BRAIN ACTIVITY DURING BIMODAL ATTENTION AND WORKING MEMORY

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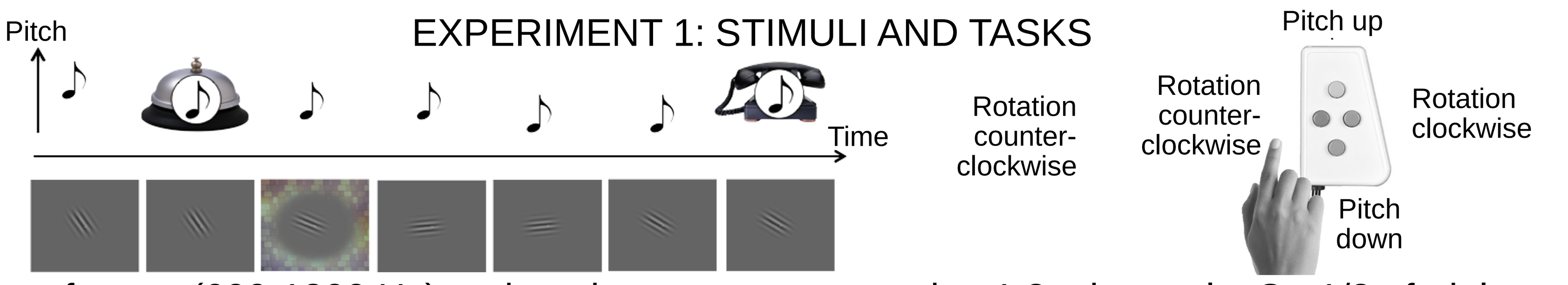
AIM

We studied healthy adults' task performance and brain activity during unimodal and bimodal working-memory tasks demanding selective attention to tones or gratings or division of attention between them, respectively. Our aim was to determine cerebral networks activated during increased demands for attention and working memory.

fMRI

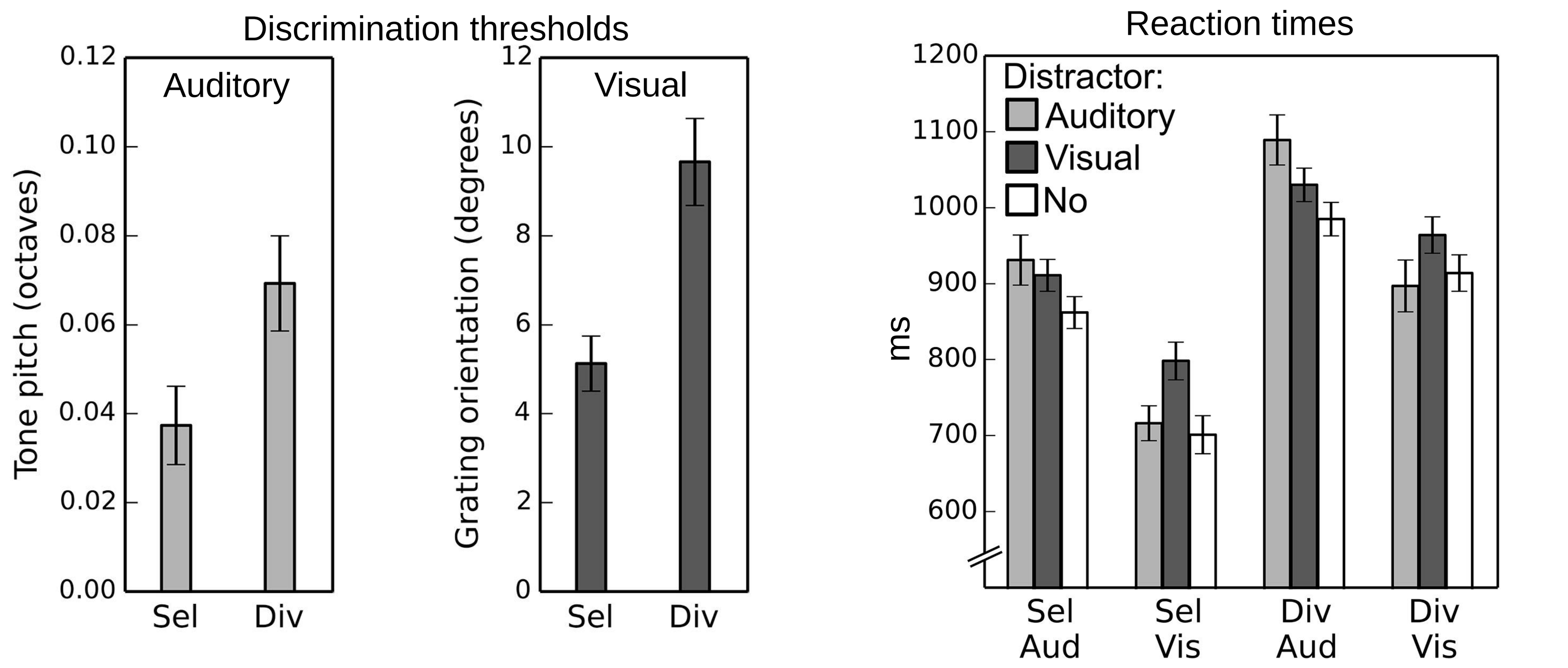
fMRI data were collected with Siemens MAGNETOM Skyra 3 T scanner using 30-channel head coil and a gradient-echo echo planar imaging sequence (TE 32 ms, flip angle 75°, voxel matrix 64 × 64, field of view 20 cm, resolution 3.1 mm × 3.1 mm × 3.0 mm; Experiment 1: TR 1900 ms; Experiment 2: TR 2300 ms).

EXPERIMENT 1: STIMULI AND TASKS



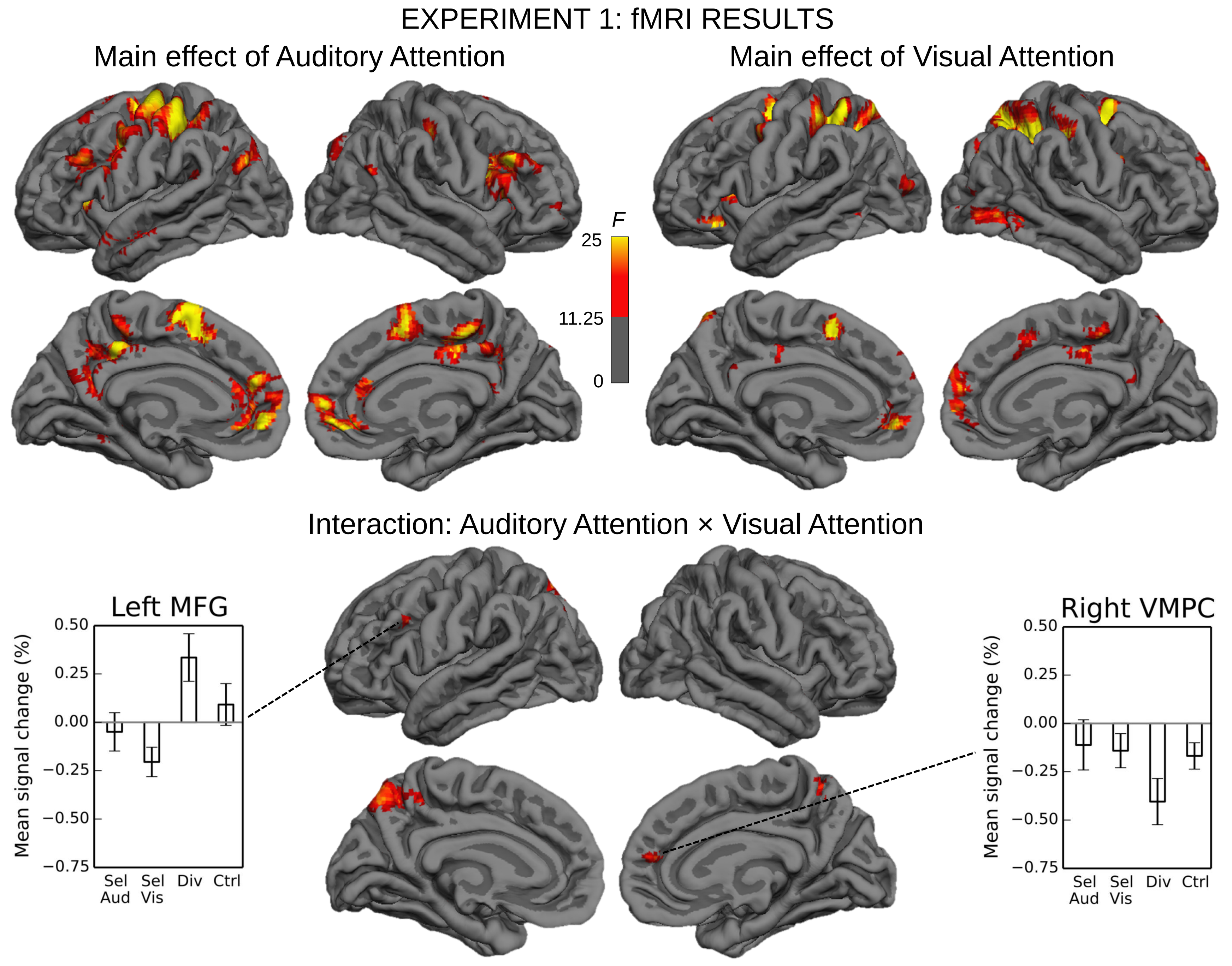
Pairs of tones (600-1800 Hz) and gratings were presented at 1.8-s intervals. On 1/3 of trials either a visual distractor (complex texture) or an auditory distractor (complex sound) occurred. During *selective auditory attention* and *selective visual attention* the participants indicated in 1-back tasks whether the tone pitch was higher/lower or whether the grating had turned clockwise/counter-clockwise in relation to the previous trial. During *divided attention*, they indicated in which modality and to which direction change occurred. Change magnitude was adaptively adjusted to keep the correct-response rate at 70.7 %. In a *control task*, all stimulus pairs were responded to with the same button press.

EXPERIMENT 1: PERFORMANCE



Performance data from 15 participants (age 19–37 yrs; 7 males). **Left:** Mean auditory and visual discrimination thresholds (error bars show SEMs) were higher during selective (Sel) than during divided (Div) attention (t-tests, $p < 0.001$). **Right:** Mean reaction times (RTs; error bars show SEMs) to auditory targets during selective auditory attention (Sel Aud) and divided attention (Div Aud), and to visual targets during selective visual attention (Sel Vis) and divided attention (Div Vis) on trials with an auditory distractor, a visual distractor and no distractor. RTs were longer for divided than selective attention, longer to the tones than gratings, and, in most cases, longer on trials with a distractor than on trials with no distractor. Moreover, auditory RTs were prolonged more by auditory than visual distractors while the opposite was true for visual RTs, and the visual RTs differed more between divided and selective attention than did the auditory RTs. [ANOVA showed significant effects ($p < 0.001$) of Attention Mode (selective vs. divided), Modality (auditory vs. visual) and Distractor (auditory vs. visual vs. no distractor), and significant Attention Mode × Modality ($p < 0.05$), Modality × Distractor ($p < 0.001$) and Attention Mode × Modality × Distractor ($p < 0.05$) interactions.]

EXPERIMENT 1: fMRI RESULTS

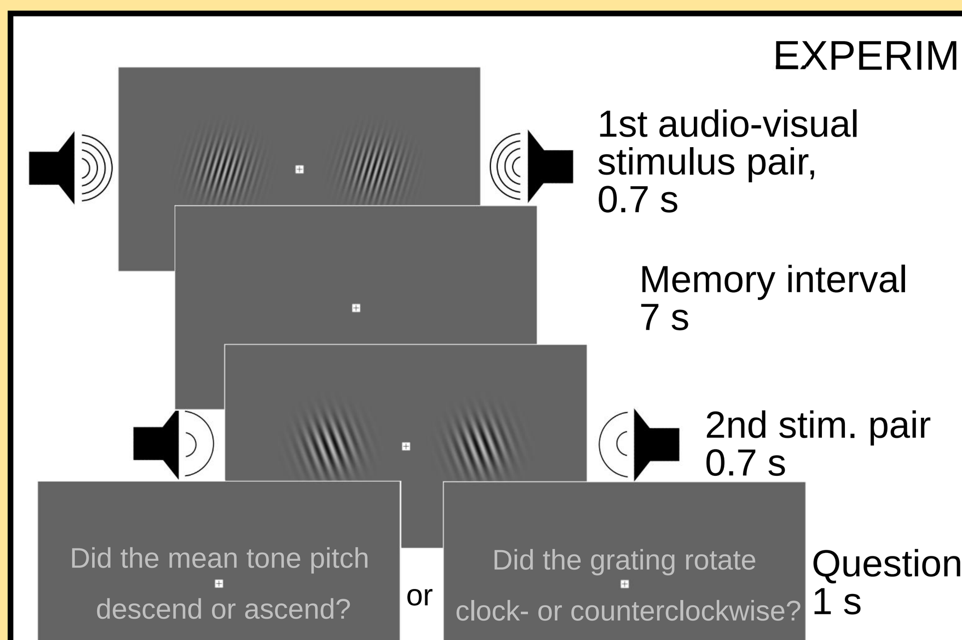


fMRI data (N = 15) were analyzed with ANOVA including factors Auditory Attention (selective auditory & divided attention vs. selective visual attention & control task) and Visual Attention (selective visual & divided attention vs. selective auditory attention & control task). There were significant effects (voxel-wise $p < 0.001$, cluster size > 50 voxels) of Auditory Attention and Visual Attention in wide cortical regions and significant Auditory Attention × Visual Attention interaction in a few cortical voxel clusters. Post-hoc *t* tests indicated significant differences in the mean signal change (in relation to activity during rest) between the conditions only in two clusters: In the left middle frontal gyrus (MFG), the signal change was significantly ($p < 0.05$) higher for divided (Div) than selective auditory (Sel Aud) or selective visual (Sel Vis) attention, while in the right ventromedial prefrontal cortex (VMPC), divided attention differed significantly only from selective visual attention and to the opposite direction. Effects of auditory and visual distractors (not shown) were observed only in auditory and visual cortical areas, respectively.

EXPERIMENT 1: CONCLUSION

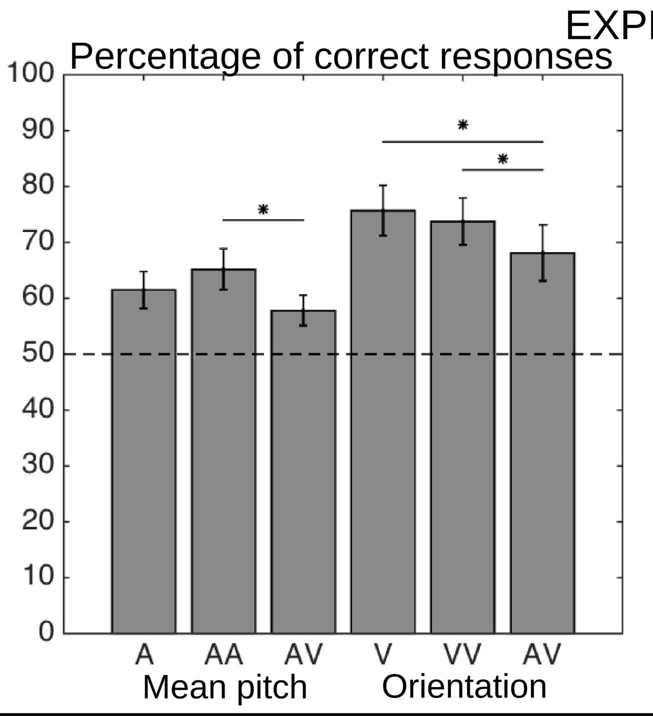
The results support previous findings (e.g., Johnson & Zatorre, *J Cogn Neurosci*, 2007; Salo et al., *Front Hum Neurosci*, 2015) suggesting that the left dorsolateral prefrontal cortex is involved in top-down control of division of attention and integration of dual-task performance.

EXPERIMENT 2: STIMULI AND TASKS



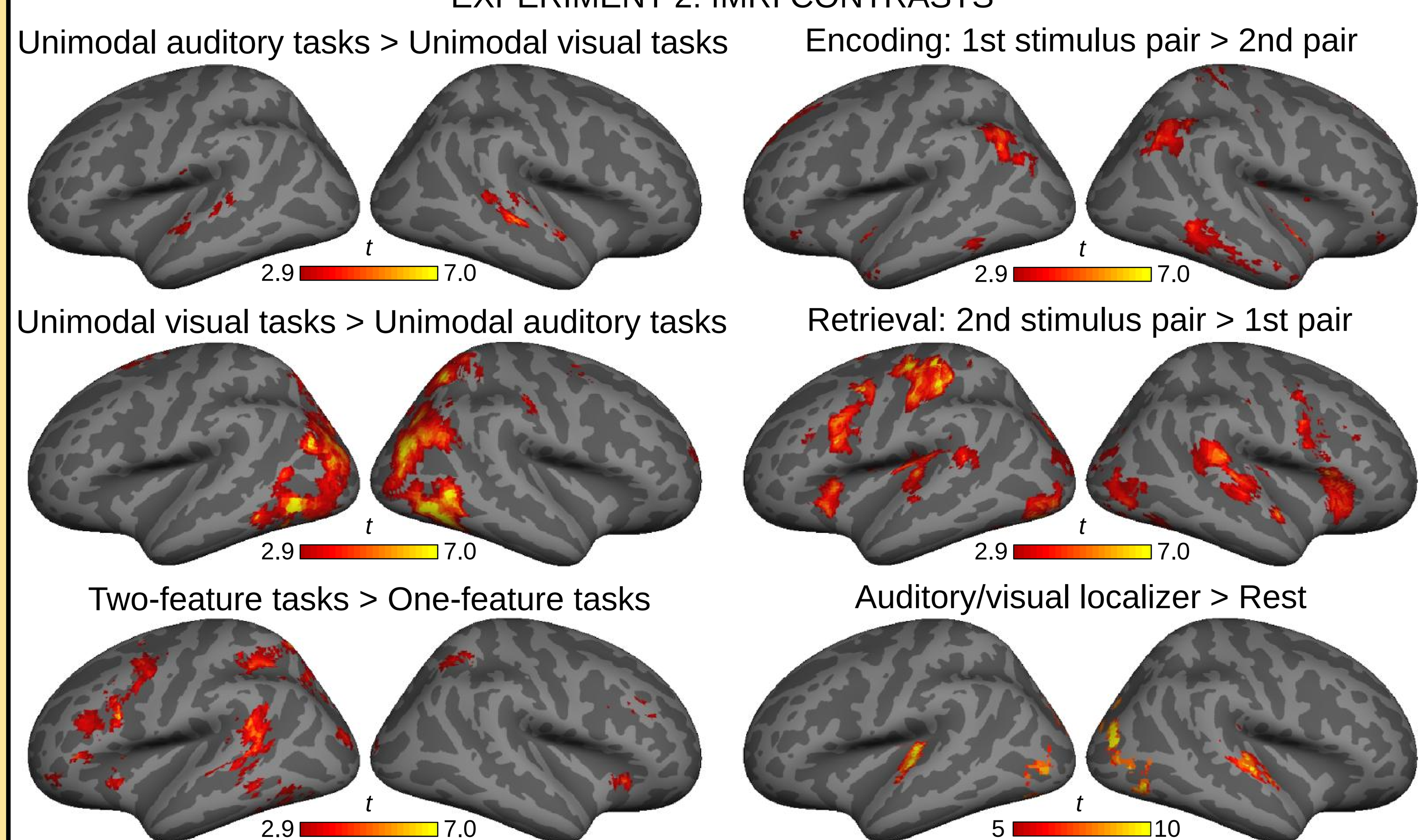
Streams of 14 tones varying in frequency were presented together with two identical gratings. In the 1st auditory-visual stimulus pair of each trial, the mean tone frequency was randomly 800, 1000, 1200 or 1400 Hz and frequency range ±75, ±87.5, ±100 or ±125 Hz, and the grating orientation was randomly ±20 or ±60 deg from vertical and spatial frequency 0.5, 1.0, 1.5 or 2.0 c/deg. In different conditions, the participants' task was to memorize either one or two auditory features (mean pitch or mean pitch and magnitude of pitch variation), one or two visual features (orientation or orientation and spatial frequency) or two features in different modalities (orientation and mean pitch) of the 1st stimulus pair. After a 7-s memory interval, 2nd stimulus pair with all the features changed was presented. The amount of change was ±15 deg, ±0.25 c/deg, ±20 Hz, and ±75 Hz, for orientation, spatial frequency, mean frequency and frequency range, respectively. After the 2nd pair a question concerning one memorized stimulus feature was presented and the participant responded by pressing one of two response buttons. The next trial started after 1.5 s.

EXPERIMENT 2: PERFORMANCE



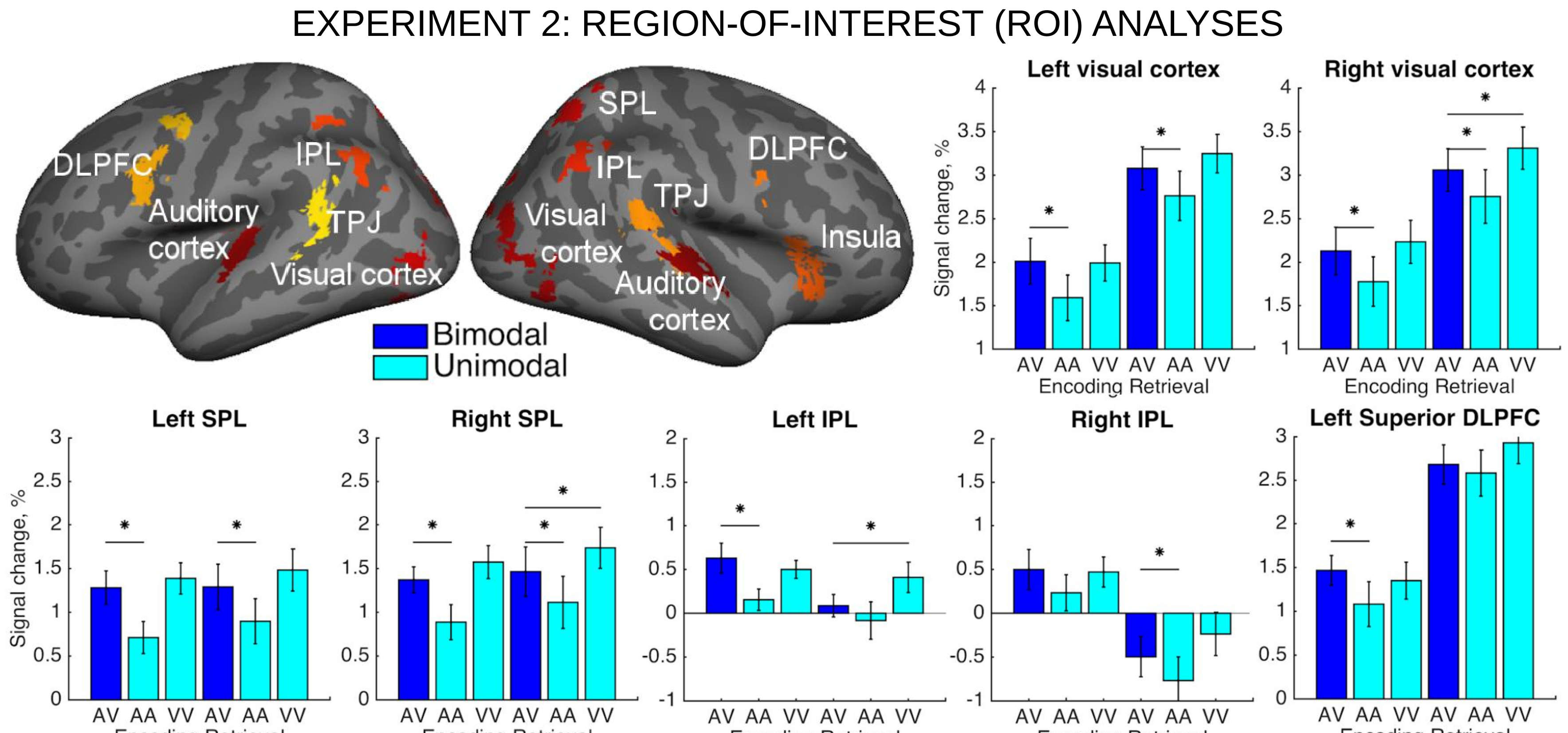
Memory performance in 17 participants (age 20–36 yrs; 6 males) for the mean tone pitch and grating orientation was significantly (* $p < 0.05$) lower in the bimodal (AV) memory condition than in the unimodal two-feature auditory (AA) and visual (VV) memory conditions (error bars show SEMs). Memory performance for orientation was also significantly lower in the AV condition than in the V condition with one to-be-memorized visual feature, while memory performance for mean pitch did not differ significantly ($p = 0.14$) between the AV condition and A condition with one to-be-memorized auditory feature. In the AA and VV conditions, the proportions of correct responses for to-be-memorized pitch range and spatial frequency were on average 77.9 % (SEM 5.0) and 85.3 % (3.3), respectively.

EXPERIMENT 2: fMRI CONTRASTS



Significant between-condition differences (p(FWE) < 0.05, cluster size > 100) in fMRI contrasts calculated to determine regions of interest (ROIs; see below) for further data analysis, because direct contrasts between two-feature bimodal (AV) and unimodal (AA and VV) memory conditions did not reveal marked between-condition differences. The data for auditory localizer (tones varying randomly in frequency between 800–1400 Hz) and visual localizer (spherical checkerboards with 5 rings and 12 wedges flickering at 8 Hz) were measured separately and combined here for illustrative purposes.

EXPERIMENT 2: REGION-OF-INTEREST (ROI) ANALYSES



Voxels indicating significant differences in the contrasts shown above were used to form ROIs. Yet, to obtain ROIs of roughly similar size, thresholds of $t = 5.96$ and $t = 7.23$ were used for the auditory and visual localizers (vs. rest), respectively, and a threshold of $t = 4.01$ for the other contrasts. (The visual-cortex and superior parietal ROIs extended even to the medial cortical surface.) Mean signal changes (error bars show SEMs) are shown for the ROIs in the visual cortex, superior and inferior parietal lobule (SPL/IPL) and left superior dorsolateral prefrontal cortex (DLPFC). In these ROIs only, there were significant differences (*t* tests, * $p < 0.05$) between two-feature bimodal (AV) and unimodal (AA and VV) conditions for the 1st and/or 2nd audio-visual stimulus pair starting memory encoding and retrieval, respectively. In these ROIs, higher activity was observed in the AV condition than in the AA condition either during encoding or retrieval. No ROI showed higher activity for the AV condition than for the VV condition.

EXPERIMENT 2: CONCLUSIONS

1. The left dorsolateral prefrontal cortex is involved in dual tasking especially when at least one of the component tasks is visual.
2. Superior and inferior parietal areas are more involved in visual than auditory working memory.

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