# Affective and executive network processing associated with persuasive anti-drug messages

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| Complete List of Authors:| Ramsay, Ian; University of Minnesota, Psychology  
Yzer, Marco; University of Minnesota, Journalism and Mass Communication  
Luciana, Monica; Univ Minnesota, Psychology  
Vohs, Kathleen; University of Minnesota, Carlson School of Management  
MacDonald, Angus; University of Minnesota, Psychology |
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Affective and executive network processing associated with persuasive anti-drug messages

Ian S. Ramsay¹, Marco C. Yzer², Monica Luciana¹, Kathleen D. Vohs³, Angus W. MacDonald III¹, ⁴

¹ Department of Psychology, University of Minnesota
² School of Journalism and Mass Communication, University of Minnesota
³ Carlson School of Management, University of Minnesota
⁴ Department of Psychiatry, University of Minnesota School of Medicine

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Correspondence should be addressed to:
Angus W. MacDonald III
Elliott Hall 75 East River Road
Minneapolis, MN 55455
Email: angus@umn.edu

Abstract
Previous research has highlighted brain regions associated with socio-emotional processes in persuasive message encoding, whereas cognitive models of persuasion suggest that executive brain areas may also be important. The current study aimed to identify lateral prefrontal brain areas associated with persuasive message viewing, and understand how activity in these executive regions might interact with activity in the amygdala and medial prefrontal cortex.

Seventy adolescents were scanned using fMRI while they watched 10 strongly convincing anti-drug public service announcements (PSAs), 10 weakly convincing anti-drug PSAs, and 10 advertisements (ads) unrelated to drugs. Anti-drug PSAs compared to non-drug ads more strongly elicited arousal-related activity in the amygdala and medial prefrontal cortex. Within anti-drug PSAs, those that were pre-rated as strongly persuasive versus weakly persuasive showed significant differences in arousal-related activity in executive processing areas of the lateral prefrontal cortex. In support of the notion that persuasiveness involves both affective and executive processes, functional connectivity analyses showed greater co-activation between the lateral prefrontal cortex and amygdala during PSAs known to be strongly (versus weakly) convincing. These findings demonstrate that persuasive messages elicit activation in brain regions responsible for both emotional arousal and executive control, and represent a crucial step toward a better understanding of the neural processes responsible for persuasion and subsequent behavior change.

**Keywords**: persuasion, perceived convincingness, fMRI, arousal, executive control, health messages

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**Introduction**
Seven decades of research has dramatically advanced our understanding of persuasion, and the mechanisms by which it can affect attitudes and behavior. Much of this work implicates affective and cognitive responses to persuasive messages (Dillard & Shen, 2012), however, the brain processes that underlie these mechanisms are only just beginning to be understood. Findings from the health communication literature suggest that the most persuasive messages generate emotional arousal (Palmgreen, 1991; Stephenson, 2006) and elicit executive functioning (Petty & Cacioppo, 1981; Lang, 2006), processes broadly associated with amygdalar and medial prefrontal areas that modulate social and emotional responses (socio-emotional; Adolphs, 2001; Phan, 2003), and lateral prefrontal brain areas that engage executive control (Miller & Cohen, 2001) respectively. Groundbreaking work using fMRI in adults has begun to show that activation in amygdalar and medial prefrontal brain areas is related to persuasive message perception and processing (Falk, 2010a; Langleben, 2010), and predictive of behavioral change (Falk, 2010b; Chua, 2011; Falk, 2012). However, less is clear about the relative contributions of executive brain areas (dorsolateral and ventrolateral prefrontal cortices), and whether they are involved in any stage of persuasion. As such, the current work tested whether viewing anti-drug public service announcements (PSAs), pre-rated to be strongly versus weakly persuasive, would engage key areas in socio-emotional and executive brain regions among adolescents aged 15-19 years old. This is an age range during which drug experimentation spikes and prefrontal cortical functions are continuing to develop.
One clear conclusion from the communication literature in adults and adolescents is that the most persuasive behavioral change messages heighten self-reported arousal and negative affect (Palmgreen, 1991; Stephenson, 2006; Yzer, 2011). These are indicators that the audience has become motivationally engaged. Given that negativity and arousal are mediated by areas such as the amygdala, insula, thalamus, and frontomedial cortex (Anders, 2004), this conclusion implicates the involvement of a socio-emotional processing network in message engagement. Other work shows that this network becomes engaged in times of self-referential processing (Dunlop, 2008; Northoff, 2006; Chua, 2011) or threat (Somerville, Whalen, & Kelley, 2010), which not coincidently are states that occur when individuals process health messages (Keller & Block, 1996; Wood, 2000). However, this effect can be precarious, as too much affective engagement during persuasion can compromise the encoding, interpretation, and retrieval of a message’s content by overtaxing the brain’s limited cognitive resources (Lang, 2000; Lang 2006, Langleben, 2009). Hence, the effect of engagement on persuasion is not a simple one, and it may be that regulatory processes must be engaged so that the message content can be encoded and assimilated.

This argument implies that successful persuasion attempts will involve more than just socio-emotional systems. Indeed, persuasion models often emphasize executive control. For instance, some models propose that persuasive messages are processed through a so-called “central route,” in which executive control assimilates new and stored information, anticipates
consequences of decisions, and integrates this information with arousal states (Petty & Cacioppo, 1983, 1986; Petty, Brinol, & Priester, 2009). Executive control processes often are considered central functions of lateral prefrontal areas (Miller & Cohen, 2001), which possess a rich set of connections throughout the brain, including connections to subcortical areas such as the amygdala. These connections may be particularly important for emotion generation and regulation (Davidson, 2004; Wager 2008), which in turn are critically involved in persuasion (DeSteno, 2004). Other regions of the PFC might also be involved given that the ventrolateral region contributes to lower levels of encoding and information processing (D'Esposito, 1999), while ventromedial and orbitofrontal regions further integrate context with evaluative judgments that contribute to higher level control processes (O'Doherty, 2001; Bechara, Tranel, & Damasio, 2000).

Consequently, an emerging question concerns the manner in which executive and affective brain processes interact during persuasive message encoding.

Previous research aimed at understanding the neural correlates of persuasion has primarily focused on adults. Yet a central target of such research should be adolescents, who are, developmentally, likely to engage in risky behaviors (Reyna & Farley, 2006). This propensity toward risk-taking is explained by observations that affective drives related to sensation-seeking and other aspects of reward processing may be heightened during adolescence relative to both childhood and adulthood (Steinberg, 2010; Luciana & Collins, 2012), over-taking the influence of control processes, which develop linearly across this age range (Casey, 2010; Steinberg 2008). This dynamic implies that teenagers may
be particularly susceptible to executive dysregulation (Hare, 2008), and tempted
by risky behaviors such as drug use (Steinberg, 2010). Therefore, identifying the
balance between socio-emotional and executive control processing during
persuasive message viewing in an adolescent population is particularly germane
to understanding persuasion from public health, behavioral, neural, and
theoretical standpoints.

Integrating cognitive, neuroscientific, and developmental theories, as well
as important knowledge related to advertising and mass communication, we
hypothesized that effective persuasion among adolescents would be
characterized by activity in socio-emotional regions as well areas crucial for
executive processing. To identify these regions, the current study measured
interactions between self-reports of arousal and BOLD signal response (arousal-
related activity) while viewing strongly persuasive (a condition we labeled
“strong”) anti-drug PSAs, weakly persuasive (“weak”) anti-drug PSAs, and non-
drug product advertisements (“ads”). Previous work indicates that variation in
real-time self-reports of arousal can provide a window into variations in the
perceived convincingness of PSAs (Stephenson & Palmgreen, 2001; Lang &
Yegiyan 2008). In fact, at $r = .68-.78$, this relationship could be strong enough to
suggest a single construct measured by either real-time or post-hoc ratings
(Yzer, 2011). As such, comparing arousal-related activity in the brain over time
among the strong, weak, and non-drug conditions allowed us to examine how
increases in perceived convincingness are reflected in the brain.
One potential risk of this strategy is that differences simply related to arousal will appear to be differences related to convincingness. To address this concern at the outset, we examined how arousal-modulated activity was different in strongly compared to weakly convincing PSAs. Using this approach, we hypothesized arousal-related activity increases in strong compared to weak anti-drug PSAs in the socio-emotional network (including the amygdala and medial prefrontal cortex), as well as in the executive network (lateral prefrontal cortex). These analyses would then lead us to investigate functional connectivity in regions associated with perceived convincingness irrespective of self-reported arousal.

**Methods**

**Participants**

Seventy teenagers (50% male; age range =15 to 19 years, $M=16.75$ yrs, $SD=1.54$) participated in exchange for monetary compensation. Subjects were recruited from the broad metro community, using a participant database comprised of willing families from the Twin Cities metro area contacted based on a search of birth records. Participants in the eligible age ranges were identified and screened for handedness (right), fMRI contraindications, and psychiatric diagnosis. Five participants were subsequently removed due to motion artifacts (>5mm displacement from the origin) or system technical errors. Experience with drugs or alcohol was not a criterion for study inclusion, but thirty-four (52%) of the remaining 65 participants reported ever using a controlled substance. Other than
alcohol, marijuana was the most commonly used substance. Twenty-five participants (35.7%) reported having used marijuana at least once.

**Procedures**

Participants viewed thirty 30-second commercial clips while undergoing a fMRI scan. The commercials consisted of ten anti-drug PSAs (about various narcotic substances) previously identified in individuals of the same age range as “strongly” convincing, and ten anti-drug PSAs previously identified as “weakly” convincing (Yzer, 2011), along with ten non-drug ads (advertisements for a violent video game, chewing gum, toothpaste, etc.) chosen for their negative valence. Prominent features of the persuasive anti-drug PSAs included negative consequence frames, intense imagery, narrative structure, social appeals, and plot twists or surprise endings. The ten non-drug ads were selected from the advertisement database at www.adcritic.com. Ads were selected by the investigators on the basis that they featured negative valence and contained structural elements allowing them to be edited to last 30 seconds. Each subject also underwent an eight-minute resting scan at the end of the protocol. To ensure that subjects remained awake, they made a button press approximately every 60 seconds when they noticed that a fixation-cross changed color.

Immediately following the scanning session, participants re-watched and made continuous arousal ratings in response to all of the video clips. (This procedure avoided the problem of imaging the combined activity associated with rating and watching while in the scanner, as skin conductance response
differences between rating and watching conditions were found in pilot subjects.) Participants rated how they felt on a moment-to-moment basis using a 7-point sliding scale (0 = “Bored”; 3 = “Neutral”; 6= “Stirred Up”, Yzer, 2011). Ratings were made by sliding a cursor along a horizontal line using the computer's trackpad, which were recorded at a rate of 10 per second, and then averaged to 1 per second. This “Bored” to “Stirred Up” arousal scale was chosen specifically; as momentary ratings of arousal were shown in a previous study of individuals within the same age range to correlate closely to a scale measuring perceived message convincingness (Yzer, 2011). Items forming this convincingness scale were completed immediately following each clip, as participants responded to nine 7-point items, containing the stem phrase, 'To me, this ad 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. Items measuring how convincing (1), believable (2), memorable (3), and how good the message (4) was were summed to form a measure of perceived convincingness (α=.92). The remaining items formed a valence measure of perceived pleasantness, which was not explicitly used for this study (For more information on the content, development, and validity of these scales, see Yzer et al., 2011).
Last, subjects completed questionnaires related to previous drug and alcohol use, externalizing behavior (Krueger, 2007), and ‘Need for Cognition’ (Cacioppo & Petty, 1982).

**MRI Acquisition & Preprocessing**

Participants viewed the anti-drug PSAs and non-drug advertisements in 3 pseudorandom blocks, each containing ten 30-second clips with 30 seconds of baseline fixation between each clip. 310 functional scans were collected using a 3 Tesla Siemens Trio MRI scanner, and a 12-channel head coil (repeat time (TR) = 2 seconds, echo time (TE) = 40, flip angle = 90 degrees, voxel size = 3.5 x 3.5 x 2 mm thickness, FOV= 22 cm, 35 axial slices). 240 resting scans used these same parameters. T1 reference images were also collected (voxel size = .86 x .86 x 1.5 mm thickness, 256 x 256 x 124 dimensions). Data were preprocessed using FSL (see: [http://www.fmrib.ox.ac.uk/fsl/](http://www.fmrib.ox.ac.uk/fsl/)). Images were motion corrected using rigid body transformations (FLIRT), spatially smoothed at FWHM = 10.0 mm, normalized using the mean volume intensity, and filtered with a high pass frequency cutoff of 120 seconds.

**fMRI Analysis**

General linear model (GLM) analyses were conducted using FSL, in which individual continuous arousal ratings of each PSA were used as regressors for each participant’s BOLD response (as recommended by Spiers & Maguire, 2007 for understanding brain activation in naturalistic contexts). Group images were
cluster-thresholded at $Z=2.3$ and a brainwise significance threshold of $p=0.05$.

Initial GLM analyses were carried out using three subject-specific regressors obtained from individuals' post-scan moment-to-moment arousal ratings. These included regressors for strong anti-drug PSAs, weak anti-drug PSAs, and the non-drug advertisements, allowing us to model each of these conditions against a 30-second baseline resting period that preceded each video clip. Individual conditions, two-way contrasts of all conditions, as well as a contrast including both classes of anti-drug PSAs against non-drug ads, were all included in the model. The directionality of effects obtained from the GLM analyses were ascertained graphically by extracting individual subject parameter estimates as percent signal change in each relevant ROI.

Psychophysiological interaction (PPI) analyses were conducted to examine the impact of PSAs without using arousal as an intermediate regressor.

PPI analyses included interactions between the raw time course of a region of interest (ROI) and a block-designed GLM that modeled strong, weak, and non-drug ads uniformly. Interactions between each physiological regressor and each GLM contrast were included in the model. Separate PPI analyses were carried out for individual ROIs in question. The directionality of the connectivity in the PPI analysis used a similar technique to the GLM, however parameter estimates were expressed as $Z$-scores.

Resting-state fMRI was available for 62 of the 65 subjects after three were removed due to movement or sleep. The mean time course was extracted from 5 structural ROIs including left middle frontal gyrus (MFG), right MFG, left inferior
frontal gyrus (IFG), right IFG, and bilateral amygdala (Harvard-Oxford Cortical Structural Atlas) for each subject individually. Four individual time courses were correlated per subject (each prefrontal cortex region was compared to amygdala) and converted to Z-scores using Fisher’s transformation. One-sample T-tests were performed for each distribution to determine whether the mean correlation was significantly different from zero and whether the relationship was positive or negative. Bonferroni’s method was used to correct for multiple comparisons.

Results

Perceived Message Convincingness

As expected, message convincingness was stronger for anti-drug PSAs that were pre-rated to be strongly \( (M=4.93 \pm .71) \) compared to weakly \( (M=4.23 \pm .76) \) convincing (Figure 1a; \( t(63)=7.62 \ p=0.000 \ d=.95 \)). Arousal ratings for strong, weak, and non-drug ads differed significantly from one another (Figure 1b), with strong anti-drug PSAs having the highest average (Figure 1c; \( F(2,87)=5.93 \ p=.0039 \)). Additionally, mean arousal ratings for individual anti-drug PSAs was significantly correlated with message convincingness \( (r=0.356 \ p=0.002) \), ensuring that ratings of arousal were meaningfully related to perceived convincingness, as demonstrated previously in Yzer et al. (2011). No relationships between arousal ratings and previous drug use were found.

Arousal-related fMRI Analysis
Whole brain arousal-related activation was modeled in a GLM comparing strong anti-drug PSAs, weak anti-drug PSAs, and non-drug advertisements, the main effects of which elicited broad activation in frontal, temporal, and occipital brain regions (compared to baseline fixation). Contrasting all anti-drug PSAs (combining the strong and weak conditions) with non-drug ads allowed an examination of neural activity related to processing anti-drug messages compared to messages unrelated to drugs. This contrast revealed greater arousal-related activation for anti-drug PSAs in the bilateral amygdala (Figure 2a), medial orbitofrontal cortex (mOFC; Figure 2a), paracingulate gyrus (Figure 2b), bilateral hippocampus, and superior temporal gyrus (Table 1a). Analysis of the arousal-related parameter estimates showed bilateral amygdala activation during the combined strong and weak anti-drug PSAs but not during non-drug ads (Figure 2a). The mOFC and paracingulate gyrus showed significant arousal-related deactivation across the anti-drug PSA and non-drug ad conditions, but significantly more deactivation for the non-drug ads (Figure 2a; Figure 2b).

Contrasting strong versus weak anti-drug PSAs showed the differential arousal-related activity related to message convincingness. This contrast revealed differences in areas of the lateral prefrontal cortex, notably bilateral MFG (Figure 3a) and left IFG (Figure 3b). Arousal-related activity in bilateral MFG showed deactivation across strongly and weakly convincing message conditions, but significantly greater deactivation for weak anti-drug PSAs. The left IFG showed increased arousal-related activation during strong anti-drug PSAs and deactivation during the weak anti-drug PSAs. There were also differences in
bilateral parahippocampal gyrus (Figure 3c), lingual gyrus, occipital lobe, and precuneus (Table 1b).

**Individual Differences in Arousal-related Activity**

Although this study was not designed to assess developmental mechanisms, age was examined as a potential contributor to the observed effects. Individual differences in substance-related experience and in ‘need for cognition,’ a putative marker of message engagement (Cohen, 1955; Cacioppo & Petty, 1982), were also assessed. No differences in arousal-related activity were found on the basis of age, drug-use, or need-for-cognition, either by adding these variables as covariates of interest in a GLM or comparing older to younger participants and drug-users to non-users. However, individual differences in perceived convincingness, assessed separately for strong and weak anti-drug PSAs, was positively correlated with arousal-related individual parameter estimates in the left IFG (Figure 4a; Figure 4c) and left MFG (Figure 4b; 4d). No significant relationships between perceived convincingness of anti-drug PSAs and individual parameter estimates were found in amygdalar or medial prefrontal regions of interest.

**Functional Connectivity Analysis**

To determine whether socio-emotional and executive brain regions co-activated during persuasive message encoding, we used a seed-based connectivity method that was independent of the arousal-related activity. A
psychophysiological interactions (PPI; Friston, 1997) analysis assessed connectivity between regions identified in the initial GLM as greater in strong compared to weak anti-drug PSAs, notably left IFG and bilateral MFG. When including the mean time series of the left IFG as a physiological regressor, strong anti-drug PSAs showed significantly more positive co-activity in both bilateral amygdala and insula compared to weak anti-drug PSAs (Figure 5a). Significant differences were also observed in occipital cortex as well as both lateral and inferior temporal gyri (Table 2). Seeding from either the right or left MFG did not show significant connectivity with relevant regions of interest.

Resting-State Connectivity

To determine the extent to which the correlation between the amygdala and executive control regions of lateral prefrontal cortex was driven up by persuasive message content, or driven down by unpersuasive message content, we examined spontaneous activity during rest in a subset of 62 participants who also underwent resting-state fMRI. Using seed-based connectivity, we examined the relationship between individual regions of lateral prefrontal cortex (LMFG, RMFG, LIFG, and RIFG) to the amygdala. Activation in all regions of the lateral PFC were negatively related to the amygdala during these scans (Table 3).

Discussion

The present study demonstrated that while arousal-related activity engaged areas of the socio-emotional network, such as the amygdala and medial
prefrontal cortex, when viewing anti-drug PSAs, lateral prefrontal executive control areas were more engaged when comparing arousal-related activity for strong versus weak anti-drug PSAs. This effect was associated with behavioral reports of persuasiveness, as increases in self-reported perceived convincingness of anti-drug PSAs correlated with increases in arousal-related BOLD activity in the lateral prefrontal cortex, but not in the amygdala or medial prefrontal cortex regions. This is critical, as perceived effectiveness has been shown to lead to actual effectiveness and subsequent behavior change (Dillard, 2007a). We also found that areas of both socio-emotional and executive control networks showed stronger positive functional connectivity during strong compared to weak anti-drug PSAs, whereas the connectivity between these structures was negative during rest.

These findings align with theories of persuasion, demonstrating that convincingness is reflected by interactions between executive control and affective reactivity. The Elaboration Likelihood Model (Petty & Cacioppo, 1986) fits particularly well into this framework, as higher order cognitive processing clearly plays a role in the way individuals may consider, conceptualize, and plan to guide their future actions which are thought to be important functions of the lateral prefrontal cortices. However, we were unable to demonstrate individual neural differences as they related to ‘Need for Cognition,’ a putative marker of an individual’s desire to engage in thought processes that lead to guided decisions (Cohen, 1955; Cacioppo & Petty, 1982). This may reflect the passive nature in which individuals, especially adolescents, view and encode health
communication messages. Additionally, much of this cognitive processing likely occurs long after a message is encoded, as successful messages are thought to elicit storage and retrieval processes (Lang, 2006) that allow individuals to reflect on messages to make decisions that will guide their behavior. Future studies may consider examining the sequelae of viewing a persuasive message, rather than brain activation associated with consumption of the message.

The functional connectivity findings in this study suggest that connectedness between the left IFG and amygdala may be an exceptional neural response to persuasive message viewing, as these same brain areas were shown to be anti-correlated at rest. This negative relationship has been previously demonstrated both in resting state fMRI (Roy, 2009) and more prominently in the context of emotion regulation (Hariri, 2000; Hariri, 2003; Ochsner, 2005). However, the current results are congruous with findings among adolescents who showed a similar pattern of connectivity between the IFG and amygdala when misinterpreting threat (Guyer, 2008). While a strong negative coupling exists between these regions (Nomura, 2004), this effect is attenuated, at least in adolescents, by increases in anxiety symptoms (Monk, 2008). In the current study, it is possible that persuasive messages enlist a similar neural connection between ventral regions of the prefrontal cortex and the amygdala. While this relationship may be maladaptive when threat appraisal is inaccurate or misguided (Beck & Clark, 1997), this neural circuit may be crucial for properly encoding affectively laden messages that contain useful information about the world. This is also consistent with cognitive theories that propose that threat
responses engage a defensive system (Lang, 2006) relying on the integration of affective and executive information in response to negatively valenced stimuli (Bradley, 2009; Yzer, 2011).

Co-activation between these systems has been invoked elsewhere in the neuroscience literature to characterize changes in decision-making. 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 responds to the reward and punishment structures in the environment. Additionally, intracellular recordings in rats have demonstrated that during aversive conditioning paradigms, responses in the prefrontal cortex are facilitated by projections from the amygdala (Quirk, 2003; Rosenkranz, 2003; Laviolette, 2005). Integrating these findings with the current results suggests that amygdalar involvement in executive processing may be required for frontal brain regions to accurately and effectively translate anti-drug messages into reactions, rules, and goals.

Previous research on the neural correlates of persuasion has modeled BOLD activity in response to static (Falk, 2010a), dynamic (Falk, 2011), and self-relevant (Chua, 2011) persuasive messages, and has demonstrated that regions of the subgenual and dorsal medial prefrontal cortex were positively associated with increased persuasion and subsequent behavior change. In the present study, these same regions showed significant differences when contrasting arousal-related activity between anti-drug PSAs and non-drug ads, but not when
comparing strong versus weak anti-drug PSAs. In light of these findings, we propose that the socio-emotional network is necessary, but not sufficient, for persuasive message processing. These affective and self-referential experiences are presumably important for alerting individuals to the message features that are personally salient, but may not indicate processes such as encoding into long-term memory or integration to influence future behavior. Alternatively, activity in executive control regions likely relies on and integrates information from socio-emotional brain areas to make judgments about incoming persuasive information. The executive regions engaged here by the strong versus weak PSAs were not strictly speaking “activations” or “deactivations” but reflected how activation increased or decreased as a function of arousal. Although beyond the scope of the current study, one could conjecture that deactivations that reduce integration across these regions may reduce the capacity of weak messages to guide future behavior.

The second-by-second self-report approach used to generate regressors in the current study allowed us to model the heterogeneity of brain processes engaged across a message’s time course as well as individual differences in subjective arousal (Phan, 2003), which provided a proxy for perceived convincingness. To our knowledge, this is the first study to use this kind of technique for studying persuasion (for review see Spiers & Maguire, 2007). Ancillary analyses were also performed to assure that arousal was not confounding these results or acting as a source of noise. To ensure that it was not, we ran an additional model including box-car functions for each condition.
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(strong, weak and non-drug), and a single regressor for arousal across all stimuli
(entered as a covariate of non-interest). Despite regressing out activity
associated with arousal, the drug versus non-drug and strong versus weak
contrasts showed results largely similar to the arousal-related fMRI analysis
(Figures 2 & 3). In spite of these similarities we have reported the arousal-related
model because it allowed us to observe a more interpretable perspective on the
brain dynamics elicited by these PSAs. Indeed this may be a source of
divergence between the current findings and similar studies of persuasion,
however we do replicate findings by Falk and colleagues (2010a) showing
increased activation in the ventrolateral prefrontal cortex for strong greater than
weak anti-drug PSAs. As such, this inferior region of the lateral prefrontal cortex
may be a particularly important hub for understanding persuasion, as it is not
only important for generating and regulating emotion (Wager, 2008), but also
organizes and relays executive processes that are crucial for behavioral inhibition
and decision-making (Sakagami & Pan, 2007).

Our conclusions regarding the neural systems involved in persuasion are
limited insofar as they were observed in the context of anti-drug messages,
which were negatively valenced and focused on a particular behavior. As such,
these results do not speak to other paths to persuasion, such as those that use
positively valenced messages in order to be convincing. At an earlier phase of
the study, positively valenced anti-drug PSAs were included in the corpus of
messages tested, but adolescent raters did not find any of them to be strong.
Also, this study used self-reported arousal as a stand-in for perceived
convincingness; two constructs that were strongly correlated in a previous sample (Yzer, 2011), but only moderately correlated in the current one. This was not entirely unexpected, as the current study examined a limited number of PSAs from both above and below the median level of arousal in the initial study. This limited range likely contributed to a lower correlation, but the fact that its still moderate and significant is an encouraging indication of their strong relationship. To this end, perceived convincingness served as a proxy for message’s potential to change attitudes and behavior. Though previous research demonstrates that convincingness and potential behavioral change are closely related constructs (Dillard, 2007b), additional work will be required to identify whether engagement of socio-emotional areas, executive control areas, or an interaction between these two networks is predictive of behavior change in response to a persuasive message.

Last, we did not find differences related to development, despite the well-understood functional and structural changes that the socio-emotional and executive control brain systems undergo during from 15 to 19 years. Because the study was reasonably powered to detect such differences, these findings suggest the nature of persuasion, at least for health communication messages, does not qualitatively change across this age range. A future study including a broader age range of younger children and post-adolescent adults would be required to better assess the developmental contours of the neural basis of persuasion.

To conclude, the current experiment demonstrated that lateral prefrontal brain areas are critically involved when encoding strong versus weak anti-drug
messages. We also demonstrated increased co-activation between LIFG and the amygdala in strong compared to weak anti-drug PSAs. These findings inform the general principles underlying the frequently observed mutual antagonism of limbic and prefrontal brain regions, as these regions were shown to be functionally anti-correlated at rest. This study also underscores the utility of developing the neuroscience of health communication. The implications of these findings could prove useful to understanding persuasion, for example by directing more attention to the importance of the lateral prefrontal cortex in conjunction with sub-cortical socio-emotional regions, and to better understand what message features shift these areas from being mutually antagonistic to positively correlated. Last, the current findings to some degree arbitrate and synthesize theories of health communication, by demonstrating that the persuasive power of messages corresponds to interactions between affective and executive processes in the brain.
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Table 1.

Regions with Arousal-Related Differences in (a) Anti-drug PSA’s versus Non-drug Ads, and in (b) Strong versus Weak Anti-drug PSAs.

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<tr>
<th>b) Strong v. Weak Anti-Drug PSAs</th>
<th>Voxels</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Structure</th>
<th>Max Z</th>
<th>Effect**</th>
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<td>25,959</td>
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<td>Precuneous Cortex</td>
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<td>-60</td>
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<td>Precuneous Cortex</td>
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<td>40</td>
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<td>-48</td>
<td>6</td>
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<td>Inferior Frontal Gyrus(Left)</td>
<td>4.64</td>
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<td>58</td>
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<td>Middle Frontal Gyrus(Right)</td>
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<td>0&gt;S&gt;W</td>
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<td>Middle Frontal Gyrus(Right)</td>
<td>3.35</td>
<td>0&gt;S&gt;W</td>
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<td>42</td>
<td></td>
<td>Middle Frontal Gyrus(Right)</td>
<td>3.10</td>
<td>0&gt;S&gt;W</td>
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</tbody>
</table>

Note. D = anti-drug PSAs, ND = non-drug ads. S = strong anti-drug PSAs, W = weak anti-drug PSAs. Threshold Z>2.3, p<.05, cluster corrected.
Table 2.

PPI Analysis of Regions Co-activated with Left Inferior Frontal Gyrus (IFG) in Strong vs. Weak Anti-drug PSAs.

<table>
<thead>
<tr>
<th>Voxels</th>
<th>X</th>
<th>Y</th>
<th>Z</th>
<th>Structure</th>
<th>Max Z</th>
<th>Effect*</th>
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<tbody>
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<td>-16</td>
<td>Lateral Occipital Cortex (Right)</td>
<td>4.62</td>
<td>S&gt;W&gt;0</td>
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<td>44</td>
<td>-54</td>
<td>-32</td>
<td></td>
<td>Cerebellum</td>
<td>4.20</td>
<td>S&gt;W&gt;0</td>
</tr>
<tr>
<td>44</td>
<td>-34</td>
<td>-20</td>
<td></td>
<td>Inferior Temporal Gyrus (Right)</td>
<td>2.76</td>
<td>S&gt;W&gt;0</td>
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<td>-32</td>
<td>-24</td>
<td></td>
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<td>2.74</td>
<td>S&gt;W&gt;0</td>
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<td>44</td>
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<td>Inferior Temporal Gyrus (Right)</td>
<td>2.69</td>
<td>S&gt;W&gt;0</td>
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<tr>
<td>2,423</td>
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<td>-60</td>
<td>-44</td>
<td>Cerebellum</td>
<td>2.52</td>
<td>S&gt;W&gt;0</td>
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<tr>
<td>-42</td>
<td>-54</td>
<td>-22</td>
<td></td>
<td>Temporal Occipital Cortex (Left)</td>
<td>3.76</td>
<td>S&gt;W&gt;0</td>
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<td>-44</td>
<td>-64</td>
<td>-18</td>
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<td>Occipital Fusiform Gyrus (Left)</td>
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<td>-58</td>
<td>-20</td>
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<td>Temporal Occipital Cortex (Left)</td>
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<td>S&gt;W&gt;0</td>
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<td>-72</td>
<td>-4</td>
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<td>S&gt;W&gt;0</td>
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<td>-48</td>
<td>-50</td>
<td>-20</td>
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<td>Inferior Temporal Gyrus (Left)</td>
<td>3.36</td>
<td>S&gt;W&gt;0</td>
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<td>2,396</td>
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<td>-62</td>
<td>-44</td>
<td>Cerebellum</td>
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<td>S&gt;W&gt;0</td>
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<td>Amygdala (Left)/Insula (Left)</td>
<td>4.41</td>
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<td>Amygdala (Right)/Insula (Right)</td>
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<td>Amygdala (Left)/Insula (Left)</td>
<td>3.58</td>
<td>S&gt;W&gt;0</td>
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<td>-4</td>
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<td>Amygdala (Left)/Insula (Left)</td>
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<td>-16</td>
<td>-12</td>
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<td>Amygdala (Left)/Insula (Left)</td>
<td>3.33</td>
<td>S&gt;W&gt;0</td>
</tr>
</tbody>
</table>

*Note. S = strong anti-drug PSAs, W = weak anti-drug PSAs. Threshold Z>2.3, p<.05, cluster corrected.*
Table 3.
Seed-based Connectivity between Lateral Prefrontal Cortex Areas and the Amygdala During Rest.

<table>
<thead>
<tr>
<th>Seed Region</th>
<th>Mean R</th>
<th>T-Value</th>
<th>df</th>
<th>p-value</th>
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</thead>
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<td>Middle Frontal Gyrus (Left)</td>
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<td>0.0000</td>
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<td>Middle Frontal Gyrus (Right)</td>
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<td>0.0059</td>
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</table>

Note: The mean resting-state time courses across voxels in anatomically-defined regions of interest. Correlations were Fisher's Z-transformed. One-sample t-tests ascertained directionality and significance. All four prefrontal ROIs showed a significant negative correlation with the amygdala at rest.
Perceived Effectiveness Ratings. (a) Differences in perceived convincingness between strong and weak anti-drug PSAs. (b) Plots of mean momentary arousal ratings over time for individual anti-drug PSAs and non-drug ads. (c) Differences in mean arousal across the time courses of strong anti-drug PSAs, weak anti-drug PSAs, and non-drug ads.

595x231mm (72 x 72 DPI)
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.

523x338mm (72 x 72 DPI)
Arousal-related activity 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. 683x366mm (72 x 72 DPI)
Correlations between arousal-related activity and perceived convincingness. Individual participant self-reports of perceived convincingness for strong anti-drug PSAs were positively correlated with arousal-related activity in (a) left IFG ($r=.30 p=.015$ df=63) and (b) left MFG ($r=.40 p=.00098$ df=63). Individual participant self-reports of perceived convincingness for weak anti-drug PSAs showed a trend-level correlation with arousal-related activity in (c) left IFG ($r=.24 p=.058$ df=63) and a significant correlation in (d) left MFG ($r=.30 p=.017$ df=63).
Bilateral amygdala and insula areas functionally connected to the left IFG in strong greater than weak anti-drug PSAs expressed in Z-space. Anatomically-defined regions shown in transparent red.

290x363mm (72 x 72 DPI)