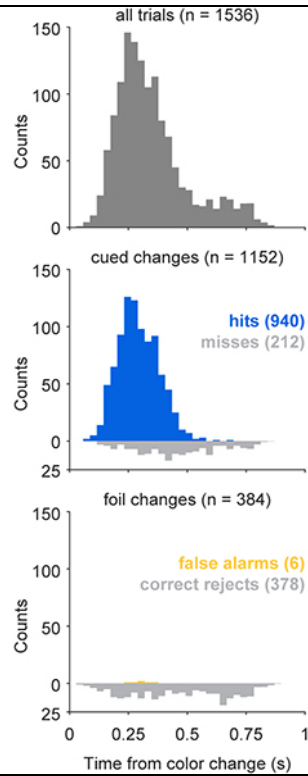


In the format provided by the authors and unedited.

Midbrain activity can explain perceptual decisions during an attention task

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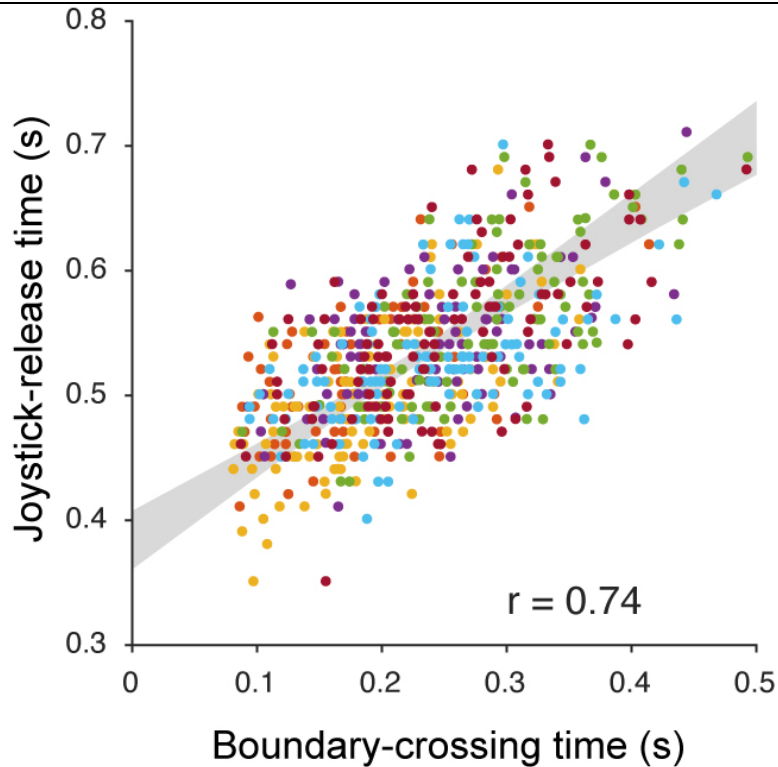
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Supplementary Figure 1

Temporal distribution of summary points in bilateral recording session trials.

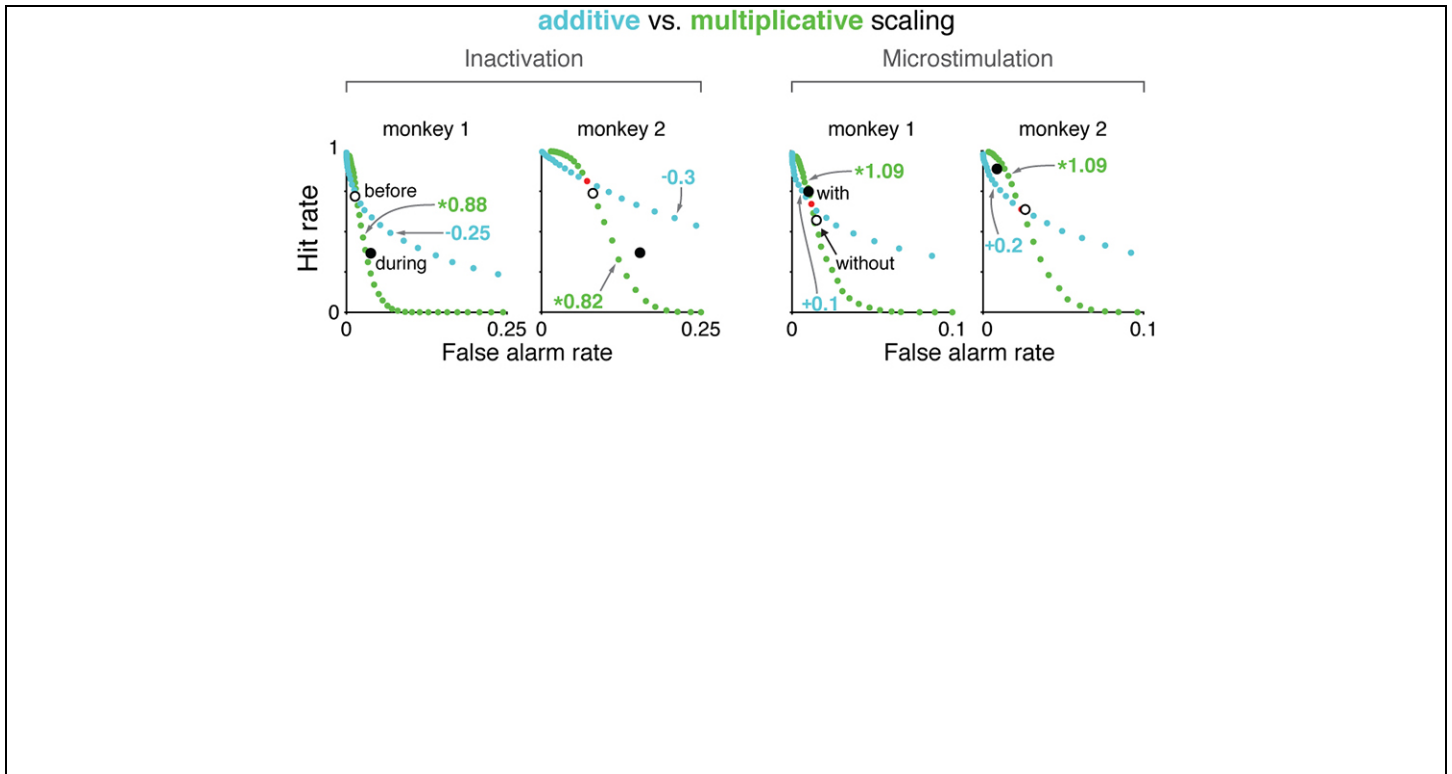
Top: histogram of the time of occurrence of each trial's "summary point" relative to the color change event for all trials ($n = 1536$). In a given trial, the summary point is the maximum difference between average right-SC and average left-SC neuronal activity. Averages were taken after binning and normalizing individual neuron activity (see Methods). For example, in a session in which we recorded simultaneously from 10 right-SC and 18 left-SC neurons, activity in each trial was averaged separately across the 10 right-SC and 18 left-SC neurons. Summary point times are plotted relative to the color change event because they reliably occurred approximately 100-900ms after the change. Middle: histograms of summary point times in cued change trials ($n = 1152$) broken down by whether the monkey correctly responded to a cued stimulus change (blue "hits"; $n = 940$), or those he had not responded to (gray "misses"; $n = 212$). Bottom: histograms from foil change trials ($n = 384$) broken down by whether the monkey had incorrectly responded to a foil stimulus change (yellow "false alarms"; $n = 6$), or had correctly withheld his response (gray "correct rejects"; $n = 378$).



Supplementary Figure 2

Relationship between model boundary-crossing time and monkey joystick release time.

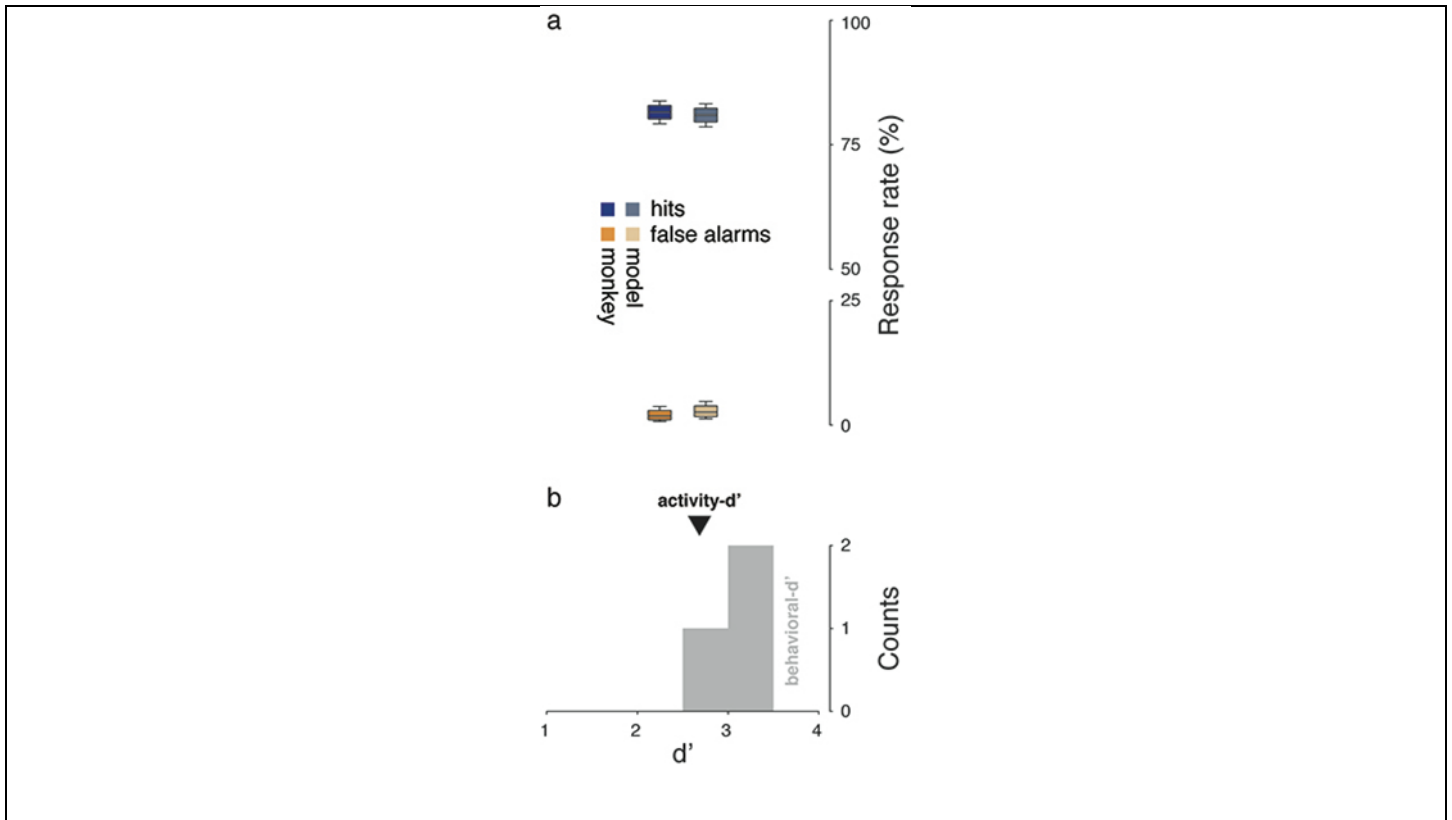
We computed a model-predicted reaction time for a subset of cue-change trials from the 3 sessions in which we recorded from right and left SC simultaneously (figure 2d). For each session, we first fit a decision boundary using each session's limited population of right and left SC neurons (in session 1: 6 left & 15 right, 2: 11 & 17, 3: 13 & 18). In these sessions, the monkey detected a change in 940/1152 cue-change trials (i.e. "hit"). The model classified 789 of the 940 hits correctly, and incorrectly classified 151/212 misses as hits. For each of the 789 correctly classified hits, we computed the time that SC activity crossed the fitted decision boundary (relative to cue-change time). Each dot is a single trial, with separate colors for left and right cue changes in each session (six colors total = 2 colors per session X 3 sessions). The data were strongly correlated ($r = 0.74$; Pearson's linear correlation coefficient), in addition, a type II linear regression yielded the line: $Y = 0.63X + 0.39$. The light gray shaded area represents the maximum and minimum values of type II regression lines computed by bootstrapping (resampling from the data with replacement 10000 times).



Supplementary Figure 3

A systematic examination of how additive vs. multiplicative scaling affects model performance.

For each monkey, a decision boundary was fit to across-sessions performance before inactivation or without microstimulation (white-filled circles), then the multiplicative (green) or additive scaling (cyan) parameter was systematically varied to compute a subset of hit and false alarm rate pairs accessible to the model; these are plotted in a space with false alarm rate on the abscissa and hit rate on the ordinate. Each green dot is a (false alarm rate, hit rate) pair resulting from multiplicative scaling by a value s_M which varies over $[0.01, 1.48]$, with $|\Delta s_M| = 0.03$ between adjacent points. Each cyan dot is a (F, H) pair from additive scaling by s_A : $[-1.55, 0.75]$, $|\Delta s_A| = 0.05$. For reference, colored text with arrows indicate s_M (green) or s_A (cyan) for individual points. Red dot (visible in middle two, and partially in right panel) indicates $s_M = 1 / s_A = 0$. Filled black circles indicate across-sessions performance during inactivation (left two plots) or with microstimulation (right two plots). For inactivation experiments, the predictions of the multiplicative and additive scaling models differ radically, with the additive scaling model predicting more strongly yoked changes in hit and false alarm rates than were observed in the data (left two plots). But over the range of performance changes observed in microstimulation experiments, the multiplicative and additive models make predictions that are difficult to disambiguate. These results also clarify why allowing the decision boundary to vary does not meaningfully improve the multiplicative scaling model's performance: predictions with a constant boundary are quite accurate, so there is no need to invoke a change in decision boundary to explain the behavioral effects of perturbing SC activity. To compare models accounting for performance changes during inactivation or microstimulation, we used a 3 factor ANOVA: (1) monkey (1 or 2), (2) model (multiplicative scaling, additive scaling, or multiplicative scaling with variable boundary), and (3) perturbation condition (inactivation or microstimulation). Data were hit and false alarm rate errors (monkey – model) during inactivation or with microstimulation only. There were 185 degrees of freedom, and 172 error degrees of freedom. Only the "model" factor and "model:condition" interaction terms were significant ($p \ll 0.01$; model $df = 2$, $F = 11.76$, model:condition $df = 2$, $F = 14.76$). Post-hoc Tukey-Kramer testing with $\alpha = 0.05$ showed that the additive model had significantly larger error than the multiplicative models for inactivation data; for microstimulation data, the errors were equivalent. The same post-hoc testing showed that the multiplicative model with variable boundary had statistically indistinguishable errors compared to the multiplicative model with constant boundary.



Supplementary Figure 4

Comparison of monkey and model performance in bilateral recording sessions.

For analyses in this figure, model input was based on the activity of 80 SC neurons from monkey 1, recorded in 3 sessions with bilaterally-placed multiple-contact probes, all other modeling procedures were as stated in main text. (a) Box plot summarizing hit (blue) and false alarm rates (orange) for monkey (high saturation fills) and model (low saturation fills). Binomial parameter probability density functions (PDFs) were estimated from counts of hits, false alarms, and total trials pooled across sessions (separately for monkey and model). Upper and lower box edges mark 25th and 75th percentile of PDF, whiskers mark 2.5th and 97.5th percentiles, and central line marks median (50th percentile). (b) Histogram of behavioral-d' values computed from each session's hit and false alarm rates. Black triangle indicates SC activity-d' (2.68).