Supplemental materials

Details of the PAPA model

Stimuli are defined by the *x* and *y*-coordinates of their horizontal and vertical bars, denoted (for the target) as $(x_{\mathrm{t,H}}, y_{\mathrm{t,H}})$ and $(x_{\mathrm{t,V}}, y_{\mathrm{t,V}})$ and (for the flanker) as $(x_{\mathrm{f,H}}, y_{\mathrm{f,H}})$ and $(x_{\mathrm{t,V}}, y_{\mathrm{t,V}})$. For an interference zone with width σ_x and length σ_y (free parameters #1 and #2) we compute a pair of distance measures between the locations of the near-collinear and parallel bars. For end-flankers these are

$$d_{\mathrm{colinear}} = d(x_{\mathrm{t,V}}, y_{\mathrm{t,V}}, x_{\mathrm{f,V}}, y_{\mathrm{f,V}}) \; \& \; d_{\mathrm{parallel}} = d(x_{\mathrm{t,H}}, y_{\mathrm{t,H}}, x_{\mathrm{f,H}}, y_{\mathrm{f,H}})$$

and for side-flankers they are:

$$d_{\mathrm{colinear}} = d(y_{\mathrm{t,H}}, x_{\mathrm{t,H}}, y_{\mathrm{f,H}}, x_{\mathrm{f,H}}) \; \& \; d_{\mathrm{parallel}} = d(y_{\mathrm{t,V}}, x_{\mathrm{t,V}}, y_{\mathrm{f,V}}, x_{\mathrm{f,V}})$$

where $d()$ is a two-dimensional Gaussian weighted measure of distance:

$$d(a_1, b_1, a_2, b_2) = \exp\left(\frac{(a_1 - a_2)^2}{2\sigma_x^2}\right)\exp\left(\frac{(b_1 - b_2)^2}{2\sigma_y^2}\right)$$

From these measures we compute, on a trial-by-trial basis, the magnitude of crowding, independently for collinear and parallel features, e.g.:

$$w_{\mathrm{colinear}} = \begin{cases} w_{\mathrm{average}}(1 - d_{colinear}) & U(0,1) < w_{\mathrm{prob}}(1 - d_{\mathrm{colinear}}) \\ 0 & \mathrm{otherwise} \end{cases}$$

where $U(0,1)$ is a uniform random variable in the interval (0,1), w_{prob} is a free parameter (#4) that – in combination with the distance measure - weights the probability that crowding will occur w_{average} is a free parameter (#3) modulating the strength of the interference zone on the magnitude of crowding. Having computed the weighting parameters w_{colinear} and w_{parallel} for the influence of the flanker, we compute the predicted position of the critical features within the crowded target using a standard weighted average. For end-flankers these are:

$$x_{\mathrm{colinear}} = w_{\mathrm{colinear}}(x_{\mathrm{f,V}} + N(0, \sigma_{\mathrm{noise}})) + (1 - w_{\mathrm{colinear}})(x_{\mathrm{t,V}} + N(0, \sigma_{\mathrm{noise}}))$$

$$y_{\mathrm{parallel}} = w_{\mathrm{parallel}}(y_{\mathrm{f,H}} + N(0, \sigma_{\mathrm{noise}})) + (1 - w_{\mathrm{parallel}})(y_{\mathrm{t,H}} + N(0, \sigma_{\mathrm{noise}}))$$

where $N(0,\sigma_{\text{noise}})$ refers to a normal deviate with zero-mean and standard σ_{noise} which sets the level of additive noise applied to the encoding of bar-position (free parameter #5) . Note that when w_{colinear} falls to zero, these expressions return the original target-bar locations (corrupted only by additive noise). For a side-flanker predicted bar-locations are:

$$x_{\text{parallel}} = w_{\text{parallel}}(x_{\text{f,V}} + N(0,\sigma_{\text{noise}})) + (1 - w_{\text{colinear}})(x_{\text{t,V}} + N(0,\sigma_{\text{noise}}))$$
$$y_{\text{colinear}} = w_{\text{colinear}}(y_{\text{f,H}} + N(0,\sigma_{\text{noise}})) + (1 - w_{\text{colinear}})(y_{\text{t,H}} + N(0,\sigma_{\text{noise}}))$$

Finally, in order to generate a predicted response from these position measures we determine the quadrant that their resulting angle (the arctangent of the *y* and *x* values) falls into and classify the result as an upwards, rightwards, leftwards or downwards facing ‘T’ accordingly.