SUPPLEMENTARY INFORMATION

Behavioral effect of SC inactivation

Across all sessions, the spatial asymmetry in the hit rate caused by SC inactivation was highly significant ($p<0.0001$, logistic regression, see Methods). Within individual sessions, the effect was significant in all but one experiment (Fig. 1d, see Methods, all $p<0.005$). In the remaining experiment, performance dropped significantly in the affected region following inactivation (33% drop, Fisher's exact test: $p=0.04$), but this drop was not significantly different from the one occurring in the unaffected region (14% drop).

SC inactivation also tended to increase the frequency of inappropriate "false alarm" responses to changes in the uncued stimulus, but only for stimuli located outside the affected part of the visual field (Fig. 1c,e). This effect was significant when all sessions were grouped together (logistic regression, see Methods, $p<0.0001$, $n=12$), but not for individual sessions.

Putative continuously isolated neurons

Neurons whose waveform and ISI distribution remained constant throughout the experiment[1] are referred to as putative continuously isolated neurons (MST: n=36 cells, MT: n=18 cells; percentage of total population: before inactivation: MST: 52%, MT: 41%; during inactivation: MST: 47%, MT: 33%). We use the term "putative continuously isolated neurons" because with extracellular recordings it is not possible to definitively establish that it was the same neuron isolated before and during inactivation. However, the logic of our interpretation does not hinge on demonstrating effects on the same neurons

before and during inactivation. On the contrary, given that we confirmed the presence of cue-related neuronal effects before proceeding with the muscimol injection, and given that not all MT and MST neurons show significant cue-related effects, changing isolated neurons during the experiment would be expected to reduce the probability of seeing cue-related effects during SC inactivation. Thus, the hazards associated with switching the identity of isolated neurons actually decreased the likelihood of the results we report in these experiments.

Nevertheless, for the sake of completeness, we compared the activity of these putative continuously isolated neurons before and during SC inactivation. The baseline discharge rate (Pearson correlation: MST: R=.79, p<.0001, MT: R=.93, p<.0001), the visual response (MST: R=.74, p<.0001, MT: R=.66, p=.001) and the attentional modulation (MST: R=.84, p<.0001, MT: R=.57, p=.007) of these units before and during SC inactivation were strongly correlated. In addition, these parameters were not significantly changed by the inactivation (Wilcoxon signed rank test: all p values > .05, fractional Bayes factor: all $p(H_0)$>=.95).

Change in Modulation Index when the non-preferred stimulus was presented inside the RF

Before SC inactivation, the distributions of Modulation Indices when the non-preferred stimulus was inside the RF were all significantly greater than zero (Wilcoxon signed rank test, before inactivation: MST<0.0001 , MT: p=0.05, after inactivation: MST or MT, all p<.0001). Similar to the results obtained for the preferred stimulus, these indices did not differ before and during

inactivation (Wilcoxon rank-sum test: MST: p=.96, MT: p=.41; p(H_0): MST: .9895, MT: .978).

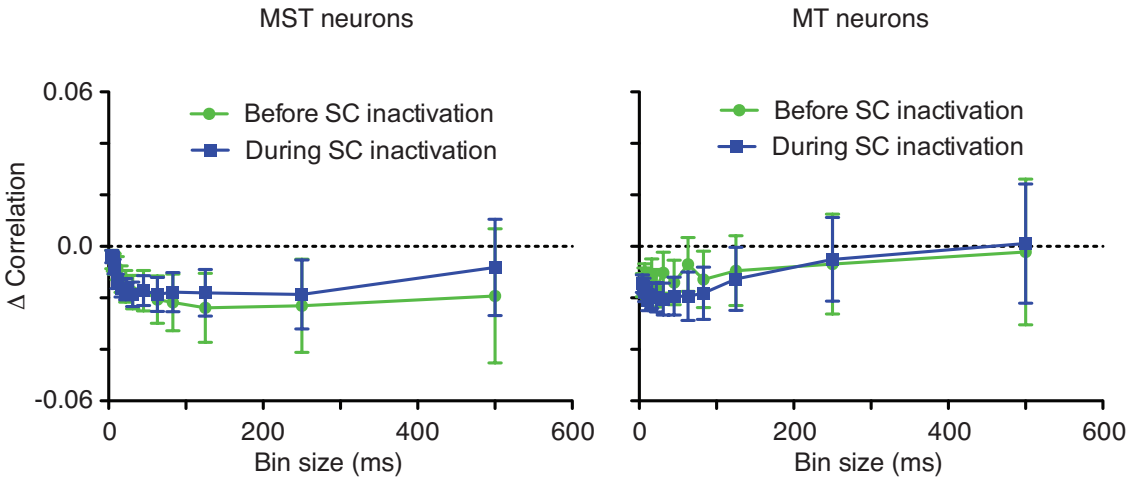
We also compared the cue-related modulation for the anti-preferred stimulus to the cue-related modulation for the preferred stimulus, both before and during SC inactivation. Modulation Indices were found to be comparable in these two conditions (Wilcoxon signed-rank test: before inactivation: MST: p=.17, MT: p=.20; during inactivation, MST: p=.58, MT: p=.11; p(H_0): before inactivation: MST: .972, MT: .978, during inactivation: MST: .991, MT: .985). On the basis of earlier studies on feature-based attention[2], we might have expected a smaller effect when the non-preferred stimulus was displayed inside the RF – attention to the non-preferred feature might have led to a suppression of activity, counter-balancing the facilitating effect of spatial attention. The fact that we found no change in modulation suggests that, in the conditions tested in this particular task, the effect of spatial attention was dominant. This finding allows us to rule out an alternate interpretation of our results: the absence of change in gain modulation during SC inactivation could have been caused by a counterbalancing, or a masking, of spatial attentional impairments by feature-based attention. The fact that we did not see any effect of SC inactivation on gain modulation even when the positive effects of feature-based attention were eliminated (i.e., when non-preferred motion was presented) – excludes this possibility.

Changes in inter-neuronal correlations using a range bin sizes

The data reported in the main text used a bin size of 31 ms. To assess how the choice of bin size might have affected these results, we repeated the

same analysis using a range of bin sizes, and show the results below with error bars indicating 95% confidence intervals. Consistent with the results using a bin size of 31 ms, we found that there were significant decreases in inter-neuronal correlations with spatial cueing for bin sizes ranging from 4 to 250 ms for MST and from 4 to 83 ms (excluding 63 ms) for MT (see Supplementary Fig. 1). Most relevant to our conclusions, these effects were not changed during inactivation of the SC, despite the presence of a large behavioral

deficit.



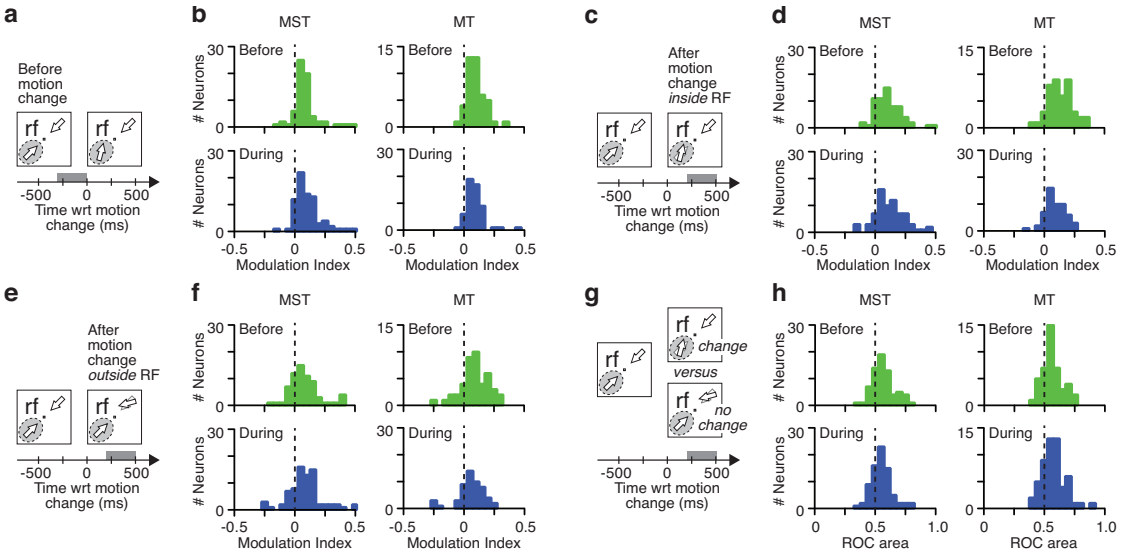
Supplementary Figure 1

Cue-related modulations during other epochs of the task

We considered whether SC inactivation might have changed cue-related modulations in MST and MT neuronal activity during other epochs of the task. In the analyses described in the main text, we followed the example of previous studies by examining activity during the delay period prior to the change in the stimulus. This approach has the advantage of measuring neuronal activity during a period of sustained attention that is unperturbed by

changes in the visual stimulus. However, it leaves open the possibility that the effects of SC inactivation in our experiments might have been temporally gated somehow, and perhaps only present during the epoch later in the trial that was crucial for the animal's performance in the task – i.e., when the motion stimulus changed.

To address this point, we again measured a Modulation Index for each neuron, before and during inactivation, but for epochs flanking when the motion stimulus changed. Once again, these measurements were unchanged by SC inactivation. For the epoch immediately preceding the change in motion (Supplementary Fig. 2, Panels a&b), the Modulation Index was significantly greater than zero both before and during inactivation, in both MST and MT (Wilcoxon signed-rank test, all $p < 0.0001$), with no evident change between pre- and post-injection (Wilcoxon rank-sum test, $p > 0.36$; Bayesian $p(H_0)>.98$). Similarly, for the epoch following the change in motion, the Modulation Indexes were greater than zero ($p < 0.003$) and unchanged by SC inactivation ($p > 0.1$; Bayesian $p(H_0)>.95$), regardless of whether the motion change occurred inside the neuron's receptive field (Supplementary Fig. 2, Panels c&d) or outside the neuron's receptive field (Supplementary Fig. 2, Panels e&f). These results demonstrate that cue-related changes in firing rate remained intact during SC inactivation, including all of the epochs crucial for performance of the task, even though SC inactivation simultaneously caused major behavioral impairments.



Supplementary Figure 2

Possible changes unrelated to the spatial cue

We tested for changes in neuronal activity unrelated to the spatial cue. First, we measured the absolute discharge rate of the MST and MT units, independently of the cue location, at different task epochs, both before and during SC inactivation. SC inactivation did not cause significant changes in any of these epochs (between 200ms before motion onset and at the time of motion onset, Wilcoxon rank-sum test: MST p = 0.39, MT p = 0.13; Bayesian $p(H_0)$: MST: .990, MT: .984), during the visual response epoch (between 50ms and 200ms after motion onset, Wilcoxon rank-sum test: MST p = 0.21, MT p = 0.71; Bayesian $p(H_0)$: MST: .97, MT:.986), and during the DELAY epoch (between 300ms and 800ms after motion onset, MST p = 0.16, MT p = 0.73; Bayesian $p(H_0)$: MST: .96, MT: .986).

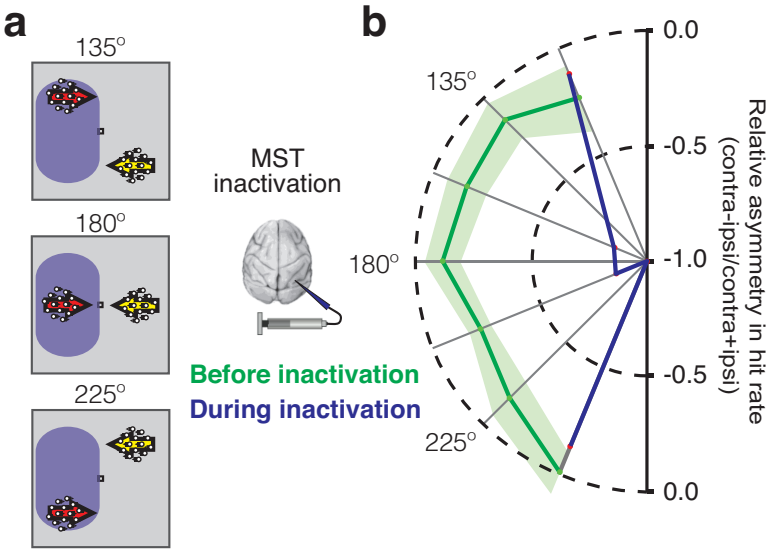
Second, we tested how well an ideal observer could perform the detection task based on comparing neuronal activity on change versus no-change trials (Supplementary Fig. 2, Panel g). The ROC areas were significantly greater than chance (Supplementary Fig. 2, Panel h), both before (green) and during

(blue) SC inactivation in both MST and MT (Wilcoxon signed-rank test, all $p < 0.008$), and were not changed by SC inactivation (Wilcoxon rank-sum test, MST: $p = 0.49$, MT: $p = 0.63$; Bayesian $p(H_0)$: MST: .958, MT: .985). At the level of individual neurons, about 20% of the units had ROC values significantly greater than chance, both before and during inactivation (based on bootstrapped standard error, before inactivation: MST: 19%, MT: 23%; during inactivation: MST: 17%, MT: 25%). These results show that neurons in MST and MT have activity that can support correct performance of the task, both before and during SC inactivation.

Effects of MST inactivation on the task

There is a large literature documenting the importance of areas MT and MST in these types of motion tasks[3-5], and the ROC analysis described above confirms that MST and MT neurons conveyed signals related to task performance. Nonetheless, to confirm that these neurons are necessary for the performance of our task, we injected muscimol directly into MST, at the same location we had previously recorded neuronal activity. Local inactivation of MST produced a profound deficit in the ability to correctly detect changes in the cued stimulus, specifically when the stimulus was placed in the visual field contralateral to the injection (see Supplementary Fig. 3). Performance dropped to as low as 0% for one location, and the deficit was largest for locations matching the receptive fields of the neurons previously recorded at this MST site. This control experiment was performed only once, but it produced the retinotopic deficit in visual motion processing expected from

previous studies, confirming that neuronal activity in the parts of MST we recorded are indeed necessary for the performance of the attention task we used.



Supplementary Figure 3

References

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