Supplementary Information for

Layer-Specific Attentional Modulation in the Human Primary Somatosensory Cortex

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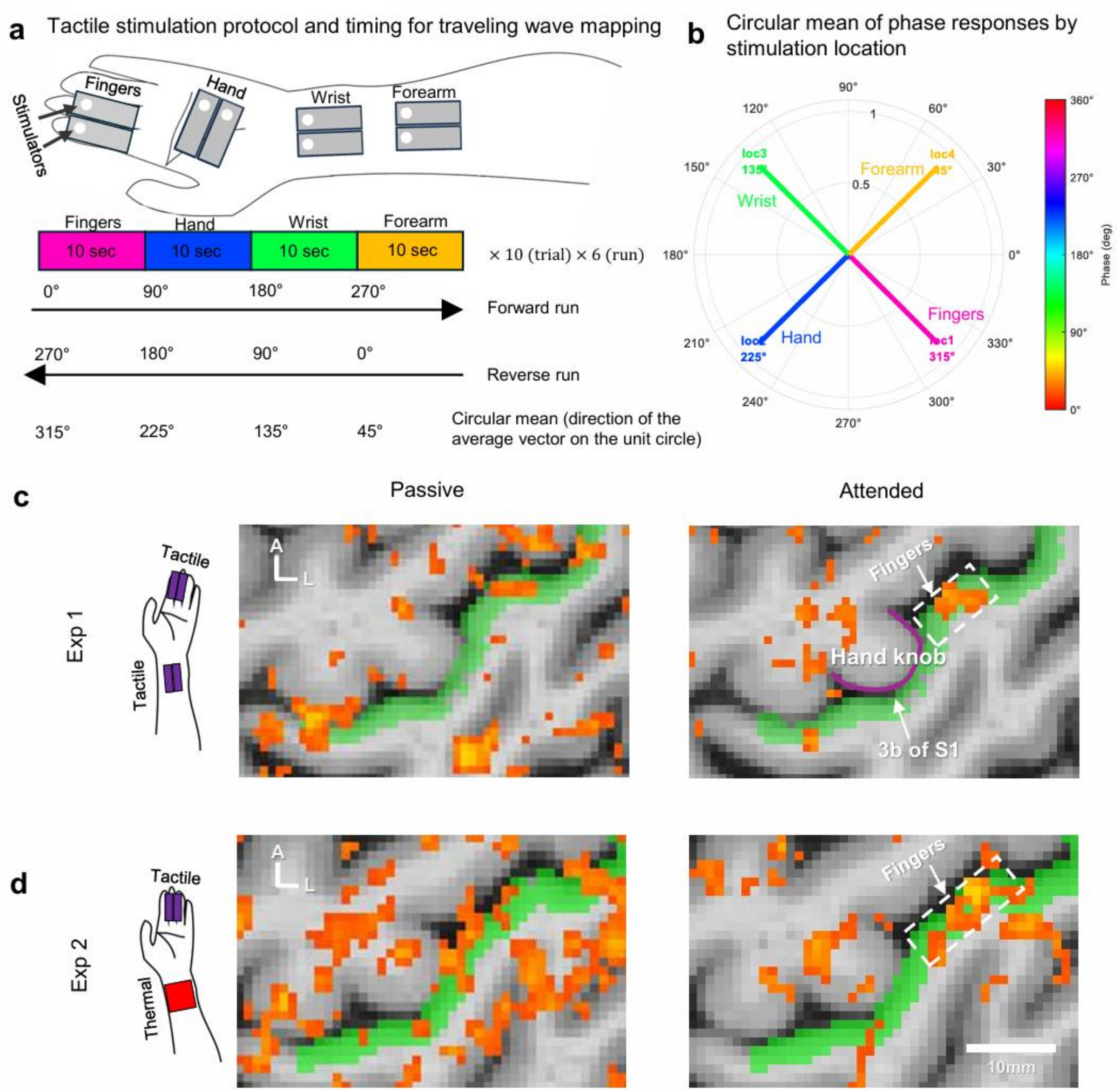
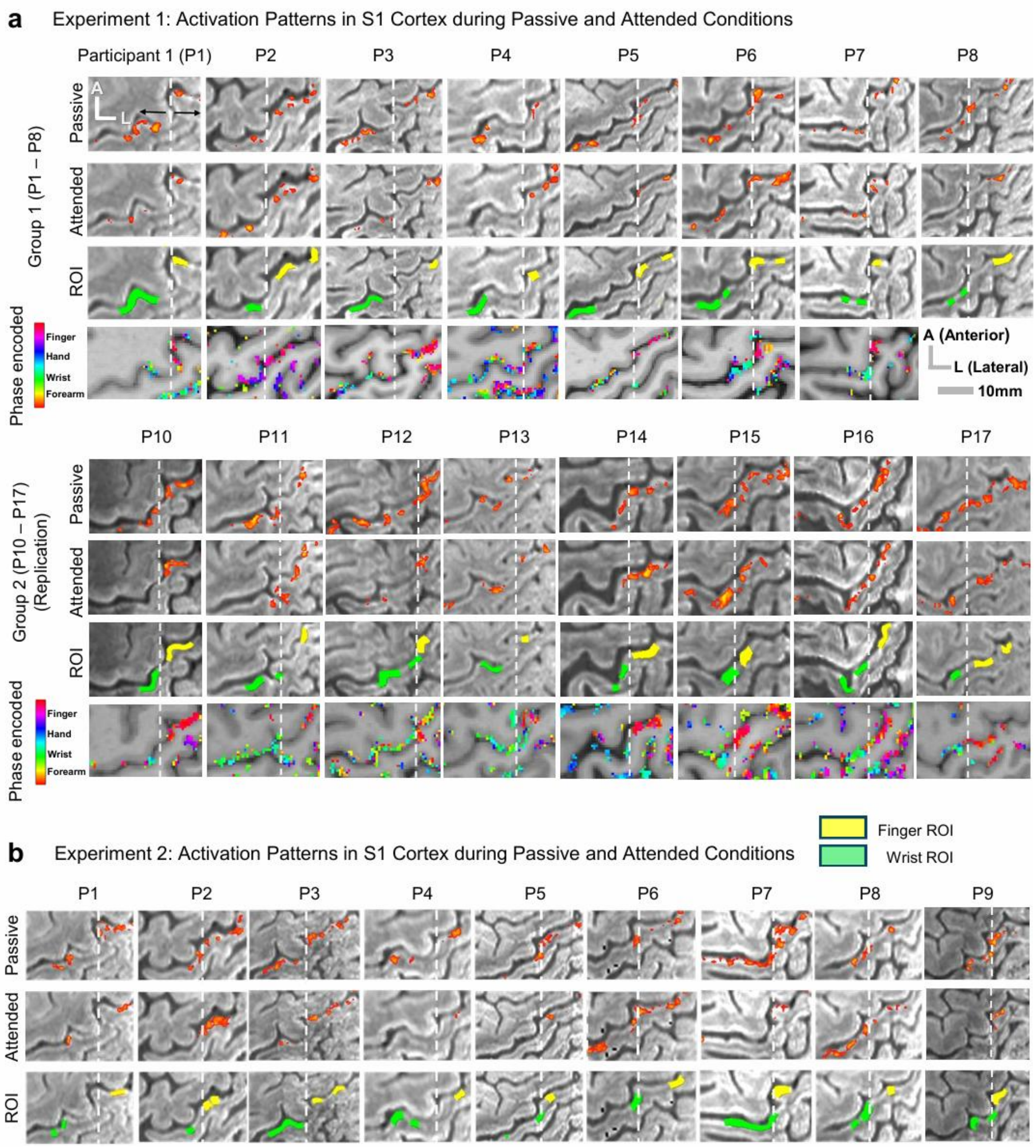
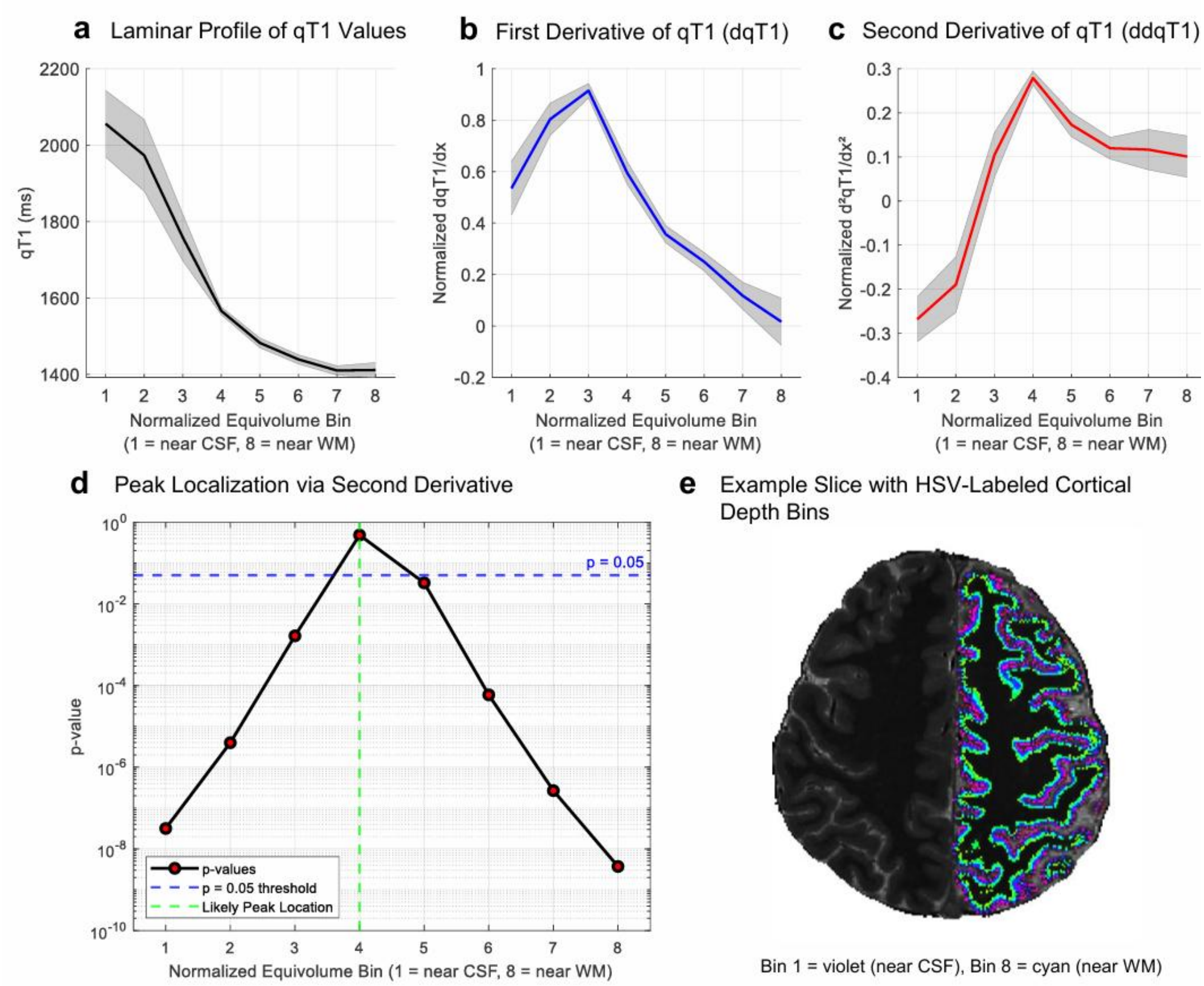


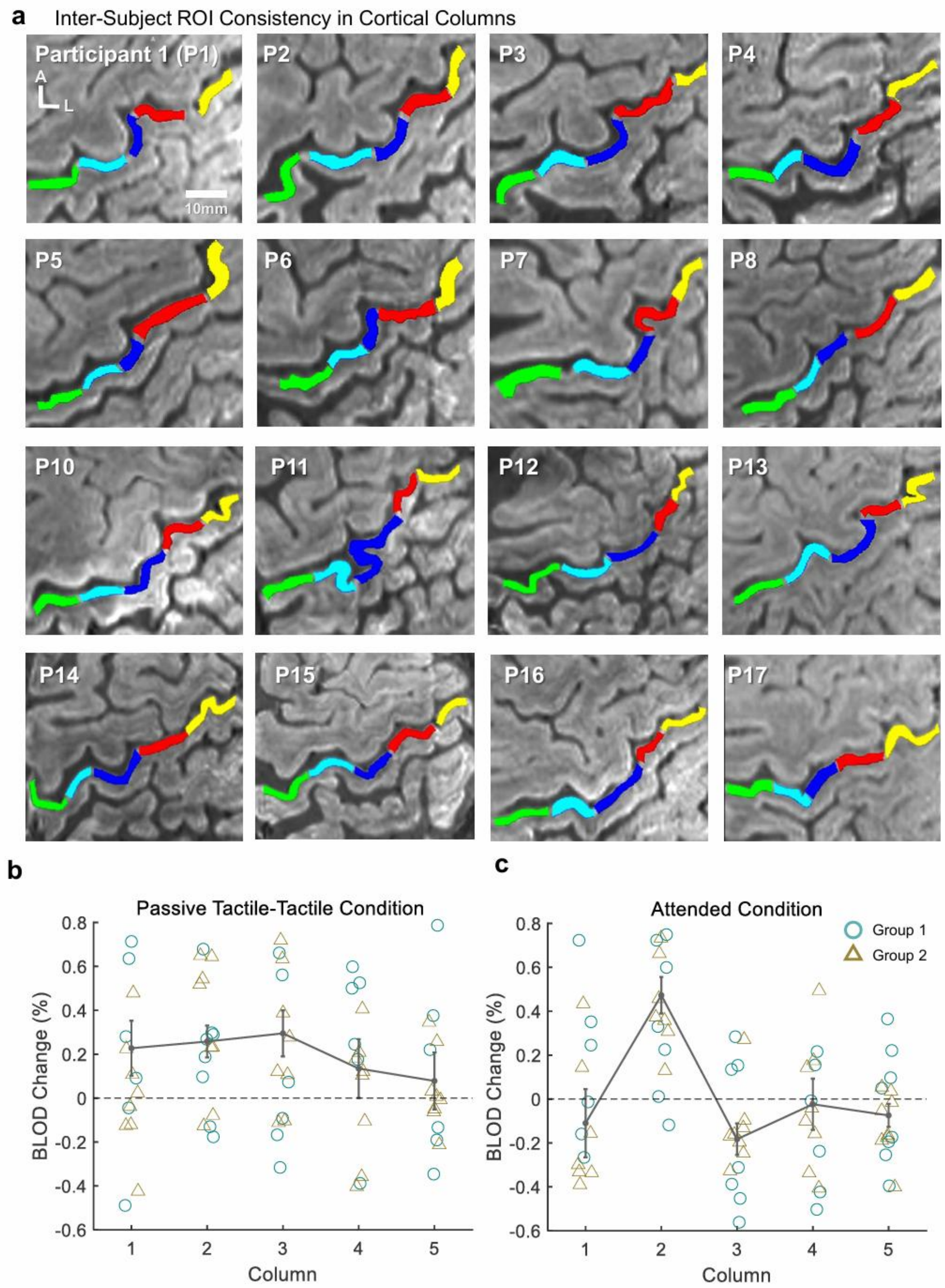
Supplementary Fig. 1 Somatotopic mapping and activation patterns across conditions in Experiments 1 and 2. a, Tactile traveling wave stimulation protocol used to map somatotopy across four body sites (fingers, hand, wrist, forearm), each stimulated for 10 seconds per cycle. Stimulation proceeded in either forward (0°–270°) or reverse (270°–0°) order across 10 cycles per run, repeated across 6 runs. b, Circular mean of voxelwise phase responses for each body location, color-coded by stimulus site. Arrows indicate the average direction on the unit circle, accounting for the circular nature of phase data. c–d, Activation maps from a representative subject in Experiment 1 (c, tactile–tactile) and Experiment 2 (d, tactile–thermal), shown for both passive and attended conditions. The hand knob (purple U-shaped region) and area 3b of S1 (green strip) are indicated for anatomical reference. In the passive condition, scattered activation patterns are visible around the hand knob within S1, with orange clusters indicating voxels showing significant BOLD responses during tactile stimulation ($z > 2.3$, cluster-corrected at $p < 0.05$) overlaid on the green strip. When attention was directed to the fingers, the number of activated voxels was markedly reduced. Activation maps were spatially smoothed with a 1.6 mm Gaussian filter.



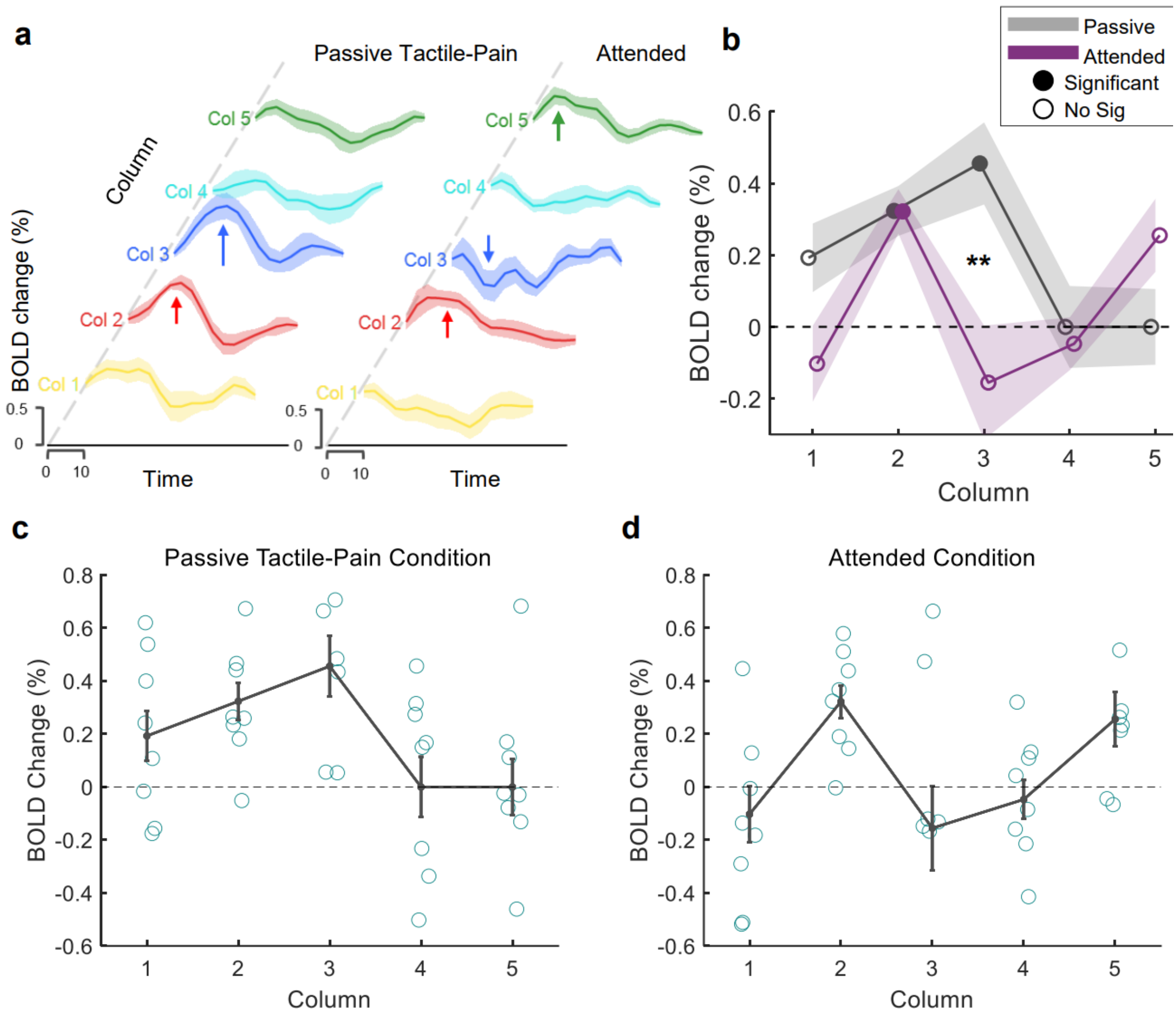
Supplementary Fig. 2 Activation Maps in Area 3b of the Primary Somatosensory Cortex (S1) During Passive and Attended Conditions. This figure displays individual-level activation maps in area 3b of the primary somatosensory cortex (S1), comparing BOLD responses during passive and attended conditions across two experiments. Z-statistic maps were thresholded at $z > 1.5$ using a canonical hemodynamic response function (HRF) model. a, Experiment 1*:* Activation patterns during tactile stimulation of the fingers and wrist. Participants were divided into two groups. Group 1 (P1–P8) completed both Experiments 1 and 2, while Group 2 (P10–P17) was subsequently recruited to replicate the findings. The bottom row for each group shows phase-encoded somatotopic maps from an independent localizer run, identifying individual spatial preferences for different stimulation sites. Finger and wrist regions of interest (ROIs) were primarily defined using these maps, then further refined using activation patterns from both passive and attended conditions. Finger ROIs (yellow) included voxels activated in both conditions and were typically located lateral to the hand knob. Wrist ROIs (green) were defined based on passive-only activation medial to the hand knob, especially in regions showing little or no activity during attended stimulation. b, Experiment 2: Activation patterns during tactile (finger) and thermal (wrist) stimulation under passive and attended conditions. ROI definition followed the same procedure as in Experiment 1: finger ROIs (yellow) reflected consistent activation across conditions, while wrist ROIs (green) were defined from passive-only responses. Note: Phase-encoded localizer data were acquired from 15 participants across both experiments. In Experiment 2, no new localizer runs were conducted, as participants P1–P7 had already completed the localizer in Experiment 1. For participants without localizer data (e.g., P8 and P9), ROI placement was based on anatomical landmarks—particularly the hand knob—and functional activation patterns from the main experiment. In both panels, white dashed lines indicate the approximate boundary between finger and wrist representations along the medio-lateral axis of the hand knob region in S1.



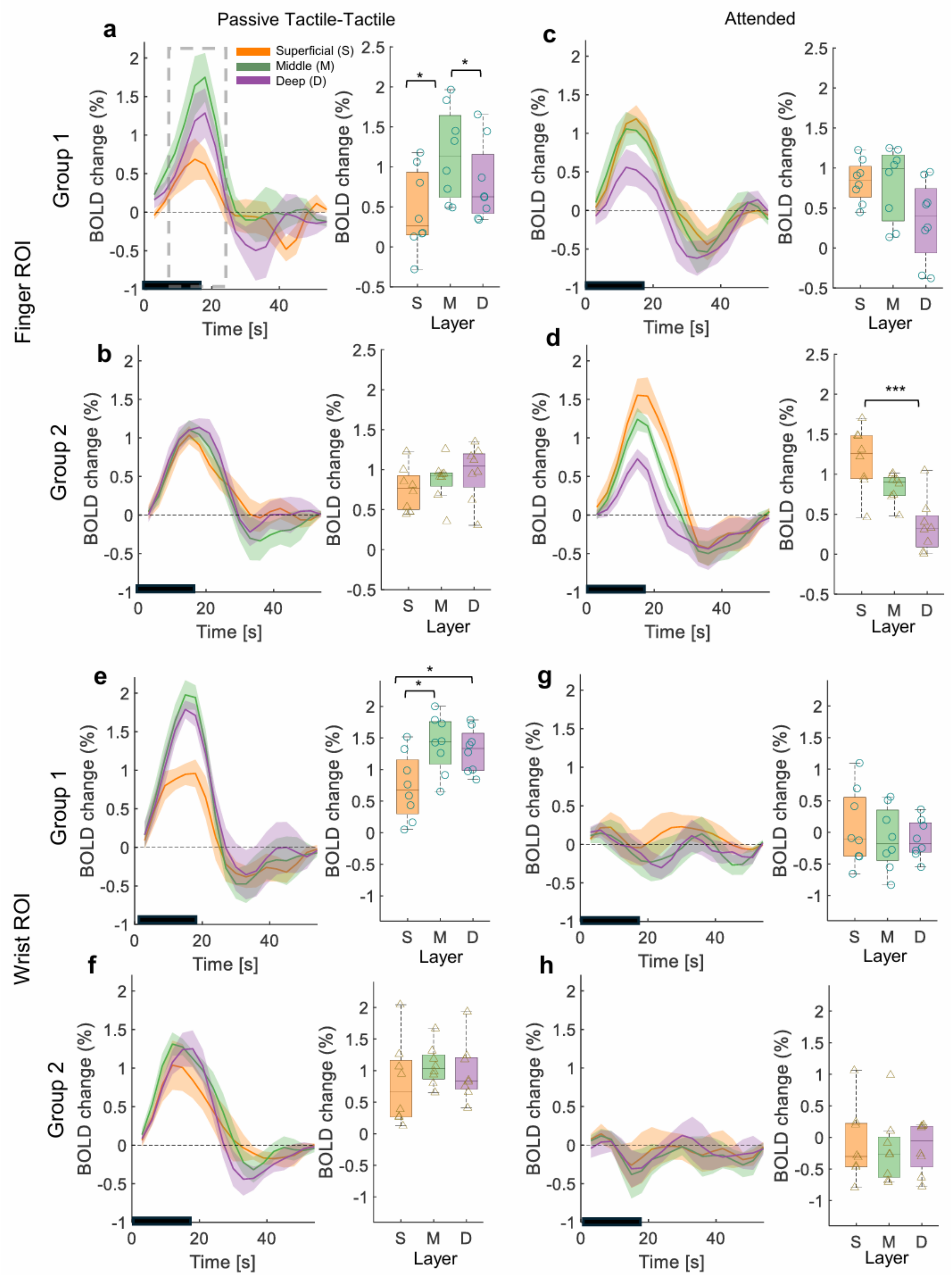
Supplementary Fig. 3 Quantitative T_1 Profile and Normalized Derivatives Across Cortical Depth in Area 3b of Primary Somatosensory Cortex (S1) Using Equivolume Binning. a, Group-averaged qT1 profile across 8 equivolume cortical depth bins in area 3b of S1 (n = 17). Bin 1 corresponds to the pial surface (near CSF), and Bin 8 to the white matter boundary. Shaded regions represent the standard error of the mean (SEM) across subjects. b, Normalized first derivative of the qT_1 profile, reflecting the rate of change across depth. A peak around Bin 3–4 indicates the steepest transition in qT_1 values. c, Normalized second derivative of the qT_1 profile, capturing curvature (i.e., concavity). The peak indicates the most pronounced inflection point. Derivative values were scaled to a maximum absolute value of 1 to enable shape-based comparison independent of physical units. d, Statistical evaluation of individual second-derivative peak locations relative to each bin depth. For each participant (n = 17), the cortical depth of the maximal second derivative was identified and compared to the fixed bin depths (ranging from 0.9375 near CSF to 0.0625 near WM) using one-sample t-tests. These depth values correspond to the center of each equivolume bin. Resulting p-values are plotted on a logarithmic scale across bins. The dashed blue line indicates the significance threshold (p = 0.05); the dashed green line marks the depth of Bin 4 (0.5625), which did not significantly differ from the individual peaks. This supports Bin 4 as a valid group-level reference for the point of maximal qT_1 curvature. Note that bin numbers increase from superficial (Bin 1) to deep (Bin 8), while depth values represent the normalized center of each bin in cortical depth space. e, Axial slice from a representative subject showing qT_1 anatomical contrast with 8 equivolume cortical depth bins overlaid using an HSV colormap. The left hemisphere shows raw qT_1; the right hemisphere displays bin contours. Colors progress from violet (Bin 1, near CSF) to cyan (Bin 8, near WM), representing increasing cortical depth.



Supplementary Fig. 4 Predefined Columnar Strips as Regions of Interest (ROIs) for Layer-Specific Neural Analysis**.** a, Single-slice anatomical overlays from sixteen participants in Experiment 1 (*n* = 16) showing the consistent placement of columnar ROIs (colored lines) along the cortical surface. These columns were defined anatomically to capture somatotopic progression across the central sulcus. b, BOLD percent signal changes during passive tactile-tactile stimulation for each individual column ROI (1–5). Each marker represents a subject from Experiment 1 (*n* = 16). Cyan circles and golden triangles denote subjects from Group 1 (*n* = 8) and Group 2 (*n* = 8), respectively. Black lines show the group mean ± SEM. c, Same as in b, but for the attended condition.

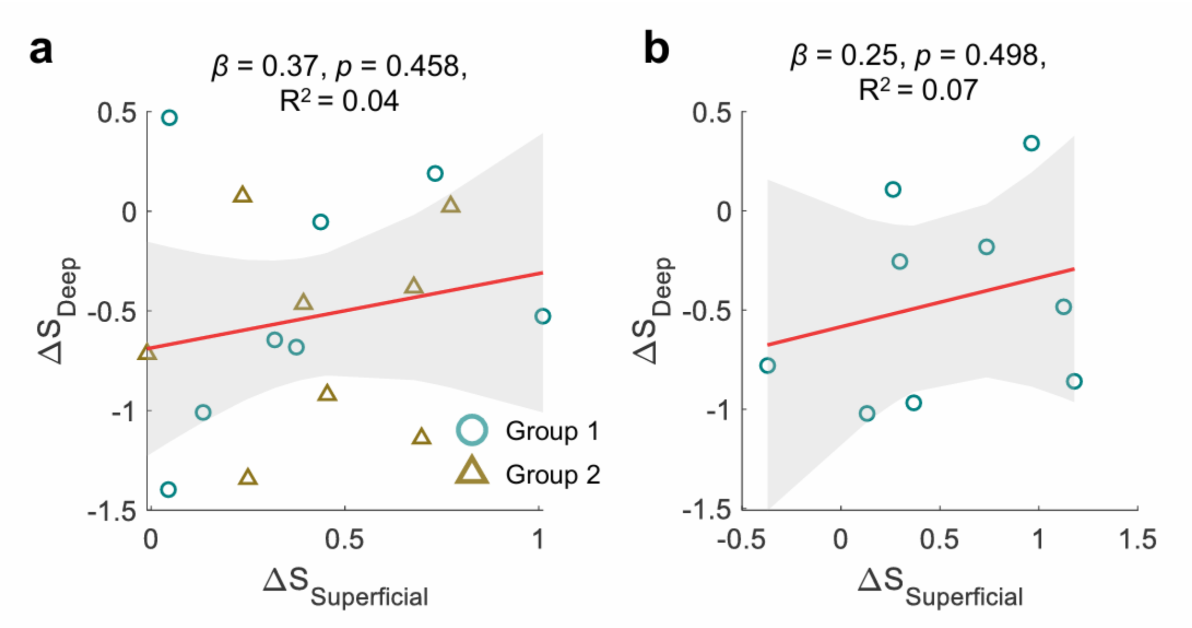


Supplementary Fig. 5 Attention-Modulated BOLD Signal Changes Across Columnar ROIs in S1 in Experiment 2. a, Time courses of percent BOLD signal change for each columnar ROI (Cols 1–5) during passive (left) and attended (right) tactile-pain conditions (mean ± SEM, $n = 9$). Colored arrows highlight condition differences, including a marked reduction in Column 3 under attention (blue arrow). Column 2 (red arrow) showed similarly elevated responses across both conditions. b, Mean percent BOLD signal change during stimulation for each column. In the passive condition, Columns 2 and 3 showed significant activation relative to baseline (Column 2: 0.32 ± 0.07%, $t(8) = 4.657$, $p = 0.002$, $d = 1.552$; Column 3: 0.46 ± 0.11%, $t(8) = 3.986$, $p = 0.004$, $d = 1.329$; one-sample t-tests). Under attention, Column 3 showed a significant reduction compared to passive ($t(8) = -5.195$, $p < 0.001$, $d = -1.732$), while Column 2 responses remained comparable ($t(8) = -0.014$, $p = 0.989$, $d = -0.005$). These condition-dependent patterns align with the time courses in panel a. Filled circles indicate columns showing significant activation relative to baseline after Benjamini–Hochberg FDR correction across the five columns within each condition ($q < 0.05$). Asterisks mark significant condition differences after FDR correction across the five columns (paired t-test; Benjamini–Hochberg FDR-corrected $p < 0.01$). c, Individual participant percent BOLD signal changes in the passive condition for each columnar ROI. d, Same as c, but for the attended condition. Shaded regions in a–b and error bars in c–d indicate ± SEM across participants.



Supplementary Fig. 6 Layer-specific BOLD modulation by attention in Group 1 and Group 2 in Experiment 1. Finger (a–d) and wrist (e–h) ROIs are shown separately for Group 1 (a,c,e,g) and Group 2 (b,d,f,h). Left panels show BOLD time courses during passive (a–b, e–f) and attended (c–d, g–h) conditions for each cortical layer (superficial, orange; middle, green; deep, purple). Lines represent the mean across subjects and shaded bands indicate ± SEM.

Right panels show mean BOLD responses during stimulation for each layer. Boxplots show the median (center line), interquartile range (box), and 1.5 × IQR whiskers. A 2 (Condition: passive, attended) × 3 (Layer: superficial, middle, deep) repeated measures ANOVA revealed significant Condition × Layer interactions in the finger ROI for both Group 1 ($F(2,14) = 10.687$, $p = 0.002$, $\eta^2 = 0.604$) and Group 2 ($F(2,14) = 23.483$, $p < 0.001$, $\eta^2 = 0.770$). In Group 1, attention increased activity in the superficial layer ($p = 0.015$, $d = 1.137$, passive vs. attended paired *t*-test), marginally suppressed the deep layer ($p = 0.077$, $d = -0.733$), and did not significantly change the middle layer ($p = 0.202$, $d = -0.498$). In the wrist ROI, Group 1 showed a significant interaction ($F(2,14) = 8.929$, $p = 0.003$, $\eta^2 = 0.561$) and a main effect of condition ($F(1,7) = 150.556$, $p < 0.001$, $\eta^2 = 0.956$), with all layers suppressed under attention (all $p < 0.008$). In Group 2, a similar Condition × Layer interaction was observed in the finger ROI ($F(2,14) = 23.483$, $p < 0.001$, $\eta^2 = 0.770$), driven by increased activity in the superficial layer ($p = 0.003$, $d = 1.597$) and suppression in the deep layer ($p = 0.013$, $d = -1.178$), while the middle layer showed no significant modulation ($p = 0.727$, $d = -0.128$). In the wrist ROI, no significant interaction was observed ($F(2,14) = 1.468$, $p = 0.264$, $\eta^2 = 0.173$), although a strong main effect of condition was present ($F(1,7) = 117.744$, $p < 0.001$, $\eta^2 = 0.944$), with all layers suppressed under attention (all $p < 0.003$). Post hoc Tukey's HSD tests were used for layerwise comparisons in the figure, whereas paired *t*-tests reported in the Supplementary Materials compare passive and attended conditions within each layer and reflect raw *p*-values as descriptive follow-up tests to significant ANOVA interactions. Data are derived from $n = 8$ independent participants per group. All statistical tests were two-sided.



Supplementary Fig. 7 Relationship between superficial and deep layer attentional modulation in the attended finger ROI. Scatter plots show individual participants' attention-induced changes (ΔS) in superficial and deep layers for a, Experiment 1 and b, Experiment 2. Symbols indicate participant groups (Group 1, open circles; Group 2, open triangles in Experiment 1). The red line shows the linear regression fit and shaded areas indicate 95% confidence intervals. In both experiments, superficial and deep layer modulations were not significantly correlated (Experiment 1: $\beta = 0.37$, $R^2 = 0.04$, $p = 0.458$; Experiment 2: $\beta = 0.25$, $R^2 = 0.07$, $p = 0.498$), ruling out a simple direct inhibition account within cortical columns. Data are derived from $n = 16$ independent participants in Experiment 1 and $n = 9$ in Experiment 2.

Table S1 | Summary of statistical analyses for main and supplementary figures.

Figure	Panel	Experiment	ROI / Layer / Column	Condition	Analysis type	Effect / Comparison	Statistical test	df	Raw p-value	Corrected p / q	Correction	Interpretation
Fig. 3	c	Exp. 1	S1 columns	–	RM-ANOVA	Condition × Column	F-test	F(4,60)	0.0218	–	–	Significant interaction
Fig. 3	c	Exp. 1	Column 2	–	One-sample test	Baseline vs Passive	t-test	t(15)	0.003	0.015	BH-FDR (within 5 columns)	Significant activation
Fig. 3	c	Exp. 1	Column 3	–	One-sample test	Baseline vs Passive	t-test	t(15)	0.013	0.0325	BH-FDR (within 5 columns)	Significant activation
Fig. 3	c	Exp. 1	Column 2	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	0.0206	0.0516	BH-FDR (within 5 columns)	Marginal
Fig. 3	c	Exp. 1	Column 3	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	0.0076	0.0382	BH-FDR (within 5 columns)	Suppression
Fig. 4	a	Exp. 1	Finger	Passive	One-way ANOVA	Layer main effect	F-test	F(2,30)	0.009	–	–	Significant
Fig. 4	a	Exp. 1	Finger	Passive	Post hoc	Middle vs	Tukey’s	F(2,30)	–	0.021	Tukey	Significant

Figure	Panel	Experiment	ROI / Layer / Column	Condition	Analysis type	Effect / Comparison	Statistical test	df	Raw p-value	Corrected p / q	Correction	Interpretation
						Superficial	HSD					
Fig. 4	b	Exp. 1	Wrist	Passive	One-way ANOVA	Layer main effect	F-test	F(2,30)	0.001	–	–	Significant
Fig. 4	b	Exp. 1	Wrist	Passive	Post hoc	Middle vs Superficial	Tukey's HSD	F(2,30)	–	0.005	Tukey	Significant
Fig. 4	b	Exp. 1	Wrist	Passive	Post hoc	Deep vs Superficial	Tukey's HSD	F(2,30)	–	0.046	Tukey	Significant
Fig. 4	c	Exp. 1	Finger	Attended	One-way ANOVA	Layer main effect	F-test	F(2,30)	<0.001	–	–	Significant
Fig. 4	c	Exp. 1	Finger	Attended	Post hoc	Superficial vs Deep	Tukey's HSD	F(2,30)	–	<0.001	Tukey	Significant
Fig. 4	c	Exp. 1	Finger	Attended	Post hoc	Middle vs Deep	Tukey's HSD	F(2,30)	–	0.006	Tukey	Significant
Fig. 4	e	Exp. 1	Finger – Superficial	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	<0.001	0.002	BH-FDR	Enhancement
Fig. 4	e	Exp. 1	Finger – Deep	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	0.002	0.003	BH-FDR	Suppression

Figure	Panel	Experiment	ROI / Layer / Column	Condition	Analysis type	Effect / Comparison	Statistical test	df	Raw p-value	Corrected p / q	Correction	Interpretation
Fig. 4	e	Exp. 1	Finger – Middle	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	0.17	0.17	BH-FDR	n.s.
Fig. 4	f	Exp. 1	Wrist – All layers	–	Post hoc	Passive vs Attended	Paired t-test	t(15)	<0.001	<0.001	BH-FDR	Suppression
Fig. 5	a	Exp. 2	Finger – All layers	Passive	One-way ANOVA	Layer main effect	F-test	F(2,16)	0.190	–	–	n.s.
Fig. 5	b	Exp. 2	Wrist – All layers	Passive	One-way ANOVA	Layer main effect	F-test	F(2,16)	0.087	–	–	n.s.
Fig. 5	c	Exp. 2	Finger	Attended	One-way ANOVA	Layer main effect	F-test	F(2,16)	0.001	–	–	Significant
Fig. 5	c	Exp. 2	Finger	Attended	Post hoc	Superficial vs Deep	Tukey's HSD	F(2,16)	–	<0.001	Tukey	Significant
Fig. 5	c	Exp. 2	Finger	Attended	Post hoc	Middle vs Deep	Tukey's HSD	F(2,16)	–	0.008	Tukey	Significant
Fig. 5	e–f	Exp. 2	Finger	–	RM-ANOVA	Condition × Layer	F-test	F(2,16)	0.002	–	–	Significant interaction
Fig. 5	e–f	Exp. 2	Wrist	–	RM-ANOVA	Main effect of	F-test	F(1,8)	<0.001	–	–	Global

Figure	Panel	Experiment	ROI / Layer / Column	Condition	Analysis type	Effect / Comparison	Statistical test	df	Raw p-value	Corrected p / q	Correction	Interpretation
						Condition						suppression
Fig. 5	e	Exp. 2	Finger – Superficial	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.016	0.0345	BH-FDR	Enhancement
Fig. 5	e	Exp. 2	Finger – Deep	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.023	0.0345	BH-FDR	Suppression
Fig. 5	e	Exp. 2	Finger – Middle	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.906	0.906	BH-FDR	n.s.
Fig. 5	f	Exp. 2	Wrist – Superficial	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.013	0.013	BH-FDR	Suppression
Fig. 5	f	Exp. 2	Wrist – Middle	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.001	0.003	BH-FDR	Suppression
Fig. 5	f	Exp. 2	Wrist – Deep	–	Post hoc	Passive vs Attended	Paired t-test	t(8)	0.002	0.003	BH-FDR	Suppression
Fig. 6	b	Behavioral	Single wrist task	–	Paired comparison	Diagonal vs off-diagonal	Paired t-test	t(11)	3.45×10^{-4}	–	–	Accurate localization
Fig. 6	c	Behavioral	Dual task	–	Paired comparison	Single vs dual accuracy	Paired t-test	t(11)	6.03×10^{-7}	–	–	Reduced accuracy

Figure	Panel	Experiment	ROI / Layer / Column	Condition	Analysis type	Effect / Comparison	Statistical test	df	Raw p-value	Corrected p / q	Correction	Interpretation
Fig. 6	c	Behavioral	Dual task	–	Paired comparison	Diagonal vs off-diagonal	Paired t-test	t(11)	0.091	–	–	n.s.
Supp. Fig. 5	b	Exp. 2	S1 columns	–	RM-ANOVA	Condition × Column	F-test	F(4,32)	<0.001	–	–	Significant interaction
Supp. Fig. 5	b	Exp. 2	Column 2	–	One-sample test	Baseline vs Passive	t-test	t(8)	0.002	0.008	BH-FDR (within 5 columns)	Significant activation
Supp. Fig. 5	b	Exp. 2	Column 3	–	One-sample test	Baseline vs Passive	t-test	t(8)	0.004	0.010	BH-FDR (within 5 columns)	Significant activation
Supp. Fig. 5	b	Exp. 2	Column 3	–	Paired comparison	Passive vs Attended	Paired t-test	t(8)	<0.001	0.0041	BH-FDR (within 5 columns)	Suppression
Supp. Fig. 5	b	Exp. 2	Column 2	–	Paired comparison	Passive vs Attended	Paired t-test	t(8)	0.989	0.989	BH-FDR (within 5 columns)	n.s.

Table Footnote. Only statistical tests explicitly described in the main text or highlighted in the figures are included. Post hoc comparisons across columns or layers were corrected using the Benjamini–Hochberg false discovery rate (BH-FDR) procedure within the specified comparison family. Tukey's HSD p-values are already corrected for multiple comparisons within each ANOVA and are reported as such. Exact p-values are provided where available; values reported as $p < 0.001$ reflect software output. All statistical tests were two-sided. Marginal effects indicate $q < 0.1$ after FDR correction. Behavioral results involve targeted planned comparisons and were therefore not corrected for multiple comparisons, as described in the main text.