PERSUASIVE MESSAGES ARE CHARACTERIZED BY LIMBIC AND PREFRONTAL CO-ACTIVATION AND IMPROVED RECOLLECTION

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Abstract

Persuasion theories posit that both affective and executive processes in response to health messages are important for successful behavior change. However, it remains unclear how the brain networks responsible for these processes interact while viewing persuasive messages. The current fMRI study asked 65 adolescents (ages 15 to 19) to make momentary affective appraisals in response to 10 anti-drug public service announcements (PSAs) previously found to be strongly convincing, 10 found to be weakly convincing, and 10 comparison advertisements not related to drugs. Results showed that while both strong and weak anti-drug PSAs elicited arousal-related brain activity in limbic (amygdala, nucleus accumbens, OFC) and medial prefrontal brain regions, strong compared to weak anti-drug PSAs elicited more arousal-related activity in lateral prefrontal cortical regions associated with executive control (IFG, MFG). A functional connectivity analysis also showed greater functional co-activation between amygdala and the lateral prefrontal cortex during strong compared to weak anti-drug PSAs. A memory test given to a subset of 30 subjects after a one-week delay suggested that strongly convincing anti-drug PSAs were associated with better declarative memory. In contrast to extant views of an antagonistic relationship between limbic and prefrontal neural networks, the present findings demonstrate that strongly persuasive messages elicit increased simultaneous

activation in brain regions responsible for emotional arousal and executive control.

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Introduction

Recent neuroimaging studies of persuasion have documented the neural correlates of behavior change (Falk, 2010a; Chua, 2011), and the effects of message content on memory encoding (Langleben, 2009). While each study has implicated either limbic or prefrontal brain regions, they do not explain how limbic and prefrontal networks interact during persuasive message processing. The question remains vexing, as limbic and prefrontal neural networks consistently have shown an antagonistic relationship during numerous cognitive tasks in both human (Hariri, 2000; Davidson, 2002; Hariri, 2003; Phelps, 2003; Kim, 2003; Ochsner, 2005; New, 2007) and non-human primates (Amaral, 1992). This antagonism has also been observed in resting state networks (Roy, 2009), suggesting that affective and executive brain networks are intrinsically oppositional.

In contrast, health communication research using behavioral methods has shown that persuasive messages require an optimal level of emotional arousal for successful attention and information acquisition to occur (Palmgreen, 1991; Stephenson, 2006). At the same time, sufficient cognitive resources also must be dedicated to executive functions such as message interpretation and memory encoding in order to successfully produce behavior change (Lang, 2000; 2006). This suggests that while the brain regions underlying affective arousal and

executive functions generally inhibit one another (Hariri, 2000; Ochsner, 2002), they must also work together in some circumstances.

Because mechanisms underlying persuasive communication are difficult to evaluate in animal models, hypotheses about these processes largely draw on work in humans. Physiological research in humans has demonstrated that affective and executive functions were coordinated when anti-drug PSAs rated as highly arousing elicited increases in volitional attention (Lang, 2004). In our own work, we generated a catalogue of previously aired anti-drug PSAs, each of which was scored by an adolescent sample on a continuum of perceived convincingness. Our findings indicated that PSAs that induced strong arousal were seen as relatively more convincing than PSAs known to elicit weaker levels of arousal (Yzer, 2011). These findings suggested that in contrast to previously observed antagonism, individuals would simultaneously engage both prefrontal (MFG, IFG) and limbic (amygdala, nucleus accumbens, OFC) brain regions in response to strong but not weakly convincing anti-drug PSAs. We also predicted that these increases in attention would be associated with better recollection for strong compared to weak anti-drug PSAs.

We investigated these hypotheses in 65 adolescents who underwent fMRI scanning while viewing 20 anti-drug PSAs and 10 comparison advertisements not related to drugs (non-drug ads). Ten strongly and 10 weakly convincing anti-drug PSAs were selected from our catalogue of PSAs. The non-drug ads were

produced for and aired on television, and had similar levels of negative valence and arousal compared to the selected sample of anti-drug PSAs. Participants provided momentary ratings of arousal while viewing the same anti-drug PSAs and non-drug ads outside of the scanner. These momentary arousal ratings were used as individualized regressors to predict arousal-related BOLD activity in response to each message. We then followed up with a subset of 30 individuals after a one-week delay to assess their long-term memory for the PSAs and ads.

Methods

Participants

Subjects were recruited from the community, using the University of Minnesota Institute of Child Development (ICD) participant database. To comprise the database, the ICD uses birth records in the Twin Cities metro area to contact families. Those who consent to be recruited for developmental research studies become part of the database. Parents of children ages 15 to 19 years were telephoned to determine eligibility and inquire whether their child would be interested in participating in the study. Participants were screened for handedness (right), fMRI incompatibility (i.e. claustrophobia, metallic foreign bodies, pace-makers, etc.) and psychiatric diagnosis. 70 participants were recruited (50% male). Participants were selected from the 15 to 19 year-old age range (Mean = 16.75 SD = 1.54). 25 (35.7%) reported having ever used

marijuana in their lifetime. Of those individuals, 3 (12%) reported most recently using over 12 months prior, 18 (72%) reported using more than one month prior but within the last year, 1 (4%) reported to have used in the last month, 2 (8%) reported to have used in that week, and 1 (4%) had used in the last 24 hours. For purposes of the current study, a 'drug-user' was defined as any individual who reported having used within the last year (N=22). The average age of first use was 15.92 years old. Five subjects were subsequently removed from all final analyses due to motion artifacts or scanner errors.

Procedures

Eligible participants came into the laboratory for a 3.5-hour session. All participants provided signed assent or consent. Subjects under the age of 18 were required to have additional parental consent to participate. Participants viewed a series of thirty 30-second commercial clips while undergoing a fMRI scan. The commercials consisted of 10 anti-drug PSAs previously identified as "strong" in convincingness (Yzer, 2011), 10 anti-drug PSAs previously identified as "weak" (Yzer, 2011), and 10 non-drug ads (e.g., an advertisement for a violent video game) matched for negative valence and a moderate level of arousal-evoking content. Immediately following the scan session, subjects were required to re-watch and make momentary arousal ratings in response to the anti-drug PSAs and non-drug ads. Participants made these ratings following the scan,

because a preliminary study revealed differences in psychophysiological indices when making ratings versus simply watching. They were asked to rate how they felt on a moment-to-moment basis on a 7-point sliding scale (0 = “Bored”; 3 = “Neutral”; 6= “Stirred Up”). Subjects made their ratings by sliding a cursor along a horizontal line positioned beneath the video player on their computer screen using the computer’s track pad. Measurements were made at a rate of 10 per second, which were then averaged to 1 per second, leaving subjects with 30 time-sequenced arousal ratings for each video clip they viewed. Following each clip, subjects gave retrospective evaluations of the video, answering nine 7-point items. These items contained the stem phrase, ‘To me, this ad was…:’ and was followed by a scale with the anchors (1) *extremely unconvincing – extremely convincing*, (2) *extremely unbelievable – extremely believable*, (3) *extremely forgettable – extremely memorable*, (4) *extremely bad – extremely good*, (5) *extremely unpleasant – extremely pleasant*, (6) *extremely negative – extremely positive*, and (7) *extremely not for someone like me – extremely for someone like me*. The last two questions were in response to the phrase ‘This ad made me feel…’ on scales with the anchors (8) *bored – stirred up* and (9) *unhappy – happy*. Averaging scores on the *unpleasant -pleasant* and *negative - positive* items derived a measure of perceived message pleasantness. Perceived message convincingness was derived from averaging the *unconvincing - convincing, unbelievable - believable, forgettable - memorable,* and *bad - good*

items (see Yzer *et al.* 2011 for more detail on the factor analysis that derives these scales).

Long-Term Memory Assessment

Long-term memory for the anti-drug PSAs and non-drug ads was tested in a subset of 30 subjects (Mean Age = 17.03, SD = 1.71). Phone calls were placed between 6 and 8 days after the initial testing session to assess free-recall and cued-recall of the previously viewed anti-drug PSAs and non-drug ads. The experimenter first asked whether the subject could recall any of the videos they were shown one week prior, and to elaborate on any details they could remember. Next, the experimenter tested cued-recall of specific message features by administering a structured memory test (modeled after the Logical Memory subtest from the WMS-III). Subjects were required to answer 'yes' or 'no' in response to the veracity of six to seven statements about each message's specific features.

fMRI Acquisition

Subjects viewed the anti-drug PSAs and non-drug advertisements in 3 blocks, each containing 10 30-second clips with 30 seconds of fixation between each clip. Functional scans were collected using a 3 Tesla Siemens Trio MRI scanner, and a 12-channel head coil. The following parameters were employed

for data collection: 310 scans, repeat time (TR) = 2 s, echo time (TE) = 40, flip angle = 90 degrees, voxel size = 3.5 x 3.5 x 3.5 mm thickness, FOV= 22 cm, 35 axial slices. T1 reference images were collected with the following parameters: voxel size = .86 x .86 x 1.5 mm thickness, 256 x 256 x 124 dimensions.

fMRI Image Processing

Data was preprocessed using FSL (see: http://www.fmrib.ox.ac.uk/fsl/) and its accompanying toolbox. Images were motion corrected using rigid body transformations, spatially smoothed at FWHM = 10.0 mm, normalized using the mean volume intensity, and filtered with a high pass frequency cutoff of 120 seconds. GLM analysis was conducted using FEAT. Momentary arousal ratings of each PSA were used as regressors for each individual's BOLD response. Group images were cluster thresholded at Z=2.3 and a brainwise significance threshold of p=0.05.

Results

Perceived Message Convincingness

Replicating previous findings (Yzer, 2011), perceived message convincingness was significantly greater for strong compared to weak anti-drug PSAs (Figure 1a; $t(128)=5.33$ $p=.0000004$), and perceived message

pleasantness was significantly greater for weak compared to strong anti-drug PSAs (Figure 1b; $t(128)=-4.24$, $p=.00005$). Mean momentary arousal ratings for the three different types of messages are illustrated in Figure 1c. These ratings were also significantly different from one another, with strong anti-drug PSAs perceived as most arousing (Figure 1d; $F(2,87)=5.93$ $p=.0039$). No relationships between arousal ratings and previous drug use were found.

Long-Term Memory

Memory of specific message features was tested in a subset of 30 participants. After a one-week delay, free-recall memory was shown to differ between the three conditions in an ANOVA (Figure 2a; $F(2,87)=7.17$, $p=.001$). To better understand this result, Tukey's HSD test compared strong versus weak anti-drug PSAs (adjusted $p<.004$) and strong anti-drug PSAs versus non-drug ads (adjusted $p=.005$) showing that strong anti-drug PSAs were remembered better than both weak anti-drug PSAs and non-drug ads. Cued-recall memory for specific message features after a one-week delay were also shown to differ among the conditions in an ANOVA (Figure 2b; $F(2,87)=8.04$, $p=.0006$). Tukey's HSD test showed that cued-recall was better for non-drug ads compared to strong anti-drug PSAs (adjusted $p<.004$) and non-drug ads compared weak anti-drug PSAs(adjusted $p<.0006$). Cued-recall for strong compared to weak anti-drug PSAs did not statistically differ, and no significant relationships between

users status and long-term memory were found. Therefore, differences in perceived convincingness appeared to map on to one aspect of memory, free-recall, but not cued-recall.

BOLD fMRI Analysis

Whole brain activation was modeled in a GLM for strong anti-drug PSAs, weak anti-drug PSAs, and non-drug advertisements, all of which showed broad activation in frontal, temporal, and occipital brain regions. Contrasting all anti-drug PSAs with non-drug advertisements, we found greater activation for anti-drug PSAs in limbic regions including bilateral amygdala (Figure 3a) and medial orbitofrontal cortex (mOFC; Figure 3a), as well as paracingulate gyrus (Figure 3b), bilateral hippocampus, and superior temporal gyrus (Table 1a). Analysis of the parameter estimates showed bilateral amygdala activation during both strong and weak anti-drug PSAs and bilateral deactivation during non-drug ads (Figure 3a). The mOFC and paracingulate gyrus showed significant deactivation across both conditions but significantly more deactivation for the non-drug ads (Figure 2a; Figure 3b).

Contrasting strong versus weak anti-drug PSAs revealed no statistically significant differences in any limbic region. There were differences in the prefrontal cortex, notably bilateral middle frontal gyrus (MFG; Figure 4a) and left inferior frontal gyrus (IFG; Figure 4b). Activity in the bilateral MFG showed

deactivation across strong and weak conditions, but significantly greater deactivation for weak anti-drug PSAs. The left IFG showed increased activation during strong anti-drug PSAs and deactivation during the weak anti-drug PSAs. There were also differences in bilateral parahippocampal gyrus (Figure 4c), lingual gyrus, occipital lobe, and precuneus (Table 1b). No significant relationships were found between previous drug use and activity in the aforementioned regions of interest. In a contrast orthogonal to the one used to identify the prefrontal regions, individual differences in perceived convincingness for strong anti-drug PSAs positively correlated with individual parameter estimates in the left IFG (Figure 5a) and left MFG (Figure 5b). No significant relationships between perceived convincingness of strong anti-drug PSAs and individual parameter estimates were found in limbic regions of interest.

Functional Connectivity Analysis

The GLM in this study allowed observations of brain activity only as they related to a subject's self-reported arousal. We therefore used seed-based connectivity, independent of arousal-related activity, to determine whether brain regions are actively connected during processing of persuasive messages. A psychophysiological interactions (PPI; Friston, 1997) analysis assessed connectivity between regions of interest identified in the initial GLM, notably bilateral amygdala, bilateral MFG, and left IFG.

Using the mean time series of the amygdala as a regressor, differences in connectivity were found between anti-drug PSAs and non-drug advertisements in left IFG, left MFG, frontal pole, and paracingulate gyrus (Table 2a). Amygdala activity did not co-activate with the left IFG during anti-drug PSAs, but was inversely co-activated during non-drug advertisements (Figure 6a). Similarly, connectivity from the amygdala to the left MFG showed no co-activity between anti-drug PSAs and an inverse co-activation during non-drug advertisements.

Strong anti-drug PSAs co-activated with the amygdala in both left IFG and left MFG, but did not co-activate in the same regions during weak anti-drug PSAs. Of particular importance, strong anti-drug PSAs had slightly greater connectivity from amygdala to left IFG and left MFG than weak anti-drug PSAs (Figure 6b; left IFG Strong>Weak: t(df)=1.77(105.82) p_{oneway}=.04; left MFG Strong>Weak: t(df)=1.77(127.88) p_{oneway}=.027).

A larger effect was observed when using the mean time series of the left IFG as a regressor directly examining differences in functional connectivity between strong and weak anti-drug PSAs. In this case, strong anti-drug PSAs co-activated with activity in both the amygdala and insula while weak anti-drug PSAs were inversely co-activated in the same regions (Figure 7a). Significant differences were also observed in occipital cortex as well as both lateral and inferior temporal gyri (Table 2b).

When the mean time series of the left MFG was included as a physiological regressor, we observed differences in strong versus weak anti-drug PSAs. Activity in the left MFG positively co-activated with the amygdala during strong anti-drug PSAs and negatively co-activated during weak anti-drug PSAs (Figure 7b). There was no co-activation between left MFG and insula during strong anti-drug PSAs, but there was negative co-activation during weak anti-drug PSAs (Figure 7c). Significant differences were also observed in occipital cortex and putamen, as well as both middle and inferior temporal gyrus (Table 2c). The time course from the right MFG did not show significant connectivity with relevant regions of interest.

Users versus Non-Users

To better understand neural and behavioral differences between marijuana users (n=22, defined as having used during the past year) and non-users, the two groups were compared across all message conditions. No differences were found between groups in any condition or contrast using standard, brainwise levels of significance thresholding. When using a more liberal thresholding procedure (uncorrected $p<.01$) interaction effects were found for both groups when contrasting all anti-drug PSAs with non-drug ads. Comparing non-users greater than users on anti-drug PSAs versus non-drug ads, we found activation in the left IFG (Figure 8). When comparing users greater

than non-users on anti-drug PSAs versus non-drug ads, we saw increased activation in the dorsal medial prefrontal cortex (Figure 8).

Discussion

The present study used general linear models and functional connectivity to demonstrate that anti-drug messages perceived as strongly convincing evoke co-activation of limbic and prefrontal networks during fMRI. Moreover, increases in perceived convincingness of strong anti-drug PSAs correlated with increases in BOLD activity in the lateral prefrontal cortex, but not in limbic regions. We also demonstrated that weakly convincing anti-drug messages activated limbic regions while decreasing activity in the lateral prefrontal cortex. Last, we showed that in a subset of participants, strongly convincing anti-drug PSAs were remembered better than both weak anti-drug PSAs and non-drug ads after a weeklong delay.

Previous research on the neural correlates of persuasion has modeled BOLD activity in response to static (Falk, 2010b), dynamic (Falk, 2011), and self-relevent (Chua, 2011) persuasive messages, and has demonstrated that regions of the subgenual and dorsal medial prefrontal cortex were positively associated with subsequent behavior change. In the present study, these same regions showed significant differences when contrasting anti-drug PSAs with non-drug ads, but not when comparing strong versus weak anti-drug PSAs.

Integrating these findings, we propose that the medial prefrontal cortex likely is involved in the general strategies adopted when one views messages intended to be persuasive, whereas activity in lateral regions of the prefrontal cortex are modulated in response to increases in perceived convincingness. It is conceivable that differential activation in medial prefrontal regions, which are implicated in self-referential processing (Northoff, 2006), may be necessary – but not sufficient – for persuasion, as our findings suggest the importance of arousal related co-activation of limbic and prefrontal networks.

There may also be specific factors relating to individual differences and the ways in which viewers use previous experiences to approach persuasive messages. In our preliminary analysis comparing users and non-users, we were unable to show any group differences. However, when viewing a cluster-uncorrected analysis for exploratory purposes, we found that individuals who had used drugs in the last year engaged medial regions of the prefrontal cortex in response to anti-drug PSAs, while non-users preferentially engaged lateral prefrontal cortex. In spite of findings suggesting that chronic cannabis users exhibit reduced BOLD activity globally (Tunving, 1986; Lundqvist, 2001), especially in regions important for attention (Chang, 2006), working memory (Jager, 2006), and cognitive control (Gruber, 2005), the current results might 3/5/12 1:34 PMsuggest that users and non-users employ differing strategies when viewing anti-drug PSAs. More experienced drug users may engage a

region similar to that found in smokers watching tailored anti-smoking PSAs, indicative of self-referential processing (Chua, 2011). Conversely, non-users might recruit the left IFG, potentially suggestive of emotional regulation (Wager, 2008). Even though these results are limited in that they did not correct for multiple comparisons, a more controlled study that actively recruits users and non-users may show significant results indicating that relevant experience plays an important role in the way the brain processes persuasive messages.

The current results inform behavioral findings in a related study of 47 adolescents using the same 20 strong and weak anti-drug PSAs. In that study we found differences in convincingness and self-reported arousal between strong and weak anti-drug PSAs, but found no differences in objective measures of arousal (i.e. skin conductance response). This pattern suggested that participants' self-reports of their arousal were not manifestations of an autonomic response, but instead reflected a top-down interpretation of their response to the PSAs, perhaps indicating their level of interest or involvement. The current findings converge with those results to reinforce the evidence that prefrontal regions are important to the experience of arousal and the subsequent perception of convincingness.

Several theories have described what factors make health communications persuasive. One proposal, the Limited Capacity Model of Motivated Mediated Message Processing (LC4MP, Lang, 2000, 2006), states that

message processing calls on limited cognitive resources for encoding, storage, and retrieval. LC4MP postulates that messages that are too cognitively demanding will attenuate comprehension and retention, limiting their capacity to change behavior. Consistent with LC4MP, Langleben and colleagues (2009) reported prefrontal deactivation and reduced memory in response to PSAs with high levels of message sensation value, a feature of putatively strong (as opposed to weak) anti-drug PSAs. Despite showing prefrontal disengagement in response to these PSAs, it was unclear whether the researchers' observed reductions were also associated with increased limbic activation.

Findings from the current study also were consistent with the LC4MP hypothesis, as we found deactivation in bilateral MFG during anti-drug PSAs, suggesting that arousing material in a message may reduce activity in certain areas of the prefrontal cortex. This disengagement was particularly marked for PSAs rated as weakly convincing, consistent with evidence that weak messages with arousing content are less effective than strong messages with arousing content (Lang, 2008). We also observed deactivation during anti-drug PSAs in the medial orbitofrontal cortex, a region commonly associated with reward processing (Liu, 2011), which suggests that anti-drug PSAs also disengage structures in the reward system.

In contrast with the LC4MP hypotheses, our findings showed increased activation in the left IFG for strong PSAs and deactivation for weak PSAs,

indicating that this region of the lateral prefrontal cortex may hold specific relevance to the processing of strongly persuasive content. Long established as a region important for both phonetic and semantic verbal comprehension (Paulesu, 1993; Smith, 1999; Baddeley, 2003), it is also understood as a region for emotional generation and regulation (Wager, 2008) as well as response inhibition (Aron, 2003). Thus, many of the specific functions of the IFG are likely implicated by previous research in persuasive message processing and subsequent decisions.

The long-term memory findings from this study suggest that perceived convincingness is associated with better recollection, as free-recall memory was best for strong anti-drug PSAs. While the LC4MP model does propose that arousing or otherwise cognitively demanding messages may induce “cognitive overload” (Lang, 2006), it also maintains that sufficient arousal is necessary to orient and engage the viewer. In this case, the strong anti-drug PSAs, in spite of having prominent arousing features, appear to fulfill this quality. This is demonstrated by increased activation in the parahippocampal gyrus (see Figure 4c), suggesting that these messages were preferentially encoded and, as a result, better remembered after the weeklong delay. Conversely, cued-recall memory was best for non-drug ads with no differences between strong or weak anti-drug PSAs. This suggests that certain aspects of these non-drug messages are particularly well suited for cued memory. One proposal is that humor appeals,

which were prominent among the non-drug ads, facilitated encoding and retrieval (Shanker-Krishnan 2003) and led to better remembering during the cued memory task. In spite of the current findings, it remains unclear whether subjects' memory for convincing messages was due to the message features specifically as opposed to the message as a whole. Future examinations of long-term memory for anti-drug PSAs should aim to account for these issues directly.

Other work (Falk, 2010a; Chua, 2011) reported differences in prefrontal brain regions using regressors that modeled an entire message uniformly, but did not report differences in activation of limbic brain regions. Accordingly, these epoch, or "box-car" models may not reflect the heterogeneity in quality and content across the time course of a message. These models also cannot account for individual differences in subjective arousal, making them less sensitive to changes in limbic and prefrontal brain regions (Phan, 2003). The momentary arousal approach used to generate regressors for the current study sidestepped these concerns, because it allowed us to model the timing of relevant events, and individual differences in response to these events.

The nature of the mechanism implemented by the limbic-prefrontal co-activation is beginning to be explored. Rougier and colleagues (2005) provided a computational model showing that the prefrontal cortex relies on input about rewards and punishments to effectively organize experiences into rules. The model thereby illustrates how executive control follows from the reward and

punishment structures in the environment. Integrating this model with the current findings suggests that amygdalar involvement in cognitive processing may be required for frontal brain regions to accurately and effectively translate anti-drug PSA messages into rules and goals. The amygdala itself may do some of this processing, with growing evidence that the amgydala reflects an interaction between emotion and cognition (Pessoa, 2008).

Our conclusions regarding limbic-prefrontal co-activation are limited in so far as they were observed only in the context of negatively valenced messages. As such, these results cannot speak to persuasion where positive valence may be associated with convincingness. Also, this study measured the perception of convincingness as a proxy for a message's potential to change attitudes and behavior. Despite previous research showing that convincingness and potential behavioral change are closely related constructs (Dillard, 2007), additional work would be required to identify whether co-activation of limbic and prefrontal networks would predict behavior change in response to a persuasive message.

To conclude, the current experiment demonstrated that strongly convincing messages simultaneously activated both affective and executive brain networks and were better remembered subsequently. Furthermore, these findings inform the general principles underlying the mutual antagonism of limbic and prefrontal brain regions. We found consistent evidence of an inverse co-activation between these regions during messages rated as weakly persuasive,

whereas both networks showed arousal-related activity increases during strongly persuasive messages.

This study also underscores the utility of developing the neuroscience of health communication. With millions of dollars spent annually on anti-drug media in the U.S. alone, these findings are relevant to prevention scientists and taxpayers alike. The implications of this limbic-prefrontal co-activation may prove crucial to an emerging understanding of persuasion, for example by directing our attention to understanding what message features cause mutual antagonism to be replaced by co-activation. Last, the current findings to some degree arbitrate and synthesize theories of health communication, by demonstrating that the synchronous activation of affective and executive processes underlies the persuasive power of messages.

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Tables

Table 1. Brain regions greater in anti-drug PSAs versus non-drug ads (**a**), and brain regions greater in strong versus weak anti-drug PSAs (**b**). Z>2.3, p<.05, cluster corrected.

a) Anti-Drug PSAs v. Non-Drug Ads						
Voxels	**X**	**Y**	**Z**	**Structure**	**Max Z**	**Effect**
38964	-60	-20	-10	Middle Temporal Gyrus(Left)	10.7	D>ND>0
	-58	-36	-2	Middle Temporal Gyrus(Left)	10.7	D>ND>0
	-48	-64	24	Lateral Occipital Cortex(Left)	10.5	D>0>ND
	-54	8	-26	Temporal Pole	10.1	D>ND>0
	-54	0	-18	Middle Temporal Gyrus(Left)	10	D>ND>0
	-4	-54	30	Cingulate Gyrus	10	0>D>ND
10050	-8	48	40	Frontal Pole	8.24	0=D>ND
	-10	38	50	Superior Frontal Gyrus	8.23	0>D>ND
	-42	4	50	Middle Frontal Gyrus(Left)	8.17	D>ND>0
	-8	56	32	Frontal Pole	7.76	0=D>ND
	2	44	-20	Frontal Medial Cortex	6.47	0>D>ND
	2	48	-18	Frontal Medial Cortex	6.11	0>D>ND
b) Strong v. Weak Anti-Drug PSAs						
Voxels	**X**	**Y**	**Z**	**Structure**	**Max Z**	**Effect**
25,959	-32	-82	28	Lateral Occipital Cortex(Left)	7.78	S>W>0
	2	-60	42	Precuneous Cortex	7.6	0>S>W
	-10	-60	16	Precuneous Cortex	6.91	0>S>W
	40	-74	28	Lateral Occipital Cortex(Right)	6.91	S>W>0
	-22	-48	-6	Lingual Gyrus	6.87	S>W>0
	8	-60	20	Precuneous Cortex	6.83	0>S>W
7,643	-30	12	54	Middle Frontal Gyrus(Left)	7.11	0>S>W
	-36	2	48	Middle Frontal Gyrus(Left)	6.43	0>S>W
	-52	10	36	Middle Frontal Gyrus(Left)	4.96	0>S>W
	-46	28	12	Inferior Frontal Gyrus(Left)	4.87	S>0>W
	-44	32	10	Inferior Frontal Gyrus(Left)	4.72	S>0>W
	-48	26	18	Inferior Frontal Gyrus(Left)	4.64	S>0>W
2364	32	12	58	Middle Frontal Gyrus(Right)	5.54	0>S>W
	34	22	52	Middle Frontal Gyrus(Right)	5.25	0>S>W
	50	14	34	Middle Frontal Gyrus(Right)	3.35	0>S>W
	52	18	42	Middle Frontal Gyrus(Right)	3.1	0>S>W

Labels: PSAs (D) non-drug ads (ND) strong anti-drug PSAs (S) weak anti-drug PSAs (W)

Table 2: Brain regions significantly co-activated with amygdala activity in anti-drug PSAs vs. non-drug ads (**a**), co-activated with left IFG activity in strong vs. weak anti-drug PSAs (**b**), and co-activated with left MFG activity in strong vs. weak anti-drug PSAs (**c**). Z>2.3, p<.05, cluster corrected.

a) Anti-Drug PSAs v. Non-Drug Ads (PPI Amygdala Seed)						
Voxels	**x**	**y**	**z**	**Structure**	**Max Z**	**Effect**
4,003	-36	48	6	Frontal Pole(Left)	3.41	0=D>ND
	-32	34	2	Inferior Frontal Gyrus(Left)	3.37	0=D>ND
	-32	38	2	Inferior Frontal Gyrus(Left)	3.36	0=D>ND
	10	54	12	Paracingulate Gyrus(Right)	3.17	0=D>ND
	-50	4	2	Central Opercular Cortex(Left)	3.11	0=D>ND
	-46	6	4	Central Opercular Cortex(Left)	3.1	0=D>ND
b) Strong v. Weak AD-PSAs (PPI LIFG Seed)						
Voxels	**x**	**y**	**z**	**Structure**	**Max Z**	**Effect**
5,720	50	-64	-16	Lateral Occipital Cortex(Right)	5.63	S>W=0
	56	-50	-16	Inferior Temporal Gyrus(Right)	4.27	S>W=0
	-24	-2	-22	Amygdala(Left)	4.2	S>0>W
	72	-40	-10	Middle Temporal Gyrus(Right)	4.01	S>0>W
	44	-52	-30	Cerebellum	3.96	S>W=0
	10	-8	-12	Amygdala(Right)	3.85	S>0>W
3,982	-50	-50	-22	Inferior Temporal Gyrus(Left)	5.01	S>W=0
	-50	-70	-4	Lateral Occipital Cortex(Left)	3.98	S>W=0
	-14	-36	-26	Brain Stem	3.94	S>W=0
	-28	-60	-44	Cerebellum	3.27	S>W=0
	-26	-42	-30	Cerebellum	3.21	S>W=0
	18	-26	-32	Brain Stem	3.18	S>W=0
c) Strong v. Weak AD-PSAs (PPI LMFG Seed)						
Voxels	**x**	**y**	**z**	**Structure**	**Max Z**	**Effect**
4,974	-48	-52	-20	Inferior Temporal Gyrus(Left)	5.3	S>W=0
	-48	-66	-2	Lateral Occipital Cortex(Left)	4.38	S>W=0
	16	-26	-32	Brain Stem	3.99	S>0>W
	-16	-34	-28	Brain Stem	3.9	S>0>W
	-28	-38	-30	Cerebellum	3.14	S>W=0
	-30	-24	-4	Putamen(Left)	3.11	0=S>W
3,759	52	-66	-14	Lateral Occipital Cortex(Right)	5.78	S>0>W
	44	-64	-16	Occipital Fusiform Gyrus(Right)	5.32	S>0>W
	72	-40	-10	Middle Temporal Gyrus(Right)	4.1	S>0>W
	48	-36	-20	Inferior Temporal Gyrus(Right)	3.76	S>0>W
	66	-46	-20	Inferior Temporal Gyrus(Right)	3.73	S>0>W
	56	-48	-18	Inferior Temporal Gyrus(Right)	3.56	S>0>W

Labels: PSAs (D) non-drug ads (ND) strong anti-drug PSAs (S) weak anti-drug PSAs (W)

Figures

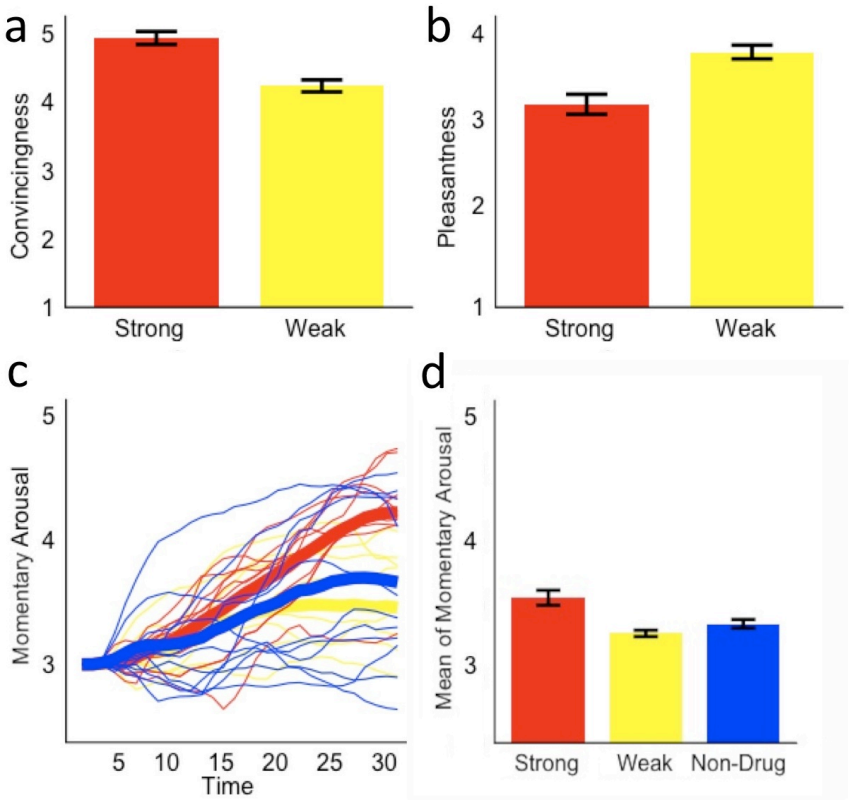

Figure 1: Perceived Effectiveness and Momentary Arousal Ratings. (**a**) Perceived convincingness was significantly higher for strong anti-drug PSAs compared to weak anti-drug PSAs, whereas (**b**) weak anti-drug PSAs were more pleasant than strong anti-drug PSAs. (**c**) Momentary arousal ratings were made outside the scanner as subjects rewatched each PSA and non-drug ad. Mean arousal by PSA or non-drug ad in bold. (**d**) Mean arousal across the time courses of strong anti-drug PSAs, weak anti-drug PSAs, and non-drug ads were all significantly different from one another.

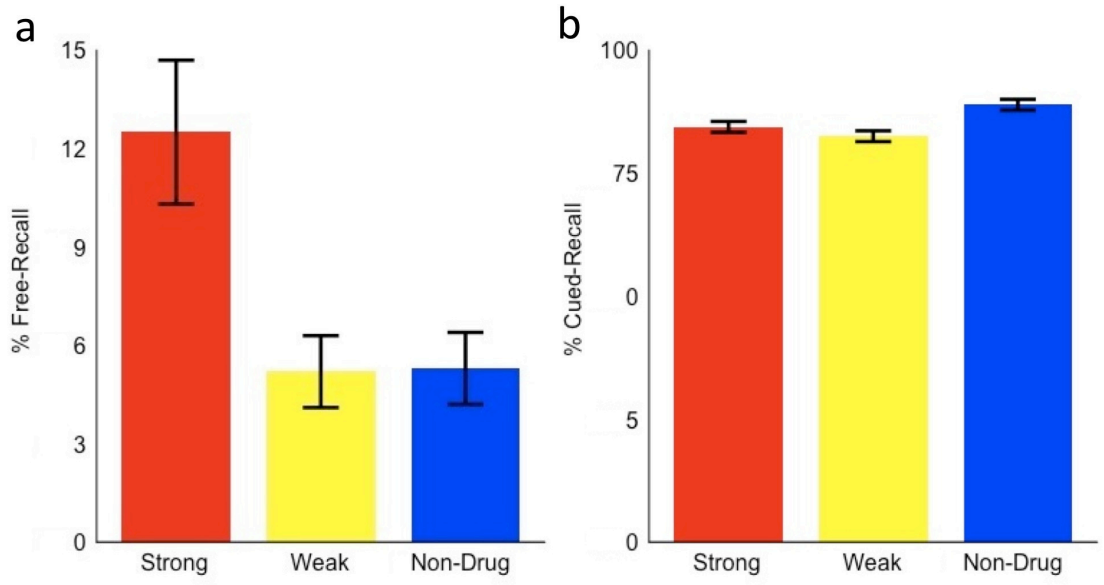

Figure 2: Long-term memory of anti-drug PSAs and non-drug ads. (**a**) Strong anti-drug PSAs were better remembered in a free-recall task compared to both weak anti-drug PSAs and non-drug ads. (**b**) Questions about non-drug ads were better remembered in a cued-recall task compared to both strong and weak anti-drug PSAs.

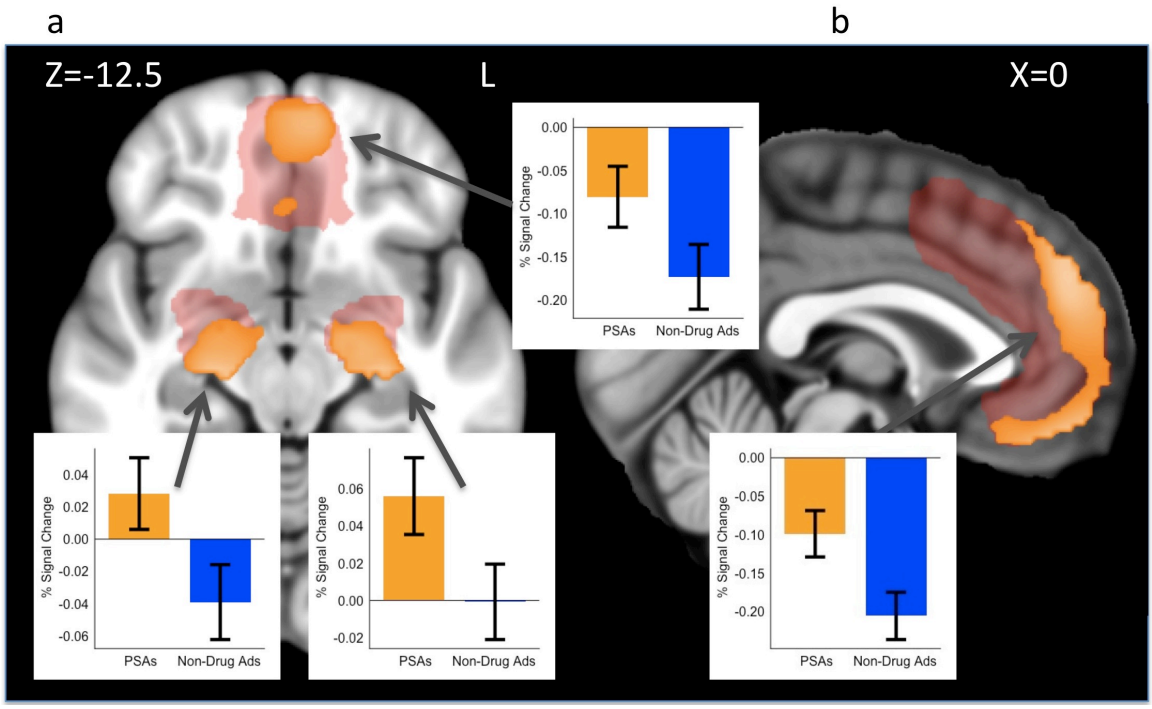

Figure 3: Arousal-related activation in anti-drug PSAs versus non-drug ads. Anatomically-defined regions shown in transparent red. (**a**) Medial OFC and bilateral amygdala. (**b**) Paracingulate gyrus.

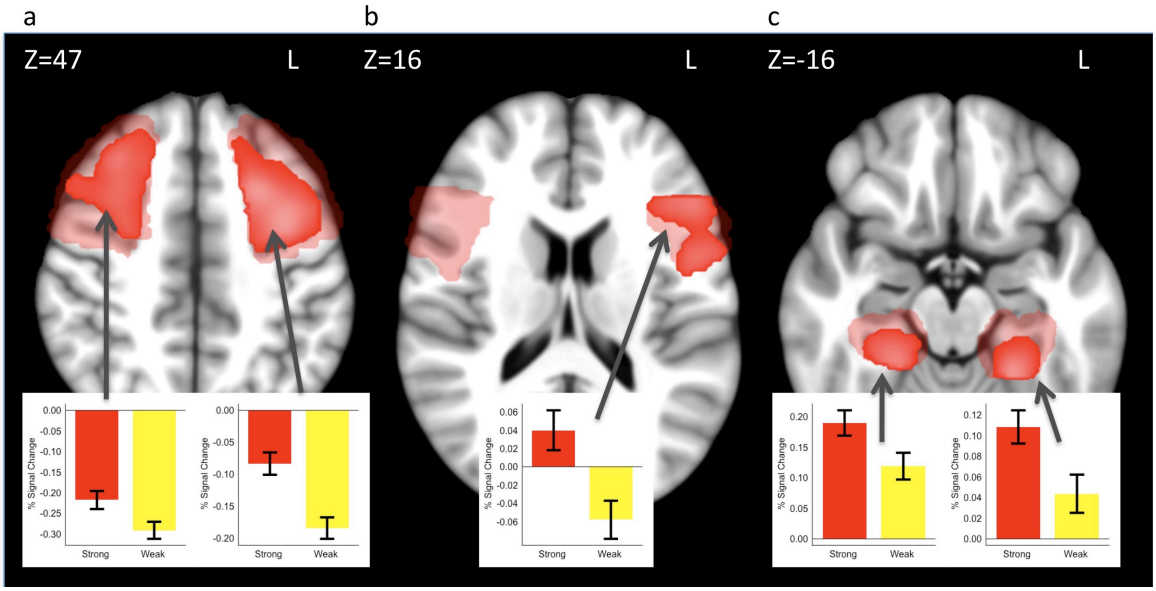

Figure 4: Arousal-related activation in strong anti-drug PSAs versus weak anti-drug PSAs. Anatomically-defined regions shown in transparent red. (**a**) Bilateral MFG. (**b**) Left IFG. (**c**) Bilateral parahippocampus.

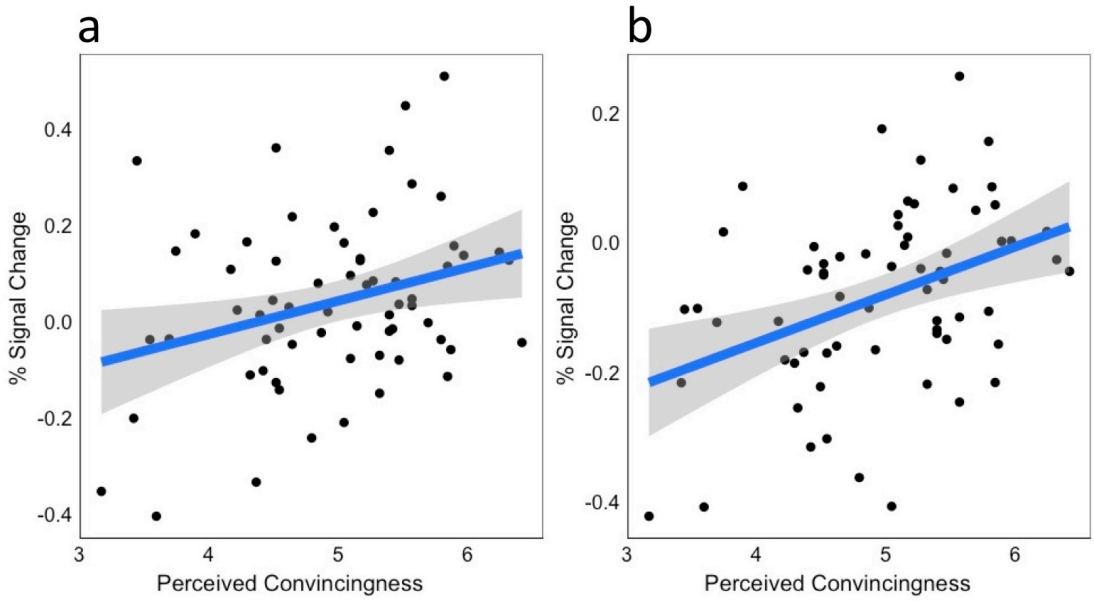

Figure 5: Correlations with perceived convincingness. Individual subject self-reports of perceived convincingness on strongly convincing ads only were positively correlated with BOLD percent signal change in (**a**) left IFG (*r*=.30 p=.015 df=63) and (**b**) left MFG (*r*=.40 p=.00098 df=63)

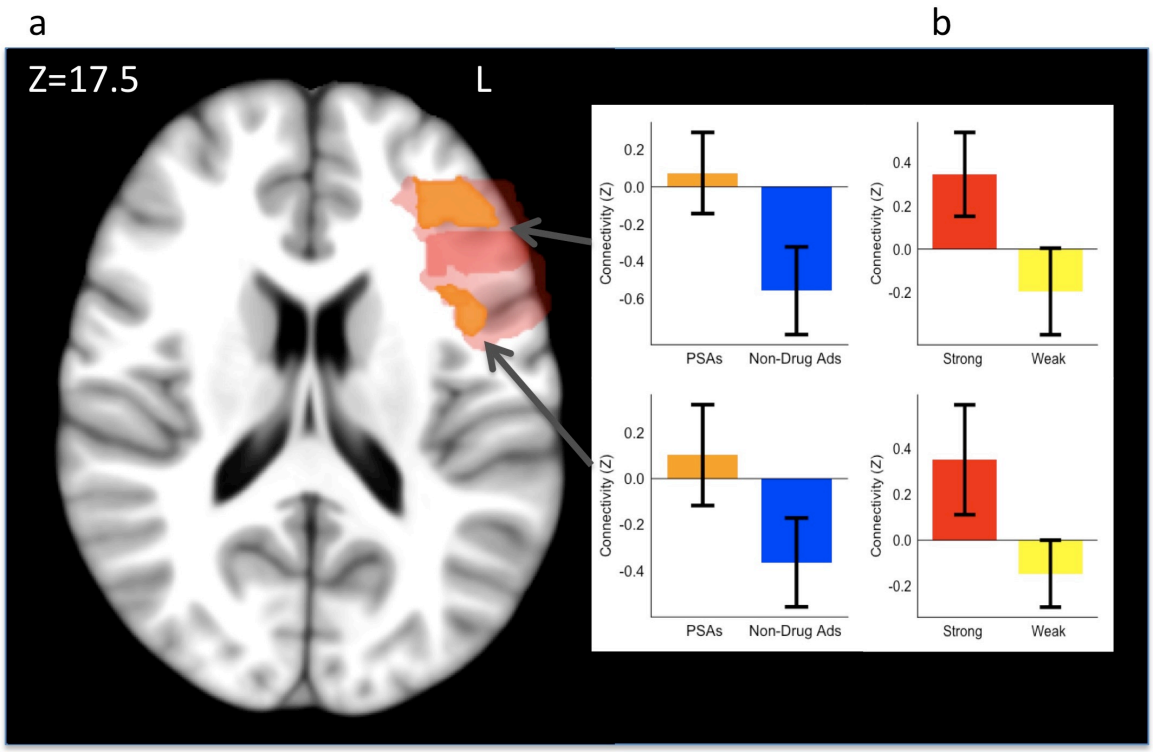

Figure 6: Brain regions functionally connected to the amygdala when comparing anti-drug PSAs versus non-drug ads. Anatomically-defined regions shown in transparent red. (**a**) Left MFG; Left IFG. (**b**) Connectivity of strong versus weak anti-drug PSAs for Left MFG and Left IFG.

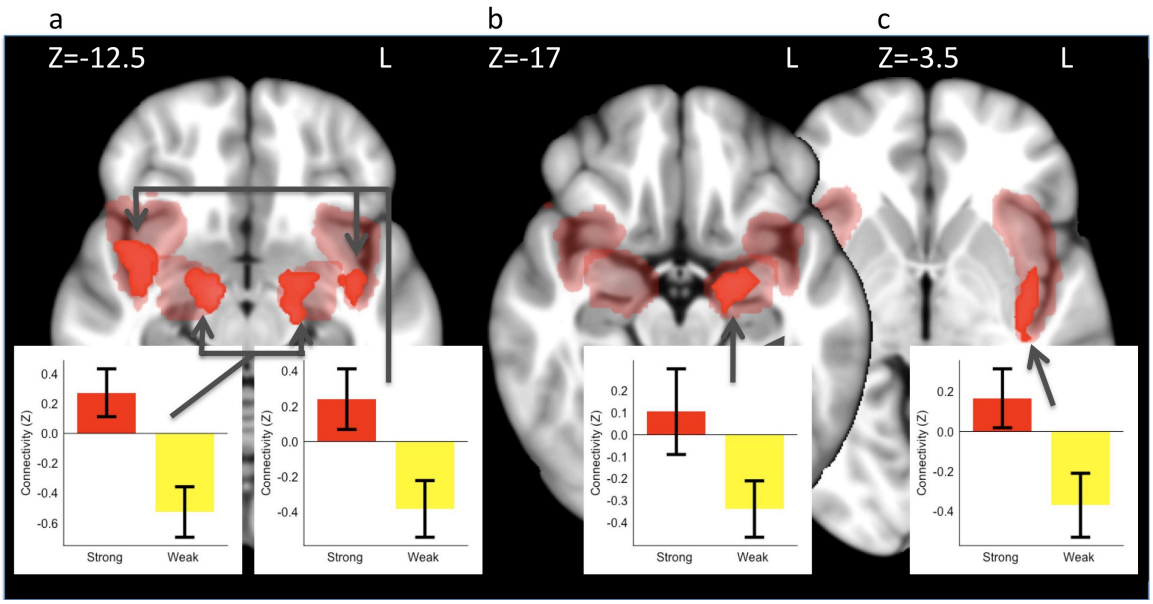

Figure 7: Brain regions functionally connected to the Left IFG when comparing strong versus weak anti-drug PSAs. Anatomically-defined regions shown in transparent red. (**a**) Bilateral amygdala; Bilateral insula. (**b**) Left amygdala. (**c**) Left insula.

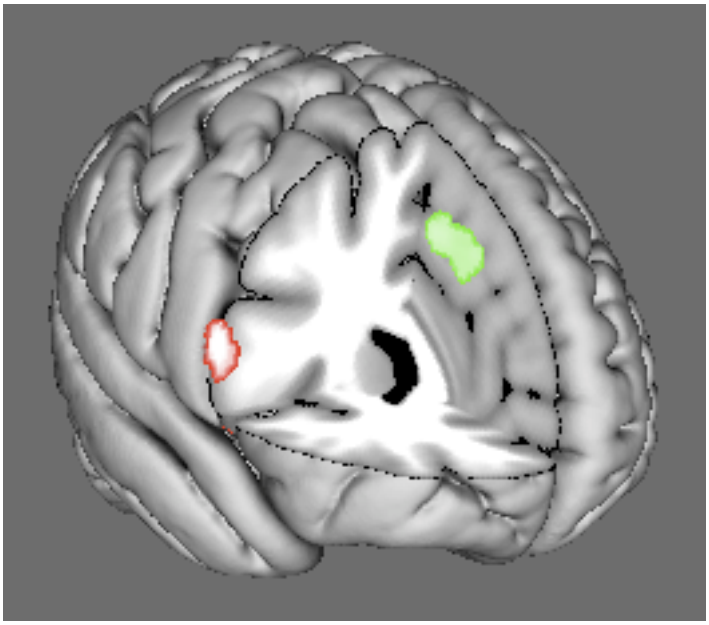

Figure 8: Users compared to Non-Users when contrasting anti-drug PSAs versus non-drug ads. Users > Non-Users: dmPFC (Green). Non-Users > Users: left IFG (Red).