Published in final edited form as:

Health Commun. 2018 August ; 33(8): 1004–1012. doi:10.1080/10410236.2017.1331185.

Communicating With Sensation Seekers: An Fmri Study of Neural Responses to Antidrug Public Service Announcements

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Abstract

This study examined the neural basis of processing high and low message sensation value (MSV) anti-drug public service announcements (PSAs) in high (HSS) and low sensation seekers (LSS) using fMRI. HSS more strongly engaged the salience network when processing PSAs (versus LSS) suggesting that high-MSV PSAs attracted their attention. HSS and LSS participants who engaged higher-level cognitive processing regions reported that the PSAs were more convincing and believable and recalled the PSAs better immediately after testing. In contrast, HSS and LSS participants who strongly engaged visual attention regions for viewing PSAs reported lower personal relevance. These findings provide neurobiological evidence that high-MSV content is salient to HSS, a primary target group for anti-drug messages, and additional cognitive processing is associated with higher perceived message effectiveness.

Keywords

drug abuse prevention; visual attention; salience network; message sensation value; message effectiveness

The efficacy of novel media messages targeted at high sensation seekers—individuals tending to be at higher risk for drug abuse, engaging in risky sex, and other risk-taking behaviors—has long been established, but few studies have examined the neural basis for processing these prevention messages. To our knowledge, none have examined differences in responses as a function of sensation seeking personality. This study employs functional Magnetic Resonance Imaging (fMRI) to examine neural system response in high and low sensation seekers (HSS and LSS) to determine whether neurobiological reactivity is related to individual differences during the processing of prevention-oriented public service announcements (PSAs).

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The present study had three major goals. First, as very few studies have examined the neurobiological basis of processing PSAs targeting risky behaviors, an important initial goal was to further characterize the neural circuitry for processing anti-drug PSAs. Replication of prior results is important for any emerging discipline. Across studies, similar neural circuitry has been implicated in processing PSAs including the *temporal pole*, *medial prefrontal* and *lateral temporal cortex* (Falk et al., 2010). These regions have been associated with higher persuasiveness, better memory and effectiveness of PSAs in inducing behavioral change such as quitting smoking. Conversely, activation in occipital regions is linked to poorer memory for PSAs but this may depend on the persuasiveness of the PSA.

Second, given that high sensation seekers (HSS;(Zuckerman, 1994)) are more likely to experiment with drugs, have different neurobiological sensitivity to drug effects, and are more likely to become substance dependent compared to low sensation seekers (Kelly et al., 2006), another goal of the present study was to examine individual differences in sensation seeking with respect to the neural substrates of processing PSAs. Understanding the neural basis of message processing may provide additional insight into individual differences in message processing, especially with respect to the trait of sensation-seeking, which has a strong biological basis. Prior research indicates that in order for anti-drug messages to be effective, they must attract the attention of the target audience-- HSS in the present study. However, no study to our knowledge has examined neurobiological response in HSS in response to persuasive messages using fMRI. If high MSV anti-drug PSAs are able to attract and hold the attention of HSS, a primary prediction of the present study is that HSS will show more evidence for arousal, attentional engagement or salience processing based on fMRI responses than they will on self-report.

A third goal was to determine whether PSA neural processing was associated with subsequent ratings of message effectiveness, perceived sensation value, and memory for the clips. Even if high MSV anti-drug PSAs attract the attention of HSS, this does not imply that the message itself was processed. To evaluate whether message content was processed, following scanning subjects provided ratings of message effectiveness and performed recognition memory and cued recall tasks. Associating these measures with fMRI activation while viewing the PSAs would meaningfully link the fMRI response to cognitive behaviors.

The present focus was on high MSV and low MSV anti-drug PSAs used in anti-marijuana prevention campaigns in the United States. However, safe sex PSAs were used as an active control condition in order to isolate fMRI response that was specific to drug content in PSAs while controlling for other shared aspects of processing messages. In addition, video clips of sporting events were used to control for low-level processing of videos without any specific message content.

Background

A substantial body of behavioral research exists on the role of sensation seeking and persuasive communication in drug abuse prevention. As noted above, extensive previous research has established that high sensation seekers (HSS)—who are significantly more likely than low sensation seekers (LSS) to engage in a number of risky behaviors, such as

drug use, unprotected sex, or sex with multiple partners — can be reached and redirected from these behaviors through prevention campaigns (Donohew, Lorch, & Palmgreen, 1998; Lorch, 1994 #2451; Palmgreen, Donohew, Lorch, Hoyle, & Stephenson, 2001). This research has focused primarily on sensation seeking as a key targeting variable in prevention campaigns because of its strong relationship with drug use and other risky behaviors, and on the characteristics of messages which can attract and hold the attention of HSS and bring about desired health behaviors.

One theoretical framework, the Activation Model of Information Exposure (Donohew, 2009) has linked sensation seeking and responses to messages. Messages containing novelty, whether through content or other features, such as pace, are more likely to attract and hold attention of high sensation seekers because novelty helps to satisfy needs for activation. Without this, the content of the messages, no matter how persuasive, would likely not be attended. However, it is not currently known how sensation seeking, a biologically defined personality trait, interacts with message sensation value at a neurobiological level.

fMRI studies of PSA processing to date have examined various message properties of PSAs and behaviors affected by PSA processing. These studies have shown that engagement of prefrontal and temporal cortex regions is associated with better memory for clips (Langleben et al., 2009) and higher persuasiveness (Falk et al., 2010) as well as effecting behavioral change, such as smoking reduction (Falk, Berkman, Whalen, & Lieberman, 2011; Wang, 2013). However, high MSV clips were not necessarily more effective. (Langleben et al., 2009) suggested that high MSV PSAs may actually induce competition between the message content of a PSA and the attention-grabbing features, resulting in poorer memory and learning for an ad.

These fMRI studies have begun to lay a foundation for understanding the neurobiological basis of processing PSAs. However, none of these studies has examined differences in neurobiological response as a function of sensation seeking personality. The present study further examined processing of high and low MSV PSAs to address the suggestion by Langleben et al. (2009) that the format of high MSV messages may actually detract from cognitive processing of these messages. The present study not only measured recognition memory for ads after a significant delay (7 weeks), but also gauged perceived message effectiveness (PME) of the PSAs following the fMRI testing session as a means to assess higher-level processing of the PSAs that is directly linked to message content. PME measures included ratings of convincingness, believability, truthfulness, relevance and liking. Although the efficacy of novel media messages targeted at persons at higher risk for drug abuse and other risky behaviors has long been established, the present study is one of a small number of human neuroimaging studies to examine how neural system organization may be different in HSS and LSS during the processing of anti-drug PSAs.

Methods

Participants

52 young adults, aged 18–25 years (n = 32 Female), participated in this fMRI study. Participants were from the Lexington-Fayette County region of Kentucky (n = 15) and the

Charleston County region of South Carolina ($n = 36$). Advertisements were placed throughout the communities directing potential volunteers to contact the lab by telephone. Potential participants completed a telephone questionnaire about MRI compatibility and a brief medical history to determine their eligibility to participate. If they met all of the study's requirements (i.e., free of MRI contraindications, neurological, psychiatric and learning disorders, current medication use and claustrophobia; right-handed, native English speaking, between the ages of 18–25), participants were directed to a link to the Brief Sensation Seeking Scale (BSSS;(Hoyle, Stephenson, Palmgreen, Lorch, & Donohew, 2002)) on REDCap, a secure internet survey tool (Harris et al., 2009). Based on data from Harrington et al.(2003), young adults scoring in the upper (score ≥ 32 for both males and females, $M_{BSSS} = 34.78$, $SD_{BSSS} = 1.88$) or lower (score ≤ 27 for males and ≤ 25 for females, $M_{BSSS} = 20.59$, $SD_{BSSS} = 4.58$) quartiles of college-student scores on the BSSS, were contacted by telephone and invited to participate ($n = 23$ HSS, $n = 29$ LSS).

PSA task and Stimulus materials

An initial pilot study was conducted to select stimulus materials for this study that varied in perceived message sensation value (PMSV; high or low). Public service announcements (PSAs) used in prior anti-drug or safe-sex media campaigns were used in this pilot study (Above the Influence Campaign, PDFA, ONDCP, UK BPP, Kaiser). Sports videos were obtained from the internet and depicted various sporting events that were expected to be either high or low in sensation value, according to the experimenters' judgments. Although MSV data exist for the PSAs (Morgan, Palmgreen, Stephenson, Hoyle, & Lorch, 2003), no such information existed for the sports videos. In addition, some of the PSAs were created more than a decade earlier than the current data collection and the existing ratings may not have reflected the more contemporary audience's perceptions. Therefore, in the pilot study PMSV and perceived message effectiveness (PME) were rated by 454 undergraduate students at the University of Kentucky who earned course credit for participating. All potential video clips ($n=48$: 16 anti-drug, 16 safe-sex, 16 sports), were shown to at least 100 students. Participants filled out the Brief Sensation Seeking Scale (Hoyle et al., 2002) and then viewed twelve 30-second video clips in a random order. For each clip, participants rated perceived message sensation value (PMSV) on a 5-point Likert type scale, anchored by the labels "strongly disagree" and "strongly agree". The PMSV questions asked whether each clip was dramatic, emotional, exciting, intense, or unusual. Participants also rated perceived message effectiveness that assessed aspects of the messages like convincingness, believability, liking, etc. (Palmgreen, Stephenson, Everett, Baseheart, & Francies, 2002). However, only PMSV ratings were used to select clips for the present study. The average PMSV rating was determined for each of the 48 different clips. From these clips, 8 anti-drug, 8 safe sex and 8 sports clips with the highest and lowest PMSV ratings were selected in order to maximize high and low MSV differences.¹

Materials and Procedures

For the fMRI study, participants completed two sessions at the MRI facility at the University of Kentucky or at the Medical University of South Carolina. After completing a metal screen

¹Note: average PMSV and MSV ratings for video clips from the pilot study can be requested from the corresponding author

to ensure MRI compatibility and a urine screen to test for illicit drugs and for females, pregnancy, subjects completed a standard test for visual acuity, a color vision test, and the Edinburgh Handedness Inventory (Oldfield, 1971) to ensure right handedness. Other measures included forward and backward digit span tasks, the Peabody Picture Vocabulary Test, Fourth Edition (PPVT,(Dunn & Dunn, 2007)) and Ruff's 2 & 7 selective attention test (Ruff, Niemann, Allen, Farrow, & Wylie, 1992). HSS and LSS did not significantly differ on these variables.

Subjects then completed the imaging session, which included an anatomical scan and the fMRI PSA task (2 runs). Two other fMRI tasks were completed but those results are not reported here. The PSA task presented each anti-drug, safe-sex PSA or sports clip in a 30-second task block with full audio and visual components. The full content of each of the PSA clips was able to fit in a 30-second block. Two fMRI runs were completed, with each run composed of 12 task blocks (3 clip types $\times$ 2 MSV conditions $\times$ 2 repetitions) and 13 rest blocks (17.5 seconds each in which a single fixation cross appears centered on the screen and the subject is asked to visually fixate the cross). The task blocks within a run were pseudorandomly ordered. Participants were instructed to passively view the PSAs during MRI scanning but not to react overtly to the clips (e.g., laughing or grimacing).

Following scanning, subjects provided ratings of arousal, valence, perceived message sensation value and perceived message effectiveness for each PSA that they observed during fMRI scanning. Participants viewed all of the PSAs they viewed earlier (but in a different random order) and were asked to provide ratings for each PSA using an analog scale, converted into a Likert scale. For arousal participants were asked to indicate whether they felt excited about the clip, with anchors "not at all" (value=1) and "extremely" (value=5). For valence, participants were asked to indicate whether the clip was "unpleasant / negative" (value=1) or "pleasant / positive" (value = 5). The five PME and nine PMSV questions were anchored by the label "strongly disagree" (value=1) and the label "strongly agree" (value=5).

Participants also completed two memory tests using REDcap. In the recall task, conducted immediately after scanning and approximately 7 weeks following scanning, participants viewed a still photo of a key scene from the each of the 24 PSAs and were asked 5 true or false questions about details from and content of the clips. In the recognition test, conducted approximately 7 weeks following scanning (and prior to the recall task), participants viewed a random series of 24 two-second clips, 12 previously seen PSAs (2 high MSV and 2 low MSV each for drug, sex and sports clips) and 12 distracter clips. For each, subjects answered whether or not they saw the clip during the scanning session.

fMRI Image Acquisition.—MR images were acquired using two Siemen 3T Trio MRI system (Siemens Medical Solutions, Erlangen, Germany) which had the same hardware and software versions at each site. Subjects completed two 309-volume whole-brain functional runs (T2*-sensitive gradient echo sequence echo planar imaging (GRE-EPI); TE = 27 ms, TR = 2000 ms, flip angle = 76°, 64 $\times$ 64 matrix, FOV = 23.7 cm $\times$ 23.7 cm, interleaved acquisition of 36 transaxial contiguous 3.7-mm) followed by a high-resolution T1-weighted anatomical scan using magnetization-prepared rapid acquisition with gradient echo

(MPRAGE) sequence with TE = 2.56 ms, TI=1100ms, TR = 2100 ms, flip angle = 12°, 256 × 224 matrix, FOV = 25.6 cm × 22.4 cm, with 192 contiguous sagittal slices and a slice thickness of 1 mm. We also collected field map information to correct for geometric distortions caused by static-field inhomogeneity.

fMRI Data Analysis.—Preprocessing and analysis were conducted using the FSL software package (version 4.1.7, FMRIB Software Library, Oxford Center for Functional Magnetic Resonance Imaging of the Brain, Oxford University, Oxford, U.K.). Preprocessing included brain extraction (BET), motion correction (MCFLIRT), spatial smoothing with a 7-mm FWHM kernel and temporal high-pass filtering (cutoff=300s) Due to excessive head motion, 6 subjects' imaging data were not included in the fMRI analysis. After preprocessing, statistical analyses were performed at the single-subject level by using the general linear model within FSL (FEAT, FMRI Expert Analysis Tool, version 5.98). Six explanatory variables (EVs) were modeled: 3 clip types (Drug, Sex, Sport) × 2 MSV (high, low). Each EV was convolved with a double gamma hemodynamic response function (HRF) and temporal derivatives were added to the model. For each subject, contrast maps were registered via the subject's high-resolution T1-weighted anatomical image to the Montreal Neurological Institute (MNI)-152 template (FSL's MNI avg152, T1, 2 mm³) using a 12-parameter affine transformation. Higher level group analysis used fixed effects to average within-subjects sessions, then random effects (with FSL's FLAME 1) for group statistical maps. In addition to the overall average activation differences for contrasts of clip types and MSV, we also calculated the group difference of HSS and LSS for different clip types or MSV contrasts. Regions of interest (ROI) were defined by clusters (threshold of $Z > 2.58$ and a corrected cluster significance threshold of $p = 0.05$). For very large clusters, we use AAL atlas masks for anatomical separation into smaller clusters (Tzourio-Mazoyer et al., 2002). The percent BOLD signal change corresponding to each condition (3 clip types × 2 MSV) was extracted within each ROI using Featquery. Because data were collected at two different sites, we conducted independent samples t-tests in each ROI to determine whether there was a systematic difference in fMRI signal across sites. For task vs. fixation percent signal change, none of the ROIs showed a significant site effect at $p=0.05$.

Results

Behavioral Results

Repeated measures ANOVAs with MSV as a repeated factor and SS as a between-subjects factor were used to explore potential differences in ratings of arousal, valence, perceived message sensation value, perceived message effectiveness and recognition memory. High MSV clips were rated as more arousing, $F(1, 48) = 24.1$, $p < .0001$, and more negative, $F(1, 48) = 57.5$, $p < .0001$, than low MSV clips. PMSV ratings were also similar across groups and, as expected, high MSV clips were rated as more dramatic, $F(1, 48) = 25.4$, $p < .0001$, emotional, $F(1, 48) = 21.6$, $p < .0001$, exciting, $F(1, 48) = 33.1$, $p < .0001$, and intense, $F(1, 48) = 126.3$, $p < .0001$, than low MSV clips. On message effectiveness, low MSV clips were rated as reminding participants of their own lives more than high MSV clips, $F(1, 48) = 16.7$, $p < .0001$. Believability, $F(1, 48) = 13.7$, $p < .0001$, and truthfulness ratings, $F(1, 48) = 14.9$, $p < .0001$, were significantly higher on low than on high MSV clips, and for these

variables, an interaction with SS (p 's $< .05$) revealed that HSS participants drove the lower ratings for the high MSV clips. No SS group differences or interactions emerged for the recognition memory measures (overall accuracy, hit rate, false alarm rate) after 3 outliers were removed based on values greater than 1.5 times the interquartile range, but there was a marginal effect of MSV, $F(1, 48) = 3.0$, $p < .10$, with high MSV drug PSAs (91%, $SE = .013$) recognized more accurately than low MSV drug PSAs (86%, $SE = .023$).

We also conducted a 3-way mixed ANOVA with MSV and time point (immediate v. delayed) as repeated factors and SS as a between-subjects factor for recall memory accuracy. All of the main effects were significant, but no interactions. Low MSV drug PSAs (82% accuracy, $SE = .017$) were recalled better than high MSV drug PSAs [77% accuracy, $SE = .012$, $F(1, 33) = 7.23$, $p = .011$]. Memory for the PSAs declined from immediate (82% accuracy, $SE = .014$) to delayed testing [77%, $SE = .014$; $F(1, 33) = 16.1$, $p = .0001$]. LSS (82%, $SE = .016$) recalled details of the clips more accurately than HSS (77%, $SE = .019$; $F(1, 33) = 5.34$, $p = .027$].

Voxel-wise fMRI results

Drug > Sports and Drug > Sex contrasts isolated extensive networks of regions, with Drug > Sex recruiting primarily occipital and parietal regions and Drug > Sports isolating regions in the *left inferior parietal*, *lateral temporal inferior frontal* and *dorsomedial prefrontal cortex* (Figure 1a). The high MSV > low MSV contrast isolated bilateral occipital and parietal regions as well as right fronto-opercular cortex. The low MSV > high MSV contrast activated regions centered in *bilateral superior temporal* that extended into *inferior parietal cortex* (Figure 1b). One region was significant for HSS > LSS for all drug videos: the *anterior cingulate* (Figure 1c). No regions were activated more by LSS than HSS for all drug videos combined. Also, no regions showed an MSV $\times$ SS interaction.²

Correlations between fMRI signal and PMSV, PME ratings

This next analysis examined whether fMRI response to high MSV clips was related to PME or PMSV of the clips. To reduce the number of correlations we conducted, we first ran a principal components analysis (PCA; varimax rotation; IBM Statistics, Chicago, IL) on the high MSV fMRI signal versus baseline in all 20 regions isolated in the voxel-wise contrasts described above. Four components with eigenvalues > 1 emerged from the PCA. One component included left-hemisphere regions and the bilateral superior temporal cortex activation associated with the high MSV > low MSV contrast. We refer to this component as a “comprehension” component (Figure 1d) given the role of these regions in higher level cognitive processing and that prior fMRI studies of PSA processing implicated these regions in remembering or being persuaded by PSAs (Falk et al., 2011; Falk, 2010; Langleben et al., 2009; Wang et al., 2013). A second component included regions in the middle and superior occipital cortex, the parieto-occipital sulcus and the right supramarginal gyrus. We refer to this component as a “visuo-spatial processing” component (Figure 1e) given the role of these regions in processing spatial and dynamic aspects of visual stimuli (Ungerleider & Haxby, 1994). A third component included inferior parietal and inferior frontal regions

²Note: a table of all of the individual activation maxima can be requested from the corresponding author.

bilaterally (Figure 1f) which are often linked to “visual attention” (Corbetta, 1998; Fox, 2006). The final component, labeled “salience/default mode” (Figure 1g) includes regions associated with detecting salient events (insula and anterior cingulate cortex; (Menon & Uddin, 2010)) as well as a critical hub in default mode states (the precuneus; (Utevsky, Smith, & Huettel, 2014)).

The next set of analyses examined correlations between fMRI response (operationalized as the factor loading on each of the four fMRI components) and high MSV PME and PMSV ratings. Because PME and PMSV are not unitary constructs and the behavioral data indicated that individual differences were only apparent for some items (at least for PME), each PME and PMSV question was examined separately. Higher activation in the comprehension network when viewing PSAs was associated with higher ratings of PME dimensions of convincingness ($r=.31$ for “this clip would help convince people your age not to use drugs”, $r=.39$ for “this clip would help convince you not to use drugs”), liking ($r=.32$) and believability ($r=.32$) as well as higher ratings on the emotional PMSV item ($r=.31$) with $n=45$, $p < .05$ for all correlations. Higher activation in the visual attention network was associated with lower ratings on the PME item “this clip made me think of my own life” ($r=.31$, $n=45$, $p < .05$). The other two network components were not associated with PME or PMSV ratings. In addition, none of the correlations between fMRI signal in each of the four components and PMSV or PME ratings for low MSV clips was significant.

We also examined whether each of the four networks showed differences between HSS and LSS for high or low MSV clips using an independent-samples t-test. The salience/default mode network was more strongly engaged by HSS. For high MSV clips, the average fMRI signal was .07 (SD = .25) in HSS and -.09 (SD = .20) in LSS, $t(44) = 2.5$, $p = .017$, Cohen’s $d=.72$. For low MSV clips, the average fMRI signal was -.07 (SD = .21) in HSS and -.26 (SD = .25) in LSS, $t(44) = 3.0$, $p = .005$, Cohen’s $d=.90$.

Correlations between fMRI signal and memory for the PSAs

This analysis determined whether fMRI response was associated with memory for the PSAs immediately after scanning or 7 weeks following exposure to the PSAs. In addition to having omitted data from 3 subjects as outliers with respect to recognition memory accuracy (no data were omitted for the recall task), scatterplots for significant correlations were inspected for potential outliers. Outliers were removed then the correlations were rerun to determine whether outlier swayed the correlation. Only one correlation survived this screening process: greater activation in the comprehension network while viewing PSAs was correlated with higher accuracy for immediate recall of specific details of the low MSV PSAs, $r = .49$, $p = .001$, $n = 44$.

Discussion

One goal of the present study was to add to the current understanding of neural circuitry involved in processing anti-drug PSAs. As expected, processing complex media messages recruited an extensive network of brain regions that reflect many aspects of both lower level and higher level cognitive processing.

Visuo-spatial network.

The majority of the regions in this network (*occipital and parietal regions*) were activated more by drug PSAs than by safe sex PSAs, with additional overlapping occipital activation for high MSV versus low MSV PSAs. Langleben et al (2009) also reported that high MSV clips activated a large expanse of occipital cortex, similar to the present study. We interpret this activation as reflecting greater demands on visuo-spatial processing due to the nature of the high MSV clips, rather than the subject matter. The high MSV clips had more action, scene changes, and varied stimulation than low MSV clips. Greater demands on visual processing in the high MSV clips may have amplified the fMRI signal in occipito-parietal regions through voluntary, directed attention (O'Craven, Rosen, Kwong, Treisman, & Savoy, 1997). The drug clips activated this visuo-spatial network more than the sex clips. This is likely related to the higher PMSV ratings for the high MSV drug clips than the high MSV sex clips. Because this study used PSAs that had been used in prior campaigns, it was not possible to equate the different clip types on PMSV while also maximizing high MSV in the drug PSAs.

Visual-attention network.

Regions associated with visual attention (*bilateral inferior parietal cortex and right inferior frontal gyrus*) were more active for high versus low MSV clips and for Drug versus Sex clips. These regions have been implicated in various aspects of attention such as eye movements related to orienting attention to specific locations (Corbetta, 1998) and reorienting attention in a top-down, externally driven manner (Fox, Corbetta, Snyder, Vincent, & Raichle, 2006). Activation of regions associated with eye movements related to attention is likely due to the rapid scene changes in high MSV clips. Greater engagement of the visual attention network is consistent with the idea that high MSV clips were, in fact, designed to engage attention and this is likely attributed to the higher PMSV ratings for drug versus sex clips.

An alternative explanation for activation in bilateral inferior parietal and right inferior frontal regions could be related to differences in language processing of high versus low MSV clips. Aspects of the inferior parietal lobe (particularly the supramarginal gyrus) play an important role in speech perception (Benson et al., 2001), lexical processing and reading (Joseph, Noble & Eden, 2001). In addition, the right inferior frontal gyrus is known for processing the emotional (rather than semantic) content of speech (Buchanan et al., 2000). The high MSV clips clearly had more prosodic variation and emotional content than some of the low MSV clips, which may explain the greater engagement of the right inferior frontal cortex. In addition, some of the high MSV clips included prominent displays of wording. Hence, it is possible that this particular network reflects processing of the greater emotional content in the MSV videos, or greater demands on processing written language rather than visuo-spatial attention.

Comprehension network.

The comprehension network included *middle and superior temporal cortex, temporal pole, angular gyrus, superior frontal gyrus, and the inferior frontal gyrus*. Drug clips, as compared to sports clips, activated much of this network (all in the left hemisphere) and low MSV

versus high MSV clips activated the *bilateral superior temporal cortex, primary and secondary auditory cortex and inferior parietal cortex*. Langleben et al. (2009) also reported extensive activation in similar regions that compose the present comprehension network, and these regions were isolated by the contrast of anti-smoking PSAs versus neutral wildlife videos or by high MSV versus low MSV PSAs in that study.

The left-lateralized activation in the present study is consistent with regions that have been implicated in processing different aspects of language (Price, 2010), including speech comprehension, semantic processing and sentence comprehension (*left lateral temporal, inferior frontal and inferior parietal cortex*). Although the majority of sports clips included narration, which would also make demands on processing and comprehending speech, the sports clips contained no persuasive message. Persuasive messages attempt to personally engage and influence the listener in the second-person whereas narrated sports clips do not. Because of this, they also are likely to engage brain systems associated with understanding the intentions, thoughts and actions of another individual (i.e., theory of mind).

At least two components of the present comprehension network, the *left temporal pole and dorsomedial prefrontal cortex (superior frontal gyrus in the present study)*, have been linked to social cognition and theory of mind. According to Olson (2007), the *temporal pole* is a site that integrates many sources of sensory information and links that information to emotional memories in order to support personal semantic memory. In addition, the *dorsomedial prefrontal cortex* has been associated with attributing mental states to others (Frith & Frith, 2006) and with understanding the indirect meaning of utterances (Basnakova, Weber, Petersson, van Berkum, & Hagoort, 2014). Collectively, the comprehension network likely reflects higher level processing of the persuasive content of Drug PSAs. It is important to note that the individual components of the comprehension network are involved in many other types of cognitive processing than suggested here. However, as a collective network, these components process higher level aspects of language and associations with the self.

Salience and Default Mode network.

Another constellation of regions, referred to here as the *salience and default mode networks*, was activated more by Drug versus Sex clips (*precuneus*), by high MSV versus low MSV drug clips (*right insula*) and by HSS versus LSS for drug clips (*anterior cingulate cortex*).

One common feature of salience and default mode networks is that they are both involved in switching between attentional or behavioral states such as switching between “rest” and “task” states or switching attention to more salient stimuli and readying the body for action in response to the more salient stimulus (Menon & Uddin, 2010; Raichle, 2007; Utevsky et al., 2014). In the present context, activation in these regions may have reflected redirecting attention from a more internal focus in the rest (or low MSV) conditions to a more externally oriented focus for the high MSV PSAs. We acknowledge that this is speculative and there are other functions of these regions that should be considered. For example, the precuneus has been linked to a parietal memory system (Gilmore, Nelson, & McDermott, 2015), which may largely serve to direct attention to internal memories. This is certainly a possibility in the present study. Similarly, the insula and anterior cingulate, while often considered critical components of the salience network (Menon & Uddin, 2010) have been implicated in

myriad affective and cognitive functions such as pain processing (Jensen et al., 2016), autonomic function, (Beissner, Meissner, Bar, & Napadow, 2013) and evaluation of task performance (Vaden et al., 2013). Of these possibilities, pain processing and task performance evaluation seem less likely explanations for insula-cingulate activation in the present context. The role of the insula and cingulate in autonomic processing, however, would be consistent with the role of these regions in salience detection. More salient stimuli (e.g., high MSV clips) are more likely associated with stronger autonomic responses which would engage salience regions more strongly.

A second goal of the present study was to examine differences in HSS and LSS with respect to processing anti-drug PSAs. To our knowledge, sensation seeking differences have not been addressed in prior fMRI studies of PSA processing. The primary difference in fMRI activation between HSS and LSS was in the salience / default mode component in which activation was higher in HSS than LSS. As already described, this network is associated with reorienting attention to salient events and readying an individual for action. We suggest that the high MSV clips, which were designed to be attention-grabbing and salient to HSS, accomplished this goal. Although the high MSV clips were not rated differently on arousal, valence or PMSV by HSS and LSS, the neurobiological response indicated differential engagement of attentional systems invoked for salient stimuli (Lang, Chung, Lee, Schwarz, & Shin, 2005). In addition, even though the high MSV clips were rated as lower in believability or truthfulness in HSS, the clips appeared to attract their attention more compared to LSS.

A third goal of this study was to determine whether neural processing of anti-drug PSAs was associated with ratings of message effectiveness, perceived sensation value and memory for the PSAs. Individuals who more strongly recruited the comprehension network also rated the high MSV PSAs as more convincing, believable, likable and emotional and recalled details of the low MSV PSAs better immediately after viewing the PSAs. As mentioned, the comprehension network not only includes regions associated with processing the meaning of sentences and speech, but also attaching personal affective significance to information that is integrated in the temporal pole. Langleben et al. (2009) and Falk et al. (2010) also reported activation in the temporal pole when processing PSAs or persuasive messages. Collectively, this evidence suggests that the comprehension network is critical for processing the perceived effectiveness of persuasive messages.

Although Langleben et al (2009) also reported that temporal pole activation was positively correlated with recognition memory performance, they concluded that this better recognition was due to the low MSV clips given that the temporal pole was activated more strongly for the low MSV clips and that recognition memory was better for low MSV clips. In the present study, details of the low MSV clips were also recalled better than details of the high MSV clips in both the immediate and delayed cued recall tests, which is consistent with Langleben et al's finding. Langleben et al. (2009) and Lang et al. (2005) have suggested that low MSV PSAs are more likely to be remembered because the surface features do not overload attentional and cognitive systems like high MSV PSAs do.

Although a similar process may have driven the present findings with cued recall, it may not explain why the high MSV clips were recognized more accurately after 7 weeks. Lang et al. (2005) note that recognition and cued recall tap into different memory processes: recognition memory reflects orienting and encoding whereas cued recall reflects storage processes. Orientation/encoding and storage may be dissociated processes, and the present findings tend to support this with respect to the message sensation value of the PSAs. Specifically, details of the low MSV PSAs were recalled better than details of the high MSV PSAs (for both immediate and delayed tests), but high MSV PSAs were recognized more accurately than low MSV PSAs after 7 weeks. More accurate recognition of high MSV PSAs may be driven by a stronger orienting response to these PSAs, which could be driven by responses in the visual attention and salience neural systems.

The comprehension network did not show a differential response for HSS and LSS, suggesting that even some HSS engaged this system and were convinced by and remembered the PSAs. This is a hopeful result for anti-drug prevention campaigns that intend to reach HSS who are more likely to experiment with drugs and are more vulnerable to substance dependence. Apparently, the deeper the message is processed, the more likely it is to be convincing and remembered. Even HSS demonstrated this deeper level of processing. Such an effect has been known for many years in the cognitive psychology literature: processing stimuli more deeply (Craik & Lockhart, 1972) or relating to stimuli personally leads to better memory (Westmacott & Moscovitch, 2003). The present study provides neurobiological evidence for such an effect with respect to processing persuasive messages.

In contrast to the recruitment of the comprehension network, individuals who strongly recruited the visual attention network did not relate to the PSAs at a personal level. The visual attention network is linked to shifting and/or maintaining attention to specific stimuli in the external environment. Given the strong role of this system in guiding eye movements during shifts of attention, we speculate that activation in this system may reflect attention to the surface features of the messages in terms of the rapid presentation of information and frequent scene changes. Excessive attention to such features may detract from processing the central content of a message, which in turn, would not enable relating to messages at a personal level. This fMRI activation was also not modulated by SS, again suggesting that some HSS showed reduced visual attention activation but also found the clips to be personally relevant. Langleben et al. (2009) suggested the same potential mechanism to explain their finding that higher visual association cortex activation was correlated with poorer recognition performance but temporal pole and medial prefrontal activation was correlated with better recognition memory performance.

The dissociation between the comprehension and visual attention networks with respect to subsequent ratings of effectiveness and cued recall memory performance may be explained by a framework proposed years ago by Petty and Cacioppo (1986) – the Elaboration Likelihood Model (ELM) of persuasive message processing. Elaboration refers to the extent to which individuals examine message arguments. In this model, more cognitively oriented individuals process information centrally whereas those less cognitively oriented process information peripherally. Central processors are said to employ careful and critical study of

the content along dimensions central to themselves. Peripheral processors rely on heuristic cues in making assessments. For them, a cue is any stimulus in the message other than the arguments themselves that affects their attitudes. Relating this to the present study, individuals who engaged the comprehension network may be more aligned with “central processors” given that higher comprehension network activation was associated with higher PME and immediate recall of PSA details. Individuals who engaged the visual attention network more strongly may be aligned with “peripheral processors” given that the visual attention network is strongly implicated in guiding eye movements to external stimuli. The peripheral processors, then, may have devoted more neural resources to processing the surface features of PSAs at the expense of not dedicating resources to processing the content and the arguments of the messages.

Limitations

The present study examined fMRI response to complex stimuli that invoked activation in a wide range of perceptual, attention and cognitive brain systems. The data reduction approach (PCA) allowed us to interpret four broad brain systems rather than individually interpret each brain region that was activated. However, this approach may have overgeneralized the function of each of the 4 brain components and may have overlooked different contributions of processing PSAs from each of the individual regions within a component. Nevertheless, the interpretation of each component is well grounded in extensive prior research.

Conclusion

This study offers further explanation of how individuals respond to prevention messages, once exposed to them. It indicates that fMRI response can add explanatory power to understanding how people perceive and remember PSAs. HSS are a target audience for anti-drug PSAs because they are more vulnerable to substance use and dependence. As a group, HSS did not rate high MSV PSAs as believable or truthful, but they showed a greater salience network response to the high MSV PSAs. This suggests that self-report measures and neurobiological responses can lead to different conclusions regarding the effectiveness of persuasive messages. Individuals who were persuaded by and remembered the PSAs more strongly engaged brain networks that are linked to processing the meaning of messages and relating information to one’s own life. Both HSS and LSS showed evidence for this level of processing the messages, which supports behavioral findings that high MSV PSAs can be an effective means for influencing individuals who are at risk for substance abuse and other risky behaviors.

Acknowledgements

We would like to thank Faraday Davies and Grace Baik for their help with data collection. This work was supported by the National Institute on Drug Abuse under grant number DA024401.

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Figure 1.

Group-level brain activation for (a) contrast of anti-drug vs. safe sex PSAs (bilateral visual cortex, bilateral superior parietal cortex and temporo-parietal junction) and anti-drug PSAs vs. sports clips (left temporal cortex, left inferior frontal, left inferior parietal cortex and midline superior frontal cortex), (b) contrast of high message sensation value vs. low message sensation value anti-drug PSAs (bilateral visual cortex, bilateral temporo-parietal junction, right precuneus, right precentral and inferior frontal cortex) and vice versa (bilateral lateral temporal cortex, bilateral postcentral/parietal cortex), and (c) contrast of high sensation seekers (HSS) vs. low sensation seekers (LSS) for the anti-drug PSAs (bilateral anterior cingulate cortex and right superior frontal cortex). The regions of activation in (a)–(c) were submitted to a principal components analysis which yielded 4 components of regional fMRI activation: (d) a comprehension network, (e) a visuo-spatial processing network, (f) a visual attention network and (g) a salience detection/default mode network. In (d)–(g) the darker activation represents activation in that network from all contrasts, whereas lighter patches of activation represent overlap in activation from specific contrasts.