Affective and Executive Network Processing Associated with Persuasive Antidrug Messages

Ian S. Ramsay, Marco C. Yzer, Monica Luciana, Kathleen D. Vohs, and Angus W. MacDonald III

Abstract

■ Previous research has highlighted brain regions associated with socioemotional 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 pFC. Seventy adolescents were scanned using fMRI while they watched 10 strongly convincing antidrug public service announcements (PSAs), 10 weakly convincing antidrug PSAs, and 10 advertisements (ads) unrelated to drugs. Antidrug PSAs compared with nondrug ads more strongly elicited arousal-related activity in the amygdala and medial pFC. Within antidrug PSAs, those that were prerated as strongly persuasive versus weakly persuasive showed significant differences in arousal-related activity in executive processing areas of the lateral pFC. In support of the notion that persuasiveness involves both affective and executive processes, functional connectivity analyses showed greater coactivation between the lateral pFC and amygdala during PSAs known to be strongly (vs. 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. ■

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 (Stephenson & Southwell, 2006; Palmgreen et al., 1991) and elicit executive functioning (Lang, 2006; Petty, Cacioppo, & Goldman, 1981), processes broadly associated with amygdalar and medial prefrontal areas that modulate social and emotional responses (socioemotional; Phan et al., 2003; Adolphs, 2001), 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, Rameson, et al., 2010; Langleben et al., 2009) and predictive of behavioral change (Falk, Berkman, & Lieberman, 2012; Chua et al., 2011; Falk, Berkman, Mann, Harrison, & Lieberman, 2010). 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 antidrug public service announcements (PSAs), prerated to be strongly versus weakly persuasive, would engage key areas in socioemotional 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 (Yzer, Vohs, Luciana, Cuthbert, & Macdonald, 2011; Stephenson & Southwell, 2006; Palmgreen et al., 1991). 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, Lotze, Erb, Grodd, & Birbaumer, 2004), this conclusion implicates the involvement of a socioemotional processing network in message engagement. Other work shows that this network becomes engaged in times of self-referential processing (Chua et al., 2011; Dunlop, Wakefield, & Kashima, 2008; Northoff et al., 2006) or threat (Somerville, Whalen, & Kelley, 2010), which not coincidently are states that

University of Minnesota

Journal of Cognitive Neuroscience 25:7, pp. 1136–1147
doi:10.1162/jocn_a_00391

occur when individuals process health messages (Wood, 2000; Keller & Block, 1996). 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 (Langleben et al., 2009; Lang, 2000, 2006). 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 socioemotional 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, Brinol, & Priester, 2009; Petty & Cacioppo, 1986; Petty, Cacioppo, & Schumann, 1983). 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 (Wager, Davidson, Hughes, Lindquist, & Ochsner, 2008; Davidson, 2004), which in turn are critically involved in persuasion (DeSteno, Petty, Rucker, Wegener, & Braverman, 2004). Other regions of pFC might also be involved given that the ventrolateral region contributes to lower levels of encoding and information processing (D'Esposito, Postle, Ballard, & Lease, 1999), whereas ventromedial and orbito-frontal regions further integrate context with evaluative judgments that contribute to higher level control processes (O'Doherty, Kringelbach, Rolls, Hornak, & Andrews, 2001; Bechara, Damasio, & 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 (Luciana & Collins, 2012; Steinberg, 2010), overtaking the influence of control processes, which develop linearly across this age range (Casey et al., 2010; Steinberg, 2008). This dynamic implies that teenagers may be particularly susceptible to executive dysregulation (Hare et al., 2008) and tempted by risky behaviors such as drug use (Steinberg, 2010). Therefore, identifying the balance between socioemotional 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 socioemotional 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") antidrug PSAs, weakly persuasive ("weak") antidrug PSAs, and nondrug 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 (Lang & Yegiyan, 2008; Stephenson & Palmgreen, 2001). 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 et al., 2011). As such, comparing arousal-related activity in the brain over time among the strong, weak, and nondrug 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 with weakly convincing PSAs. Using this approach, we hypothesized arousal-related activity increases in strong compared with weak antidrug PSAs in the socioemotional network (including the amygdala and medial pFC) as well as in the executive network (lateral pFC). 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 = 15–19 years, $M = 16.75$ years, $SD = 1.54$ years) participated in exchange for monetary compensation. Participants were recruited from the broad metro community, using a participant database comprising 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 (>5 mm displacement from the origin) or system technical errors. Experience with drugs or alcohol was not a criterion for study inclusion, but 34 (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-sec commercial clips while undergoing an fMRI scan. The commercials consisted of 10 antidrug PSAs (about various narcotic substances) previously identified in individuals of the same age range as "strongly" convincing and 10 antidrug PSAs previously identified as "weakly" convincing (Yzer et al., 2011), along with 10 nondrug ads (advertisements for a violent video game, chewing gum, toothpaste, etc.) chosen for their negative valence. Prominent features of the persuasive antidrug PSAs included negative consequence frames, intense imagery, narrative structure, social appeals, and plot twists or surprise endings. The 10 nondrug 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 sec. Each participant also underwent an 8-min resting scan at the end of the protocol. To ensure that participants remained awake, they made a button press approximately every 60 sec when they noticed that a fixation cross changed color.

Immediately following the scanning session, participants rewatched 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 participants.) 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 et al., 2011). Ratings were made by sliding a cursor along a horizontal line using the computer's track pad, which were recorded at a rate of 10/sec and then averaged to 1/sec. 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 et al., 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 ($\alpha = .92$). 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, participants completed questionnaires related to previous drug and alcohol use, externalizing behavior (Krueger, Markon, Patrick, Benning, & Kramer, 2007), and "need for cognition" (Cacioppo & Petty, 1982).

MRI Acquisition and Preprocessing

Participants viewed the antidrug PSAs and nondrug advertisements in three pseudorandom blocks, each containing ten 30-sec clips with 30 sec of baseline fixation between each clip. Three hundred ten functional scans were collected using a 3-T Siemens Trio MRI scanner and a 12-channel head coil (repetition time = 2 sec, echo time = 40, flip angle = 90°, voxel size = 3.5 × 3.5 × 2 mm thickness, field of view = 22 cm, 35 axial slices). Two hundred forty resting scans used these same parameters. T1 reference images were also collected (voxel size = .86 × .86 × 1.5 mm thickness, 256 × 256 × 124 dimensions). Data were preprocessed using FMRIB Software Library (see: www.fmrib.ox.ac.uk/fsl/). 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 sec.

fMRI Analysis

General linear model (GLM) analyses were conducted using FMRIB Software Library, 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 had a brainwise significance threshold of $p = .05$. Initial GLM analyses were carried out using three subject-specific regressors obtained from individuals' postscan moment-to-moment arousal ratings. These included regressors for strong antidrug PSAs, weak antidrug PSAs, and the nondrug advertisements, allowing us to model each of these conditions against a 30-sec 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 antidrug PSAs against nondrug 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.

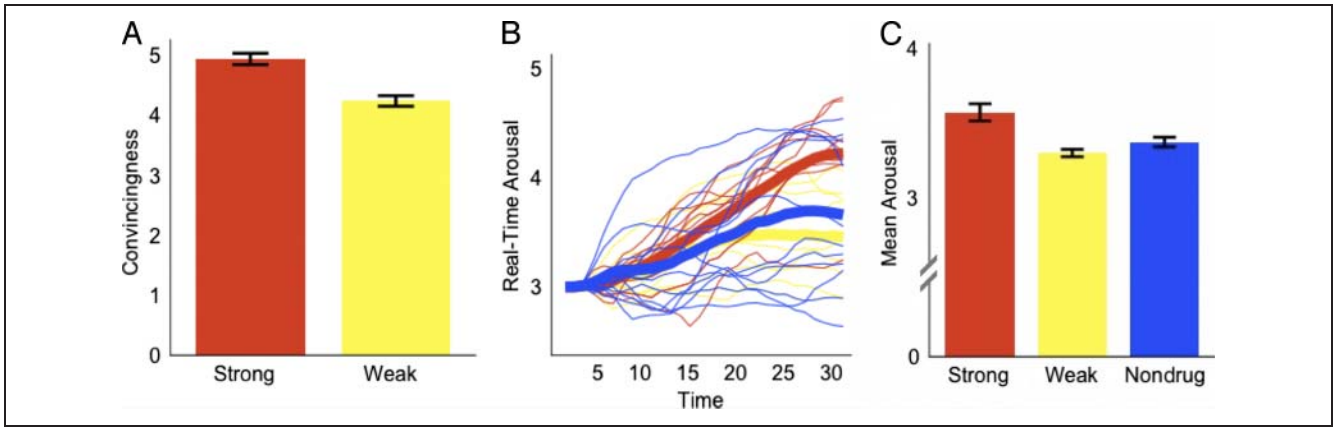

Figure 1. Perceived effectiveness ratings. (A) Differences in perceived convincingness between strong and weak antidrug PSAs. (B) Plots of mean momentary arousal ratings over time for individual antidrug PSAs and nondrug ads. (C) Differences in mean arousal across the time courses of strong antidrug PSAs, weak antidrug PSAs, and nondrug ads.

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 ROI and a block-designed GLM that modeled strong, weak, and nondrug 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 participants after three were removed due to movement or sleep. The mean time course was extracted from five structural ROIs including left middle frontal gyrus (MFG), right MFG, left inferior frontal gyrus (IFG), right

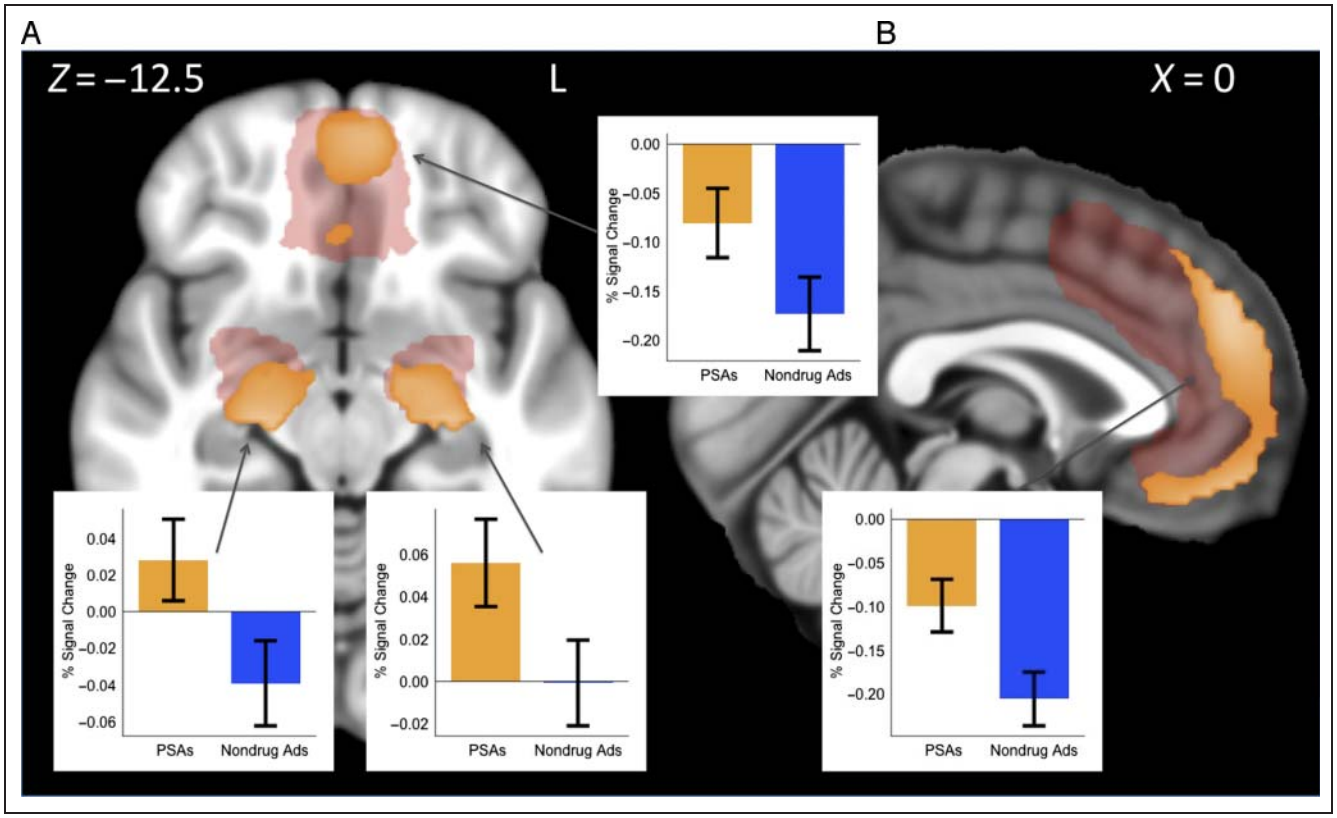

Figure 2. Arousal-related activation in antidrug PSAs versus nondrug ads. Anatomically defined regions shown in transparent red. (A) Medial OFC and bilateral amygdala. (B) Paracingulate gyrus.

Table 1. Regions with Arousal-related Differences in (a) Antidrug PSA's versus Nondrug Ads and (b) Strong versus Weak Antidrug PSAs

a) Antidrug PSAs vs. Nondrug Ads

Voxels	*X*	*Y*	*Z*	*Structure*	*Max Z*	*Effect*
38,964	−60	−20	−10	Middle temporal gyrus (left)/amygdala	10.70	D > ND > 0
	−58	−36	−2	Middle temporal gyrus (left)/amygdala	10.70	D > ND > 0
	−48	−64	24	Lateral occipital cortex (left)	10.50	D > 0 > ND
	−54	8	−26	Temporal pole	10.10	D > ND > 0
	−54	0	−18	Middle temporal gyrus (left)/amygdala	10.00	D > ND > 0
	−4	−54	30	Cingulate gyrus	10.00	0 > D > ND
10,050	−8	48	40	Frontal pole	8.24	0 = D > ND
	−10	38	50	Superior frontal gyrus	8.23	0 > D > ND
	−42	4	50	MFG (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 vs. Weak Antidrug 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	7.60	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	MFG (left)	7.11	0 > S > W
	−36	2	48	MFG (left)	6.43	0 > S > W
	−52	10	36	MFG (left)	4.96	0 > S > W
	−46	28	12	IFG (left)	4.87	S > 0 > W
	−44	32	10	IFG (left)	4.72	S > 0 > W
	−48	26	18	IFG (left)	4.64	S > 0 > W
2,364	32	12	58	MFG (right)	5.54	0 > S > W
	34	22	52	MFG (right)	5.25	0 > S > W
	50	14	34	MFG (right)	3.35	0 > S > W
	52	18	42	MFG (right)	3.10	0 > S > W

D = antidrug PSAs; ND = nondrug ads; S = strong antidrug PSAs; W = weak antidrug PSAs. Threshold $Z > 2.3$, $p < .05$, cluster corrected.

IFG, and bilateral amygdala (Harvard–Oxford Cortical Structural Atlas) for each participant individually. Four individual time courses were correlated per participant (each pFC region was compared with 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 antidrug PSAs that were prerated to be strongly (M = 4.93, SD = 0.71) compared with weakly (M = 4.23, SD = 0.76) convincing (Figure 1A; $t(63) = 7.62, p = .000, d = 0.95$). Arousal ratings for strong, weak, and nondrug ads differed significantly from one another (Figure 1B), with strong antidrug PSAs having the highest average (Figure 1C; $F(2, 87) = 5.93$ $p = .0039$). Additionally, mean arousal ratings for individual antidrug PSAs was significantly correlated with message convincingness (r = 0.356 $p = .002$), 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 antidrug PSAs, weak antidrug PSAs, and nondrug advertisements, the main effects of which elicited broad activation in frontal, temporal, and occipital brain regions (compared with baseline fixation). Contrasting all antidrug PSAs (combining the strong and weak conditions) with nondrug ads allowed an examination of neural activity related to processing antidrug messages compared with messages unrelated to drugs. This contrast revealed greater arousal-related activation for antidrug PSAs in the bilateral amygdala (Figure 2A), medial OFC (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 antidrug PSAs but not during nondrug ads (Figure 2A). The mOFC and paracingulate gyrus showed significant arousal-related deactivation across the antidrug PSA and nondrug ad conditions, but significantly more deactivation for the nondrug ads (Figure 2A and B).

Contrasting strong versus weak antidrug PSAs showed the differential arousal-related activity related to message convincingness. This contrast revealed differences in areas of the lateral pFC, 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 antidrug PSAs. The left IFG showed increased arousal-related activation during strong antidrug PSAs and deactivation during the weak antidrug 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

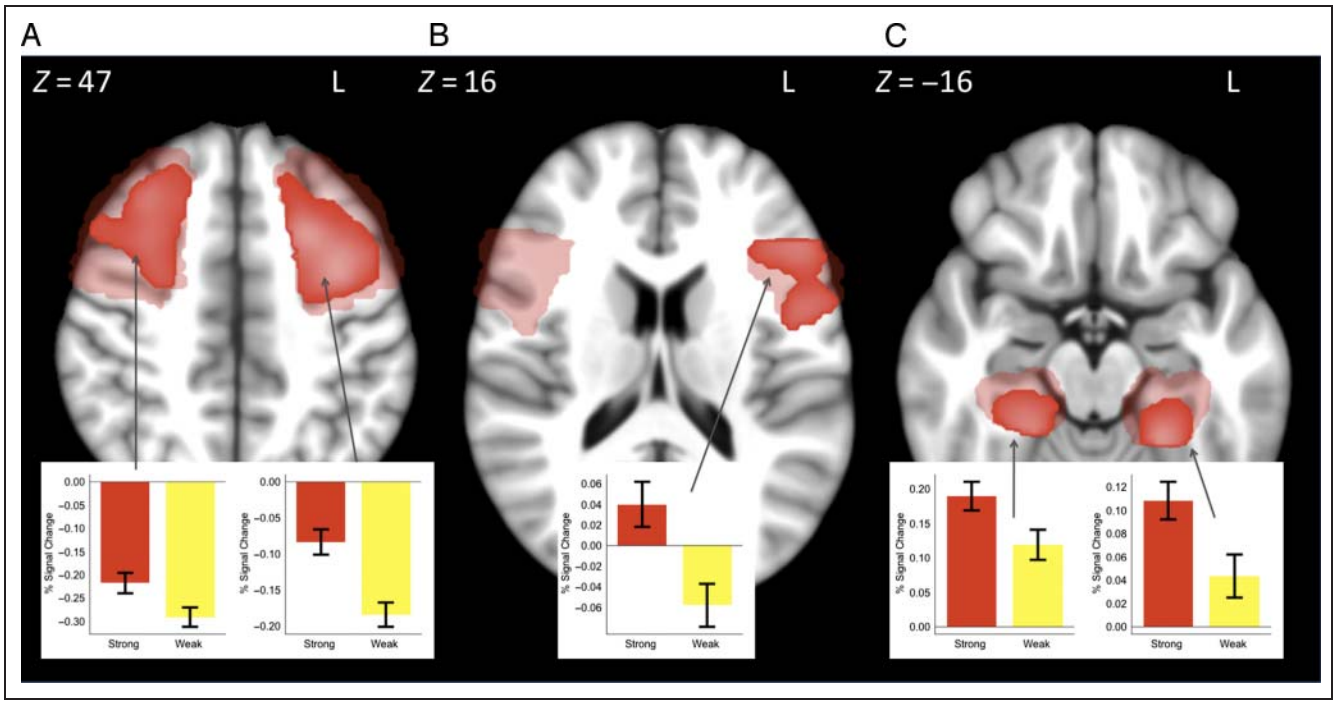

Figure 3. Arousal-related activity in strong antidrug PSAs versus weak antidrug PSAs. Anatomically defined regions shown in transparent red. (A) Bilateral MFG. (B) Left IFG. (C) Bilateral parahippocampus.

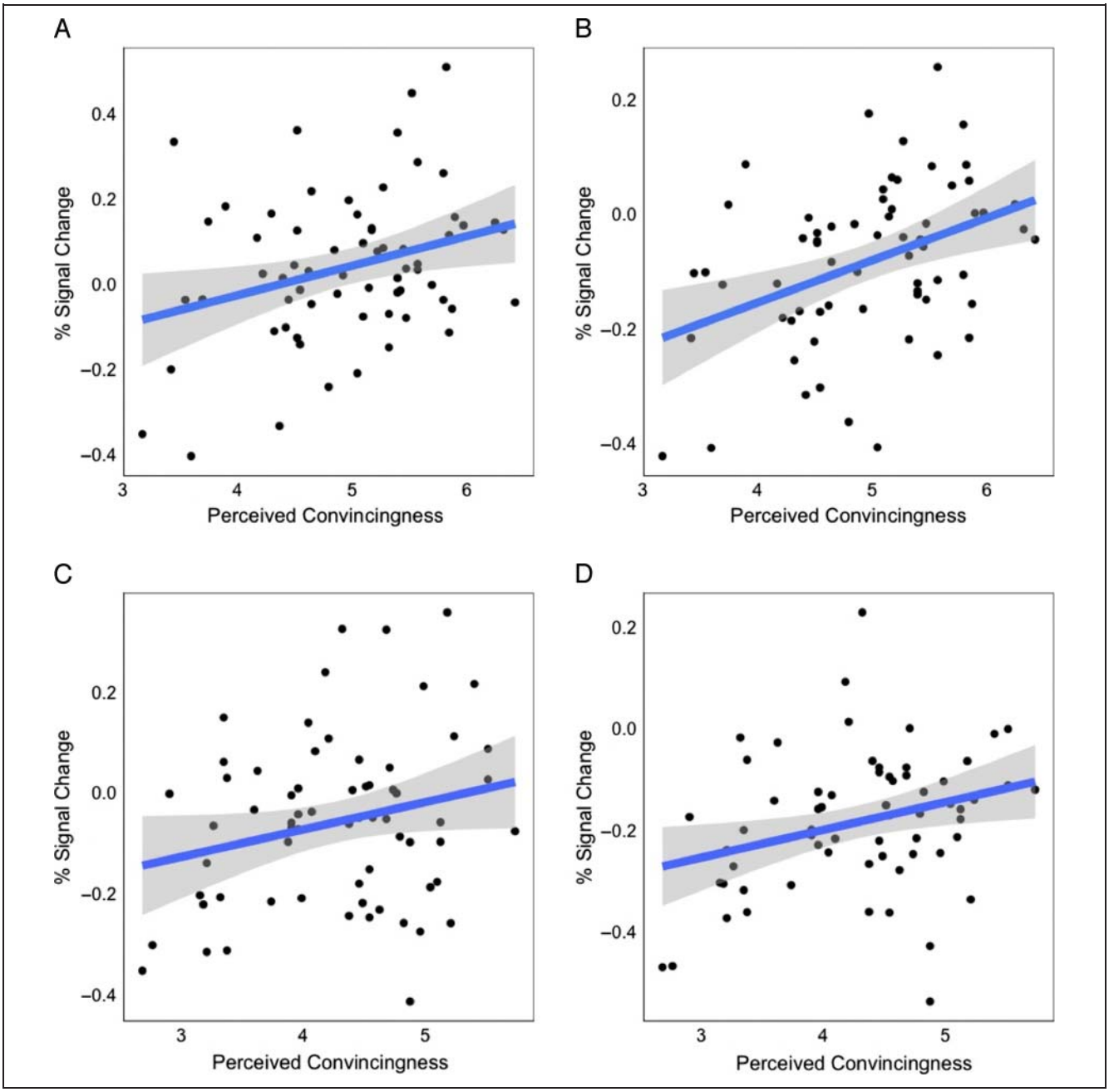

Figure 4. Correlations between arousal-related activity and perceived convincingness. Individual participant self-reports of perceived convincingness for strong antidrug PSAs were positively correlated with arousal-related activity in (A) left IFG (r = .30, p = .015, df = 63) and (B) left MFG (r = .40, p = .00098, df = 63). Individual participant self-reports of perceived convincingness for weak antidrug 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).

contributor to the observed effects. Individual differences in substance-related experience and in "need for cognition" a putative marker of message engagement (Cacioppo & Petty, 1982; Cohen, Stotland, & Wolfe, 1955) 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 antidrug PSAs, was positively correlated with arousal-related individual parameter estimates in the left IFG (Figure 4A and C) and left MFG (Figure 4B and D). No significant relationships between perceived convincingness of antidrug PSAs and individual parameter estimates were found in amygdalar or medial prefrontal ROIs.

Functional Connectivity Analysis

To determine whether socioemotional and executive brain regions coactivated during persuasive message encoding, we used a seed-based connectivity method that was independent of the arousal-related activity. A PPI (Friston et al., 1997) analysis assessed connectivity between regions identified in the initial GLM as greater in strong compared with weak antidrug PSAs, notably left IFG and bilateral MFG. When including the mean time series of the left IFG as a physiological regressor, strong antidrug PSAs showed significantly more positive coactivity in both bilateral amygdala and insula compared with weak antidrug 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 ROIs.

Resting State Connectivity

To determine the extent to which the correlation between the amygdala and executive control regions of lateral pFC 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 pFC (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).

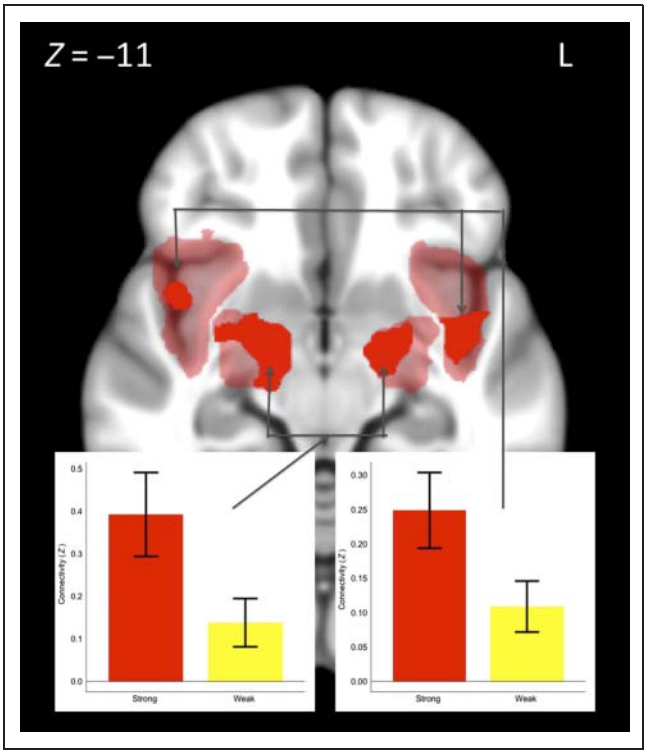

Figure 5. Bilateral amygdala and insula areas functionally connected to the left IFG in strong greater than weak antidrug PSAs expressed in *Z* space. Anatomically defined regions shown in transparent red.

DISCUSSION

This study demonstrated that, whereas arousal-related activity engaged areas of the socioemotional network, such as the amygdala and medial pFC, when viewing antidrug PSAs, lateral prefrontal executive control areas were more engaged when comparing arousal-related activity for strong versus weak antidrug PSAs. This effect was associated with behavioral reports of persuasiveness, as increases in self-reported perceived convincingness of antidrug PSAs correlated with increases in arousal-related BOLD activity in the lateral pFC, but not in the amygdala or medial pFC regions. This is critical, as perceived effectiveness has been shown to lead to actual effectiveness and subsequent behavior change (Dillard, Shen, & Vail, 2007). We also found that areas of both socioemotional and executive control networks showed stronger positive functional connectivity during strong compared with weak antidrug 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 (Cacioppo & Petty, 1982; Cohen et al., 1955). 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 anticorrelated at rest. This negative relationship has been demonstrated both in resting state fMRI (Roy et al., 2009) and more prominently in the context of emotion regulation (Ochsner & Gross, 2005; Hariri, Mattay, Tessitore,

Table 2. PPI Analysis of Regions Coactivated with Left IFG in Strong versus Weak Antidrug PSAs

Strong vs. Weak Antidrug PSAs (PPI LIFG Seed)						
Voxels	*X*	*Y*	*Z*	*Structure*	*Max Z*	*Effect*
2,710	48	−68	−16	Lateral occipital cortex (right)	4.62	S > W > 0
	44	−54	−32	Cerebellum	4.20	S > W > 0
	44	−34	−20	Inferior temporal gyrus (right)	2.76	S > W > 0
	44	−32	−24	Inferior temporal gyrus (right)	2.74	S > W > 0
	44	−30	−30	Inferior temporal gyrus (right)	2.69	S > W > 0
	30	−60	−44	Cerebellum	2.52	S > W > 0
2,423	−42	−54	−22	Temporal occipital cortex (left)	3.76	S > W > 0
	−44	−64	−18	Occipital fusiform gyrus (left)	3.68	S > W > 0
	−46	−58	−20	Temporal occipital cortex (left)	3.68	S > W > 0
	−50	−72	−4	Lateral occipital cortex (left)	3.46	S > W > 0
	−48	−50	−20	Inferior temporal gyrus (left)	3.36	S > W > 0
	−28	−62	−44	Cerebellum	3.26	S > W > 0
2,396	−26	−2	−18	Amygdala (left)/insula (left)	4.41	S > W > 0
	10	−8	−12	Amygdala (right)/insula (right)	4.00	S > W > 0
	8	−4	−6	Thalamus (right)	3.99	S > W > 0
	−18	−2	−12	Amygdala (left)/insula (left)	3.58	S > W > 0
	−8	−4	−14	Amygdala (left)/insula (left)	3.42	S > W > 0
	−16	−16	−12	Amygdala (left)/insula (left)	3.33	S > W > 0

S = strong antidrug PSAs; W = weak antidrug PSAs. Threshold $Z > 2.3$, $p < .05$, cluster corrected.

Fera, & Weinberger, 2003; Hariri, Bookheimer, & Mazziotta, 2000). 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 et al., 2008). Although a strong negative coupling exists between these regions (Nomura et al., 2004), this effect is attenuated, at least in adolescents, by increases in anxiety symptoms (Monk et al., 2008). In the current study, it is possible that persuasive messages enlist a similar neural connection between ventral regions of the pFC and the amygdala. Although 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 (Yzer et al., 2011; Bradley, 2009).

Table 3. Seed-based Connectivity between Lateral Prefrontal Cortex Areas and the Amygdala during Rest

Seed Region	*Mean R*	*T*	*df*	*p*
MFG (left)	−0.24	−11.07	61	.0000
MFG (right)	−0.28	−14.45	61	.0000
IFG (left)	−0.09	−3.21	61	.0021
IFG (right)	−0.07	−2.85	61	.0059

The mean resting state time courses across voxels in anatomically defined ROIs. 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.

Coactivation between these systems has been invoked elsewhere in the neuroscience literature to characterize changes in decision-making. Rougier, Noelle, Braver, Cohen, and O'Reilly (2005) provided a computational model showing that the pFC 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 pFC are facilitated by projections from the amygdala (Laviolette, Lipski, & Grace, 2005; Quirk, Likhtik, Pelletier, & Paré, 2003; Rosenkranz, Moore, & Grace, 2003). 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 antidrug messages into reactions, rules, and goals.

Previous research on the neural correlates of persuasion has modeled BOLD activity in response to static (Falk, Rameson, et al., 2010), dynamic (Falk, Berkman, Whalen, & Lieberman, 2011), and self-relevant (Chua et al., 2011) persuasive messages and has demonstrated that regions of the subgenual and dorsal medial pFC were positively associated with increased persuasion and subsequent behavior change. In this study, these same regions showed significant differences when contrasting arousal-related activity between antidrug PSAs and nondrug ads, but not when comparing strong versus weak antidrug PSAs. In light of these findings, we propose that the socioemotional 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 socioemotional 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 deactivitations 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 et al., 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 a 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 (strong, weak, and nondrug) and a single regressor for arousal across all stimuli (entered as a covariate of noninterest). Despite regressing out activity associated with arousal, the drug versus nondrug and strong versus weak contrasts showed results largely similar to the arousal-related fMRI analysis (Figures 2 and 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, Rameson, et al. (2010), showing increased activation in the ventrolateral pFC for strong greater than weak antidrug PSAs. As such, this inferior region of the lateral pFC may be a particularly important hub for understanding persuasion, as it is not only important for generating and regulating emotion (Wager et al., 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 antidrug 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 to be convincing. At an earlier phase of the study, positively valenced antidrug 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 et al., 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 it is 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. Although previous research demonstrates that convincingness and potential behavioral change are closely related constructs (Dillard, Weber, & Vail, 2007), additional work will be required to identify whether engagement of socioemotional 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 socioemotional and executive control brain systems undergo 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 postadolescent 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 antidrug messages. We also demonstrated increased coactivation between LIFG and the amygdala in strong compared with weak antidrug 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 anticorrelated 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 pFC in conjunction with subcortical socioemotional 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.

Acknowledgments

Preparation of this article was supported by grant R21DA024430 from the National Institute on Drug Abuse. Ian Ramsay was supported by grant T32MH017069 awarded by the National Institute of Mental Health. We thank the time and effort of the participants and their families as well as Andrew Poppe, Krista Wisner, Edward Patzelt, Ron Faber, Joseph Lowinske, Madelyn Steen, Anthony Grandelis, Stacy Smith, and Pete Kollasch for their assistance and input on the project.

Reprint requests should be sent to Angus W. MacDonald III, Elliott Hall 75 East River Road, Minneapolis, MN 55455, or via e-mail: angus@umn.edu.

REFERENCES

Adolphs, R. (2001). The neurobiology of social cognition. *Current Opinion in Neurobiology, 11,* 231–239.

Anders, S., Lotze, M., Erb, M., Grodd, W., & Birbaumer, N. (2004). Brain activity underlying emotional valence and arousal: A response-related fMRI study. *Human Brain Mapping, 23,* 200–209.

Bechara, A., Damasio, H., & Damasio, A. R. (2000). Emotion, decision making and the orbitofrontal cortex. *Cerebral Cortex, 10,* 295–307.

Beck, A. T., & Clark, D. A. (1997). An information processing model of anxiety: Automatic and strategic processes. *Behaviour Research and Therapy, 35,* 49–58.

Bradley, M. M. (2009). Natural selective attention: Orienting and emotion. *Psychophysiology, 46,* 1–11.

Cacioppo, J. T., & Petty, R. E. (1982). The need for cognition. *Journal of Personality and Social Psychology, 42,* 116–131.

Casey, B. J., Jones, R. M., Levita, L., Libby, V., Pattwell, S. S., Ruberry, E., et al. (2010). The storm and stress of adolescence: Insights from human imaging and mouse genetics. *Developmental Psychobiology, 52,* 225–235.

Chua, H. F., Ho, S. S., Jasinska, A. J., Polk, T. A., Welsh, R. C., Liberzon, I., et al. (2011). Self-related neural response to tailored smoking-cessation messages predicts quitting. *Nature Neuroscience, 14,* 426–427.

Cohen, A. R., Stotland, E., & Wolfe, D. M. (1955). An experimental investigation of need for cognition. *Journal of Abnormal Psychology, 51,* 291–294.

Davidson, R. J. (2004). What does the prefrontal cortex "do" in affect: Perspectives on frontal EEG asymmetry research. *Biological Psychology, 67,* 219–233.

D'Esposito, M., Postle, B. R., Ballard, D., & Lease, J. (1999). Maintenance versus manipulation of information held in working memory: An event-related fMRI study. *Brain and Cognition, 41,* 66–86.

DeSteno, D., Petty, R. E., Rucker, D. D., Wegener, D. T., & Braverman, J. (2004). Discrete emotions and persuasion: The role of emotion-induced expectancies. *Journal of Personality and Social Psychology, 86,* 43–56.

Dillard, J. P., & Shen, L. (2012). *The SAGE handbook of persuasion: Developments in theory and practice* (2nd ed.). Thousand Oaks, CA: SAGE Publications, Inc.

Dillard, J. P., Shen, L., & Vail, R. G. (2007). Does perceived message effectiveness cause persuasion or vice versa? 17 consistent answers. *Health Communication Research, 33,* 467–488.

Dillard, J. P., Weber, K. M., & Vail, R. G. (2007). The relationship between the perceived and actual effectiveness of persuasive messages: A meta-analysis with implications for formative campaign research. *Journal of Communication, 57,* 613–631.

Dunlop, S., Wakefield, M., & Kashima, Y. (2008). Can you feel it? Negative emotion, risk, and narrative in health communication. *Media Psychology, 11,* 52–75.

Falk, E. B., Berkman, E. T., & Lieberman, M. D. (2012). From neural responses to population behavior: Neural focus group predicts population-level media effects. *Psychological Science, 23,* 439–445.

Falk, E. B., Berkman, E. T., Mann, T., Harrison, B., & Lieberman, M. D. (2010). Predicting persuasion-induced behavior change from the brain. *The Journal of Neuroscience, 30,* 8421–8424.

Falk, E. B., Berkman, E. T., Whalen, D., & Lieberman, M. D. (2011). Neural activity during health messaging predicts reductions in smoking above and beyond self-report. *Health Psychology, 30,* 177–185.

Falk, E. B., Rameson, L., Berkman, E. T., Liao, B., Kang, Y., Inagaki, T. K., et al. (2010). The neural correlates of persuasion: A common network across cultures and media. *Journal of Cognitive Neuroscience, 22,* 2447–2459.

Friston, K. J., Buechel, C., Fink, G. R., Morris, J., Rolls, E., & Dolan, R. J. (1997). Psychophysiological and modulatory interactions in neuroimaging. *Neuroimage, 6,* 218–229.

Guyer, A. E., Lau, J. Y. F., McClure-Tone, E. B., Parrish, J., Shiffrin, N. D., Reynolds, R. C., et al. (2008). Amygdala and ventrolateral prefrontal cortex function during anticipated peer evaluation in pediatric social anxiety. *Archives of General Psychiatry, 65,* 1303–1312.

Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry, 63,* 927–934.

Hariri, A. R., Bookheimer, S. Y., & Mazziotta, J. C. (2000). Modulating emotional responses: Effects of a neocortical network on the limbic system. *NeuroReport, 11,* 43–48.

Hariri, A. R., Mattay, V. S., Tessitore, A., Fera, F., & Weinberger, D. R. (2003). Neocortical modulation of the amygdala response to fearful stimuli. *Biological Psychiatry, 53,* 494–501.

Keller, P. A., & Block, L. G. (1996). Increasing the persuasiveness of fear appeals: The effect of arousal and elaboration. *Journal of Consumer Research, 22,* 448–459.

Krueger, R. F., Markon, K. E., Patrick, C. J., Benning, S. D., & Kramer, M. D. (2007). Linking antisocial behavior, substance use, and personality: An integrative quantitative model of the adult externalizing spectrum. *Journal of Abnormal Psychology, 116,* 645–666.

Lang, A. (2000). The limited capacity model of mediated message processing. *Journal of Communication, 50,* 46–70.

Lang, A. (2006). Using the limited capacity model of motivated mediated message processing to design effective cancer communication messages. *Journal of Communication, 56(Suppl. 1),* S57–S80.

Lang, A., & Yegiyan, N. S. (2008). Understanding the interactive effects of emotional appeal and claim strength in health messages. *Journal of Broadcasting & Electronic Media, 52,* 432–447.

Langleben, D. D., Loughead, J. W., Ruparel, K., Hakun, J. G., Busch-Winokur, S., Holloway, M. B., et al. (2009). Reduced prefrontal and temporal processing and recall of high "sensation value" ads. *Neuroimage, 46,* 219–225.

Laviolette, S. R., Lipski, W. J., & Grace, A. A. (2005). A subpopulation of neurons in the medial prefrontal cortex encodes emotional learning with burst and frequency codes through a dopamine D4 receptor-dependent basolateral amygdala input. *The Journal of Neuroscience, 25,* 6066–6075.

Luciana, M., & Collins, P. F. (2012). Incentive motivation, cognitive control, and the adolescent brain: Is it time for a paradigm shift? *Child Development Perspectives, 6,* 392–399.

Miller, E. K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24,* 167–202.

Monk, C. S., Telzer, E. H., Mogg, K., Bradley, B. P., Mai, X., Louro, H. M., et al. (2008). Amygdala and ventrolateral prefrontal cortex activation to masked angry faces in children and adolescents with generalized anxiety disorder. *Archives of General Psychiatry, 65,* 568–576.

Nomura, M., Ohira, H., Haneda, K., Iidaka, T., Sadato, N., Okada, T., et al. (2004). Functional association of the amygdala and ventral prefrontal cortex during cognitive evaluation of facial expressions primed by masked angry faces: An event-related fMRI study. *Neuroimage, 21,* 352–363.

Northoff, G., Heinzel, A., de Greck, M., Bermpohl, F., Henrik, D., & Panksepp, J. (2006). Self-referential processing in our brain—A meta-analysis of imaging studies on the self. *Neuroimage, 31,* 440–457.

Ochsner, K. N., & Gross, J. J. (2005). The cognitive control of emotion. *Trends in Cognitive Sciences, 9,* 242–249.

O'Doherty, J., Kringelbach, M. L., Rolls, E. T., Hornak, J., & Andrews, C. (2001). Abstract reward and punishment representations in the human orbitofrontal cortex. *Nature Neuroscience, 4,* 95–102.

Palmgreen, P., Donohew, L., Lorch, E. P., Rogus, M., Helm, D., & Grant, N. (1991). Sensation seeking, message sensation value, and drug use as mediators of PSA effectiveness. *Health Communication, 3,* 217–227.

Petty, R. E., & Cacioppo, J. T. (1986). The elaboration likelihood model of persuasion. In L. Berkowitz (Ed.), *Advances in experimental social psychology* (Vol. 19, pp. 123–205). New York: Academic Press.

Petty, R. E., Cacioppo, J. T., & Goldman, R. (1981). Personal involvement as a determinant of argument-based persuasion. *Journal of Personality and Social Psychology, 41,* 847–855.

Petty, R. E., Cacioppo, J. T., & Schumann, D. (1983). Central and peripheral routes to advertising effectiveness: The moderating role of involvement. *Journal of Consumer Research, 10,* 135–146.

Phan, K., Taylor, S., Welsh, R., Decker, L., Noll, D., Nichols, T., et al. (2003). Activation of the medial prefrontal cortex and extended amygdala by individual ratings of emotional arousal: A fMRI study. *Biological Psychiatry, 53,* 211–215.

Quirk, G. J., Likhtik, E., Pelletier, J. G., & Paré, D. (2003). Stimulation of medial prefrontal cortex decreases the responsiveness of central amygdala output neurons. *The Journal of Neuroscience, 23,* 8800–8807.

Reyna, V. F., & Farley, F. (2006). Risk and rationality in adolescent decision making. *Psychological Science, 7,* 1–44.

Rosenkranz, J. A., Moore, H., & Grace, A. A. (2003). Plasticity and responses to previously conditioned stimuli. *The Journal of Neuroscience, 23,* 11054–11064.

Rougier, N. P., Noelle, D. C., Braver, T. S., Cohen, J. D., & O'Reilly, R. C. (2005). Prefrontal cortex and flexible cognitive control: Rules without symbols. *Proceedings of the National Academy of Sciences, U.S.A., 102,* 7338–7343.

Roy, A. K., Shehzad, Z., Margulies, D. S., Kelly, A. M. C., Uddin, L. Q., Goyimer, K., et al. (2009). Functional connectivity of the human amygdala using resting state fMRI. *Neuroimage, 45,* 614–626.

Sakagami, M., & Pan, X. (2007). Functional role of the ventrolateral prefrontal cortex in decision-making. *Current Opinion in Neurobiology, 17,* 228–233.

Somerville, L. H., Whalen, P. J., & Kelley, W. M. (2010). Human bed nucleus of the stria terminalis indexes hypervigilant threat monitoring. *Biological Psychiatry, 68,* 416–424.

Spiers, H. J., & Maguire, E. A. (2007). Decoding human brain activity during real-world experience. *Trends in Cognitive Neuroscience, 11,* 356–365.

Steinberg, L. (2008). A social neuroscience perspective on adolescent risk-taking. *Developmental Review, 28,* 78–106.

Steinberg, L. (2010). A dual systems model of adolescent risk-taking. *Developmental Psychobiology, 52,* 216–224.

Stephenson, M., & Palmgreen, P. (2001). Sensation seeking, perceived message sensation value, personal involvement, and processing of anti-marijuana PSAs. *Communication Monographs, 48,* 49–71.

Stephenson, M. T., & Southwell, B. G. (2006). Sensation seeking, the activation model, and mass media health campaigns: Current findings and future directions for cancer communication. *Journal of Communication, 56(Suppl. 1),* S38–S56.

Wager, T. D., Davidson, M. L., Hughes, B. L., Lindquist, M. A., & Ochsner, K. N. (2008). Prefrontal-subcortical pathways mediating successful emotion regulation. *Neuron, 59,* 1037–1050.

Wood, W. (2000). Attitude change: Persuasion and social influence. *Annual Review of Psychology, 51,* 539–570.

Yzer, M. C., Vohs, K. D., Luciana, M., Cuthbert, B. N., & MacDonald, A. W. (2011). Affective antecedents of the perceived effectiveness of antidrug advertisements: An analysis of adolescents' momentary and retrospective evaluations. *Prevention Science, 12,* 278–288.