SUPPLEMENTARY DISCUSSION

Analysis of variation in eye position on attention modulation

A critical feature of attention experiments is that the visual stimulus remains the same, and only the subject's use of the stimulus changes. Within a given experiment, we always placed the same stimulus in the RF. However, small changes in fixation from trial to trial slightly change the position of the stimulus in the RF, and may possibly result in differences in neuronal response. This is particularly important for LGN and TRN RFs because of their small size. For eccentricities ≤ 20°, RF diameters of TRN neurons in our experiments (n = 12) were on average 0.83°, while LGNm (n = 15) were 0.73°, and LGNp RFs (n = 23) were 0.62°. The RFs in the two structures were therefore about the same size and should be similarly affected by any small eye position changes.

For neurons in each area, we analyzed the position of the eyes during fixation to determine whether there were any systematic differences in eye position between ATTin and ATTout trials that might account for the response differences we observed. For each neuron, we calculated the mean point of fixation for both ATTin and ATTout trials during the first 100 ms of stimulus presentation (when attentional changes were observed in both LGN and TRN). We calculated a difference vector showing the difference in fixation between ATTin and ATTout trials. We then rotated the vector representing the difference in fixation around the center of the screen (the actual fixation point), so that the neuron's RF was directly to the right. This enabled us to see any systematic variations in fixation relative to the RF. Supplementary Figure 3 shows each of the resulting fixation differences (the endpoints of the mean difference vectors for each neuron ± 1 SE of the mean). Differences in fixation while recording from TRN neurons are shown in black, while blue and red are for LGNm and LGNp, respectively. The mean horizontal and vertical fixation differences between ATTin and ATTout trials relative to the neuronal RF are shown as arrows on the axes. The magnitude of the mean difference for all neurons was only 0.04° (TRN: 0.07°, LGNp: 0.05°, LGNm: 0.01°).

There was neither substantial nor significant correlation between the magnitude of the attentional effect on neuronal responses and the difference in fixation. TRN ($r = -0.11$, $p = .954$), LGNm ($r = .14$, $p = .577$), and LGNp ($r = 0.23$, $p = 0.158$) all had very weak correlations. In retrospect, it would have been puzzling to find that the effects we observed were due to differences in fixation position. Recall that the modulation of neuronal responses was different in TRN and LGN: LGN increased with attention whereas TRN decreased. Since all the neurons we recorded responded similarly to the stimuli, with fast rigorous on-responses, the pattern of fixation differences would have to be different for days on which we recorded from TRN and for those on which we recorded from LGN. That is, the monkeys would have had to consistently change their fixation patterns for experiments in TRN and experiments in LGN to cause systematic differences in modulation. Since the monkeys had no way of knowing from which area we were recording on any given day, it is implausible on principle that fixation differences caused the modulation we observed.

Comparison of TRN attentional modulation in visual/visual and visual/auditory tasks

Our first account of attentional modulation in TRN[31] used a task very different from the task in the current report. Our previous task did not shift attention between two visual stimuli, but between a visual stimulus (a spot) and an auditory stimulus (a tone). When shifting attention into the RF of a visual TRN neuron from an auditory stimulus, the initial visual responses in TRN did not decrease, but rather increased. The two different attention experiments were done in the same two monkeys so that in making comparisons we can exclude any differences between animals. Supplementary Figure 4a shows the results for both experiments using the same ATTmod measure. Closed symbols show neuronal changes in the within-modality experiments, when attention shifted from a localized visual stimulus outside the RF of the TRN neuron to a stimulus in the RF. Open symbols show modulation in the across-modality experiments, when attention was shifted from an unlocalized auditory stimulus to the visual stimulus in the RF. The ordinate is the baseline TRN response when attention was directed away from the visual TRN RF, and the abscissa is ATTmod due to directing attention toward the visual stimulus in the RF. Both the previous experiment and the current experiment include the condition when attention is shifted to a visual stimulus in the RF, but note that the stimulus in the RF was a spot when shifting attention between modalities, and a bar when shifting attention within the visual modality. Although the difference in stimuli (and the relative invasion of any RF surround) makes it difficult to directly compare the absolute magnitudes of the responses, we can still compare the effects attention had on these responses.

The most obvious difference between the two experiments is the direction of the attentional effect. Shifting attention within modality from one visual stimulus to another yields a decrease in initial TRN visual activity as shown by the solid symbols falling largely to the left of the vertical unity line. Shifting attention to a visual stimulus across modalities (from an auditory to a visual stimulus) yields an increase in TRN activity as shown by the open symbols in Supplementary Figure 4a falling largely to the right of the unity line. The mean change in response from attention for the shift within modalities for these two monkeys was -4.8%, whereas across modalities it was +6.3%.

Note also the difference in the magnitudes of the responses. Baseline responses in the absence of attention were on average higher within the visual modality (closed symbols, mean = 294 spikes/s), than across modalities (open symbols, mean = 179 spikes/s). When attention was directed to the stimulus in the RF in each experiment, the mean ATTvis response (across modalities) was 189 spikes/s, and the mean ATTin response (within modality) was 278 spikes/s, a difference possibly attributable to the different stimuli used in the two experiments, as mentioned above.

While the observations in these two attention experiments appear at odds with each other, the combination of the directions of the attentional effects and the magnitudes of the visual responses might provide some insight into understanding the differences. The key is considering the nature of the attention experiments: global attention shifting between visual and auditory modalities in our previous experiments and local shifts between two visual stimuli in our current visual attention experiments. When shifting attention across modalities, attending to the auditory stimulus inhibits the visual modality so firing rates are lower in visual TRN during ATTaud trials as shown schematically in the left half of Supplementary Figure 4b. Attention shifting from the auditory to the visual modality (ATTvis) increases the visual response in TRN by presumably releasing visual TRN from the inhibitory influence of the auditory sector, as there is clear evidence of interactions between different sectors of TRN[32-34]. Provided auditory TRN acts on visual TRN more uniformly, rather than in a spatially selective manner, the modulation of visual TRN in the across-modalities task can be viewed as visual TRN being activated and deactivated by global inhibition from auditory TRN.

Local spatial modulation, however, is related to the competition within different regions of the visual TRN. Consequently the results from our current experiments can be viewed as the interactions within visual TRN in its active state, when attention is on visual stimuli (Supplementary Figure 4b, right side). Now when attention is directed within the visual modality, TRN responses are reduced at the location of attention and this reduction selectively enhances LGN responses by reducing inhibition at the attended location. Directing visual attention out of the RF of a TRN neuron increases its response, inhibiting LGN at the unattended location. The part of the puzzle that is missing is the behavior of LGN when attention shifts between auditory and visual stimuli

(Supplementary Figure 4b, left side). Shifting attention from a visual stimulus to an auditory one results in a decrease in TRN activity, which, according to the local TNR/LGN circuit, should result in an increase in the initial visual response in LGN when attention shifts to an auditory stimulus. Although we did not record from LGN neurons in our previous experiment, and so have no data from LGN for this condition, recall that the current experiment shows that there are other attentional influences acting on LGN, as the later stages of the visual response are modulated in the absence of any TRN modulation: additional influences that could possibly create the desired effect in LGN when attention is shifted to an auditory stimulus. So although the previous and current experiments appear to have conflicting results, consideration of the difference between global and local spatial selectivity provides a possible resolution to this perceived conflict.

SUPPLEMENTARY NOTES

Bootstrap analysis

To obtain latency estimates and to compute their significance, we used a bootstrap analysis. For the latency of the visual response in areas LGNm, LGNp. and TRN, we calculated the mean spike density plot for the ATTin condition. If the data set for an area, and therefore the mean spike density plot, consisted of N neurons, we created a subset of N neurons chosen from the original set with replacement. That is, if the original set consisted only of neurons A, B, and C, possible subsets might be (A, A, B), (A, C, C), (A, B, C), (B, B, C), etc. For each of 1000 iterations a new subset was chosen and the mean ATTin spike density plot was calculated from this subset. We fit a normal cumulative density function (CDF) to each of these 1000 spike density plots, and estimated the latency from the curve fit to the spike density plot in the same way we did for individual neurons (when the fit curve reached 10% of the spike density plot peak). In this manner we acquired a distribution of 1000 latency estimates for each area. From these distributions of estimates we were able to obtain the median latency (used as the characteristic latency for an area) and we were also able to determine the significance of the latency differences between areas using the Wilcoxon rank-sum test for equal medians.

For the latency of the attentional modulation for each area, a bootstrap analysis identical to the one above was performed, but rather than fitting the normal CDF to the ATTin curve, we fit it to the difference between the ATTin and ATTout curves.

References for Supplementary Information

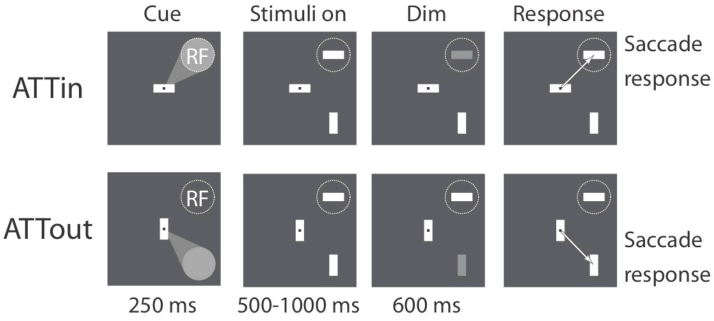
31. McAlonan, K., Cavanaugh, J. & Wurtz, R. H. Attentional modulation of thalamic reticular neurons. J Neurosci 26, 4444-50 (2006).

32. Crabtree, J. W., Collingridge, G. L. & Isaac, J. T. A new intrathalamic pathway linking modality-related nuclei in the dorsal thalamus. Nat Neurosci 1, 389-94 (1998).

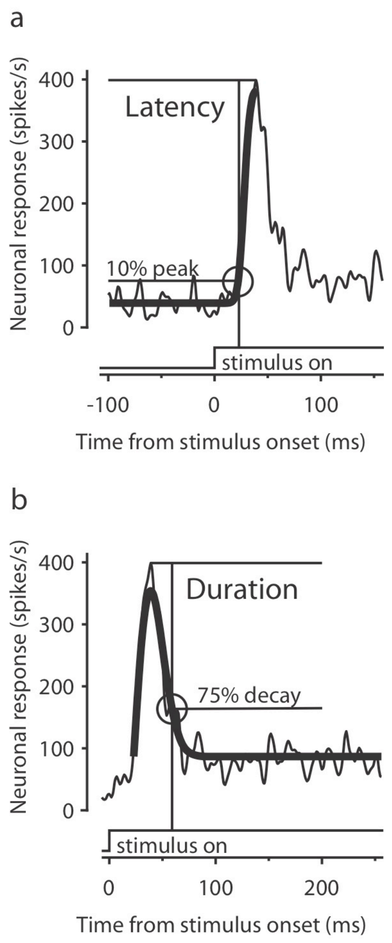
33. Crabtree, J. W. & Isaac, J. T. New intrathalamic pathways allowing modality-related and cross-modality switching in the dorsal thalamus. J Neurosci 22, 8754-61 (2002).

34. Kimura, A., Imbe, H., Donishi, T. & Tamai, Y. Axonal projections of single auditory neurons in the thalamic reticular nucleus: implications for tonotopy-related gating function and cross-modal modulation. Eur J Neurosci 26, 3524-35 (2007).

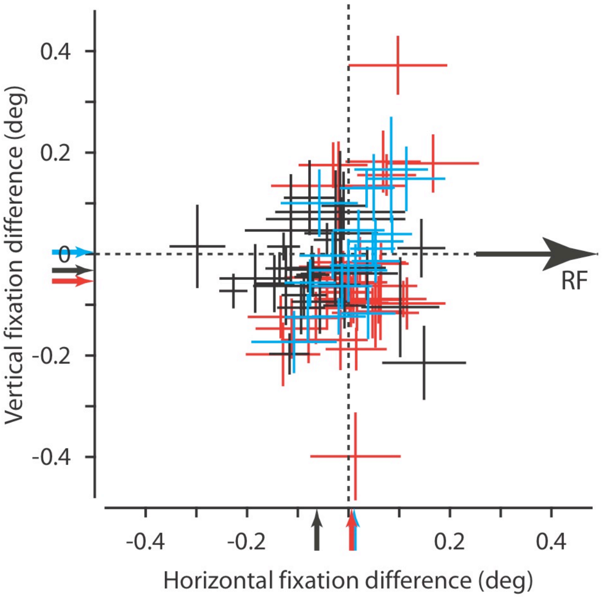
SUPPLEMENTARY FIGURES AND LEGENDS



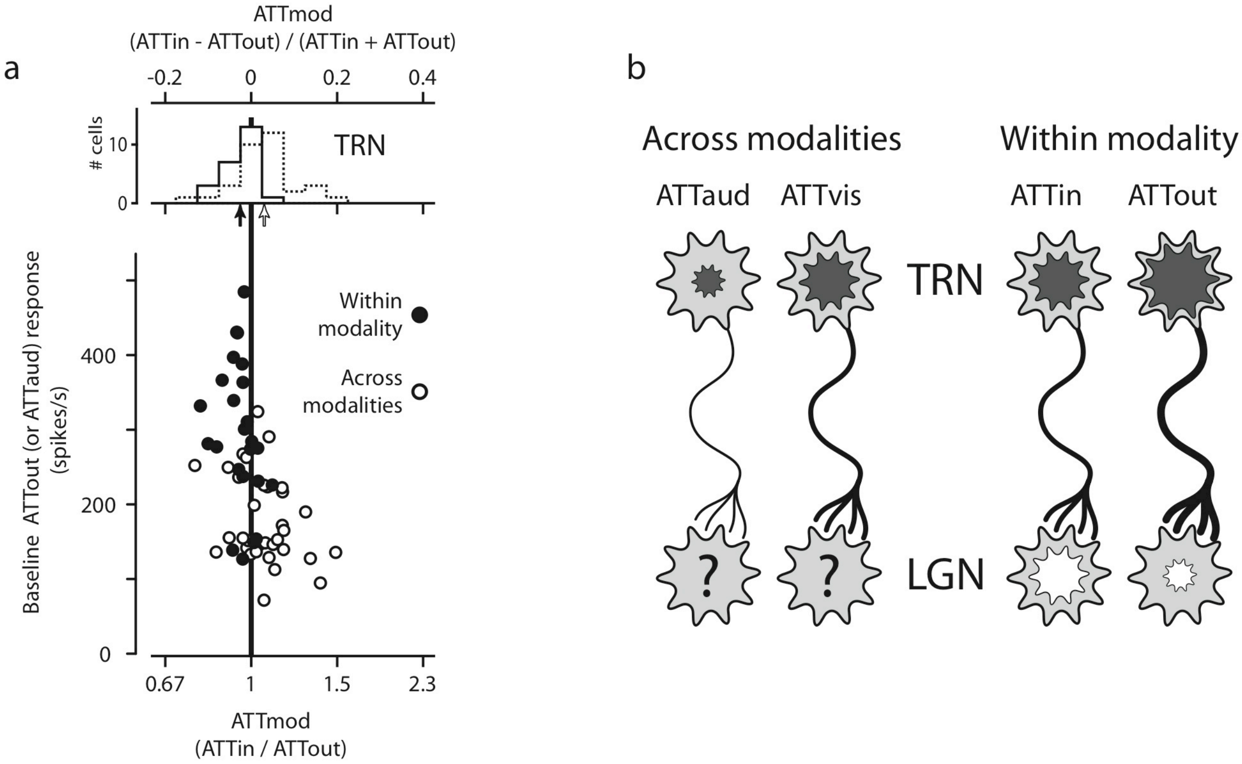
Supplementary Figure 1. Visual Spatial Attention task used for both LGN and TRN neurons. See Methods for further details.



Supplementary Figure 2. Determination of visual response latency and duration. **a**, The visual response latency is taken as the time at which the fit curve climbed to 10% of the peak neuronal response (circle), and the latency extracted from this fit is shown by the vertical line through the circle. **b**, The end of the visual response duration was taken as the time the fit curve decays to the point 75% of the way from the peak response to the end of the fit curve (circle). The vertical line denotes the end of the visual response. See Methods for details.



Supplementary Figure 3. Differences in eye position during the initial visual response. For each neuron we have plotted the difference in eye position between ATTin and ATTout trials during fixation as the intersection of each pair of lines. The lengths of the lines represent ±1 SE of the horizontal and vertical differences during the first 100ms of stimulus presentation. Positions have been rotated around the center to place the neuronal RF to the right, as indicated by the large black arrow.



Supplementary Figure 4. Modulation of TRN from attentional shifts within and across sensory modalities. **a**, Baseline response versus attentional modulation (ATTmod) for attentional shifts within and across sensory modalities. Solid symbols are a subset of those in Figure 3c. Baseline response for data across modalities is the ATTaud response. Distributions of ATTmod appear above the scatterplot for within modality (solid lines) and across modalities (dashed line). Distribution medians are denoted by the solid arrow (within modality) and open arrow (across modalities) below the distributions. **b**, Schematic representation of relative activity in LGN and TRN from shifting attention within and across modalities.