

Supplementary Information for:

**Neurofeedback modulation of insula activity via MEG-based brain-machine
interface: A double-blind randomized controlled crossover trial**

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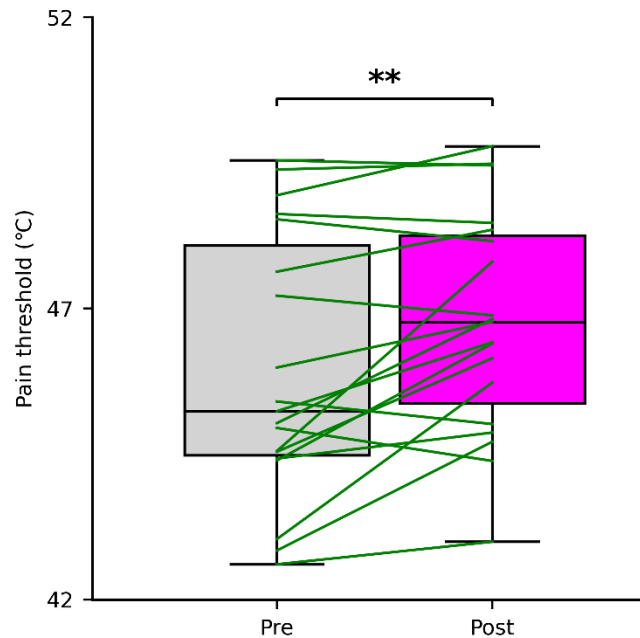
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Supplementary Table 1. Repeated Measures ANOVA Results for Modulation and

Pre-post Effects on the Pain Threshold.

Source	Sum of Squares	Degrees of Freedom (Num DF)	Denominator DF (Den DF)	F Value	P Value
Modulation	0.337	1	18	0.337	0.5688
Time	10.5213	1	18	10.5213	0.0045
Modulation × Time	0.2246	1	18	0.2246	0.6412

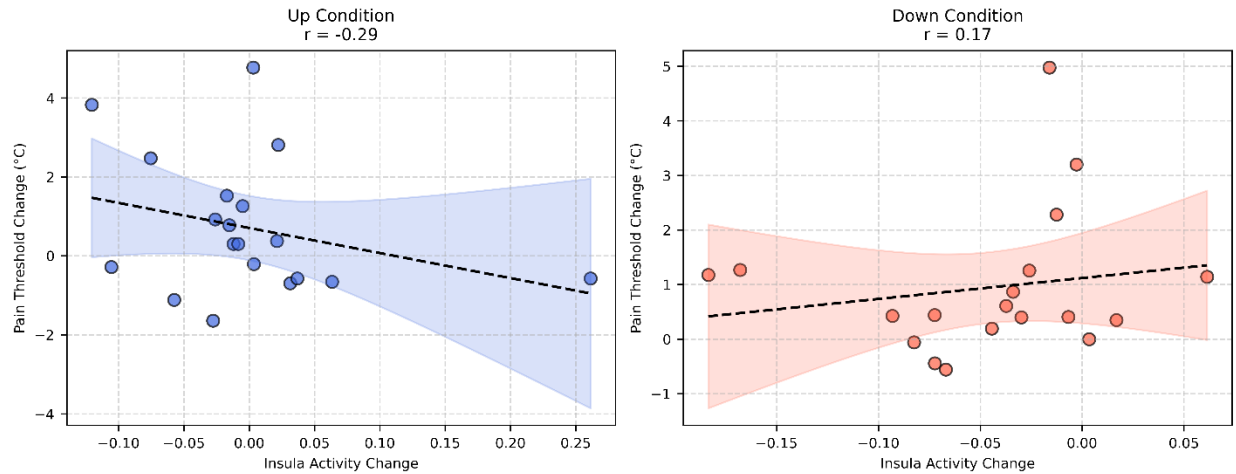
The effect of modulation (up vs. down) on the pain threshold was not statistically significant ($p = 0.5688$), whereas the effect of time (pre vs. post) was significant ($p = 0.0045$), indicating a change in the pain threshold over time. The interaction between modulation and time did not significantly affect the pain threshold ($p = 0.6412$), suggesting that the impact of modulation does not vary by time point.



Supplementary Figure 1. Effect of time on pain threshold.

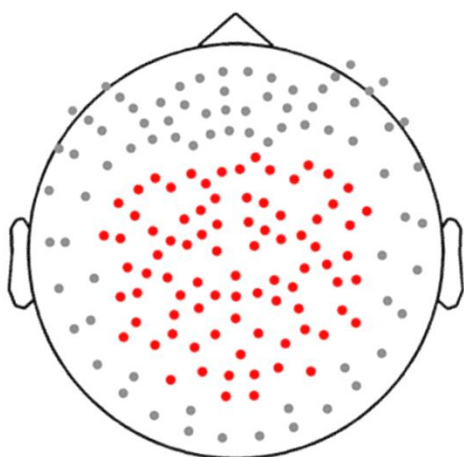
Pain thresholds (the average of the thresholds for Upmodulation and Downmodulation experiment) pretraining (gray) was significantly lower than posttraining (magenta) ($t = -3.2437$, $p = 0.0045$; $n = 19$). All the data were analyzed by two-tailed paired Student's t tests with Bonferroni correction. Green lines connect data points from the same individual. Asterisks (*) denote statistically significant differences ($*p < 0.05$, $**p < 0.01$). In the boxplots, centerlines represent medians, the box limits represent the lower and upper quartiles, the whiskers represent 1.5 times the interquartile range.

Compare Correlations via Bootstrap
Up-Down diff = -0.464, $p = 0.532$
95% CI = (-0.979, 0.100)



Supplementary Figure 2. Correlation analyses between insular activity changes and pain threshold changes

Scatter plots illustrating the relationship between insular activity changes and pain threshold changes in two conditions: *Up* (left panel) and *Down* (right panel). Each panel displays individual participant data points ($n=19$) alongside a simple linear regression line (dashed) with the corresponding 95% confidence interval (shaded region). The difference in these two correlation coefficients ($\Delta r = r_{Up} - r_{Down}$) was tested via a bootstrap approach



Supplementary Figure 3. Selected MEG sensors.

The locations of the MEG sensors used for online neurofeedback are indicated by red points.