Both cognitive factors and local inhibition mediate the effect of a surrounding frame in visual search for oriented bars

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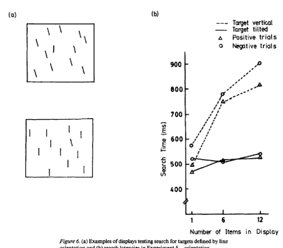
2

It is easier to search for tilted line elements amongst vertical distractors than vice-versa (Treisman & Gormican, 1988).



When a vertical or tilted square frame surrounds the elements, there is an advantage for targets tilted *relative to the frame*.

3

Treisman & Gormican suggested two explanations:

1. the frame defines the orientation against which tilt is defined, and targets parallel to the frame lack a "tilt" feature, making them harder to find;
2. targets tilted relative to the frame have a unique orientation, making them more salient than targets parallel to the frame, which receive competition from it.

6

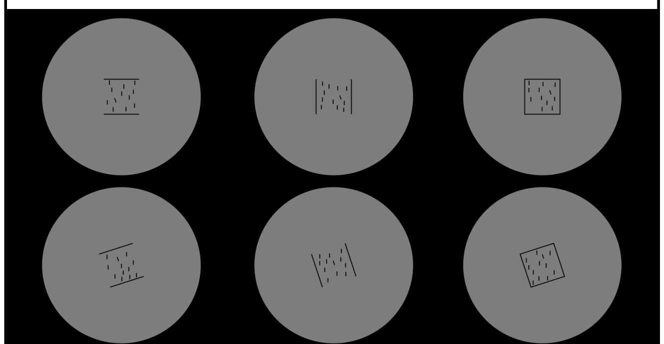
This predicts that a frame consisting of just the left and right sides should have an effect as strong as a complete frame, whereas a frame consisting of just the top and bottom sides should have no effect.

This was tested in Experiment 1. We presented arrays of 12 elements, surrounded by one of six types of frame (shown below). Orientation of the elements was 0° or 18° from vertical. In half the trials, the stimulus contained a "target", which had a different orientation from the rest. Subjects were asked to indicate, as quickly as possible, whether a target was present or not.

7

Experiment 1 stimuli

Top & Bottom | Left & right | Complete square



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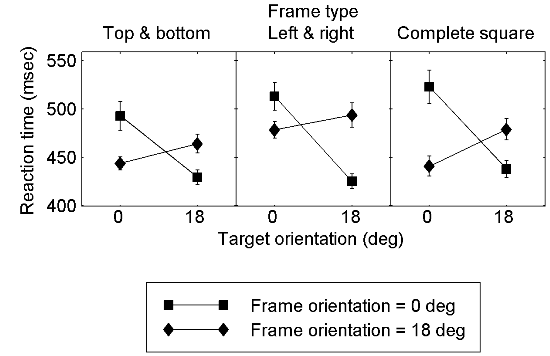
Experiment 1 results

Reaction times (RTs) were found from "target-present" trials. Outliers > 3 SDs from the mean were rejected. Mean RTs after rejecting outliers are plotted in panels 11 to 15. Error bars show standard errors of the mean.

For the "Complete square" and "Left & right" frames, there was an advantage for targets tilted relative to the frame. For the "Top & bottom" frame, most subjects showed an advantage for targets tilted relative to the gravitational vertical, whatever the frame orientation. However, the "Top & bottom" frame still had some effect.

11

Experiment 1: subject AI



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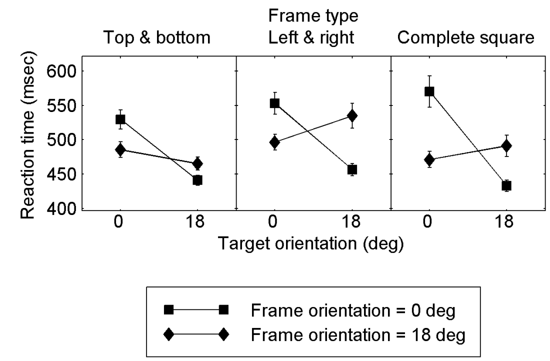
Experiment 1: subject AJ



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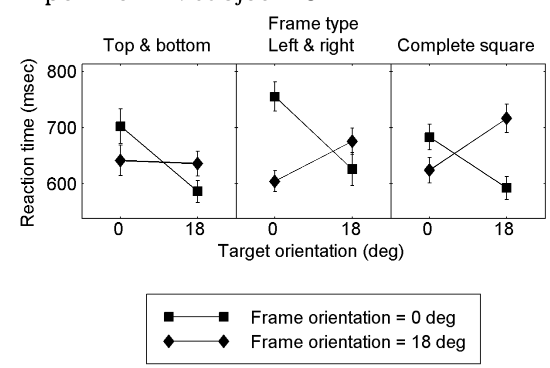
Experiment 1: subject AJA



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Li (2002) proposed a saliency mechanism that explains these results using iso-orientation inhibition between nearby V1 cells: cells responding to an element parallel to the frame receive more inhibition than those responding to an element with a unique orientation. This implements the second of Treisman & Gormican's proposed explanations of the effect.

The advantage for tilted targets in the absence of a frame could arise if there were more cells tuned to vertical orientations: this would give rise to greater inhibition between vertical distractors than between tilted distractors, so that tilted targets popped out more than vertical ones.

5

Experiment 1

In Experiment 1, we used elements and frames that were tilted 0° or 18° clockwise from vertical.

According to our explanation of the frame effect, using Li's model, the effect of the frame is caused by iso-orientation inhibition by cells responding to the left and right sides of the frame.

The top and bottom sides of the frame should have no effect, because they are never parallel to any of the elements, and so they should not inhibit responses to targets or distractors.

9

The size of the interaction between frame and target orientation was quantified using the following expression:

$$\text{interaction strength} = \frac{\left(RT_{0,0} - RT_{0,18}\right) + \left(RT_{18,18} - RT_{18,0}\right)}{RT_{0,0} + RT_{0,18} + RT_{18,0} + RT_{18,18}}$$

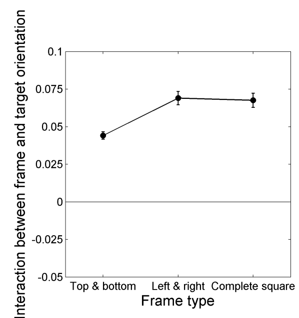
where $RT_{a,b}$ is the reaction time when the frame orientation is *a*, and target orientation is *b*.

This expression has a positive value if the advantage for tilted targets seen with a vertical frame is reduced or reversed when the frame is tilted. It has a zero value if the frame orientation has no effect.

10

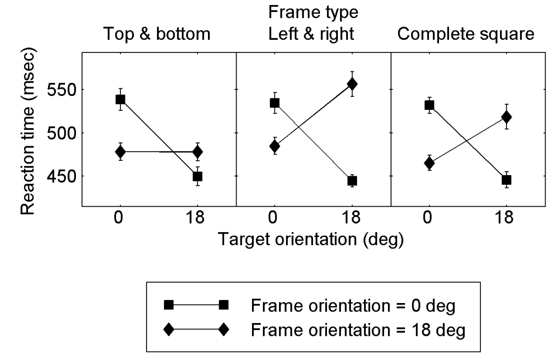
The interaction strength was calculated for each type of frame, for each subject. The mean across subjects is plotted below. Error bars indicate standard errors of the mean.

As predicted, the "Left & Right" frame had the same effect as the "Complete square" frame. However, the effect of the "Top & bottom" frame was significantly above zero.



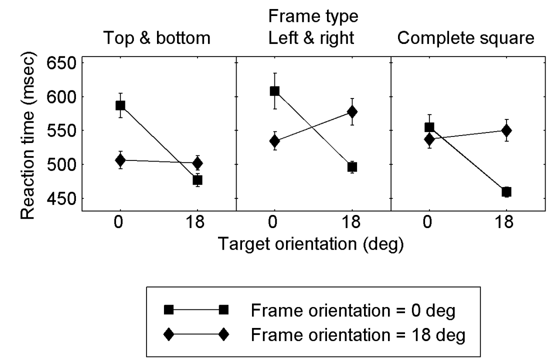
14

Experiment 1: subject LZ



15

Experiment 1: subject NG



16

Experiment 2

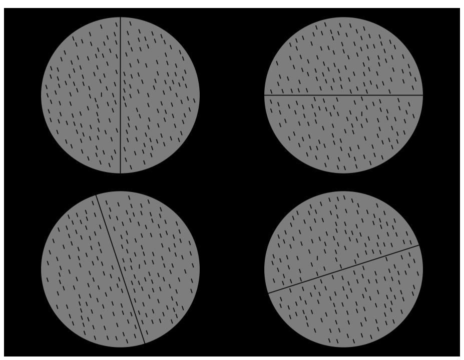
In Li's (2002) model, inhibition decreases with increasing distance between receptive fields. This predicts that the frame should have the most effect on elements close to it.

A complication is that, as an element moves away from one side of the frame, it gets closer to the other side. Instead of a frame, Experiment 2 used a long line through the centre of the stimulus. The distance of the target from the line was varied. In Experiment 2a, the line was 0° or 18° from vertical; in Experiment 2b, it was 0° or 18° from horizontal. Elements were always 0° or 18° from vertical. Methods were the same as in Experiment 1.

17

Experiment 2 stimuli

Experiment 2a Experiment 2b

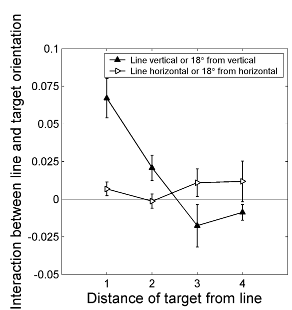


18

Experiment 2 results

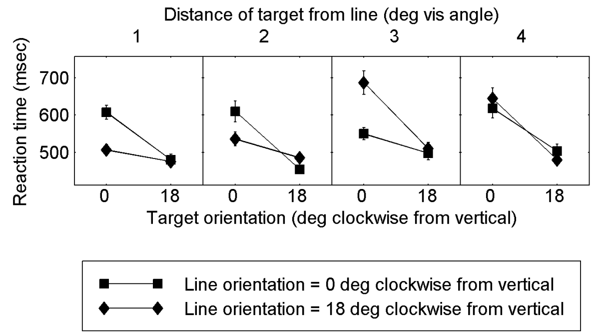
Reaction times were analysed as in Experiment 1. The means and standard errors for each subject are shown in panels 20 to 27.

The interaction between line and target orientation was quantified in the same way as the interaction between frame and target orientation in Experiment 1.



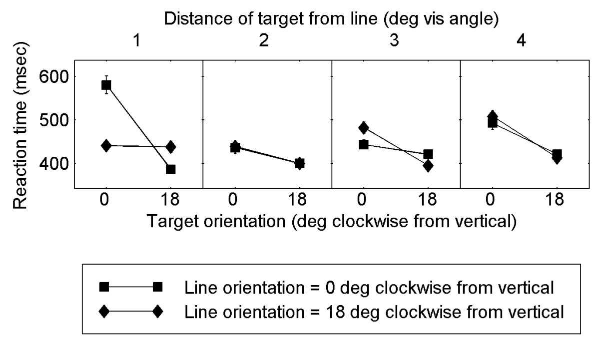
21

Experiment 2a: subject JSH



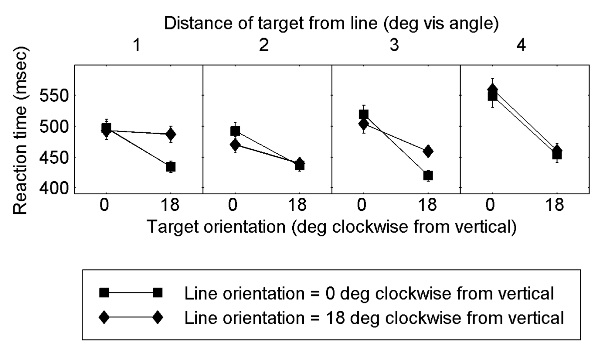
22

Experiment 2a: subject LJ



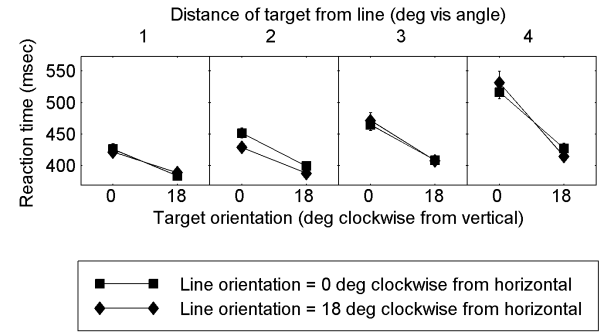
23

Experiment 2a: subject LZ



26

Experiment 2b: subject LZ



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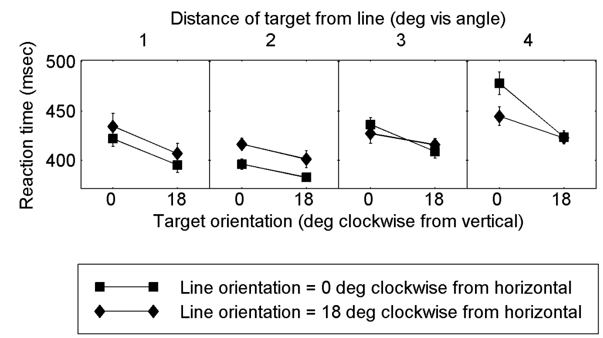
Experiment 2b: subject NG



28

Conclusions

Our results suggest that the advantage for tilted targets depends on both local inhibition and higher-level mechanisms.

The results of Experiment 2 strongly support Li's (2002) model, based on local iso-orientation suppression between nearby V1 cells. However, this model cannot account for the effect of the "Top & bottom" frame in Experiment 1. In addition, previous findings that gravito-inertial cues and subjects' posture can affect the advantage for tilted targets suggests that these effects cannot be solely determined by visual mechanisms (Marendaz *et al.*, 1993; Stivalet *et al.*, 1995).

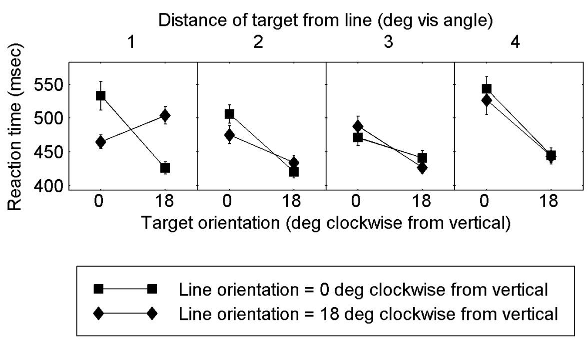
19

In Experiment 2a, tilting the vertical line by 18° reduced or reversed the advantage for targets tilted 18° from vertical, but only when the target was close to the line. These results are predicted by Li's (2002) model, in which the frame effect arises due to iso-orientation inhibition between nearby V1 cells.

In Experiment 2b, tilting the horizontal line by 18° had virtually no effect. This is also predicted by Li's (2002) model, because the lines tilted 0° or 18° from horizontal were not parallel to any elements, so they should not inhibit responses to targets or distractors.

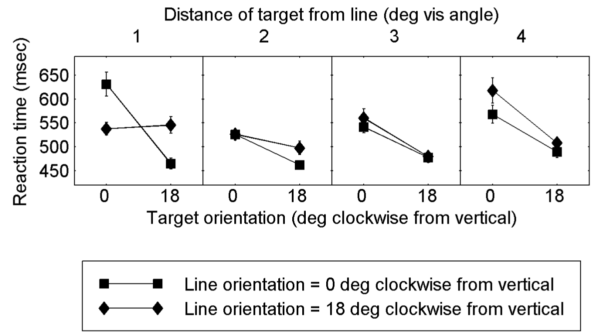
20

Experiment 2a: subject AJ



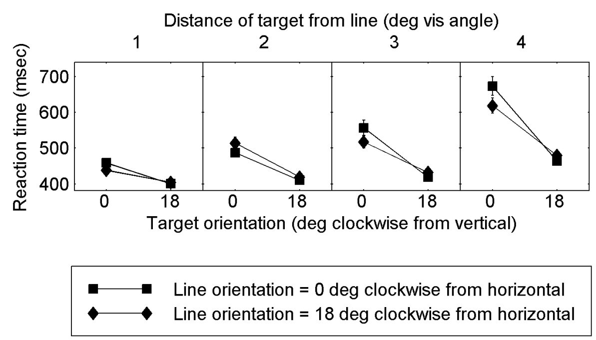
24

Experiment 2a: subject NG



25

Experiment 2b: subject LJ



29

All three frames in Experiment 1 contain configural cues that could generate a cognitive frame of reference aligned with the frame. This could favour detection of elements tilted relative to the frame of reference. The effects of the "Complete square" and "Left & right" frames could therefore be mediated by two mechanisms: a cognitive frame of reference, and the local iso-orientation inhibition mechanism. In contrast, the effect of the "Top & bottom" frame would be mediated by the cognitive frame of reference alone. This explains why the effect of the "Top & bottom" frame was smaller than that of the others, and also explains why the "Complete square" and "Left & right" frames had similar-sized effects.

30

References

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Marendaz, C., Stivalet, P., Barraclough, L. & Walkowiac, P. (1993). Effect of gravitational cues on visual search for orientation. *Journal of Experimental Psychology: Human Perception and Performance*, **19**, 1266-1277.

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Treisman, A. & Gormican, S. (1988). Feature analysis in early vision: evidence from search asymmetries. *Psychological Review*, **95**, 15-48.