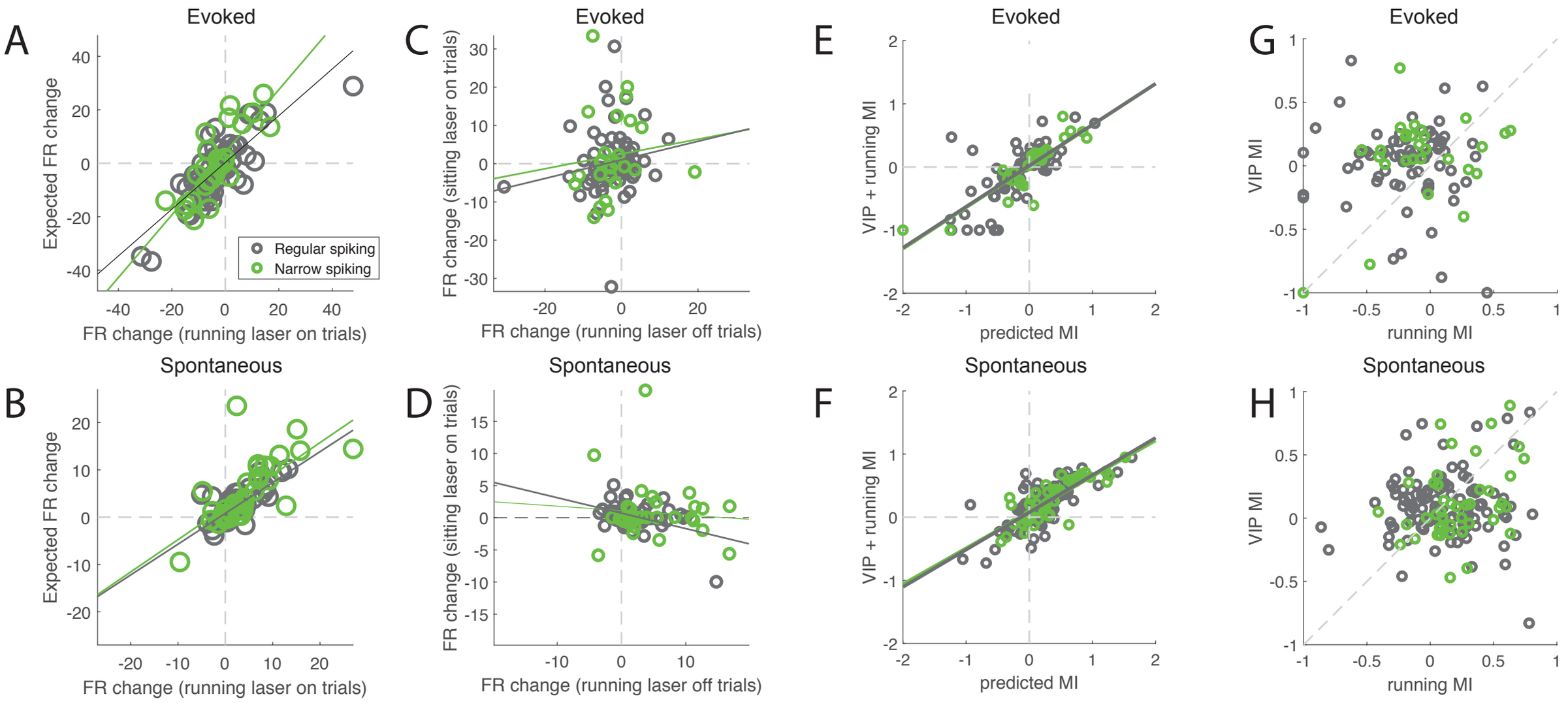


**Supplemental Figure 4.** Linearity Analysis with firing rate. To verify that the linear additivity we observed did not depend on the choice of response normalization (i.e., our use of sound modulation index), we repeated the analysis of Figure 5 using non-normalized evoked and spontaneous firing rates separately. The changes in both evoked and spontaneous firing rates during running laser-on trials were well-predicted by the sum of firing rate changes during either running or laser-on trials. This was true for both regular and narrow-spiking neurons

**A.** Change in evoked firing rate (FR change) during running laser-on trials was well-predicted by the sum of the running and VIP activation effects computed separately (Expected FR change), $\varrho = 0.7678$, $p = 10^{-18}$, suggesting that the effects of VIP activation and running do not interact. Green: narrow-spiking neurons, grey: regular-spiking neurons.

**B.** Change in spontaneous firing rate (FR) during running laser-on trials was well-predicted by the sum of the running and VIP activation effects computed separately , $\varrho = 0.7578$, $p = 10^{-21}$.

**C.** Running effects and VIP activation effects on evoked firing rates were weakly correlated across neurons. Running effect is on the x-axis (FR change on running laser-off trials), and VIP activation effect is on the y-axis (FR change on sitting laser-on trials), $\varrho = 0.2977$, $p = 0.004$.

**D.** Running effects and VIP activation effects on spontaneous firing rates were not correlated across neurons, $\varrho = -0.0853$, $p = 0.38$.

**E.** As an alternative method to verify the linear additivity we observed, we computed a modulation index for VIP activation: $VIP\ MI = \frac{laser{-}on - laser{-}off}{laser{-}on + laser{-}off}$ , a modulation index for running: $running\ MI = \frac{running - sitting}{running + sitting}$ , and a modulation index for the combined effect of running during VIP activation: $VIP + running\ MI = \frac{running\ laser{-}on - sitting\ laser{-}off}{running\ laser{-}on + sitting\ laser{-}off}$ . We then compared the actual VIP+running MI to the predicted sum of VIP MI and running MI for evoked firing rates, finding a tight correlation between observed and expected effects, $\varrho = 0.7478$, $p = 10^{-19}$.

**F.** Same analysis as in (E) but for spontaneous firing rates. Actual VIP+running MI was well predicted by the sum of VIP MI and running MI for evoked firing rates, $\varrho = 0.7543$, $p < 10^{-20}$.

**G.** An alternative method to verify that running effects and VIP activation effects were independent of one another. Comparison of VIP MI and running MI (defined above in E) for evoked firing rates showed the two were uncorrelated, $\varrho = 0.1068$, $p = 0.29$.

**H.** Same analysis as in (G) but for spontaneous firing rates. VIP MI and running MI for spontaneous firing rates were uncorrelated, $\varrho = 0.1035$, $p = 0.20$.