Amygdala Activation Is Associated with Sense of Presence during Viewing 3D-surround Cinematography

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Abstract. Cinematographic stimuli have been previously used to probe functional mapping of naturalistic stimuli, leaving whether such stimuli are also associated with a subjective increase of the sense of presence (SoP). In this functional magnetic resonance imaging, we investigated whether the SoP evaluation of 3D-surround cinematographic stimuli was associated with any change of activity within emotion-related areas, in particular the amygdala. The subjects evaluated several scenes of a commercial 3D movie presented in four different conditions: 3D vision with surround sounds (3D-Surround), 2D-Surround, 3D-Mono, and 2D-Mono. The behavioral results showed that the stereoscopic viewing, but not surround sound, increased SoP scores. The whole-brain imaging results showed that the middle occipital gyrus was involved in evaluating the SoP. The planned anatomical ROI analysis showed that also activity in the right amygdala increased with increasing SoP scores. The results suggest that 3D vision enhances the SoP and this is associated with activation of both visual cortex and emotion-related brain region.

Keywords: stereoscopy, surround sounds, sense of presence, functional MRI.

1 Introduction

Previous human brain imaging studies used cinematography to track dynamic changes of specific visual and auditory features (e.g. motion, loudness) [1-3]. Functional imaging using such naturalistic stimuli can help us to corroborate the findings of traditional laboratory paradigms that employ well-controlled but simple and stereotyped stimuli. Studies with naturalistic stimuli can help extending the results of standardized paradigms to ecologically-valid situations more similar to real life [4].

Stereoscopic vision contributes to representing the spatial layout of elements in complex visual scenes. Related to this, surround sounds can provide us with rich, multi-sources auditory scenes and enhance spatial perception. The spatial coherence between visual and auditory signals can further enhance the awareness of three-dimensional space and of being in a scene (e.g. sense of presence (SoP) [5]). In addition, previous studies showed that higher-level signals (e.g. emotional content) can also influence the SoP [6, 7], suggesting a possible association between SoP and brain activity within emotion-related regions (e.g. amygdala, see [8, 9]).

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In this functional magnetic resonance imaging (fMRI) study, we investigated the neural correlates of the SoP appraisal associated with audio-visual 3D-surround stimuli. Participants viewed short clips extracted from a commercial 3D movie. In different trials, the stimuli were shown with stereoscopic 3D or standard 2D vision, and with surround or monaural audition. After each clip, participants were asked to give score about their subjective SoP on that trial (Fig. 1A). We asked whether complex (3D- and/or surround-) stimuli would affect the SoP appraisal, and whether this would correlate with activity of emotion-related areas; e.g. the amygdala [8, 9] that previous studies associated with SoP [6, 7]. We performed a planned anatomical ROI analysis on the amygdale, as well as the whole-brain analysis.

2 Materials and Methods

2.1 Subjects

Sixteen Italian subjects (aged 21 – 39, mean = 27.3 years, 12 females and 4 males) with no history of neurological or psychiatric illness participated in this study. They had normal or corrected-to-normal visual acuity and reported no difficulty of hearing. They gave written informed consents prior to the experiment. The ethical committee of Santa Lucia Foundation has approved this study.

2.2 Stimuli and Task

The participants were presented with short movie segments, extracted from the 3D Italian version of The Three Musketeers (Constantin Film, Frankfurt, Germany). The clips were presented in qHD resolution with the frame rate of 24 Hz. We used three different movie segments / clips, each with a duration of 10.4 s. Each of the segments was presented in four different conditions, including: 3D-Surround, 3D-Mono, 2D-Surround, and 2D-Mono. The order of conditions was counterbalanced across the subjects using a balanced Latin square. On each trial, subjects were asked to watch/listen to the clip and to score the SoP on a 5-points Likert scale, within 8.32 s after the end of the clip (Fig. 1A).

Stimulus presentation was controlled using the psychophysics toolbox [10] running on Matlab (Mathworks, Inc.). The video-clips were presented using an LCD projector (NEC Corp., NP216G) operating at 120 Hz and synchronized with a linear polarizer (DepthQ®, Lightspeed Design Inc.). The subjects wore a MR-compatible passive 3D eyewear that allowed them to perceive stereoscopic vision in the 3D conditions. The sounds were delivered using a multi-speakers system constructed ad-hoc for surround presentation in the MR scanner, together with the mono sound delivered via standard MR-compatible headphones.

2.3 Image Acquisition

A Siemens Allegra (Siemens Medical Systems, Erlangen, Germany) 3T scanner equipped for echo-planar imaging (EPI) was used to acquire functional magnetic resonance images. A head-sized quadrature volume coil was used for radio frequency transmission and reception. Mild cushioning minimized head movement. Thirty-two slices of functional images were acquired using blood oxygenation level dependent imaging (192 mm × 192 mm × 120 mm, in-plane resolution = 64 × 64, pixel size = 3 mm × 3 mm, thickness = 2.5 mm, 50% distance factor, TR = 2.08 s, TE = 30 ms), covering the entire cerebrum. We acquired 116 scans in this task. The first four scans were discarded to ensure magnetization equilibrium.

2.4 fMRI Analyses

We used SPM8 (Wellcome Department of Cognitive Neurology, University College London) on Matlab to process the acquired images. In preprocessing, we performed slice-timing collection, realignment, normalization to the EPI template of SPM8 and spatial smoothing (FWHM = 8 mm). High-pass filters of 128 s were used to remove low frequency noise.

First, we performed a 2×2 within-subject ANOVA with 4 conditions given by the crossing of "vision" (3D/2D) and "audition" (Surround/Mono). Non-sphericity correction was used to account for any unequal variance between conditions and correlated repeated-measures [11]. Within this model we assessed the main effects of 3D vision and surround audition, plus any interaction between the two. The whole-brain threshold was set to p-FWE-corr. = 0.05 at the cluster-level, after applying a voxel-level threshold of p-unc. = 0.001 to find activated clusters.

In a separate analysis, we used a regression approach to further investigate brain activity that correlated with the SoP evaluation scores. For this, the subject-specific "1-st level analyses" included a single condition-regressor, which was modulated according to the individual SoP evaluation scores measured on each and every trial. At the group level, we assessed the modulatory effect using a one-sample t-test. We performed a whole-brain analysis, as well as a more targeted analysis that considered specifically the amygdale (cf. [5, 12-13]). For this, the parameter estimates associated with the SoP scores were extracted and averaged over voxels, using the MarsBaR toolbox [14]. P-values were corrected for the number of ROIs (i.e. 2, left and right amygdale) using with Bonferroni correction.

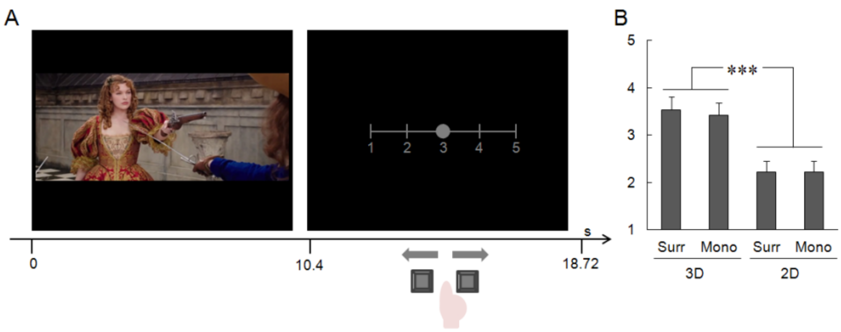

Fig. 1. A. Schematic illustration of one trial. The subject watched a 10.4 s movie-clip and evaluated the SoP on the 5-point Likert scale. For the evaluation, the subject pushed two buttons to left/right move the visual indicator. B. The behavioral data of the SoP evaluation. The graph shows the average SoP scores (± s.e.m.). The subjects scored higher for 3D than for 2D. Error bars are standard error. ***p < 0.001.

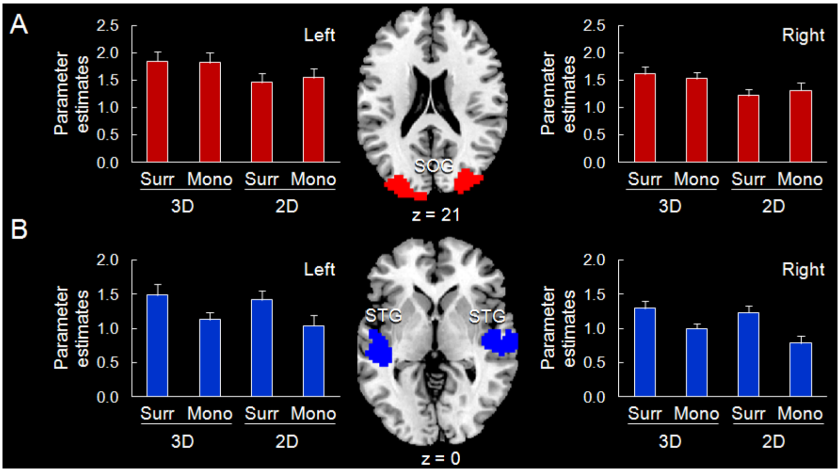

Fig. 2. A. The activation of SOG in the contrast of "3D > 2D" is shown on coronal and axial sections. Parameter estimates for the SOG cluster are shown on each side, with activity plotted separately in the four conditions. Error bars are standard errors. B. The activation of STG for the contrast "Surround > Mono" sounds is shown on an axial section. The signal plots show the parameter estimates in the four conditions. Error bars are standard errors.

3 Results

3.1 Behavioral Result

The subjects were asked to evaluate the SoP of short video-clips using a 5-points Likert scale (Fig. 1A). Each of the clip was presented four times, with different viewing/listening conditions. The results of the repeated-measures ANOVA with the factors of "vision" (3D/2D) × "audition" (Surround/Mono) showed that the 3D viewing, but not surround sound, significantly augmented the SoP ($F(1, 15) = 30.2$, $p < 0.001$, Fig. 1B), without any interaction between the two modalities.

Table 1. Summary of brain activation in the whole brain analysis

Contrast/Regions		MNI coordinates of peak *X*	*y*	*z*	*z*-score (peak)	*p*-value (cluster)	Number of voxels
3D > 2D							
Left	SOG	–24	–96	20	4.22	0.007	158
Right	SOG	33	–87	23	5.25	< 0.001	394
Left	PCG	–42	–33	68	4.93	< 0.001	371
Right	Cerebellum	24	–54	–28	4.05	0.023	117
Surr > Mono							
Left	STG	–48	–24	2	4.22	0.001	209
Right	STG	48	–15	–1	4.67	0.002	231

3.2 Imaging Results

The contrast comparing "3D > 2D" stimuli showed activation of the superior occipital gyrus (SOG, Fig. 2A), consistent with previous studies of stereoscopy [15-17]. In addition, we observed the activation in the post-central gyrus (PCG) and the cerebellum (Table 1). The surround sounds activated the superior temporal gyrus (STG) including the Heschl's gyri and planum temporale (PT, see Fig. 2B). The anatomical classification of the surround-effect confirmed that the functional activation comprised TE sub-regions on the posterior part of auditory cortex (Table 2).

We used trial-by-trial parametric analyses to further assess the relationship between stimulus processing and SoP. At the whole-brain level, this showed that activity in the middle occipital gyrus increased linearly with increasing SoP scores (see Fig. 3), consistent with the results of the ANOVA showing an effect of 3D in dorso-lateral occipital cortex, cf. Table 1 and Fig. 2A.

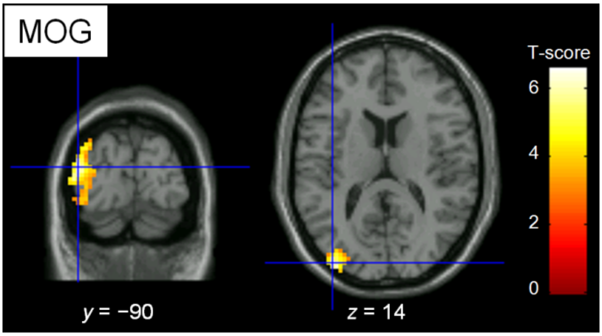

Fig. 3. The activation of the left MOG observed in the parametric analysis using SoP scores. The peak in MNI coordinates was (x = −39, y = −90, z = 14) with z-score = 4.37. The cluster size was 140. The cluster level p-FWE-corr. = 0.007.

Table 2. The classification of auditory activation using SPM anatomy toolbox [18]

	Left			Right		
	TE1.0	TE1.1	TE1.2	TE1.0	TE1.1	TE1.2
Surr > Mono	26.0%	60.2%	3.9%	39.9%	24.1%	3.7%

Next we performed the ROI analysis considering specifically the BOLD responses in the amygdalae. The results showed that the activity of the right amygdala was significantly associated with the SoP score ($t(15) = 2.31$, p-corr. < 0.05, Fig. 4), while no such effect was detected in the left amygdala ($t(15) = 1.16$, p-corr. > 0.1).

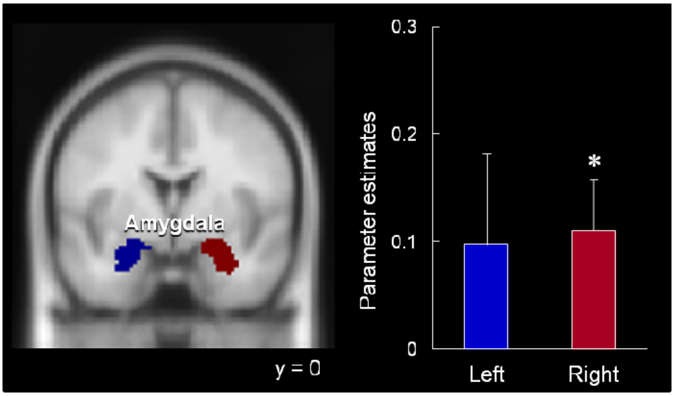

Fig. 4. The effect of SoP scores in the right amygdala. The panel on the left shows the anatomical-defined ROIs on the coronal section (y = 0). The right panel shows the parameter estimates associated with the SoP, extracted and averaged separately for the two ROIs. A significant effect (*) was observed in the right amygdala, but not in the left amygdala. Error bars are standard errors.

4 Discussion

We investigated the neural correlates of subjective SoP using complex audiovisual stimuli. Behavioral data showed that stereoscopic 3D based on binocular disparity was psychologically effective in increasing the SoP of the scene. Consistent with the previous studies, we confirmed that stereoscopic images activated dorso-lateral occipital visual areas, probably including area V3A [17, 19]. A regression analysis using trial-specific SoP scores revealed that activity in the middle occipital gyrus co-varied with subjective SoP. In addition, a more targeted analysis of activity in the amygdale revealed an effect of SoP in the right hemisphere only (Fig. 4). By contrast, surround sounds did not affect the SoP judgment. At the neutral level, the processing of surround sounds was associated with activation of the superior temporal gyrus, including the primary auditory cortex and the planum temporale.

Although we did not measure any autonomic response (e.g. skin conductance), the effect of SoP in right amygdala suggests an impact of stereoscopic viewing on the emotional response to the complex visual stimuli. Previous studies showed that movies evoking the emotion of fear (e.g. cliff, roller coaster) enhanced the SoP [6]. Here, the behavioral data measured during scanning highlighted that stereoscopic 3D viewing enhanced the SoP. Taken together behavioral and imaging data suggest that 3D viewing enhances the SoP through the evoking of emotional experience in right amygdala.

The presentation of 3D images lead to an increase of the SoP scores in this study, while previous studies reported controversial results [13, 20]. This may be due to the many factors that contribute to spatial perception in complex visual scenes. For example, together with binocular disparity, the in-depth spatial layout of objects can be obtained because of motion parallax. Further, 3D structure-from-motion also constitutes a possible source of complex visuo-spatial signals, also traditionally associated with activation of the occipital-parietal cortex [21-23]. Indeed, the simultaneous presentation with both binocular disparity and visual motion evokes the stronger and more accurate 3D perception than either depth cues presented alone [24]. All these static and dynamic factors are likely to contribute to the elevated SoP scores and the increased activation in dorso-lateral occipital cortex that we found here in the 3D viewing conditions.

The surround sounds provided our subjects with spatially rich (multi-sources) auditory input. The imaging data showed that this was associated with activation of the posterior auditory cortex and the planum temporale, consistent with the role of these regions in auditory spatial processing [25]. Unexpectedly, this auditory manipulation did not influence the SoP evaluation scores. Thus, the auditory spatial information presented in this study was psychologically less influential to the SoP evaluation than 3D vision. This may indicate some segregation of visual and auditory spatial processing in the current context, as also evidenced by the lack of any significant interaction between the two modalities. Nonetheless, future studies we seek using audio-visual stimuli entailing a more explicit spatial correspondence / relationship between the two modalities, which may reveal stronger interactions between the two senses and/or some influence of sounds-spatiality on SoP.

In conclusion, our findings showed that the occipital cortex - putatively including V3A/B - was involved in the SoP evaluation, in parallel with the behavioral results that the stereoscopic viewing lead to an augmented SoP. Moreover, the right amygdala was also associated with SoP. We suggest that stereoscopic viewing increased the subjective SoP, via enhanced scene processing in emotion-related brain areas.

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