When size matters: attention affects performance by contrast or response gain

Supplementary materials

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Supplementary Table 1: Effects of exogenous attention (n=4 observers).

	c_{50}	68% confidence interval (CI) of c_{50}	d'_{max}	68%-CI of d'_{max}	R^2 of fits	n	68%-CI of n
valid	0.225	[0.209; 0.232]	2.69	[2.57; 2.75]	0.992	2.48	[2.37; 2.66]
neutral	0.282	[0.262; 0.292]	2.81	[2.63; 2.86]	0.992		
invalid	0.321	[0.298; 0.340]	2.46	[2.32; 2.57]	0.976		

(**a**) When small Gabor stimuli were paired with spatial uncertainty (relatively large attention fields), exogenous attention yielded changes in contrast gain, as measured by the contrast yielding half-maximum performance (c_{50}: $p_{valid\text{-}invalid}$ <0.001). There was little or no evidence for a change in response gain, as measured by the asymptotic performance at high contrasts (d'_{max}: $p_{valid\text{-}invalid}$ =0.057). Validly cueing exogenous attention to the target enhanced contrast sensitivity, indicated by the significantly lower contrast needed to yield half-maximum performance compared to the neutral condition (c_{50}: $p_{valid\text{-}neutral}$ <0.001). Invalidly cueing attention resulted in decreased contrast sensitivity, indicated by significantly increased contrast at half-maximum performance compared to the neutral condition (c_{50}: $p_{neutral\text{-}invalid}$=0.038).

	c_{50}	68%- CI of c_{50}	d'_{max}	68%-CI of d'_{max}	R^2 of fits	n	68%-CI of n
valid	0.174	[0.161; 0.185]	2.64	[2.53; 2.71]	0.982	2.48	[2.37; 2.66]
neutral	0.170	[0.159; 0.182]	2.15	[2.06; 2.20]	0.982		
invalid	0.177	[0.166; 0.201]	1.41	[1.36; 1.50]	0.973		

(**b**) When stimuli were large and presented at fixed locations (attention field relatively small), exogenous attention significantly improved asymptotic performance at high contrasts (d'_{max}: $p_{valid\text{-}invalid}$ <0.001), consistent with a response gain change, with no evidence for a change in contrast gain (c_{50}: $p_{valid\text{-}invalid}$ =0.322). Directing exogenous attention to the target location yielded a benefit in the estimated maximum attainable performance at high contrasts (d'_{max}: $p_{valid\text{-}neutral}$ <0.001), whereas directing exogenous attention to the distracter location yielded a cost in performance (d'_{max}: $p_{neutral\text{-}invalid}$ <0.001).

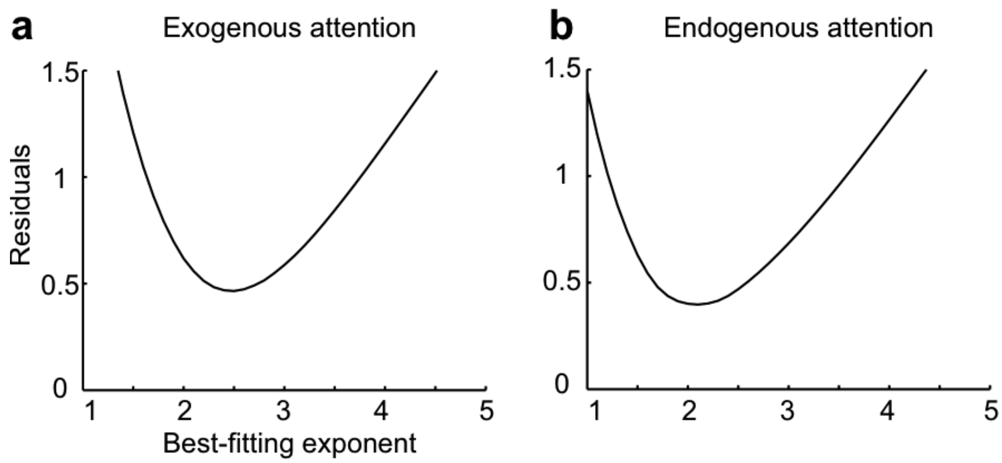
Supplementary Table 2: **Effects of endogenous attention (n=4 observers).**

	c_{50}	68%-confidence interval (CI) of c_{50}	d'_{max}	68%-CI of d'_{max}	R^2 of fits	n	68%-CI of n
valid	0.309	[0.284; 0.328]	2.99	[2.82; 3.10]	0.988	2.00	[1.85; 2.22]
neutral	0.292	[0.275; 0.336]	2.73	[2.62; 2.96]	0.978		
invalid	0.410	[0.346; 0.452]	2.68	[2.41; 2.88]	0.969		

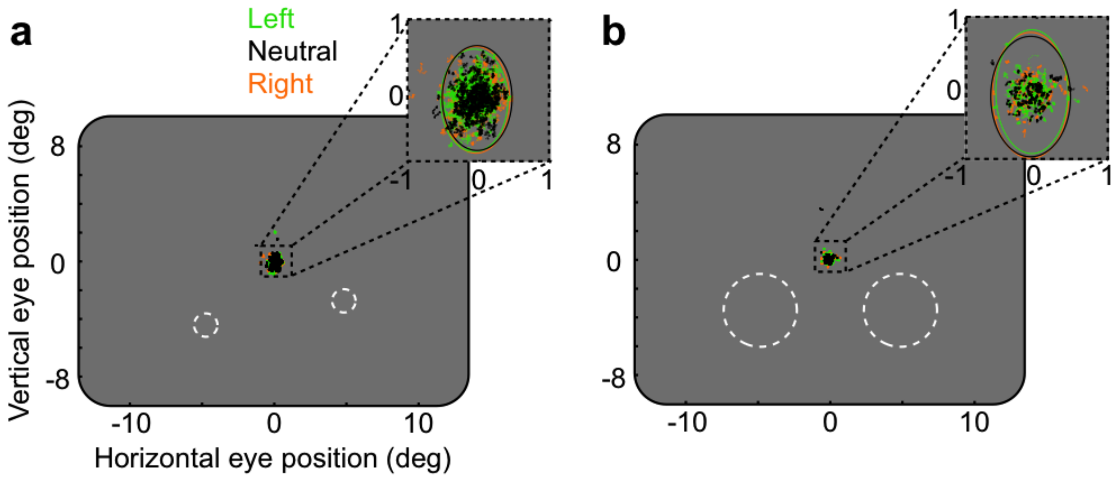
(**a**) Small stimuli and spatial uncertainty yielded changes in contrast gain, as measured by the contrast yielding half-maximum performance (c_{50}: $p_{valid\text{-}invalid}$ =0.012), with no evidence for a change in response gain (d'_{max}: $p_{valid\text{-}invalid}$ =0.078). Observers did not benefit reliably in the valid compared to the neutral condition (c_{50}: $p_{valid\text{-}neutral}$=0.524), but there was evidence for a decrement in half-maximum performance for the invalid compared to the neutral condition (c_{50}: $p_{neutral\text{-}invalid}$=0.031).

	c_{50}	68%-CI of c_{50}	d'_{max}	68%-CI of d'_{max}	R^2 of fits	n	68%-CI of n
valid	0.305	[0.274; 0.316]	2.81	[2.64; 2.89]	0.991	2.00	[1.85; 2.22]
neutral	0.282	[0.263; 0.335]	2.47	[2.35; 2.64]	0.992		
invalid	0.295	[0.264; 0.323]	2.06	[1.91; 2.18]	0.981		

(**b**) Large center stimuli surrounded by irrelevant flankers (to minimize attention field) yielded changes in response gain, indicated by a robust increase in asymptotic performance (d'_{max}: $p_{valid\text{-}invalid}$ <0.001), with no evidence for a change in contrast gain (c_{50}: $p_{valid\text{-}invalid}$ =0.473). Endogenous attention to the target location improved performance at high contrasts (d'_{max}: $p_{valid\text{-}neutral}$ =0.043), while directing endogenous attention to the distracter location yielded a cost in performance at high contrasts (d'_{max}: $p_{neutral\text{-}invalid}$ =0.006).

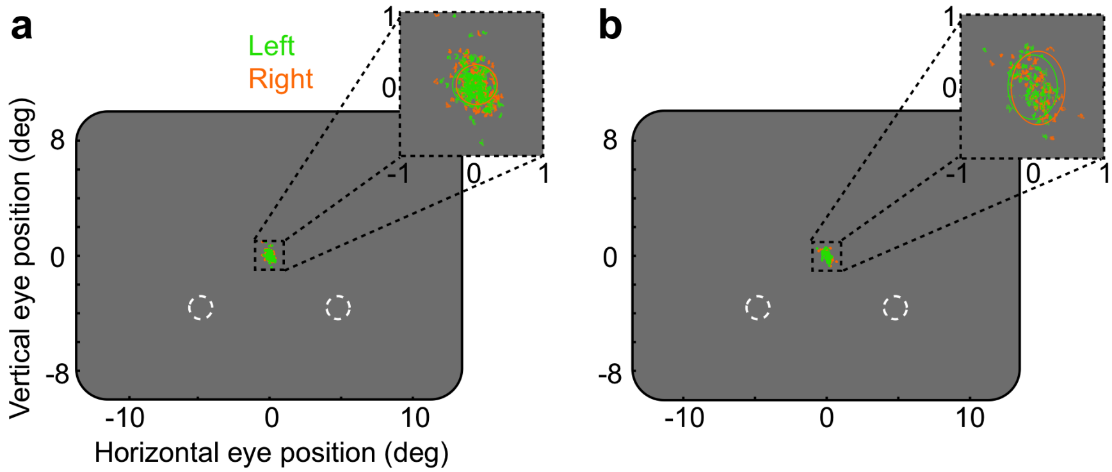


Supplementary Figure 1: Exponents, obtained by fitting the psychometric functions. (**a**) Exogenous attention. (**b**) Endogenous attention. The dip of each curve represents the best-fitting exponent, manifesting smallest residual in the nonlinear, least-squares fitting procedure. The fact that the dip is well-defined implies that the model parameters were constrained by the data. Data from the exogenous (n=4 observers) and endogenous (n=4 observers) attention experiments exhibited best fitting exponents that were similar to one another, and also similar to the values reported from single-unit electrophysiological measurements of contrast-response functions in visual cortex (Sclar, Maunsell, & Lennie, *Vis Res* 30:1-10, 1990; Geisler & Albrecht, *Vis Neurosci* 14:897-919, 1997; Busse, Wade & Carandini, *Neuron* 64:931-942, 2009).



Supplementary Figure 2: Example eye movement data during stimulus presentation of one observer for the endogenous attention experiment. Stimulus locations are indicated by white dashed circles, which were not actually displayed during the experiment. (**a**) Horizontal and vertical eye positions during presentation of small stimuli, with spatial uncertainty. (**b**) Large stimuli, without spatial uncertainty. (**a-b**) Fixation was accurate: 95% of gaze positions were within the central 1° for all pre-cue locations (left, right and neutral); the fixation cross (0.5° x 0.5°) was shown throughout the experiment.

Eye position (right eye) was measured (500 Hz) using an infrared tracker (EyeLink 1000, SR Research Ltd., Mississauga, Ontario, Canada). The eye tracker was calibrated at the beginning of each block of psychophysical trials or fMRI run. Raw data was converted to eye position in degrees of visual angle. Eye position during the fixation interval at the beginning of each trial served as baseline and was subtracted from eye position during the stimulus interval, to compensate for any slow drift in the measurements during each block/run. Saccades were detected by the standard Eyelink detection algorithm (combined velocity (30 °/sec) and acceleration criterion (8000 $°/sec^2$)), and the percentage of trials in which saccades occurred were counted. Blinks were also detected by the Eyelink software, and the time points shortly (100 ms) preceding and following blinks were excluded from analysis. The first two trials of each block/run were also ignored. For statistical comparison, trials were sorted according to cue conditions (left, right and neutral/fixation) and compared for horizontal and vertical deviations from the center.



Supplementary Figure 3: Example eye movement data (horizontal and vertical eye positions) during stimulus presentation of one observer for the fMRI experiment. Stimulus locations are indicated by white dashed circles, which were not actually displayed during the experiment. (**a**) Horizontal and vertical eye positions during presentation of small stimuli, without spatial uncertainty. (**b**) Small stimuli, with spatial uncertainty (but analyzed only for trials in which the stimuli were presented at the middle of the 5 locations, i.e., same stimulus location as for panel a). (**a**-**b**) Fixation was accurate: 95% of gaze positions were within the central 0.5° for all pre-cue locations (left and right); the fixation cross (0.5° x 0.5°) was shown throughout the experiment.

Eye position (right eye) was measured (500 Hz) using an MRI-compatible infrared tracker (EyeLink 1000, SR Research Ltd., Mississauga, Ontario, Canada). See Supplementary Figure 2 for data analysis details.