly due to a floor effect). Figure A.13 shows probe detection miss rates for both targets and distractors. A 2 x 2 x 4 ANOVA was run on miss rates with object (target vs. distractor), location (center vs. endpoint), and distance (Very Near, Near, Far, Very Far) as factors. Miss rates were higher for distractor probes than target probes (main effect of object, $F(1,9) = 30.71$, $MSE = 516$, $p < .001$, $\eta_p^2 = .77$). Miss rates for endpoint probes were higher than for center probes (main effect of location, $F(1,9) = 11.40$, $MSE = 489$, $p = .008$, $\eta_p^2 = .56$). Finally, miss rates increased with distance from fixation ($F(3,27) = 33.11$, $MSE = 419$, $p < .001$, $\eta_p^2 = .79$). Critically, none of the interactions were significant (all Fs < 1.5, all ps > .05). Thus, the effect of probe location (center vs. endpoint) does not interact significantly with distance from fixation (location x distance ($F(3,27) < 1$).

The equivalent data for Experiments 2 through 4 are presented in Table A.2 and Figures A.14-A.19, and similar data for the long near center and short endpoint results of Experiment 4 are presented in Table A.2 and Figures A.20-A.22. The results for these experiments are the same as those for Experiment 1 with one important exception: The center/endpoint difference was marginally significant in Experiment 2 (p = .06). However, this lack of significance appears to be due to the relatively noisy data resulting from the low probability of center probes in this experiment. When the more liberal criterion for including probes was used, the center/endpoint difference was more robust and significant (p = .008). Most importantly, the effect of probe location (center vs. endpoint) did not interact significantly with eccentricity in any of these experiments. Thus, we conclude that attentional concentration is the result of the probe position within the object, rather than the location of the probe relative to fixation.

DENSITY EFFECTS

How does the distance between targets and distractors affect probe detection accuracy? For example, when a distractor is nearby, is more attention devoted to targets (perhaps to boost selection, which might aid probe sensitivity), or is there interference between the target and distractor (that perhaps reduces probe sensitivity)? In this analysis we determined the average distance between each probe and the nearest part of each other object. Trials were binned according to the average distance between the probe and each object into Near, Medium, and Far categories corresponding to 0°-7°, 7°-14°, and greater than 14°, respectively. Of principal interest was whether the average distance to targets has an effect on distractor probe detection, and whether the average distance to distractors has an effect on target probe detection.

Figure A.23 shows percent error for target probes as a function of the average distance to distractor lines, and the percent error for distractor probes as a function of the average distance to target lines. The results indicate that miss rates for distractor probes decreased as the distance to the targets decreased. Similarly, miss rates for target probes decreased as the distance to the distractors decreased. A 2 x 3 ANOVA on distractor probe miss rate was performed with location (center vs. endpoint) and distance to the targets (Near, Medium, Far) as factors. Miss rates were higher for endpoint probes than for center probes (main effect of location, $F(1,9) = 52.49$, $MSE = 108$, $p < .001$, $\eta_p^2 = 85$). Miss rates increased significantly with distance from targets ($F(2,18) = 21.50$, $MSE = 243$, $p = .001$, $\eta_p^2 = .71$), but the interaction between location and distance was not significant ($F(2,18) < 1$). A separate 2 x 3 ANOVA was run on target probe miss rate with location (center vs. endpoint) and distance to the distractors (Near, Medium, Far) as factors. Miss rates were higher for endpoint probes than for center probes (main effect of location, $F(1,9) = 12.90$, $MSE = 771$, $p = .006$, $\eta_p^2 = .59$), miss rates increased significantly with distance ($F(2,18) = 6.47$, $MSE = 296$, $p = .008$, $\eta_p^2 = .42$), and the interaction between location and distance was not significant ($F(2,18) < 1$).

This pattern of results was also qualitatively replicated in several additional analyses (not reported here, to save space) in which the following distance measures were used: distance from the probe to the nearest part of other lines; distance from the probe to the nearest center of other lines; average distance from the probe to the center of the other lines; or the shortest distance from the probed line (rather than the probe itself) to the other lines.

The equivalent data for Experiments 2 through 4 are presented in Tables A.3-A.4 and Figures A.24-A.26. The results for these experiments are the same as those for Experiment 1 with one notable exception: the effect of distractor proximity was not significant for target probes in Experiment 4, and this lack of significance does not appear to be due to noisy data as the results are identical when the more liberal criterion for including probes was used.

Overall, miss rates for the detection of distractor probes decreased as the distance between the probe and the targets decreased. Thus, it appears that the distractor lines receive more attention the closer they are to target lines (or are more strongly inhibited the further they are from the target lines). In addition, however, miss rates for the detection of target probes decreased as the distance between the probe and the nearest distractor decreased. These results are collec-

Table A.2. ***Eccentricity Analyses for Each Experiment***. The first analysis for Experiment 4 (4_1) is on endpoint vs. center probes, and the second (4_2) is on short endpoint vs. long near center probes. These analyses employed the same eccentricity bins as described in the text for Experiment 1.

	Experiment				
Analysis Category	1	2	3	4_1	4_2
Average Endpoint Probe Eccentricity (°)	197	197	197	195	172
Average Center Probe Eccentricity (°)	136	131	146	147	134
Average Eccentricity for Each Bin (°)	Fig. A.12	Fig. A.14	Fig. A.16	Fig. A.18	Fig. A.20
Probe Miss Rate for Each Bin (%)	Fig. A.13	Fig. A.15	Fig. A.17	Fig. A.19	Fig. A.22
Main Effect of Object					
F	30.7	32.8	19.1	22.5	33.3
Degrees of Freedom	(1,9)	(1,4)	(1,6)	(1,8)	(1,8)
MSE	516	328	159	732	671
p	<.001	.005	.005	.001	<.001
η_p^2	.77	.89	.76	.74	.81
Main Effect of Location					
F	11.4	6.8	9.1	47.6	11.6
Degrees of Freedom	(1,9)	(1,4)	(1,6)	(1,8)	(1,8)
MSE	489	281	685	202	870
p	.008	.059 [a]	.024	<.001	.009
η_p^2	.56	.63	.60	.86	.59
Main Effect of Eccentricity					
F	33.1	31.7	18.6	5.4	30.2
Degrees of Freedom	(3,27)	(3,12)	(3,18)	(3,24)	(2,16) [b]
MSE	419	203	350	405	195
p	<.001	<.001	.000	.006	<.001
η_p^2	.79	.89	.76	.40	.79
Interaction (Location x Eccentricity)					
F	< 1	<1	2.7	<1	<1
Degrees of Freedom	(3,27)	(3,12)	(3,18)	(3,24)	(2,16)
MSE	379	463	222	335	824
p	.637	.643	.075	.861	.531
η_p^2	.06	.13	.31	.03	.08

a. The main effect of location was significant when the more liberal criterion for tracking accuracy was used to increase the number of probes included in this analysis ($F(1,6) = 15.4$, $MSE = 198$, $p = .008$, $\eta_p^2 = .72$).
b. The number of long near center and short endpoint probes was too small to include the furthest eccentricity in this analysis.

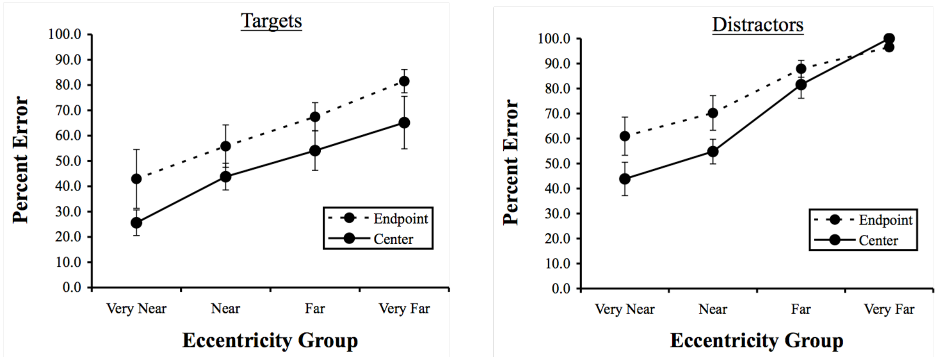

Figure A.13. ***Probe detection performance for each eccentricity group in Experiment 1***. Probe detection miss rates increased as the distance from fixation increased, but the difference between center and endpoint miss rates was roughly constant across the range of eccentricities for targets. The difference between centers and endpoints was large for distractors that were near fixation, but decreased with eccentricity, most likely due to a floor effect. Thus, even when the eccentricities of center and endpoint probes were matched, there was an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

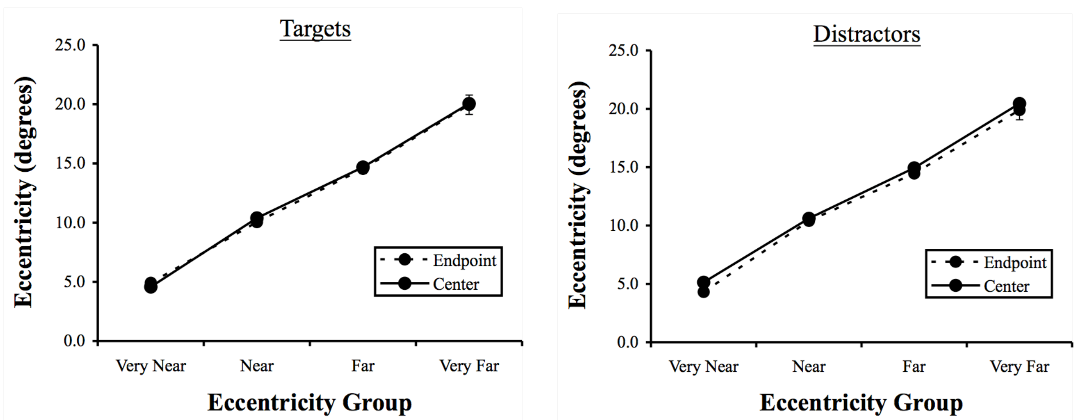

Figure A.14. ***Mean Eccentricity for each eccentricity group in Experiment 2***. The trials were binned into groups based on the distance from fixation to the probe onset position. Endpoint and center probes within each group were well matched for distance from fixation. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

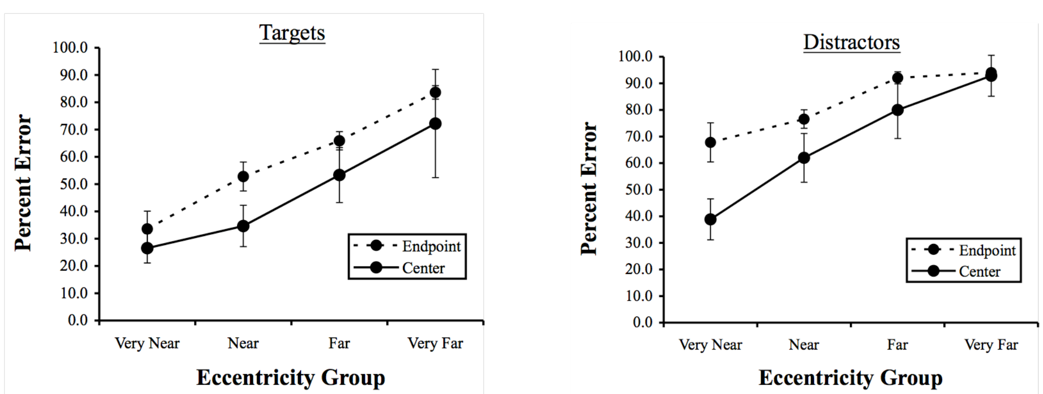

Figure A.15. ***Probe detection performance for each eccentricity group in Experiment 2***. Probe detection miss rates increased as the distance from fixation increased, but the difference between center and endpoint miss rates was roughly constant across the range of eccentricities for targets. The difference between centers and endpoints was large for distractors that were near fixation, but decreased with eccentricity, most likely due to a floor effect. Thus, even when the eccentricities of center and endpoint probes were matched, there was an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

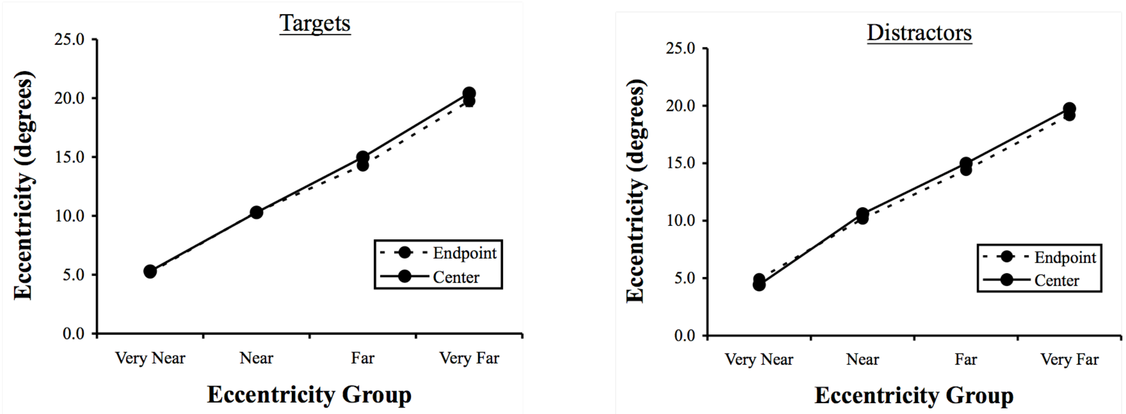

Figure A.16. ***Mean Eccentricity for each eccentricity group in Experiment 3***. The trials were binned into groups based on the distance from fixation to the probe onset position. Endpoint and center probes within each group were well matched for distance from fixation. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

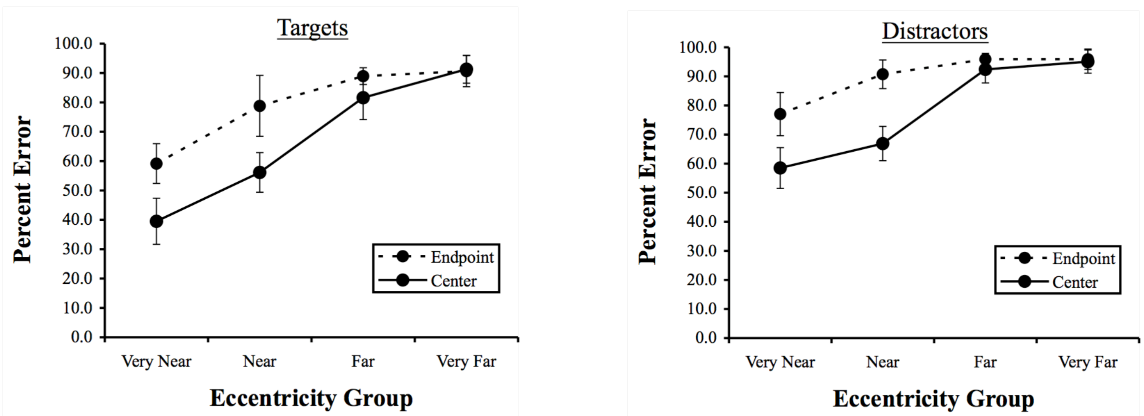

Figure A.17. ***Probe detection performance for each eccentricity group in Experiment 3***. Probe detection miss rates increased as the distance from fixation increased. The difference between center and endpoint miss rates for both targets and distractors was large for probes that were near fixation, but decreased with eccentricity, most likely due to a floor effect. Thus, even when the eccentricities of center and endpoint probes were matched, there was an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

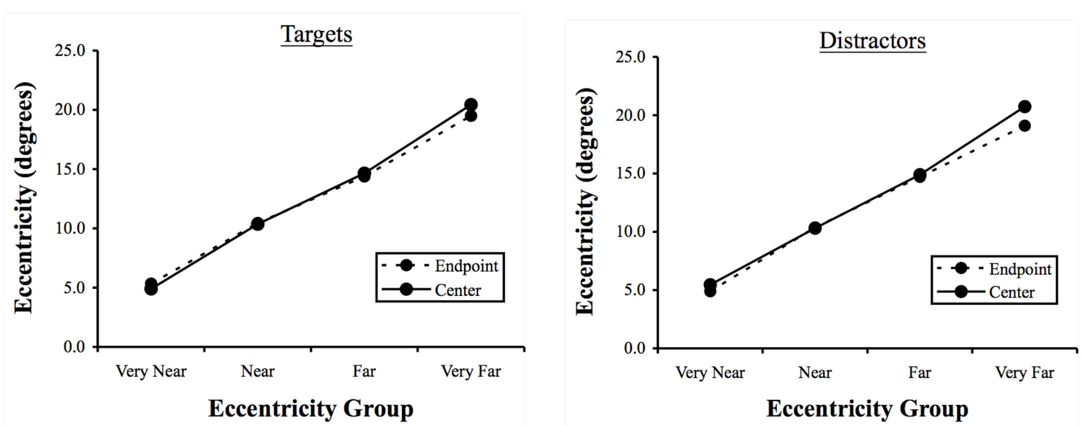

Figure A.18. ***Mean Eccentricity for each eccentricity group in Experiment 4 (center vs. endpoint analysis)***. The trials were binned into groups based on the distance from fixation to the probe onset position. Endpoint and center probes within each group were well matched for distance from fixation. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

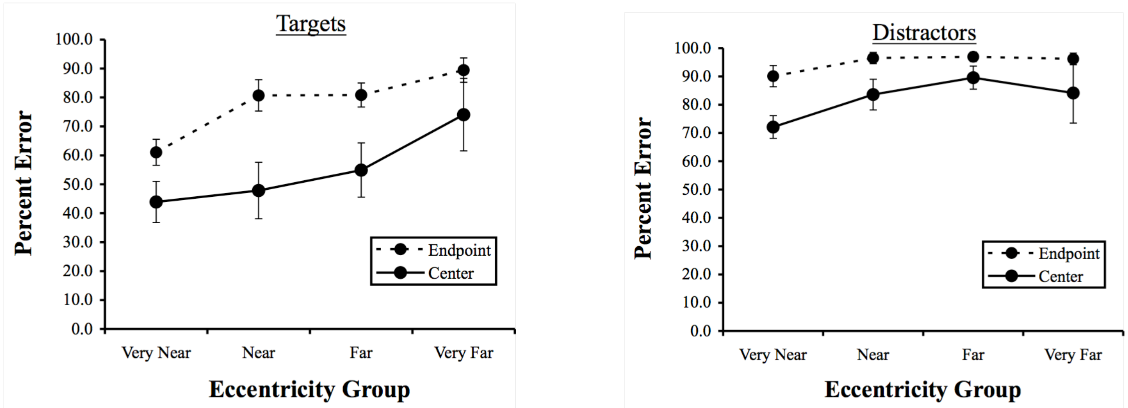

Figure A.19. ***Probe detection performance for each eccentricity group in Experiment 4 (center vs. endpoint analysis).*** Probe detection miss rates increased as the distance from fixation increased, but the difference between center and endpoint miss rates was roughly constant across the range of eccentricities for targets. The difference between centers and endpoints was large for distractors that were near fixation, but decreased with eccentricity, most likely due to a floor effect. Thus, even when the eccentricities of center and endpoint probes were matched, there was an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

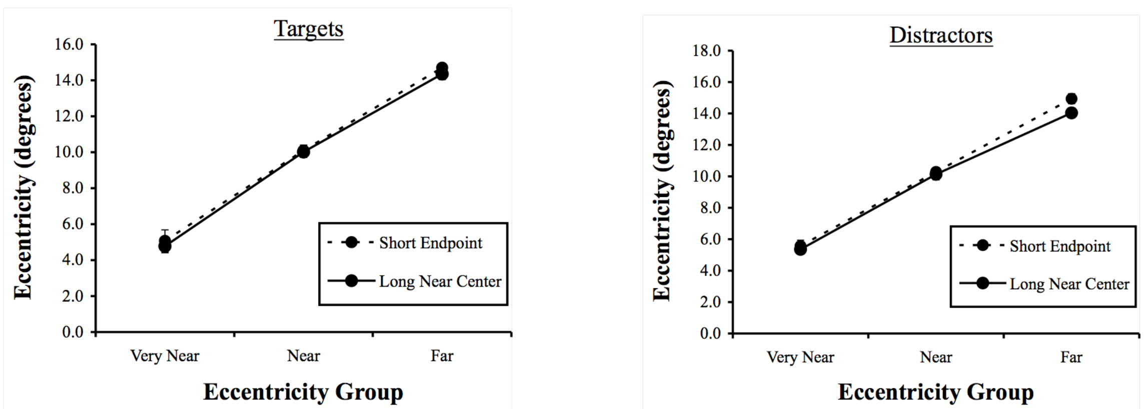

Figure A.20. ***Mean Eccentricity for each eccentricity group in Experiment 4 (long near center vs. short endpoint analysis)***. The trials were binned into groups based on the distance from fixation to the probe onset position. Short endpoint and long near center probes within each group were well matched for distance from fixation. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

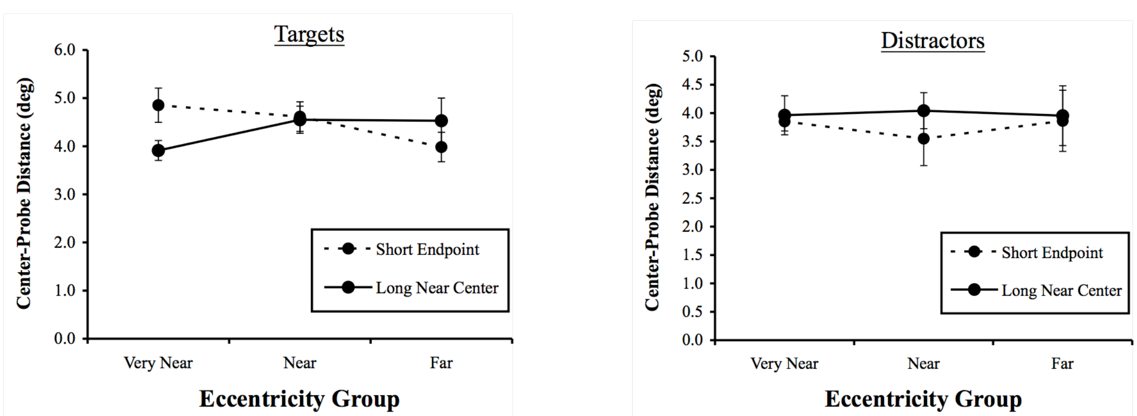

Figure 21. ***Mean center-probe distance for each eccentricity group in Experiment 4 (long near center vs. short endpoint analysis).*** Short endpoint and long near center probes within each group remained well matched for distance between the center of the line and the probe after binning into eccentricity groups. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

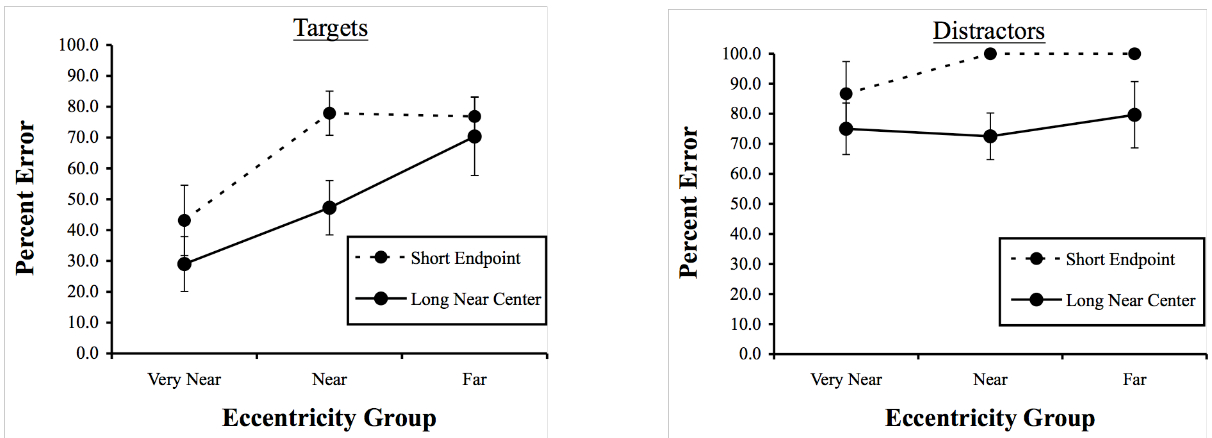

Figure 22. ***Probe detection performance for each eccentricity group in Experiment 4 (long near center vs. short endpoint analysis)***. Probe detection miss rates increased as the distance from fixation increased, but the difference between long near center and short endpoint miss rates was present across the range of eccentricities for targets. Thus, even when the eccentricities of long near center and short endpoint probes were matched, there was an attentional concentration effect. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

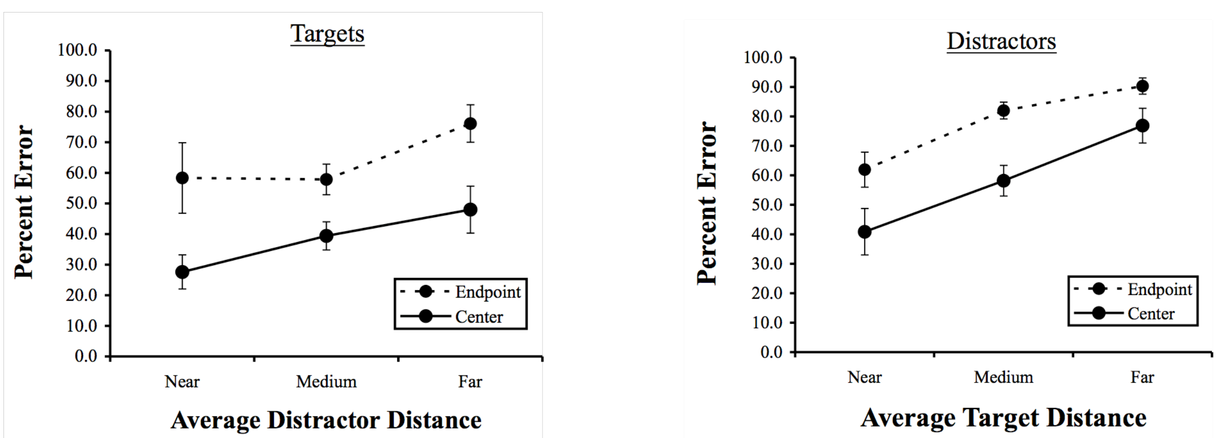

Figure 23. ***Probe detection performance as a function of target-distractor distance in Experiment 1***. The closer targets were to distractors, the lower the miss rate. Similarly, the closer the distractors were to targets the lower the miss rate. The effect of distance was comparable for center probes and endpoint probes for both targets and distractors. Thus, it appears that when targets and distractors were in close proximity to each other, they both received more attention (at the center and the endpoints) than when they were far apart. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

Table A.3. ***Density Analyses for Target Probes in Each Experiment***. These analyses employed the same distance bins as described in the text for Experiment 1.

	Experiment			
Analysis Category	1	2	3	4
Probe Miss Rate for Each Bin (%)	Fig. A.23	Fig. A.24	Fig. A.25	Fig. A.26
Main Effect of Location				
F	12.9	20.8	6.9	23.1
Degrees of Freedom	(1,9)	(1,8)	(1,8)	(1,9)
MSE	771	335	501	584
p	.006	.002	.031	.001
η_p^2	.59	.72	.46	.72
Main Effect of Distance-to-Distractors				
F	6.5	7.8	11.2	<1
Degrees of Freedom	(2,18)	(2,16)	(2,16)	(2,18)
MSE	296	525	471	412
p	.008	.004	.001	.760
η_p^2	.42	.49	.58	.03
Interaction (Location x Distance-to-Distractors)				
F	<1	<1	<1	<1
Degrees of Freedom	(2,18)	(2,16)	(2,16)	(2,18)
MSE	625	474	388	203
p	.719	.488	.750	.725
η_p^2	.04	.09	.04	.04

Table A.4. ***Density Analyses for Distractor Probes in Each Experiment***. These analyses employed the same distance bins as described in the text for Experiment 1.

	Experiment			
Analysis Category	1	2	3	4
Probe Miss Rate for Each Bin (%)	Fig. A.23	Fig. A.24	Fig. A.25	Fig. A.26
Main Effect of Location				
F	52.5	26.5	15.3	52.6
Degrees of Freedom	(1,9)	(1,8)	(1,9)	(1,9)
MSE	108	466	272	83
p	<.001	.001	.004	<.001
η_p^2	.85	.77	.63	.85
Main Effect of Distance-to-Targets				
F	21.5	32.6	3.0	29.5
Degrees of Freedom	(2,18)	(2,16)	(2,18)	(2,18)
MSE	243	208	203	48
p	<.001	<.001	.078	<.001
η_p^2	.71	.80	.25	.77
Interaction (Location x Distance-to-Targets)				
F	<1	3.1	5.1	27.4
Degrees of Freedom	(2,18)	(2,16)	(2,18)	(2,18)
MSE	334	451	295	80
p	.655	.071	.017	<.001
η_p^2	.05	.28	.36	.75

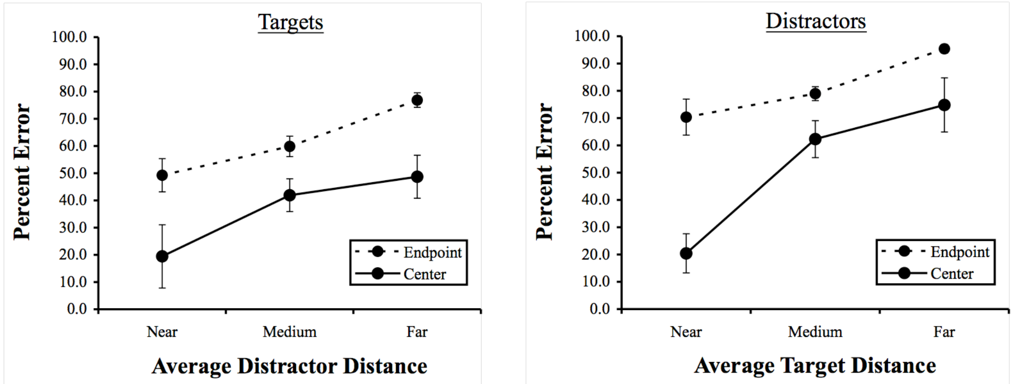

Figure A.24. ***Probe detection performance as a function of target-distractor distance in Experiment 2***. The closer targets were to distractors, the lower the miss rate. Similarly, the closer the distractors were to targets the lower the miss rate. The effect of distance was comparable for center probes and endpoint probes for targets, but appears to be larger for center probes than endpoint probes for distractors. Thus, it appears that when targets and distractors were in close proximity to each other, they both received more attention (at the center and the endpoints) than when they were far apart. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

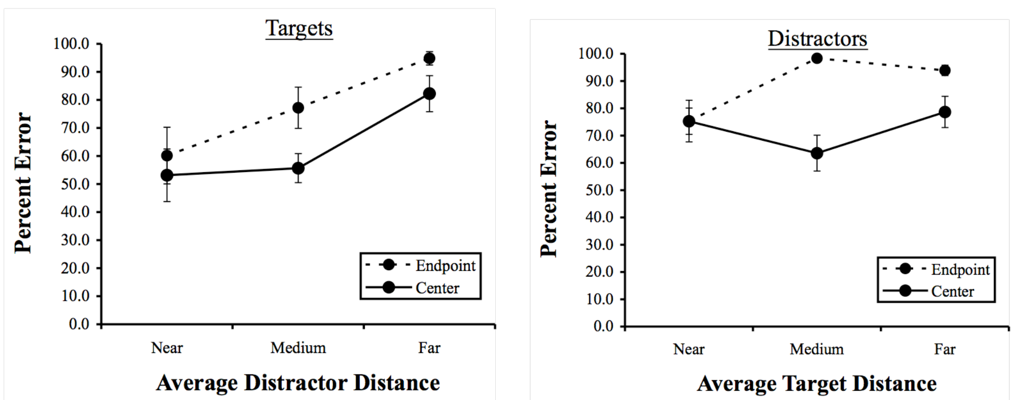

Figure A.25. ***Probe detection performance as a function of target-distractor distance in Experiment 3***. The closer targets were to distractors, the lower the miss rate. Similarly, the closer the distractors were to targets the lower the miss rate (at least for endpoint probes). The effect of distance was comparable for center probes and endpoint probes of targets, but appears to be larger for endpoints than for centers of distractors. Thus, it appears that when targets and distractors were in close proximity to each other, they both received more attention (at the center and the endpoints) than when they were far apart. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

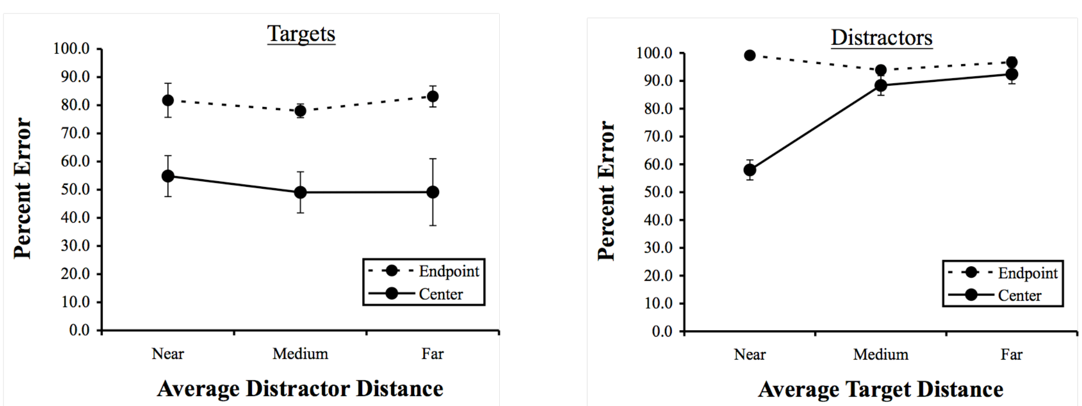

Figure A.26. ***Probe detection performance as a function of target-distractor distance in Experiment 4***. The proximity of distractors appeared to have little effect on miss rates for targets. In contrast, the closer the distractors were to targets the lower the miss rate for distractor center probes. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

tively surprising because they show that more probes are detected when targets and distractors are close to each other than when they are far apart — regardless of whether the probe appears on a target or a distractor. Thus more attention is paid to both targets and distractors when they are close to each other, resulting in improved probe detection on both. This suggests that relatively greater attention is required to select targets and maintain tracking in locally denser displays, which leads to better probe detection for both targets and distractors.

INTERSECTION EFFECTS

Because each line endpoint moved independently in our displays, the lines themselves frequently intersected each other. This analysis investigates whether the detection of target probes depends on the number of distractor lines intersecting the target line, and similarly whether the detection of distractor probes depends on the number of target lines intersecting the distractor line. There were very few instances in which the probed line intersected three other lines (e.g., a target line rarely intersected all 3 distractor lines), so the analysis focuses on trials with 0, 1, or 2 intersections.

As shown in Figure A.27, when the probe occurred on a target line, miss rates increased on endpoints and decreased on centers as the number of intersecting distractors increased. In contrast, there was little effect of the number of intersecting targets on distractor probe miss rates. A 2 x 3 ANOVA was run on target probe miss rates with location (center vs. endpoint) and number of distractor intersections (0, 1, or 2) as factors. Miss rates were significantly higher on endpoints than centers (main effect of location, $F(1,9) = 26.29$, $MSE = 552$, $p = .001$, $\eta_p^2 = .75$). The main effect of the number of intersections was not significant ($F(2,18) < 1$). However, the interaction between location and the number of intersections was significant ($F(2,18) = 3.67$, $MSE = 394$, $p = .046$, $\eta_p^2 = .29$), which is consistent with the observation that endpoint miss rates increased and center miss rates decreased as the number of intersecting distractors increased. A separate 2 x 3 ANOVA was run on distractor probe miss rates with location (center vs. endpoint) and number of target intersections (0, 1, or 2) as factors. Miss rates were significantly higher on endpoints than centers (main effect of location, $F(1,9) = 19.28$, $MSE = 353$, $p = .002$, $\eta_p^2 = .68$). Miss rates were not effected by the number of target intersections ($F(2,18) = 1.45$, $MSE = 387$, $p = .260$, $\eta_p^2 = .14$), and the interaction between location and the number of target intersections was not significant ($F(2,18) < 1$).

The data for Experiments 2 through 4 are presented in Tables A.5-6 and Figures A.28-A.30. The results for these experiments differ from those in Experiment 1. The effect of number of intersections on target probe detection is marginal in Experiment 2 ($p = .06$), and not significant in Experiments 3 and 4.

The number of lines intersecting the probed line did not have a large effect on distractor probe detection rates, but it did increase the concentration of attention near the center of target lines significantly in Experiment 1. It may be that a greater number of intersections of this type gives rise to a higher perceptual load, which in turn requires additional processing to maintain selection and tracking of the targets. If so, then these results would seem to be consistent with those for the targets in the previous density analysis: whenever the processing load is increased — by either a greater number of nearby distractors or a greater number of intersecting distractors, then greater resources are required to maintain selection, leading to a greater concentration effect.

Note, however that nearby distractors seem to facilitate probe detection for all target points, while intersecting distractors seem to facilitate only target centers (and inhibit target ends, thus increasing the concentration effect). This difference remains somewhat puzzling, but could perhaps be explained by appeal to the spread of attention into intersecting lines: because our lines were thin and featurally identical, there were no depth cues at the points of intersection, and perhaps local processes may treat such intersections as contours of a single object, through which attention may spread. This would mean that nearby distractors could be effectively selected against simply by increasing attention to the target lines as a whole, whereas doing this with intersecting distractor lines would just increase this attentional 'bleeding' into the distractors. A solution would be to increase the concentration to just a single point in the target lines in the face of multiple intersecting distractors. This finding that this effect was only marginal in Experiment 2, and absent from Experiments 3 and 4, might indicate that the incentive or requirement to attend to endpoints may counteract this strategy. In any case, further research (perhaps using displays with depth cues) is clearly necessary to determine the reasons for these differences.

TEMPORAL DYNAMICS

In this final auxiliary analysis we investigated how *changes* in line length affect probe detection, as an initial exploration of the temporal dynamics of the attentional concentration effect. Can the recent history of a line's behavior — e.g. whether it was growing or

Table A.5. ***Intersection Analyses for Target Probes in Each Experiment***. These analyses examined the effect of distractor intersections on target probe detection as described in the text for Experiment 1.

	Experiment			
Analysis Category	1	2	3	4
Probe Miss Rate for Each Bin (%)	Fig. A.27	Fig. A.28	Fig. A.29	Fig. A.30
Main Effect of Location				
F	26.3	29.2	11.5	44.8
Degrees of Freedom	(1,9)	(1,8)	(1,9)	(1,9)
MSE	552	278	566	314
p	.001	.001	.008	<.001
η_p^2	.75	.79	.56	.83
Main Effect of Distractor Intersections				
F	<1	2.4	2.1	<1
Degrees of Freedom	(2,18)	(2,16)	(2,18)	(2,18)
MSE	202	424	128	520
p	.818	.120	.153	.990
η_p^2	.02	.23	.19	<.00
Interaction (Location x Distractor Intersections)				
F	3.7	3.3	< 1	<1
Degrees of Freedom	(2,18)	(2,16)	(2,18)	(2,18)
MSE	394	517	347	478
p	.046	.062	.909	.913
η_p^2	.29	.29	.01	.01

Table A.6. ***Intersection Analyses for Distractor Probes in Each Experiment***. These analyses examined the effect of target intersections on distractor probe detection as described in the text for Experiment 1.

	Experiment			
Analysis Category	1	2	3	4
Probe Miss Rate for Each Bin (%)	Fig. A.27	Fig. A.28	Fig. A.29	Fig. A.30
Main Effect of Location				
F	19.3	23.6	9.3	18.2
Degrees of Freedom	(1,9)	(1,9)	(1,4)	(1,9)
MSE	353	584	454	233
p	.002	.001	.038	.002
η_p^2	.68	.72	.70	.67
Main Effect of Target Intersections				
F	1.5	2.1	<1	<1
Degrees of Freedom	(2,18)	(2,18)	(2,8)	(2,18)
MSE	387	754	111	276
p	.260	.156	.412	.506
η_p^2	.14	.19	.20	.07
Interaction (Location x Target Intersections)				
F	<1	1.3	1.1	1.4
Degrees of Freedom	(2,18)	(2,18)	(2,8)	(2,18)
MSE	288	332	114	315
p	.667	.290	.375	.272
η_p^2	.04	.13	.22	.14

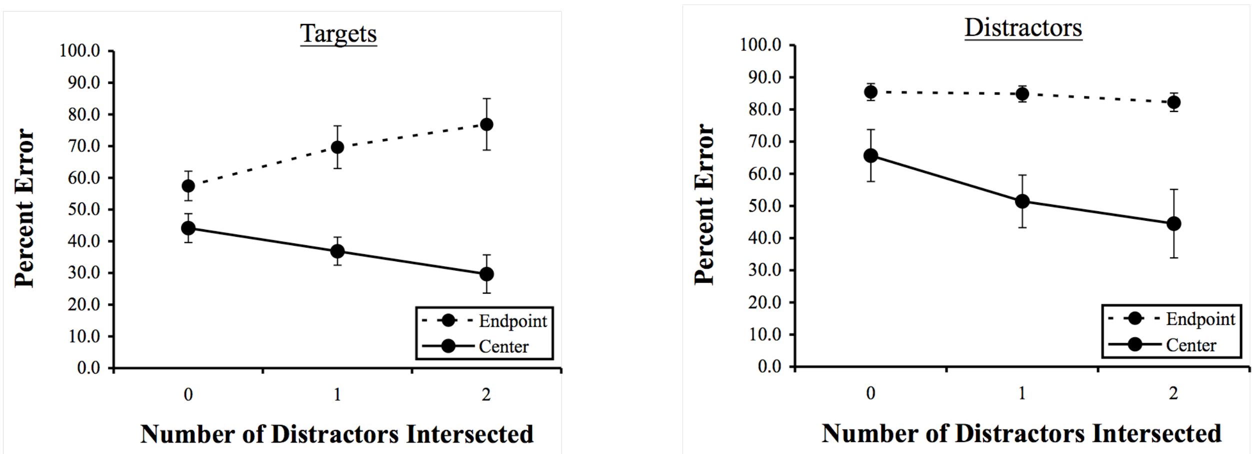

Figure A.27. ***Probe detection performance as a function of the number of target-distractor intersections in Experiment 1***. For target probes, as the number of distractors intersecting the target line increased, miss rates for center probes decreased whereas miss rates for endpoint probes increased. In contrast, for distractor probes, center probe and endpoint probe miss rates both declined slightly as the number of intersecting targets lines increased. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

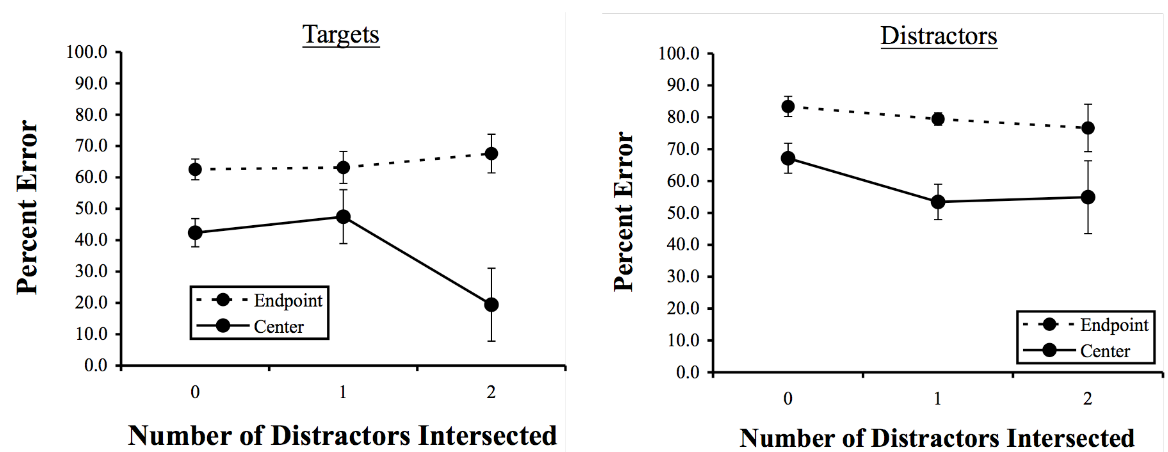

Figure A.28. ***Probe detection performance as a function of the number of target-distractor intersections in Experiment 2***. For target probes, as the number of distractors intersecting the target line increased, miss rates for center probes decreased whereas miss rates for endpoint probes increased slightly. In contrast, for distractor probes, center probe and endpoint probe miss rates both declined slightly as the number of intersecting targets lines increased. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

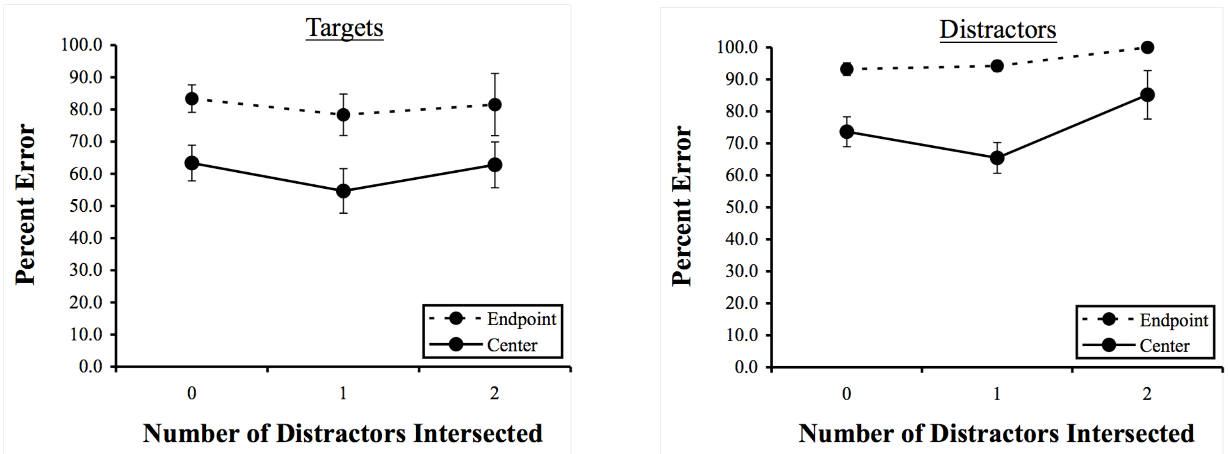

Figure A.29. ***Probe detection performance as a function of the number of target-distractor intersections in Experiment 3***. There was little effect of target-distractor intersections in this experiment. For target probes, miss rates were roughly constant as the number of distractors intersecting the target line increased. For distractor probes, center probe and endpoint probe miss rates both increased slightly as the number of intersecting targets lines increased. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

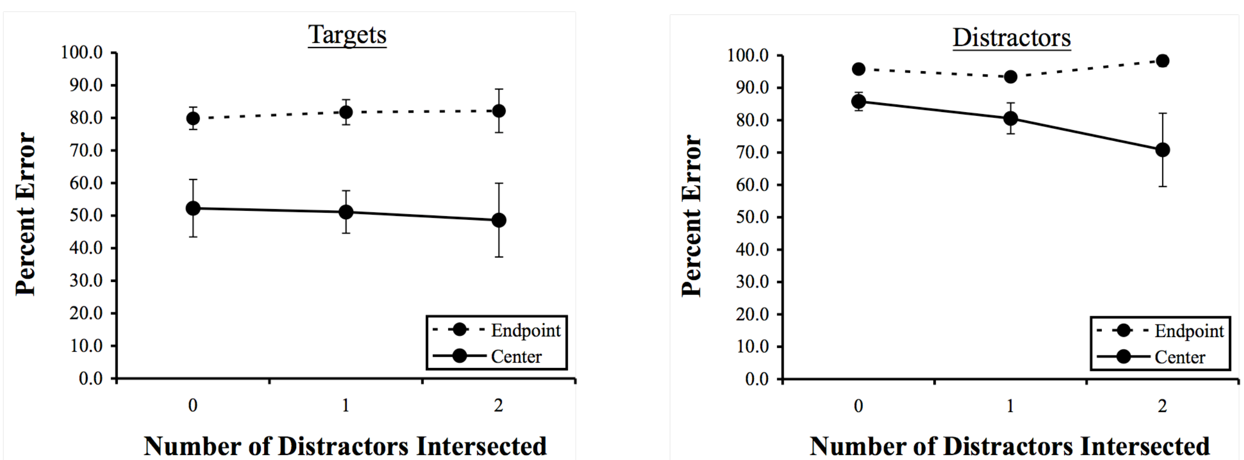

Figure A.30. ***Probe detection performance as a function of the number of target-distractor intersections in Experiment 4***. There was little effect of target-distractor intersections in this experiment. For target probes, miss rates were roughly constant as the number of distractors intersecting the target line increased. For distractor probes, center probe miss rates decreased slightly and endpoint probe miss rates were constant (near floor) as the number of intersecting targets lines increased. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

shrinking just before the probe — affect probe detection, above and beyond the length of the line during the probe? This is another question that is difficult to explore in most object-based attention paradigms, that typically employ static stimuli. Yet, in many real-world events, attention must constantly adapt to scenes that are changing because of both object motion and viewer motion. Because of this, we were eager to explore whether and how attention may adapt to *changes* in line length, beyond the steady state distribution of object-based attention on a line (be it evenly spread or concentrated at the center). (The analyses reported here constitute only a preliminary investigation of these independently-interesting issues, since our stimuli were not designed with studies of temporal dynamics in mind. We are thus studying these issues in a more focused way in current research. Nevertheless, we report these initial analyses here because they yielded some large and robust effects.)

Here we investigated whether changes in line length will affect probe detection by calculating the change in length over the 215 ms period just prior to the probe presentation. Negative values represent a decrease in length and positive values represent an increase in length. The trials were binned into 6 groups corresponding to decreases in length of 12 pixels/s or more, 6-12 pixels/s, 0-6 pixels/s, or increases in length of 0-6 pixels/s, 6-12 pixels/s, and 12 pixels/s or more.

There was a surprisingly strong effect of changes in line length on probe miss rates, although the effect seemed to be stronger for targets than for distractors (see Figure A.31). The top panel of Figure A.31 illustrates that when a target line was contracting rapidly just prior to the appearance of the probe, there was no difference in miss rates for endpoint and center probes. However, when a target line was expanding rapidly just prior to the probe, the difference between centers and endpoints was near 60%. This enormous effect is all the more surprising given that we used a relatively brief measurement period (only 215 ms) in which to assess the motion.

In contrast to this rather large difference for targets, the difference in miss rate between endpoint and center probes on distractor lines appears roughly constant as a function of the changes in line length. A 2 x 2 x 6 ANOVA was run on miss rates with object (target vs. distractor), location (center vs. endpoint), and length change velocity (Fast Contract, Medium Contract, Slow Contract, Slow Expand, Medium Expand, and Fast Expand) as factors. Miss rates were significantly lower for targets than distractors (main effect of object, $F(1,8) = 13.92$, $MSE = 1121$, $p = .006$, $\eta_p^2 = .64$). Miss rates were significantly lower for centers than endpoints (main effect of location, $F(1,8) = 19.46$, $MSE = 1564$, $p = .002$, $\eta_p^2 = .71$). Most importantly, the effect of length change velocity was also significant (main effect of length change velocity, $F(5,40) = 3.16$, $MSE = 457$, $p = .017$, $\eta_p^2 = .28$). Although the effect of length change velocity seems to be driven mainly by the target probes the interaction between object and velocity was not significant ($F(5,40) < 1$). The effect of length change velocity also seemed to be driven mainly by an increase in miss rates for target endpoints and a decrease in miss rates for target centers. This is reflected in the 3-way interaction between object, location, and length change velocity ($F(5,40) = 2.58$, $MSE = 523$, $p = .041$, $\eta_p^2 = .24$). None of the other interactions were significant (all F values < 2.0, all p values > .111).

The equivalent data for Experiments 2 through 4 are presented in Table A.7 and Figures A.32-A.34. The results for these experiments are the similar to those for Experiment 1 with two notable exceptions. First, the center/endpoint difference was marginally significant in Experiment 2 ($p = .075$), but again this lack of significance appears to be due to the relatively noisy data resulting from the low probability of center probes in this experiment. When the more liberal criterion for including probes was used, the center/endpoint difference was robust ($p = .006$). Second, the effect of velocity was weaker and not significant in Experiments 2 and 3.

Despite these inconsistencies, each analysis shows a bigger difference between target center and target endpoint miss rates for fast expanding lines than for fast contracting lines. These results suggest that the distribution of attention within objects is sensitive to changes in the spatial extent of objects. These preliminary results suggest that the current method can be used to probe the dynamic reallocation of attention on a fine time scale when attending to objects that change their size and shape

Table A.7. ***Temporal Dynamics Analyses for Each Experiment***. These analyses employed the same duration threshold and length change velocity bins as described in the text for Experiment 1.

	Experiment			
Analysis Category	1	2	3	4
Probe Miss Rate for Each Bin (%)	Fig. A.31	Fig. A.32	Fig. A.33	Fig. A.34
Main Effect of Object				
F	13.9	94.7	4.1	17.5
Degrees of Freedom	(1,8)	(1,3)	(1,6)	(1,4)
MSE	1121	54	55	1070
p	.006	.002	.088	.014
η_p^2	.64	.97	.41	.81
Main Effect of Location				
F	19.5	7.2	15.7	11.6
Degrees of Freedom	(1,8)	(1,3)	(1,6)	(1,4)
MSE	1564	2166	1259	964
p	.002	.075 [a]	.007	.027
η_p^2	.71	.71	.72	.74
Main Effect of Length Change Velocity				
F	3.2	<1	<1	<1
Degrees of Freedom	(5,40)	(5,15)	(5,30)	(5,20)
MSE	457	965	671	504
p	.017	.733	.547	.591
η_p^2	.28	.16	.12	.16
Interaction (Object x Location x Length Change Velocity)				
F	2.6	1.1	1.8	<1
Degrees of Freedom	(5,40)	(5,15)	(5,30)	(5,20)
MSE	523	428	14.7	366
p	.041	.383	.135	.534 [b]
η_p^2	.24	.28	.24	.17

a. The main effect of location was significant when the more liberal criterion for tracking accuracy was used to increase the number of probes included in this analysis as described in the text ($F(1,5) = 20.3$, $MSE = 1170$, $p = .006$, $\eta_p^2 = .80$).
b. The interaction between location and length change velocity was significant when the analysis was restricted to target probes ($F(5,30) = 2.6$, $MSE = 533$, $p = .043$, $\eta_p^2 = .31$).

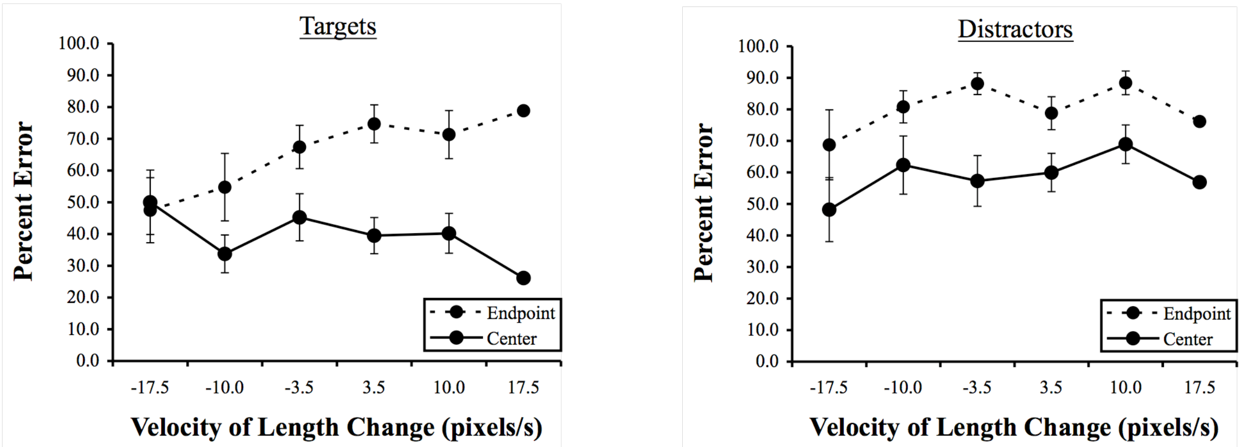

Figure A.31. ***Probe detection performance as a function of length-change velocity in Experiment 1***. The trials were binned into groups based on the velocity of line length change (negative values represent a decrease in length, positive values an increase in length). For targets, as the velocity goes from a fast decreases in line length to a fast increases in line length, miss rates for center probes decrease whereas miss rates for endpoint probes increase. For distractors, in contrast, there appears to be little or no effect of length-change on probe detection. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

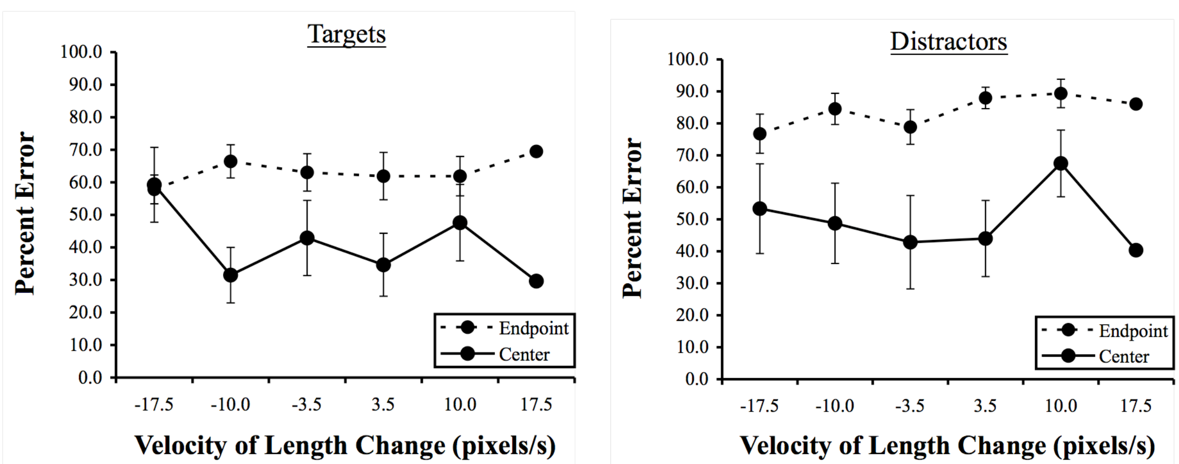

Figure A.32. ***Probe detection performance as a function of length-change velocity in Experiment 2***. The trials were binned into groups based on the velocity of line length change (negative values represent a decrease in length, positive values an increase in length). For targets, as the velocity goes from a fast decreases in line length to a fast increases in line length, miss rates for center probes decrease whereas miss rates for endpoint probes increase slightly. For distractors, the overall trend is in the same direction (except for the +10 pixels/s bin). Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

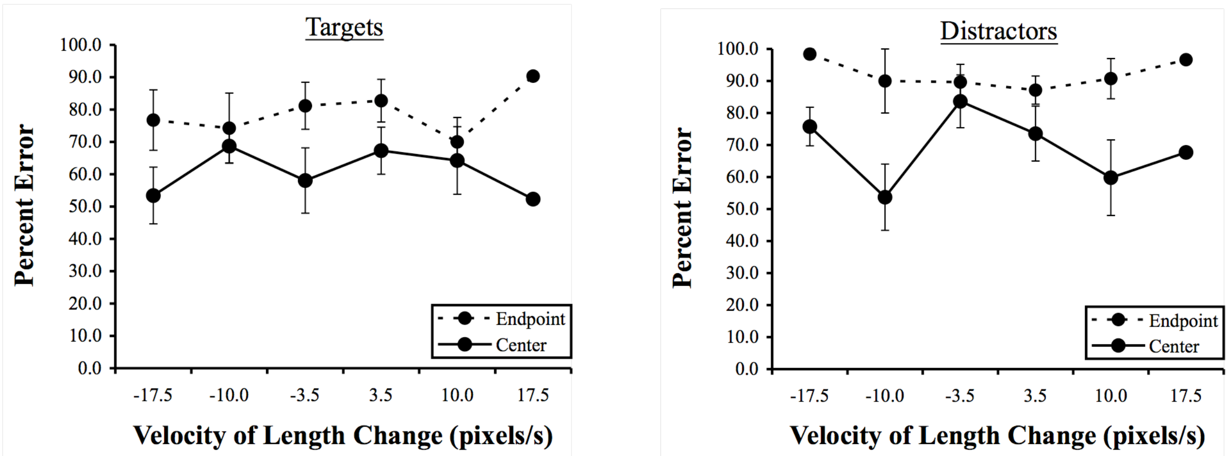

Figure A.33. ***Probe detection performance as a function of length-change velocity in Experiment 3***. The trials were binned into groups based on the velocity of line length change (negative values represent a decrease in length, positive values an increase in length). There appears to be little or no effect of length change on probe detection in this experiment. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.

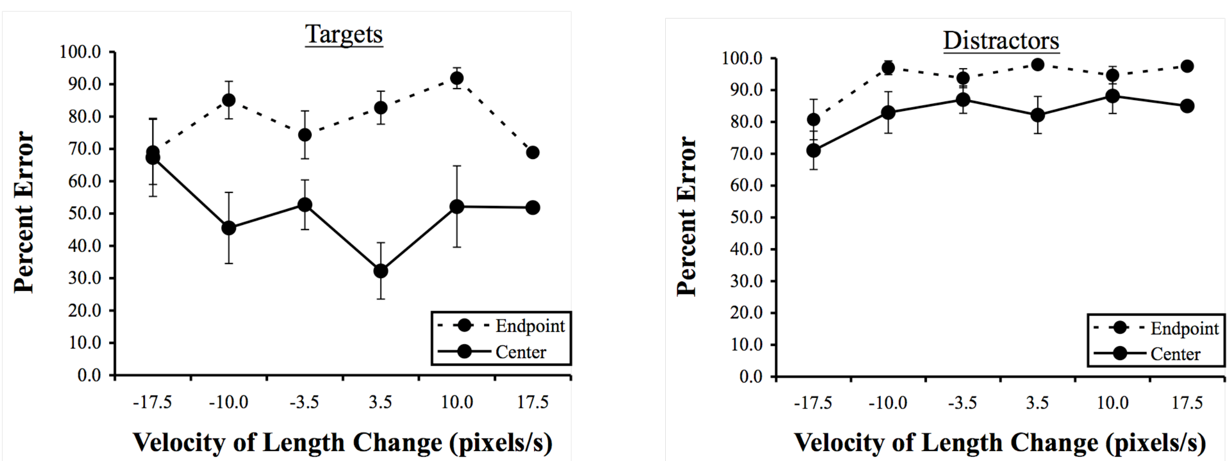

Figure A.34. ***Probe detection performance as a function of length-change velocity in Experiment 4***. The trials were binned into groups based on the velocity of line length change (negative values represent a decrease in length, positive values an increase in length). For targets, as the velocity goes from a fast decreases in line length to a fast increases in line length, the difference between center and endpoint miss rates increases (except for the last point). For distractors, in contrast, there appears to be little or no effect of length-change on probe detection. Error bars are shown when larger than the data symbols and represent +/- 1 *SE*.