Effects of Emotional Valence and Three-dimensionality of Visual Stimuli on Brain Activation: an fMRI Study

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Abstract

BACKGROUND: Examining changes in brain activation linked with emotion-inducing stimuli is essential to the study of emotions. Due to the ecological potential of techniques such as virtual reality (VR), inspection of whether brain activation in response to emotional stimuli can be modulated by the three-dimensional (3D) properties of the images is important.

OBJECTIVE: The current study sought to test whether the activation of brain areas involved in the emotional processing of scenarios of different valences can be modulated by 3D. Therefore, the focus was made on the interaction effect between emotion-inducing stimuli of different *emotional valences* (pleasant, unpleasant and neutral valences) and *visualization types* (2D, 3D). However, main effects were also analyzed.

METHODS: The effect of *emotional valence* and *visualization types* and their interaction were analyzed through a 3x2 repeated measures *ANOVA*. Post-hoc *t*-tests were performed under a ROI-analysis approach.
RESULTS: The results show increased brain activation for the 3D affective-inducing stimuli in comparison with the same stimuli in 2D scenarios, mostly in cortical and subcortical regions that are related to emotional processing, in addition to visual processing regions.
CONCLUSIONS: This study has the potential of clarify brain mechanisms involved in the processing of emotional stimuli (scenarios' valence) and their interaction with three-dimensionality.

Keywords: emotional valence (pleasant, unpleasant, neutral); 3D/2D visual stimuli; functional Magnetic Resonance Imaging (fMRI).

1. Introduction

Knowledge about emotions results largely from studies using images with emotional content in the context of laboratory experimentation. In constant development, the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) is one of the most widely used instruments for the selection of images. It now includes more than 900 emotional pictures in digital format, indexed by emotional valence, arousal and dominance, from various semantic categories: animals, landscapes, weapons, human facial expressions, mutilated bodies, etc. The emotional arousal and valence induced by the images have been measured through the *Self-Assessment Maniquin* scales (SAM; Lang, 1980).

However, the visualization of two-dimensional (2D) images as a method to induce emotions has some methodological limitations. Indeed, the laboratory investigation of emotional phenomena using simple slideshows containing drawings, words or images from the IAPS or similar systems has limited ecological validity and produces an attenuated emotional resonance in comparison to real emotional situations (Monteiro, Barbosa, & Silvério, 2011). Thus, any development of these stimulus-materials making them closer to real emotional conditions is highly valuable to research. Still, stimuli must enable experimental manipulation of emotional responses in controlled laboratory sets. Adding three-dimensional (3D) properties to emotion-inducing stimuli is one method to achieve this purpose, making emotional responses more realistic.

Nowadays 3D softwares like Blender (Blender Foundation/Institute Amesterdan), 3ds Max (Autodesk, California) or Maya (Autodesk, California) can generate stereoscopic images of great realism. The stimuli developed with those technologies go beyond simple slide-like pictures. They are equally easy to handle and present greater ecological validity than traditional stimulus-material, precisely because they are closer to real-life stimuli (Dyck, Winbeck, Leiberg, Chen, & Mathiak, 2010). For instance, Dyck and colleagues (2008) compared the recognition of 3D facial expressions (virtual expressions - avatars) with conventional photographs of human faces and found that sadness and fear were more easily recognized when presented in 3D. The work of Lee, Lim, Wiederhold, and Graham (2005) is another example. The authors investigated the effect of the two types of visualization on craving-inducing cues and concluded that participants pay more attention to 3D than to 2D stimuli. Newly

developed 3D stimuli sets may thus represent a considerable benefit to emotion research performed in controlled laboratory environments. However, these new materials and their advantages over the conventional ones must be further investigated, both through self-report studies on the induced emotional states, and through studies on the respective neuronal correlates.

Functional neuroimaging supports the involvement of the amygdalae, fusiform gyri, inferior occipital gyri, orbital gyri, parahippocampal gyri, posterior cingulate cortex, and uncus as part of the neural systems in emotional processing (Adolphs, 2002, 2003; Adolphs, Damasio, Tranel, & Damasio, 1996; Jehna et al., 2011; Lane et al., 1997; Whalen, Rauch, Etcoff, McInerney, Lee & Jenike, 1998). The role of the amygdalae in negative (Fanselow & Gale, 2003; LeDoux, 2003) and positive emotions has been recognized in literature (Murray & Ramage, 2000). Additionally, the role of the anterior insula (Craig, 2002, 2003; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004) and the anterior cingulated cortex (Decety & Jackson, 2004; Jackson, Brunet, Meltzoff, & Decety, 2006) in the processing of emotionally salient contexts is well established. The contribution of the basal ganglia and cerebellar regions to human affective function is also recognized (Baumann & Mattingley, 2012; Lane et al., 1997; Paradiso, et al., 1999).

In order to inspect the role of higher cortical mechanisms involved in emotional processing, in the current study we applied a paradigm in which subjects were involved in a long and repeated stimuli exhibition to create visual habituation. This procedure is intended to reduce the contribution of the low level visual processing mechanisms to the targeted contrasts, while emphasizing the relevance of the higher cortical mechanisms involved in emotional processing. We expected to find increased activation for the 3D affective-inducing stimuli in comparison with the same stimuli in 2D scenarios, mostly in cortical and subcortical regions that are related to emotional and high-level processing, in addition to visual processing regions.

2. Materials and Methods

2.1. Participants

The sample consisted of 12 healthy male subjects who were recruited to participate in the study from rehabilitation institutions' databases in which they were registered as caregivers of former patients. The group's mean age was 26.58 years old

(*SD* = 5.16). Participants were all right handed (self-reported) and had no contraindication for MRI, pathologies of the Central Nervous System (CNS), psychiatric disorders, trauma, or visual acuity deficits (assessed through a screening interview). All gave written informed consent to participate in this study. The protocol was approved by the Local Ethics Committee, and complies with the Declaration of Helsinki.

2.2. Stimuli

The stimuli were 3D Affective Inducing Scenarios (3DAIS) composed by 3D objects that were selected from our database, which comprises 131 objects. Sets of 15 stimuli-objects formed each scenario (Figure 1), with one set per *emotional valence* – pleasant, unpleasant and neutral (to view the final scenarios and the stimuli-objects, please see Monteiro, Barbosa, & Silvério, 2011).The 3D objects database had been previously developed to match the type of contents of the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 1999) and equally validated with the *Self-Assessment Maniquin* scales (SAM; Lang, 1980) through rating procedures similar to those of Lang and colleagues' (1999). For our database, 214 individuals rated each of the 3D objects for emotional arousal (1 - low, 9 - high) and valence (1 - unpleasant, 9 – pleasant) using the 9-point SAM scale (Monteiro, Barbosa, & Silvério, 2011).

The stimuli were then selected and grouped according to the following criteria: (a) fifteen 3D objects receiving the highest scores in valence and arousal (valence ≥ 6.0; arousal ≥ 4.0) were included in the pleasant scenario; (b) fifteen 3D objects receiving the lowest scores in valence and the highest in arousal (valence ≤ 4.0; arousal ≥ 4.0) were included in the unpleasant scenario; (c) fifteen stimuli with intermediate values in valence and low scores in arousal ($4.5 \leq$ valence ≤ 5.5, arousal ≤ 3.0) were included in the neutral scenario.

Scenarios occupying a visual angle of 32º x 22º were presented in a 150x100 cm screen with a stimulation unit (laptop computer running Windows Vista) connected to a rear projection system (multimedia projector XGA 1024x768 pixels and 2200 ANSI lumens).

A 1.5 T scanner (MAGNETON, Sonata, Siemens) with a gradient of Maximum Amplitude 40 mT/m, Minimum Rise Time 200 μs, Maximum Slew Rate 200 T/m/s was used for the MR scanning. Inside the scanner, the stimuli were back projected by means

of a radiofrequency head coil mounted mirror. Passive glasses (Zone, 2005) were used for the 3D visualization, which was created through an anaglyph image technique.

<<< insert Figure 1 here >>>

2.3. Design and Procedures

Visualization type (2D, 3D) and *emotional valence* (pleasant, unpleasant and neutral scenarios) were used as factors in a within-subjects 3x2 experimental design. The experiment consisted of a single session of fMRI scanning. The presentation of the 2D and of the 3D scenarios was counterbalanced in a block-design paradigm with two fMRI runs for the two *visualization types*, respectively. Each run had the total duration of 4'4''. The run began with 4 sec of no stimulation (then discarded) so that the MR signal could reach the equilibrium point.

Participants were given the opportunity and the necessary amount of time to put on or take off the anaglyph glasses between runs, so the initial visualization conditions (the 2D or 3D types) were matched. Each run consisted of three cycles of rest and activation with no interval between cycles. The three cycles corresponded to the three *emotional valences*, also counterbalanced to control for order effects. During the resting periods a fixation cross was displayed for 40 sec, followed immediately by one of the scenarios, displayed for another 40 sec.

Participants were instructed to avoid movements, to keep their eyes open during the whole session, and to pay attention to the image projected on the screen.

2.4. Data acquisition

For functional imaging a gradient–echo T2*-weighted Echo-Planar Imaging (EPI) sequence (TE=50ms, flip angle 90º, TR=4s) was used to measure the BOLD (blood oxygenation level dependent) effect (Ogawa, Lee, Kay, & Tank, 1990). The Field of View (FOV) was 240 x 240mm2 with a 64 x 64 matrix resulting in an effective resolution of 3.75mm x 3.75mm x 3mm(Thk). Sixty volumes with 36 slices each were acquired in axial orientation, with slices being aligned parallel to the anterior–posterior commissure. The slice thickness was 3mm with a gap of 25%. For anatomic reference, a high-resolution MPRAGE T1-weighted scan was acquired for each participant with the following parameters: TR = 2s, TE = 3.69ms, 256 x 256 matrix, FOV 240 x 240mm^2, slice thickness of 1mm leading to an effective resolution of 0.9 x 0.9 x 1 mm).

2.5. Data analysis

Preprocessing of functional data, including slice time correction, 3D motion correction, spatial smoothing and temporal filtering, was conducted using BrainVoyager QX 2.3 (2011, Brain Innovation, Netherlands). Functional and anatomical scans of the data were co-registered and normalized to Talairach space. Data were analyzed through a GLM-based random effects procedure. Resulting whole brain activation maps for all contrasts were thresholded at a p-value < 0.001 (uncorrected). Clusters were only accepted if consisting of at least seven contiguous voxels.

The effects of *emotional valence* (pleasant, unpleasant and neutral scenarios), the *visualization type* (2D and 3D types), and their interaction were computed through a 3x2 repeated measures *ANOVA*. Post-hoc *t*-tests were performed under a ROI-analysis approach on the clusters for which the ANOVA showed significant interaction effects. Talairach Client v2.4.2 was used to convert coordinates of the regions significantly activated into Talairach labels as long as these were within the defined minimum voxel size (Lancaster et al., 1997; Lancaster et al., 2000).

3. Results

The ANOVA revealed an interaction effect between *emotional valence* (pleasant, unpleasant and neutral scenarios) and *visualization types* (2D and 3D types) in several visual and emotion related areas. Table 1 lists the areas that were activated for this effect.

<<< insert Table 1 here >>>

Table 2 shows the post-hoc tests comparing *emotional valences* within *visualization types* (unpleasant vs. pleasant vs. neutral scenarios within the 2D type, and unpleasant vs. pleasant vs. neutral scenarios within the 3D type) and *visualization types* within *emotional valences* (3D vs. 2D types within the pleasant scenario, 3D vs. 2D types within the unpleasant scenarios, and 3D vs. 2D types within the neutral scenarios).

<<< insert Table 2 here >>>

Concerning the main effects, results for the factor *emotional valence* are presented in Table 3. Volumes-of-interest were created for each cluster (minimum size = 7 voxels) after a 3x2 ANOVA, with *post-hoc t-tests* being performed under a ROI-analysis approach.

<<< insert Table 3 here >>>

The areas responding to the main effect of *visualization type* are reported in Table 4.

<<< insert Table 4 here >>>

4. Discussion

In the current study we used 3D versus 2D stimuli charged with different emotional values. Our purpose was twofold: (1) to test whether the activation of brain areas involved in the visual and emotional processing of scenarios with different valence values could be modulated by three-dimensionality and (2) to study the role of cortical mechanisms involved in emotional processing. Therefore, we compared BOLD signal changes in both emotional and visual areas during presentation of VR scenarios in two different *visualization types* (2D and 3D types). In addition, we looked at other frontal and temporal regions, known to be involved in higher cognitive functions.

The most interesting finding refer to the interaction effect between *emotional valence* and *visualization type* in areas responsible for emotional and cognitive processing. As expected, we found increased activation in cortical areas, such as the postcentral gyrus and the middle frontal gyrus, but only with pleasant and unpleasant scenarios. The involvement of these regions has been previously identified in neuroimaging studies of emotion (Damasio et al., 2000, George, Ketter, Parekh, Herscovitch, & Post, 1996; Lane, Chua, & Dolan, 1999), and the activated prefrontal region may reflect the presence of high-level cognitive interpretations (Ochsner et al., 2009). We expected that the paradigm we used, which consisted of a long and repeated stimuli exhibition, would elicit these areas. The results also show the activation of subcortical structures, such as some components of the cerebellum (i.e., the declive and cerebellar tonsil) and some components of the basal ganglia (i.e., the lentiform nucleus, which refers to the globus pallidus and the putamen) (Baumann & Mattingley, 2012;

Lane et al., 1997; Paradiso, et al., 1999). The cerebellum has only recently started to be recognized as part of the neural networks responsible for emotional processing (Baumann & Mattingley, 2012; Tettamanti, et al., 2012), although its role on emotions is still unclear. In addition to these regions, we found the activation of portions of the limbic lobe (i.e., the uncus (Lawrenceet al., 2994) and cingulated gyrus (Decety & Jackson, 2004; Jackson, Brunet, Meltzoff, & Decety, 2006), traditionally recognized as being especially involved in emotional processes. Considering that current neurobiological models of emotion and several studies (Baumann & Mattingley, 2012; Kober, et al., 2008; Tettamanti, et al., 2012) recognize the mediation of both cortical and subcortical areas in emotional processing, these results are consistent with the literature.

Concerning the *valence effects* within *visualization type*, the results allowed us to understand the relation between the different emotional valences, with the direction of the contrasts occurring as expected, i.e., unpleasant>pleasant>neutral valence for the 2D visualization type, but only pleasant>neutral for the 3D visualization type. The direction of the contrasts became clearer when we examined the *emotion valence* independently of the *visualization type* (the main effect of *emotion valence*). In this case, our fMRI data are in agreement with the well-known unpleasant emotion bias. In fact, the unpleasant scenarios produced higher activation compared to pleasant and neutral ones in all the referred brain regions, namely the paracentral lobule, inferior parietal lobule, precuneus, superior temporal gyrus, middle frontal gyrus and postcentral gyrus. In some of these areas (inferior parietal lobule, precuneus, superior temporal gyrus) we also observed that pleasant scenarios elicited increased activation, compared to neutral ones.

Concerning the visualization effects *within* valence, post-hoc analyses revealed that 3D produced greater activation than 2D scenarios in the declive region, but only for the pleasant valence. Unexpectedly, the opposite effect was found in the cerebellar tonsil for the neutral scenario. Regarding the main effect of *visualization* type (independently of emotional valence), the 3D scenarios consistently produced greater activation in all the brain regions, as compared to the 2D scenarios.

Finally, the results also show the influence of three-dimensional scenarios on visual processing, although this was not the main focus of this study. Specifically, 3D scenarios produced an increased activation in regions that are part of the anterior intraparietal area (Precuneus [BA 7, 31] and Sub-Gyral [BA 40]) and inferotemporal

cortex (Fusiform Gyrus [BA 20]). These results are consistent with the literature that reports the involvement of these regions in visual processing of 3D stimuli. An example of this phenomenon is the participation of the AIP (anterior intraparietal area BA40) neurons in the perception of 3D contours and surfaces (Theys, Srivastava, van Loon, Goffin, & Janssen, 2012), or the involvement of the IT cortex in the perception of binocular disparity (Janssen, Vogels, & Orban, 2000; Uka, Tanabe, Watanabe, & Fujita, 2005; Verhoef, Vogels, & Janssen, 2012).

The observed activation of the Precuneus (BA 7) also supports the role of 3D in stereopsis, since this area has been related with this function (Fortin, Ptito, Faubert, & Ptito, 2002). In our study this region was more active during the 3D than during the 2D scenario. Moreover, part of the primary visual cortex (cuneus or BA 17) showed increased activity.

Overall, our results showed increased brain activation for the 3D affective-inducing stimuli in comparison with the same stimuli in 2D scenarios. This effect was observed mostly in cortical and subcortical regions that are related to emotional processing, in addition to visual and other regions involved in high-level cognitive processing. It is noteworthy that the contrast and light of the scenarios was not fully controlled and this could have induced differences between the neutral, pleasant and unpleasant scenarios that influenced participant's cerebral activation.

5. Conclusions

In the current study we used 3D versus 2D stimuli charged with different emotional values in order to test the impact of two different visualization types on brain regions involved in visual and emotional processing. These preliminary fMRI results suggest that 3D scenarios may be best suited for developing methodological paradigms for experimental research in the field of emotions. They may represent an advantage when compared to 2D stimuli, as they bring more realism into laboratorial settings.

Declaration of interest

There are no potentially competing interests to be declared.

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Table 1

Anatomic location, brain hemisphere, brain areas and their Talairach coordinates detected through 3x2 ANOVA analysis: *Interaction effect of* visualization effects *and* valence.

Anatomic Location	BH	BA	Coordinates			*F*	*p*	Size*
			x	y	z			
Uncus	L	36	-19.0	-8.0	-27.0	18.506	0.000019	31
Postcentral Gyrus	R	3	41.0	-20.0	51.0	13.294	0.000164	20
Middle Frontal Gyrus	R	46	53.0	28.0	24.0	16.225	0.000047	15
Declive	R		35.0	-62.0	-15.0	16.723	0.000038	15
Cerebellar Tonsil	L		-25.0	-41.0	-42.0	15.584	0.000061	13
Cingulate Gyrus	R	24	20.0	-8.0	39.0	15.697	0.000058	10
Lentiform Nucleus	L		-31.0	-14.0	6.0	15.336	0.000067	9

Note: BH = Brain Hemisphere; BA = Brodmann's area; L = left; R = right; *number of voxels.

[a] Clusters were only considered if seven or more contiguous voxels were activated.

Table 2

Random effects analysis of contrasts: Post-hoc t-*tests to identify (a)* valence effects (Pl, Unpl and N valences) *within* visualization type (2D, 3D types) and (b) visualization effects *within* valence.

Contrast	Df	*t*	*p*	Coordinates			Anatomic Location
				x	y	z	
Valence effects within *visualization type* (a)							
2D Unpl > 2D Pl	11	4.554	.001	-19.0	-8.0	-27.0	Uncus
2D Pl > 2D N	11	3.499	.005	41.0	-20.0	51.0	Postcentral Gyrus
2D Unpl > 2D N	11	5.859	.000				
3D Pl > 3D N	11	3.483	.005	53.0	28.0	24.0	Middle Frontal Gyrus
2D Unpl > 2D N	11	3.830	.003	-37.0	-38.0	-36.0	Cerebellar Tonsil
2D Pl > 2D N	11	3.391	.006	-25.0	-41.0	-42.0	
2D Pl > 2D N	11	3.400	.006	20.0	-8.0	39.0	Cingulate Gyrus
2D Unpl > 2D N	11	4.015	.002				
Visualization effects within *valence* (b)							
3D > 2D Pl	11	2.985	0.012	35.0	-62.0	-15.0	Declive
3D < 2D N	11	3.611	0.004	-13.0	-56.0	-36.0	Cerebellar Tonsil

Note: Pl = pleasant; Unpl = unpleasant and N = neutral. The results are corrected for multiple comparisons, (a) $p = .05/6 < .008$, (b) $p = .05/3 < .017$.

Table 1

Anatomic location, brain hemisphere, brain areas and their Talairach coordinates in which seven or more voxels were activated, detected through 3x2 ANOVA analysis and post-hoc t*-tests: Main effect of* emotional valence.

Anatomic Location	BH	BA	Coordinates						Contrast			
			x	y	z	*F*	*p*	Size*		*t*	df	*p*
Paracentral Lobule	L	5	-10.0	-41.0	60.0	18.957	0.000016	20	Unpl > N	5.084	11	.000
									Unpl > Pl	3.611	11	.004
Inferior Parietal Lobule	R	40	41.0	-47.0	55.0	12.306	0.000259	15	Pl > N	3.572	11	.004
									Unpl > N	4.496	11	.001
	R	40	47.0	-29.0	48.0	14.521	0.000095	7	Unpl > N	3.759	11	.003
									Unpl > Pl	4.637	11	.001
Precuneus	L	7	-31.0	-44.0	51.0	14.190	0.000110	11	Pl > N	3.515	11	.005
									Unpl > N	2.820	11	.017
									Unpl > Pl	4.458	11	.001
Superior Temporal Gyrus	R	22	62.0	-35.0	9.0	13.985	0.000120	9	Pl > N	2.985	11	.002
									Unpl > N	5.056	11	.000
									Unpl > Pl	3.274	11	.007
Middle Frontal Gyrus	R	10	32.0	34.0	18.0	14.519	0.000095	9	Unpl > N	4.441	11	.001
									Unpl > Pl	4.878	11	.000
Postcentral Gyrus	R	3	62.0	-11.0	24.0	14.828	0.000084	8	Unpl > N	5.740	11	.000
									Unpl > Pl	5.386	11	.000

Note: BH = Brain Hemisphere; BA = Brodmann's area; Pl = pleasant; L = left; R = right; N = neutral; Unpl = unpleasant; *number of voxels. The results are corrected for multiple comparisons.

Table 4.
Anatomic location, brain hemisphere, brain areas and their Talairach coordinates in which seven or more voxels were activated, detected through 3x2 ANOVA analysis and post-hoc t-tests: Main effect of visualization type.

Anatomic Location	BH	BA	Coordinates						Contrast			
			x	Y	z	*F*	*p*	Size*		*t*	df	*P*
Lentiform Nucleus	L		-16.0	-2.0	-6.0	43.408	0.000039	38	3D > 2D	6.750	11	.000
Fusiform Gyrus	L	20	-55.0	-35.0	-21.0	45.157	0.000033	25	3D > 2D	6.372	11	.000
Precentral Gyrus	L	6	-49.0	-2.0	33.0	47.479	0.000026	22	3D > 2D	3.901	11	.002
	R	6	32.0	-14.0	54.0	32.910	0.000131	10	3D > 2D	6.085	11	.000
Cuneus	L	17	-19.0	-95.0	0.0	48.263	0.000024	20	3D > 2D	3.571	11	.004
Superior Temporal Gyrus	L	42	-52.0	-32.0	15.0	35.788	0.000092	16	3D > 2D	5.369	11	.000
Precuneus	L	31	-13.0	-62.0	21.0	32.412	0.000140	14	3D > 2D	5.440	11	.000
Middle Frontal Gyrus	L	9	-46.0	31.0	30.0	26.381	0.000325	12	3D > 2D	5.490	11	.000
Inferior Frontal Gyrus	R	45	50.0	22.0	12.0	29.854	0.000197	7	3D > 2D	5.346	11	.000
Superior Frontal Gyrus	R	6	5.0	7.0	57.0	30.968	0.000169	7	3D > 2D	4.141	11	.002
Superior Temporal Gyrus	R	38	47.0	7.0	-18.0	29.348	0.000211	7	3D > 2D	4.572	11	.001
Cuneus	L	17	-16.0	-80.0	6.0	29.755	0.000199	7	3D > 2D	5.417	11	.000
Sub-Gyral	L	40	-31.0	-44.0	33.0	29.261	0.000214	7	3D > 2D	4.759	11	.001

Note: BH = Brain Hemisphere; BA = Brodmann's area; L = left; R = right; *number of voxels. The results are corrected for multiple comparisons.

Figure 1. Emotion-inducing scenarios of different valences (pleasant, neutral, unpleasant valences) projected in 2D and 3D.