Spatial or Temporal 2AFC May Give Different Results Depending on Context

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Abstract

Experiments with the same general goal have usually been carried out using spatial or temporal two-alternative forced-choice (2AFC) paradigms interchangeably by distinct or even the same research groups. This situation has occurred both in studies on visual sensitivity in dyslexia and in studies on lateral interactions in peripheral vision. Conflicting results in either field (e.g., whether or not dyslexics have a visual sensitivity deficit and whether or not peripheral detection is facilitated by the presence of flankers) appear to be resolved on the surmise that spatial and temporal 2AFC paradigms indeed produce different results. We designed experiments in which peripheral detection thresholds for Gabor patches (in the presence or absence of suprathreshold flankers) could be measured using completely equivalent spatial and temporal 2AFC paradigms so that any resultant difference can be unequivocally attributed to the effect of the paradigms themselves. The main results showed that spatial 2AFC renders significantly lower sensitivity than temporal 2AFC when the target is surrounded by flankers, but it renders about the same sensitivity as temporal 2AFC when the target is presented alone. In the end, this resulted in statistically significant facilitation only when measured with temporal 2AFC. These results suggest that splitting resources across two spatial locations appears to elevate target detection thresholds only when a peripheral discrimination task is involved. Separate experiments involving several peripheral locations further revealed that the magnitude of this differential effect of paradigm varies with retinal locus. The proven effect of these two factors (i.e., variations across paradigms and variations across retinal loci) along with large individual differences (i.e., some subjects consistently show impairment instead of facilitation) indicates that previous conclusions about lateral interactions in the periphery may need to be revisited.

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Evidence of lateral interactions in peripheral vision is inconclusive:

- Initially (Polat & Sagi, 1994a) and recently (Giorgi et al., 2004) suprathreshold flankers were shown to significantly facilitate the detection of a peripheral Gabor patch. These studies used a **temporal 2AFC** paradigm.

- Other studies failed to find facilitatory effects (Williams & Hess, 1998; Zenger-Landolt & Koch, 2001). These studies used a **spatial 2AFC** paradigm.

Giorgi et al. (2004) provided preliminary data indicating that the use of spatial versus temporal 2AFC paradigms might be responsible for these conflicting results.

We addressed this issue systematically, measuring thresholds with and without flankers in comparable spatial and temporal arrangements at each of two peripheral locations using different configurations (see Fig. 1).

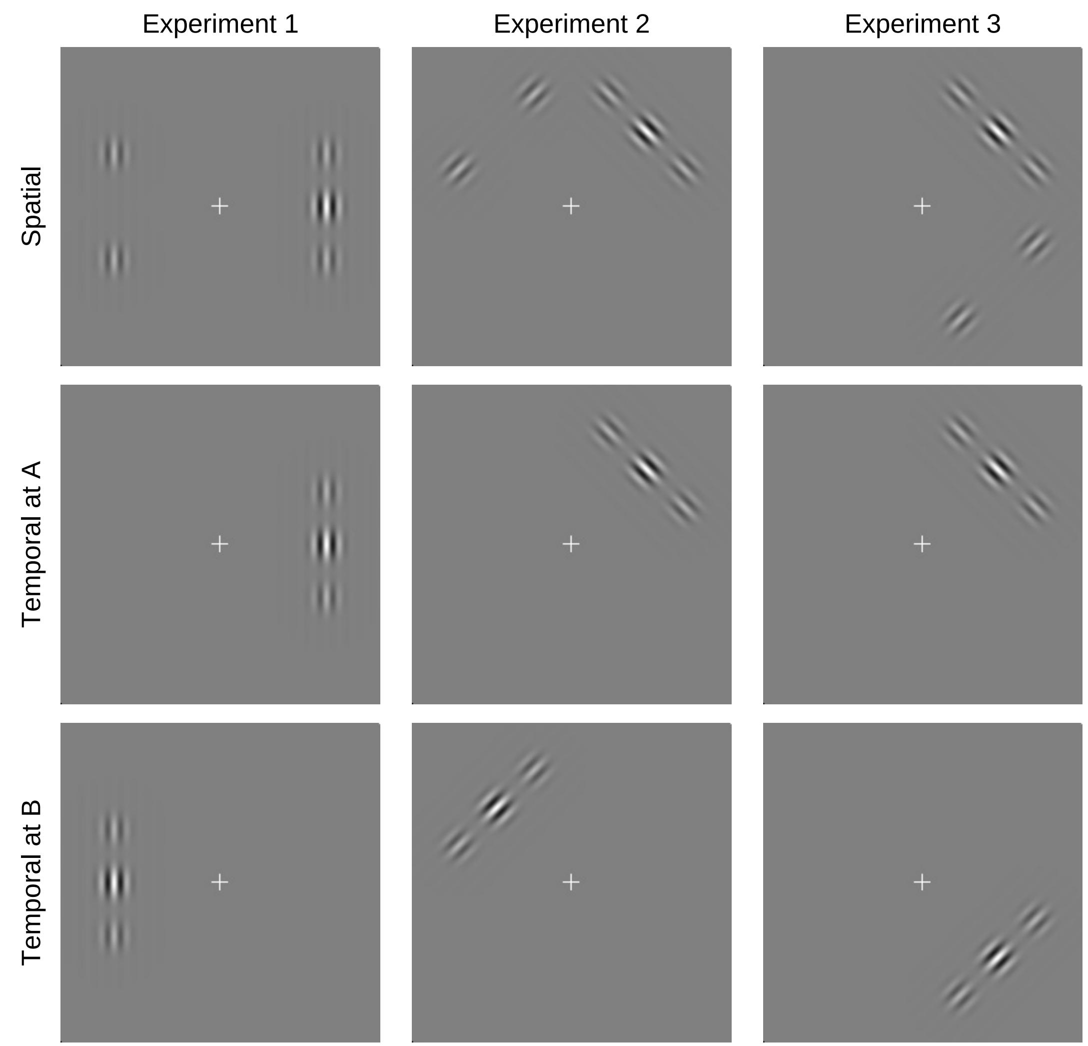

Fig. 1. Sketch of the conditions with flankers in each of three experiments. Thresholds at each of two peripheral locations were measured with spatial and temporal 2AFC paradigms.

Experiment 1. Conventional left-right configuration

- Thresholds in the left and right locations are very similar whether with or without flankers (data points around the diagonal in Fig. 2a).

- Thresholds from temporal paradigms are significantly lower than thresholds from spatial paradigms (data points below the diagonal in Fig. 2b).

- The difference is smaller in the target-alone condition (open circles in Fig. 2b) than in the target-plus-flanker condition (solid circles in Fig. 2b).

- Threshold elevation is smaller (i.e., there is more facilitation) with temporal 2AFC (data points below the diagonal in Fig. 2c).

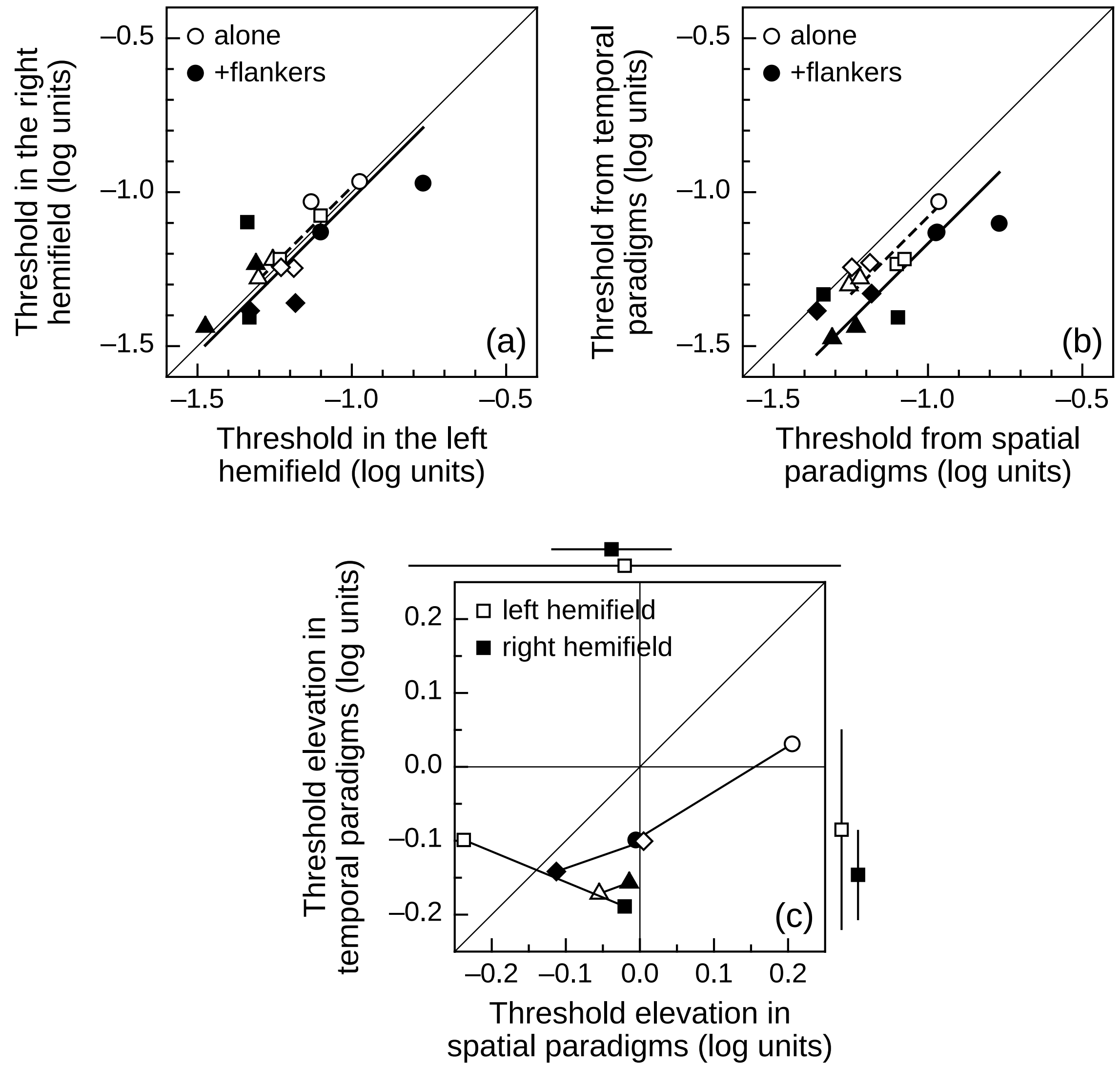

Fig. 2. Results of Exp. 1.

Is performance in the spatial paradigm affected by the distance between the two spatial locations that must be attended to simultaneously?

Experiment 2. Upper hemifield (the two peripheral locations are brought closer together while each of them is still at the same distance from fixation)

- Thresholds at both locations are very similar again (data points around the diagonal in Fig. 3a).

- Thresholds from temporal paradigms are significantly lower than thresholds from spatial paradigms (data points below the diagonal in Fig. 3b).

- The difference is not significant in the target-alone condition (open circles in Fig. 3b) but it is larger than it was in Exp. 1 in the target-plus-flanker condition (solid circles in Fig. 3b).

- Threshold elevation is again smaller (i.e., there is more facilitation) with temporal 2AFC (data points below the diagonal in Fig. 3c).

Bringing locations closer to each other does not help. Is this because the two cerebral hemispheres are involved in spatial 2AFC?

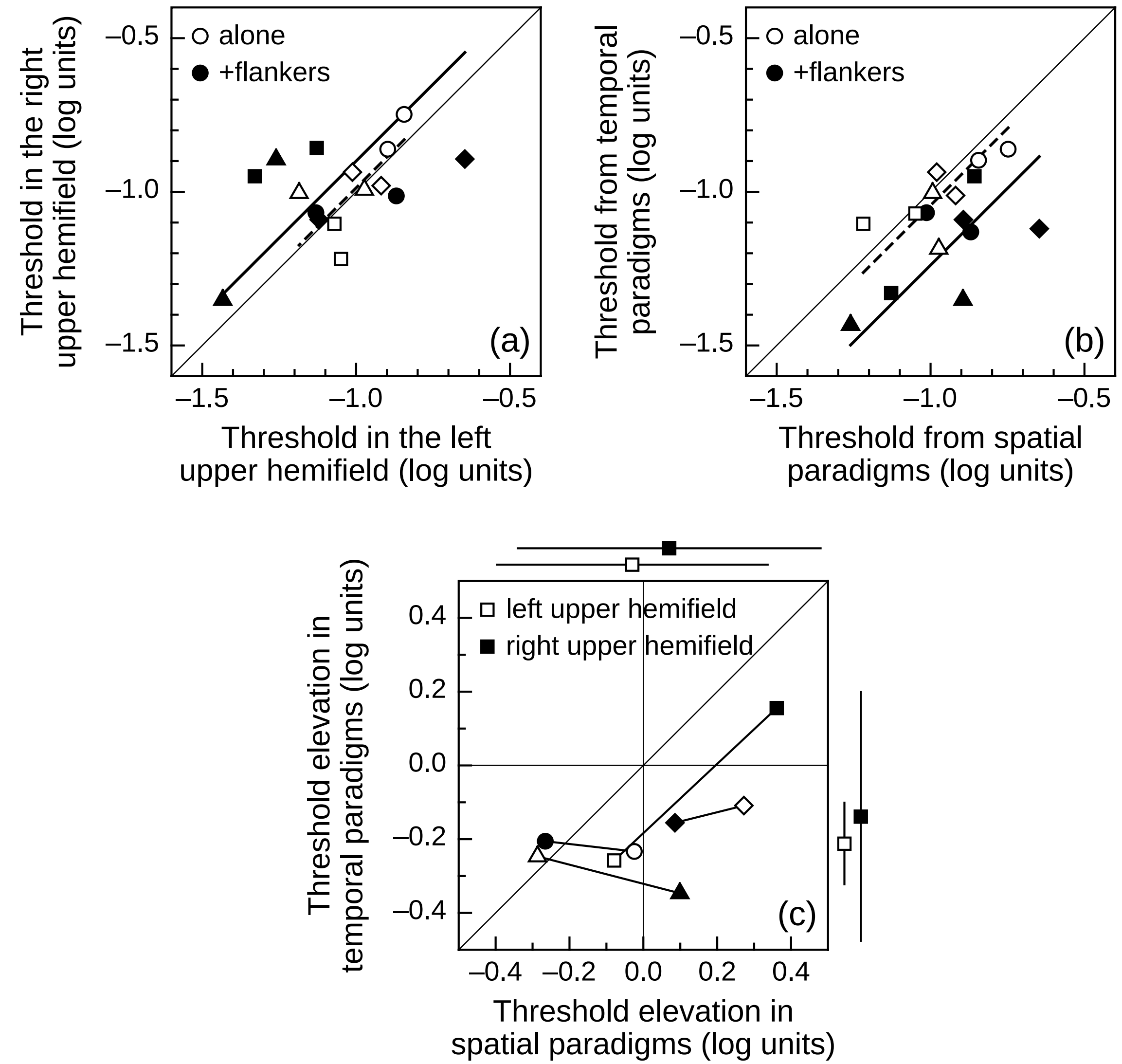

Fig. 3. Results of Exp. 2.

Experiment 3. Right hemifield (but the two peripheral locations are at the same distance from each other and from fixation as they were in Exp. 2)

- Again, thresholds at both locations are very similar (data points around the diagonal in Fig. 4a).

- Again, thresholds from temporal paradigms are significantly lower than thresholds from spatial paradigms (data points below the diagonal in Fig. 4b).

- Again, the difference is not significant in the target-alone condition (open circles in Fig. 4b) but it is similar to what it was in Exp. 2 in the target-plus-flanker condition (solid circles in Fig. 4b).

- Again, threshold elevation is smaller (i.e., there is more facilitation) with temporal 2AFC (data points below the diagonal in Fig. 4c).

These results are thoroughly analogous to those observed in Exp. 2. The number of hemispheres does not seem to matter.

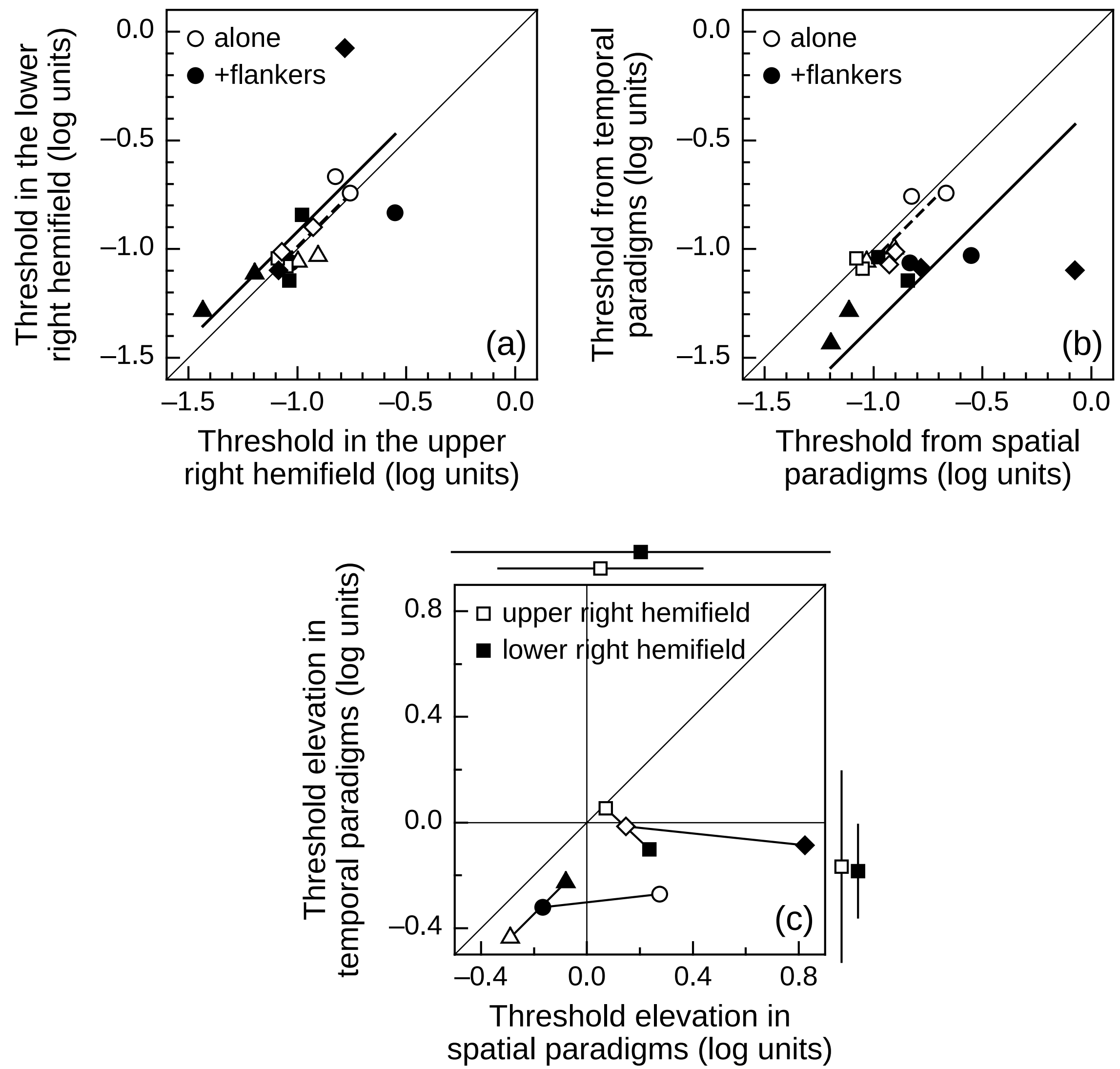

Fig. 4. Results of Exp. 3.

Summary and Conclusions

- Temporal 2AFC produces thresholds that are significantly lower than those obtained with spatial 2AFC in comparable conditions.

- The magnitude of the difference varies with retinal locus and spatial context (larger differences for target detection in the presence of flankers than for detection of the target alone).

- There are large individual differences. With spatial 2AFC, some subjects consistently show impairment (data on the right of the vertical line in Figs. 2c, 3c, and 4c) or facilitation (data on the left of the vertical line) in different conditions.

- Similar effects of spatial versus temporal paradigms appear to contaminate the assessment of visual deficits in dyslexia (Peli & García-Pérez, 1997).

- The differential role of attention and uncertainty in spatial versus temporal 2AFC paradigms ought to be investigated (Cohn & Lasley, 1974; Burgess & Ghandeharian, 1984; Carrasco et al. 2000; Cameron et al., 2002; Solomon & Morgan, 2003).

MATERIALS AND METHODS

Apparatus and stimuli. All experiments were under computer control with *VisionWorks* (Swift et al., 1997). Stimuli were displayed on an EIZO Flex-Scan FX•E7 color monitor with a spatial resolution of 1024 × 600 pixels, a luminance resolution of 2^{15} gray levels, and a frame rate of 122.7 Hz. The image area subtended 22.8 × 13.4 deg at 1 m. The voltage-to-luminance nonlinearity was compensated for via look-up tables. The temporal course of stimulus presentation was a rectangular pulse of 90 ms (11 video frames) preceded and followed by a single frame at half the nominal contrast to mitigate transients. The total presentation duration was thus 107 ms (13 frames). In experiment 1, the target stimulus was a Gabor patch with a vertical carrier of 4 c/deg and a circular Gaussian envelope with a standard deviation of 0.18 deg. The stimulus was represented internally with 22.4 pixels per cycle of the carrier and was displayed with a mean luminance of 54 cd/m^2 that blended in with a uniform 54-cd/m^2 background covering the entire image area. The center of the monitor displayed a small cross that the subjects fixated throughout the experiment. The target stimulus always appeared with its center 4 deg either to the right or to the left of the fixation cross. In separate blocks still within experiment 1 the stimulus field either consisted of the target just described or included also two collinear flanking Gabor patches of the same frequency, orientation, and size but with a fixed suprathreshold Michelson contrast of 0.4. In blocks with flankers, these were present in each of the spatial or temporal intervals (as appropriate) and were centered 1 deg above and 1 deg below the locations where the target stimulus might appear. The stimulus configuration in experiments 2 and 3 differed from that in experiment 1 only as to the location and orientation of the target and flankers, but targets continued to be 4 deg away from fixation and were oriented orthogonal to the line connecting fixation and target location, whereas flankers continued to be co-oriented and located ‘above’ and ‘below’ along the oblique orientation of the target.

Procedure. The monitor warmed up for no less than half an hour. Binocular viewing with natural accommodation and pupils was used. Subjects sat 2 m away (1 m away in experiments 2 and 3) from the display and their head was not restrained. The room was dark. The background luminance and the fixation cross were present throughout the session. Data were collected with an adaptive method of constant stimuli governed by 1-up/1-down staircases with steps down of 0.2 log units and steps up of 0.4 log units. Two separate staircases were interwoven in each block which differed only by 0.1 log units in their starting points (−0.6 versus −0.5 log contrast), that is, half the base step size of 0.2 log units that was used in each staircase. Staircases under the temporal paradigm were set up to run until 50 reversals had been completed; staircases under the spatial paradigm were set up to complete 100 reversals. A spatial trial consisted of a 107-ms presentation period signaled by a beep and in which the target appeared either at location A or at location B, newly decided at random with equiprobability on each trial. A temporal trial consisted of two 107-ms co-spatial presentations (either on location A or on B, invariant within a block) in only one of which was the target displayed, again newly decided with equiprobability on each trial. The two temporal intervals were marked by beeps of different pitch and separated by a gap of 820 ms (100 frames). Subjects indicated by a key press the location in which the target had appeared, guessing at random when necessary. If subjects had missed a trial, they could use a third key to ask for the trial to be discarded and repeated (not necessarily immediately afterwards). The session was self-paced, as the next trial did not start until the subject had responded. Each subject completed the full set of conditions of experiment 1 in 12 sessions, four involving each of the three paradigms (spatial, temporal on location A, and temporal on location B). The four sessions of each type were mere repeats. A session consisted of two blocks of trials (one for the target alone and one for the target plus flankers). Each block consisted of two interwoven staircases covering interlaced lattices as described above. Experiments 2 and 3 were completed analogously.

Data analysis. Data from all repeat sessions (400–500 trials altogether) for each of the eight conditions in a given experiment (factorial combination of spatial versus temporal paradigm, location A versus location B, and target alone versus target plus flankers) were pooled and binned by contrast level, and a logistic psychometric function Ψ given by

$$\Psi(x) = \gamma + \frac{1-\lambda-\gamma}{1+\exp\left[-b\,(x-\theta)\right]} \qquad (1)$$

was fitted to each data subset. Maximum likelihood estimates were obtained using NAG subroutine E04JYF (NAG, 1999). Bins with fewer than 20 responses were discarded. Data from temporal paradigms were fitted assuming a fixed guessing rate $\gamma = 0.5$. Data from spatial paradigms had to be fitted with the guessing rate γ regarded as a free parameter, to compensate for response biases (see Fig. 5). To reflect comparable performance levels across conditions yielding different guessing rates, threshold θ in Eq. 1 is implicitly defined as the point at which the probability of a correct response is halfway between the lower and upper asymptotes of Ψ.

Subjects. Four experienced observers with normal or corrected-to-normal vision participated. The first three subjects were authors; the fourth subject was naïve in all respects. Prior to their participation, all subjects read and signed an informed consent form that had been approved by the Institutional Review Board in accordance with NIH regulations.

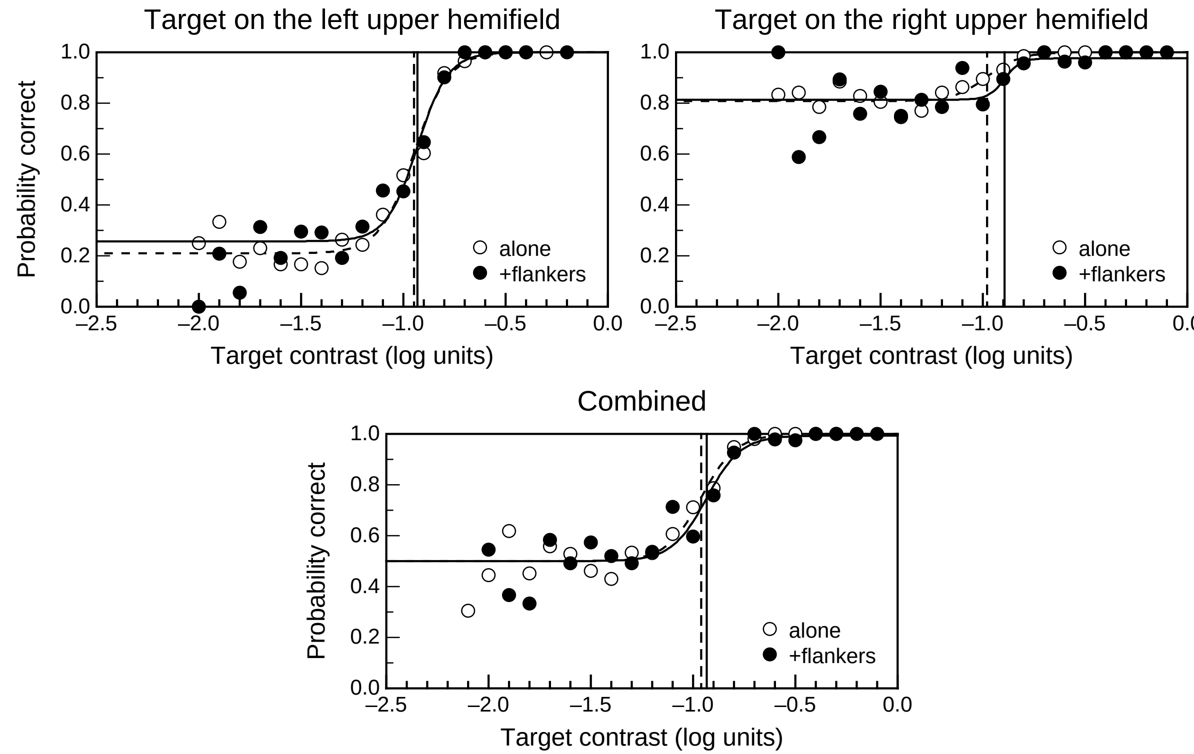

Fig. 5. Response bias shown by subject #4 in the spatial condition of experiment 2. The subject has a propensity to respond “right upper” when guessing, which increases his proportion of correct responses when the target was actually presented at that location but decreases his proportion of correct responses when the target had been presented on the other location. When data from both locations are combined (lower panel), the average rate of correct responses is righteously 50% at low contrast levels.

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