

**Adolescents' neural response to  
tobacco prevention messages and sharing engagement**

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### **Abstract**

**Introduction:** Interpersonal communication can reinforce media effects on health behavior. Recent studies have shown that brain activity in the medial prefrontal cortex (MPFC) during message exposure can predict message-consistent behavior change. Key next steps include examining the relationship between neural responses to ads and measures of interpersonal message retransmission that can be collected at scale.

**Methods:** Neuroimaging, self-report and automated linguistic measures were utilized to investigate the relationships between MPFC responses to tobacco prevention messages, sharing engagement, and smoking-relevant belief changes. Thirty-seven adolescent non-smokers viewed 12 ads from FDA's "The Real Cost" campaign during an fMRI scan session (2015 – 2016). Data were analyzed between 2016 - 2017. The extent that participants talked in detail about the main message of the ads, or sharing engagement, was measured through transcripts of participants' subsequent verbal descriptions using automatic linguistic coding. Beliefs about the consequences of smoking were measured before and after the main experiment using surveys.

**Results:** Increased brain activation in self- and value-related subregions of the MPFC during message exposure was associated with subsequent sharing engagement when participants verbally talked about the ads. In addition, sharing engagement was significantly associated with changes in participants' beliefs about the social consequences of smoking.

**Conclusions:** Neural activity in self- and value-related subregions of the MPFC during exposure to The Real Cost campaign was associated with subsequent sharing engagement, which in turn was related to social belief change. These results provide new insights into the link between

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neurocognitive responses to ads, the content of interpersonal sharing, and downstream health-relevant outcomes.

## Introduction

Cigarette smoking is the leading preventable cause of disease and death in the United States.<sup>1</sup>

The vast majority of smokers initiate before age 18,<sup>1</sup> making smoking prevention during adolescence a crucial and cost-effective means for decreasing the prevalence of smoking. Anti-smoking mass media campaigns targeting adolescents strive to strengthen target health beliefs and anti-smoking attitudes,<sup>2,3</sup> which have been identified as key determinants of behavior.<sup>4</sup>

Recent research also highlights the importance of interpersonal communication as a means for extending the reach of campaigns and reinforcing campaign messages.<sup>5-11</sup> These studies suggest that anticipating and engaging in discussions about the campaign messages may lead to favorable campaign outcomes, such as encouraging anti-smoking attitudes and behaviors.

Previous neuroimaging studies have shown that neural measures taken during health message exposure provide information about the persuasive effects of messaging<sup>12-22</sup> and the likelihood that health news is shared.<sup>23,24</sup> Most consistently, message-evoked neural activity in subregions of the medial prefrontal cortex (MPFC) has been associated with message-consistent behavioral outcomes<sup>12,13,17,25-27</sup> and message sharing.<sup>23,24</sup> Two sub-processes served by the MPFC, namely self-related processing and positive valuation, are thought to be critical to the success of persuasive messages and their sharing decisions.<sup>26,28</sup>

First, a person is more likely to be persuaded by and to share a message if they think the message has high personal relevance and high personal value.<sup>28</sup> For example, messages that are tailored to an individual,<sup>13,29</sup> and messages that increase beliefs about personal risks<sup>30,31</sup> are more

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effective than messages that do not make the receiver feel that the message content is personally relevant. Within the MPFC, studies have identified sub-clusters that are particularly activated during a range of self-related processes, such as retrieval of autobiographical memories,<sup>32,33</sup> explicit self-relatedness judgements,<sup>34–36</sup> and implicit self-referential thinking.<sup>37,38</sup> In addition, activity within these specific subregions has been associated with increased sharing of health news content.<sup>23,24</sup> The present study extends this prior work by examining whether messages that engage these forms of self-related processing are more likely to be shared in depth by adolescents.

In parallel, when people view ideas or actions as being more subjectively valuable (or positive valuation), they are more likely to act on that information<sup>39–41</sup> or share it with others.<sup>42</sup> This view is consistent with prominent theories of persuasion and behavior change, such as the reasoned action approach<sup>4</sup> and the elaboration likelihood model,<sup>43</sup> which emphasize the importance of the subjective, expected outcomes in determining behavior. Across hundreds of neuroimaging studies of subjective valuation, a different set of subregions of the MPFC is consistently engaged by diverse types of rewards, and by both the expectation and receipt of valuable outcomes.<sup>44–46</sup> Given that this portion of the MPFC also plays an important role in persuasion<sup>26</sup> and message retransmission,<sup>23,24</sup> the current study examines this role of the MPFC as a second antecedent to message sharing.

To date, no prior research has linked the neurocognitive mechanisms at play during message exposure to the content of what people share, and subsequent belief changes indicative of

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persuasion in sharers. The current study used neuroimaging methods to measure brain activity during message exposure, and examined associations between message-induced brain activity and subsequent sharing engagement. The sharing task captures the extent to which participants elaborated on specific message themes when later sharing the ideas with friends (referred to here as “sharing engagement”). The aims of this study were to examine: (1) whether neural activation in two subregions of the MPFC implicated in self-relevance<sup>35</sup> and valuation<sup>44</sup> during message exposure was each positively associated with sharing engagement; and (2) whether sharing engagement was positively associated with subsequent changes in the sharers’ smoking-relevant beliefs.

## Methods

### Participants

Forty-three adolescents were recruited from the greater Philadelphia area. All participants provided informed assent and parental consent in accordance with the procedures of the Institutional Review Board at the University of Pennsylvania. Participants were required to meet standard fMRI eligibility, age (14-17 years) and nonsmoking (defined as past-30-day non-use and lifetime history of <100 cigarettes) eligibilities. Six participants were excluded due to discomfort in scanner (n=1), failed attention check (n=1), or recording technology failure (n=4). The remaining 37 participants included 18 females. Given that the target population of The Real Cost campaign includes non-smokers who are susceptible to initiation,<sup>47</sup> we recruited non-smokers and oversampled high sensation seeking adolescents as they are at greater risk of smoking initiation.<sup>48</sup> Sensation seeking was measured with the Brief Sensation Seeking Scale

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(BSSS-4).<sup>49</sup> Eligible participants were recruited until a cap was met for each subgroup (low-moderate and high sensation seekers). The current sample includes 17 high sensation seekers (SS) defined by an average rating of three or higher to the BSSS-4 questions on a four-point scale, and 20 low to moderate sensation seekers with an average BSSS-4 rating of less than three. In addition, the baseline survey assessed participant's intention to smoke in the next six months and their self-efficacy related to saying no to smoking in various situations. On average, participants rated that they were not likely to smoke in the next 6 months ( $M = 1.19$  on a four-point scale where 1 denotes definitely will not and 4 denotes definitely will,  $SD = .40$ ). Similarly, with regard to self-efficacy ratings, participants reported that they were mostly sure they could say no to smoking ( $M = 4.54$  on a five-point scale where 1 denotes not at all sure and 5 denotes completely sure,  $SD = .84$ ).

## Materials

The stimulus messages were 12 advertisements (ads) from The Real Cost campaign, a national tobacco prevention campaign launched by the U.S. Food and Drug Administration (FDA).<sup>1</sup> Each 30-second ad aims to educate youth about smoking harms, in particular the loss of control due to addiction, the dangerous chemicals contained in cigarettes, and the negative health and cosmetic consequences that result from smoking.<sup>47</sup> See Supplementary Table 3 for short descriptions and web links for the ad stimuli used in this study.

## FMRI Tasks

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*Message exposure task.* The 12 Real Cost messages were preceded by a 3-second countdown and followed by a response screen that asked participants of their intention to share the message, which served as an attention check manipulation. The message exposure task lasted about 10 minutes. The 12 ads were presented in random order to account for potential fatigue effects associated with repeated message exposure. This study solely focuses on neural response during message exposure.

*Message sharing task.* This task followed the message exposure task and was designed to capture the content of interpersonal communication about the messages while participants were in the fMRI scanner. After being exposed to all 12 messages in the message exposure task, participants were shown 3 screenshots of each message and were asked to freely talk about the message as if talking with their peers (Figure 1a). Participants were aware that their speech could be heard by the study staff. The message sharing task was about 6 minutes in length. The instructions given to the participants were: “You will have 30 seconds to talk about each video. You may talk about anything you like, as if you were discussing it with a friend.”

## Measures

*Sharing engagement.* Participants’ descriptions of the messages in the message sharing task were transcribed and analyzed using the Linguistic Inquiry and Word Count (LIWC) English dictionary,<sup>50</sup> which counts the proportion of words in a text that belong to a range of psychologically relevant categories. Specifically, message engagement was operationalized along two dimensions: 1) the extent to which the participants talked about thoughts central to the

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main theme of negative consequences of smoking (theme relevance), and 2) the level of detail of their language (specificity) (see Figure 1b for an example transcript). Theme relevance was operationalized by counting the percentage of words most related to the anti-smoking theme of The Real Cost ads within the LIWC dictionary, which were found in the “biological processes” category; this category contained words that are key when describing cigarette smoking and its consequences, such as “smoking,” “lung,” and “inhale.” The specificity of each participant’s language was measured as the percent of words belonging to the “relativity” category, which contained words that are used to describe details of position, time, and action. The level of concrete details included in participants’ ad description was considered an indicator of their level of cognitive processing of the ad.<sup>51</sup> We combined the topic-relevance score and the specificity score into an overall sharing engagement score as an indication of individual cognitive processing of the main theme for each message during the message sharing task (see Supplementary Table 4 for example transcripts and the corresponding sharing engagement scores).

*Belief questionnaires.* To assess smoking-relevant beliefs, participants answered questions about the consequences of smoking tobacco cigarettes. Belief items were drawn from a national telephone survey of youth and young adults’ beliefs and behaviors relevant to tobacco use.<sup>6,52</sup> Beliefs were assessed as part of the baseline questionnaire (within one week prior to the fMRI scan session) and again after the fMRI scan as part of the post-scan questionnaire. To minimize social desirability bias, participants completed the online baseline questionnaire at home, and the post-scan questionnaire alone in a test room. They were assured confidentiality of their

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responses. The belief questionnaire assessed various tobacco-related beliefs, including those broadly targeted by the Real Cost campaign (health risks, dangerous chemicals, and loss of control). Though not one of the three key message pillars for the Real Cost campaign, belief items also assessed social concerns related to smoking. Participants' beliefs on the social consequences of smoking were measured through two items: If I smoke every day, I will look uncool; If I smoke every day, I will be a turnoff to other people. Participants rated on a 4-point scale, where 1 indicates strong disagreement and 4 indicates strong agreement with the statement. The additional items used in the belief questionnaire are listed in Supplementary Table 5.

## Analyses

One sample t-tests were conducted to determine whether changes in participants' belief ratings between pre- and post-scan measurements were significantly different from zero across participants. With the brain data, a region-of-interest (ROI) approach was adopted to investigate the relationship between MPFC neural activation during message exposure and sharing engagement in the subsequent message sharing task. Based on previous literature on neuroscience of persuasion and information sharing,<sup>12,23,25,26</sup> two a priori hypothesized ROIs in the MPFC were selected: one from a meta-analysis on self-related processes (self ROI; Figure 2a),<sup>35</sup> and one from a meta-analysis on valuation processes (value ROI; Figure 2b).<sup>44</sup> To examine the relationship between neural activation in the specified ROIs and sharing engagement, two separate multilevel mixed-effects regression models were constructed.<sup>53,54</sup> Both models used brain activity in each hypothesized ROI (self ROI or value ROI) as the independent variable, and

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the sharing engagement score from the message sharing task as the dependent variable. As the data were nested both within participants (there are multiple data points for each participant) and within ads (there are multiple data points for each ad), participants and ads were treated as random effects. Intercepts and slopes were allowed to vary randomly, thereby accounting for non-independence in the data from these two sources. The associations between ROI activity and sharing engagement was also assessed at the individual level using ordinary least squares (OLS) regressions, for which data were averaged across ads for each participant.<sup>a</sup> Statistical analyses were carried out in R statistical software (version 3.3.3) using lme4 (1.1-15) and lmerTest (2.0-36) packages to perform linear mixed effects modeling. In addition to the ROI analyses, a whole brain parametric search was also conducted to examine regions outside of the hypothesized ROIs associated with sharing engagement (see supplementary materials). Finally, OLS regressions were used to examine the association between sharing engagement and belief changes on health risks, loss of control, dangerous chemicals, and social concerns, respectively.

## Results

We operationalized sharing engagement with the Real Cost ads using automated linguistic coding of the participants' verbal descriptions of the ads, indicating the theme relevance and specificity of the participants' talk. In the message sharing task, participants produced an average of 73.21 words (SD = 16.12). Across all ads, the average engagement score was 13 (SD = 5.6),

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<sup>a</sup> Note that the sharing engagement score is a composite score of theme-relevance and specificity. We included additional analyses that separately examine the relationship between MPFC ROI activity and each subcategory score of sharing engagement in the supplementary materials.

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indicating that, on average, 13% of total words were related to either the biological process of smoking or details of the message.

We also measured smoking-relevant beliefs before and after exposure to the ads. In general, participants agreed with belief statements concerning the harmful consequences of smoking. Participants' mean belief ratings on the baseline survey were 3.08 (SD = 0.42) for health risks, 3.51 (SD = 0.56) for loss of control, 3.81 (SD = 0.40) for dangerous chemicals, and 3.4 (SD = 0.71) for social concerns. There were not significant group-level belief changes when comparing participants' smoking-relevant belief ratings before and after the main experiment for belief items regarding health risks ( $M_{\text{end}} = 3.15$ ,  $SD_{\text{end}} = 0.42$ ,  $t(36) = 1.4$ ,  $p = 0.2$ )<sup>b</sup>, loss of control ( $M_{\text{end}} = 3.38$ ,  $SD_{\text{end}} = 0.59$ ,  $t(36) = -1.3$ ,  $p = 0.2$ ), harmful chemicals ( $M_{\text{end}} = 3.73$ ,  $SD_{\text{end}} = 0.45$ ,  $t(36) = -0.9$ ,  $p = 0.4$ ), or social concerns ( $M_{\text{end}} = 3.28$ ,  $SD_{\text{end}} = 0.69$ ,  $t(36) = -1.2$ ,  $p = 0.2$ ). However, there was person-to-person variability, which is the focus of the current analysis.

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This study aimed to examine whether MPFC neural activation during message exposure was associated with the extent to which participants talked about the central theme of the message in detail during the message sharing task. As such, two multilevel models were constructed using the self or value ROI, respectively, as an independent variable and the sharing engagement score as the dependent variable. Participants' sharing engagement scores were significantly associated

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<sup>b</sup> All the p-values reported in this study reflect results from two-tailed tests.

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with their neural activity in the self ROI ( $\beta = 1.63$ , 95% CI: (0.59, 2.66),  $p = .008$ ) and value ROI ( $\beta = 1.36$ , 95% CI: (0.43, 2.28),  $p = 0.004$ ) during message exposure. In other words, accounting for individual differences across people in their tendencies to elaborate when sharing, greater neural activation in the self and value MPFC ROIs during message viewing was respectively associated with participants later showing greater theme-relevant engagement when talking about the ads.

We also tested if, at the individual level, mean levels of sharing engagement were associated with mean neural activity in hypothesized ROIs across all 12 ads. At the individual level, mean neural signal across all ads in the self ROI correlated with mean engagement scores ( $\beta = 2.62$ ,  $t(33) = 2.65$ ,  $p = 0.012$ ; Figure 2a). Similarly, mean neural activation in the value ROI correlated with mean engagement scores ( $\beta = 1.87$ ,  $t(33) = 2.08$ ,  $p = 0.045$ ; Figure 2b). These results suggest that participants with higher neural activity in the MPFC while viewing ads subsequently showed more sharing engagement across ads. Results of a whole brain search confirmed that brain activity in the MPFC, ventral striatum (a brain region implicated in value processing)<sup>44,55</sup> and posterior cingulate cortex (a brain region implicated in self-related processing and autobiographical memory)<sup>35,56,57</sup> were robustly associated with sharing engagement (for details, see supplementary materials).

## Sharing engagement and belief change

The extent to which participants elaborated on the main theme of the health messages they were exposed to may have downstream effects on changes in their cigarette-related beliefs. To that

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end, we investigated the correlation between participants' mean levels of sharing engagement and their changes in tobacco-relevant beliefs at the individual level. There was a significant correlation between participants' overall sharing engagement scores and changes in beliefs relevant to the social consequences of smoking, controlling for age, sex, and baseline belief ratings ( $\beta = 0.065$ ,  $t(32) = 2.16$ ,  $p = 0.038$ ; Figure 3).<sup>c</sup> This indicated that participants who engaged more with The Real Cost messages overall in the message sharing task were more likely to change their beliefs about the social consequences of smoking. We did not find similar associations between message engagement and belief change concerning health risks, loss of control, or dangerous chemicals (Table 1).

## Discussion

The persuasive effect of mass media campaigns is facilitated by interpersonal channels, as campaign messages can be spread to a larger audience through conversations.<sup>5,8,9</sup> Further, anticipation of conversations and actual elaboration in discussions may amplify the effects of discussion on campaign message effectiveness.<sup>6,7,10,11</sup> Yet, the neurocognitive mechanisms that lead to sharing about mass media messages have not been studied extensively,<sup>28,58</sup> nor is it clear how these processes might relate to the sharer's own belief change.<sup>59</sup> This study reports that neural activity in subregions of the MPFC implicated in self-related processing and positive valuation is associated with subsequent sharing engagement in a message sharing task. In turn,

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<sup>c</sup> The association between sharing engagement scores and social belief changes was also significant without controlling for demographic variables (age and sex) and baseline belief ratings ( $\beta = 0.067$ ,  $t(35) = 2.04$ ,  $p = 0.049$ ).

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engaging with the message theme during message sharing is associated with changes in the same participants' beliefs about the social consequences of smoking.

Recent studies have reinforced that self- and value-related brain activity during health message exposure can play an important role in persuasion and behavior change.<sup>26,28</sup> Our finding that neural activity in subregions of the MPFC implicated in self-related processing and valuation is associated with subsequent sharing engagement brings together previously disconnected findings that highlight the importance of interpersonal communication about mass media campaigns,<sup>8,9,59,60</sup> and research showing that brain activity within the MPFC during message exposure is related to subsequent behavior change.<sup>12-15,28,61</sup>

Prior neuroimaging studies have identified subregions of the MPFC that are preferentially engaged during various types of self-related tasks, including the retrieval of autobiographical memories<sup>32,33</sup> and engagement in explicit and implicit self-referential thoughts.<sup>34-38</sup> Recent research has also shown that brain activity in these same regions is implicated in intentions to share health news in young adults,<sup>23,24</sup> suggesting that self-relevance may be one important antecedent to decisions to share.<sup>26</sup> Our findings bring these two sets of studies together and extend this work by examining the actual content of what adolescents share in response to health campaign messages. These findings suggest that messages that initially elicit greater self-related processing in the brain are encoded more deeply and later shared with greater theme-relevant detail.

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In parallel, a large body of research shows that subregions of the MPFC are implicated in a wide range of valuation processes, including the expectation and receipt of both primary and secondary rewards.<sup>44-46</sup> Likewise, brain activity in these same regions is implicated in intentions to share health news in young adults,<sup>23,24</sup> suggesting a critical role of positively valuing content during initial exposure as one potential antecedent of subsequent sharing elaboration.

The present findings highlight the role of self- and value-related processes as important psychological antecedents of interpersonal message sharing. This account shares theoretical underpinnings with major theories of behavior change that suggest self-relevance and subjective valuation are precursors to behavioral outcomes.<sup>4</sup> This account is also consistent with the idea that a common set of psychological processes may take hold during message receipt that are associated with later sharing engagement, as well as health-relevant belief and behavior change.<sup>9,25</sup> This is one of the first studies to investigate the neural processes that associate with adolescent interpersonal sharing. Future studies in this area could explore other relevant domains, using appropriately adapted measures of sharing engagement.

Notably, these findings suggest that sharing engagement is associated with changes in social- but not health-, control- or chemicals-related beliefs. Social concerns were operationalized through participants' self-report ratings of whether they agreed that smoking would make them look uncool or make them a turn-off to their friends. Two factors may underlie the lack of association between sharing engagement and health-, control- and chemicals-related belief changes. First, the fact that sharing engagement is measured in a task that mimics interpersonal sharing might

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position it to better capture participants' thoughts and cognitions on the social consequences of smoking. Secondly, consequences related to loss of control, chemicals, health, and cosmetic effects arguably have social consequences. Thus, it may be the case that the social concern belief questions are more general and may capture more variance than belief ratings on health, chemicals, and loss of control specifically. Given that participants filled out the baseline questionnaire at home and post-scan questionnaire in the absence of study staff, and were assured confidentiality of their responses, there should be minimal social desirability bias in their responses.

An important methodological innovation of the current work is the combination of brain imaging with the use of a message sharing task to capture the content of interpersonal communication. Specifically, natural language processing (NLP) analysis allowed us to capture the theme-relevance and specificity of participants' talk. This approach brings the potential for automated analysis of message engagement at large scales (e.g., with language scraped from online discussions that would not be feasible to code by hand). Other often-used NLP techniques include supervised machine learning and topic modeling, both of which require a relatively large corpus of texts. In comparison, LIWC dictionary coding is applicable to both small and large bodies of texts. Furthermore, given that health campaigns targeted toward adolescents increasingly employ internet-based platforms, the combined use of brain imaging during message receipt with this form of scalable, semantically-rich verbal elaborations of the same messages has great potential to enhance our understanding of how adolescents' social media engagement contributes to behavior change, and to inform models of sharing across levels of

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analysis (i.e., to link processes that are typically measured in small numbers of people in the lab with large-scale outcomes that are usually measured with NLP at scale).<sup>62</sup>

### **Limitations**

Although the novel use of neuroimaging methods in the current study can unobtrusively measure neural and cognitive processes during health message exposure, it also brought several limitations. The sample size for this study ( $n = 37$ ) is relatively small, limiting our ability to draw group-level inferences. The current analyses are also subject to the constraints of reverse inference<sup>63</sup> in that the observed neural activity could be related to psychological processes or personal attributes other than the ones hypothesized in this study. However, the strong theoretical foundation on which this study was developed and the use of meta-analytically defined subregions of the MPFC mitigate these concerns. Future studies that directly manipulate these processes can **provide stronger causal links between the psychological processes proposed, activation of MPFC, and message effects**. Additionally, the message sharing task was developed to measure aspects of interpersonal communication, but the extent to which this laboratory task generalizes to real-life situations has not yet been assessed. Future work could improve this task by having participants post or share messages to real-world social media directly from the scanner, or by instructing participants to engage in in-person conversations with peers at study sessions.

Furthermore, although high sensation seeking adolescents were oversampled in this study, participants in our study sample generally reported low intention to smoke and strong anti-

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smoking beliefs at baseline. Therefore, generalizations cannot be made to adolescents with high intention to smoke. Future studies in this area could consider assessing smoking risk with other criteria (e.g., measures of smoking intention).

Finally, in the current study we used LIWC dictionary coding to index the extent to which participants talked about the main theme of The Real Cost campaign messages. The use of LIWC dictionary coding is dependent on the specific construct of interest, the context, and the characteristics of the texts being coded. Further validation of the LIWC dictionary method in related contexts on more diverse types of texts will be useful.

## **Conclusion**

Findings demonstrate that self- and value-related neural signals during adolescents' exposure to health messages were associated with subsequent sharing engagement when participants were asked to talk about the messages as if speaking to their peers. In turn, sharing engagement was significantly associated with changes in the same participants' beliefs about the social consequences of smoking, shedding new light on the interrelationships between message exposure, interpersonal sharing and belief change.

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### List of titles for all figures

Figure 1. (a) An illustration of the message sharing task; (b) an example transcript in which the participant talks about the Real Cost ad. Words in bold are from the LIWC biological process category, indicating message theme relevance, and words that are underlined are from the LIWC relativity category, indicating level of detail in the description.

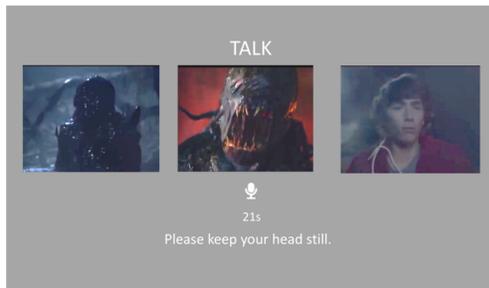
Figure 2. Neural activity during message viewing predicts subsequent sharing engagement. The sharing engagement score is plotted against percent signal change in activity from the: (a) self ROI ( $\beta = 2.62$ ,  $t(33) = 2.65$ ,  $p = 0.012$ ); and (b) value ROI ( $\beta = 1.87$ ,  $t(33) = 2.08$ ,  $p = 0.045$ ).

Figure 3. At the individual level, mean sharing engagement across all ads predict participants' changes in beliefs about the social consequences of smoking between baseline and post-scan questionnaires, controlling for age, sex, and baseline social belief ratings ( $\beta = 0.065$ ,  $t(32) = 2.16$ ,  $p = 0.038$ ).

## MPFC neural activity and sharing engagement

Figure 1

(a)

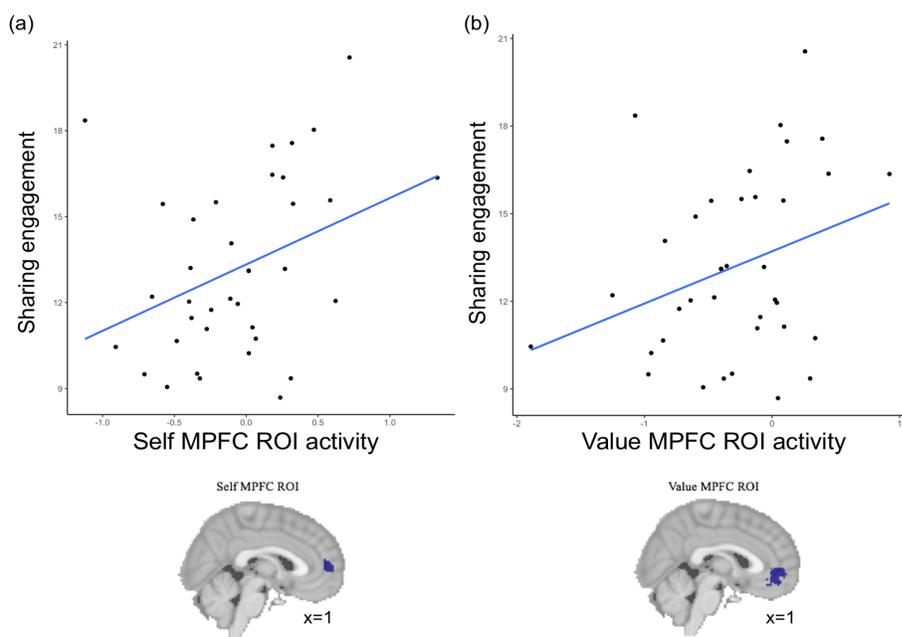


(b)

“Uh this one was that one where it looks like this kids trying his first time **smoking**. So he sits out behind the house, and a bunch of these crazy alien-looking things run out of the woods, and when they are right about to hit them they all funnel themselves into a **breath** and enter the guy’s **mouth**. And then he **coughs** it back up as it was the **cigarette smoke**. Uh sort of showing all the **toxic** and dangerous things that are going in every time you take a **breath** of the **cigarette**, and it was pretty creepy as well”

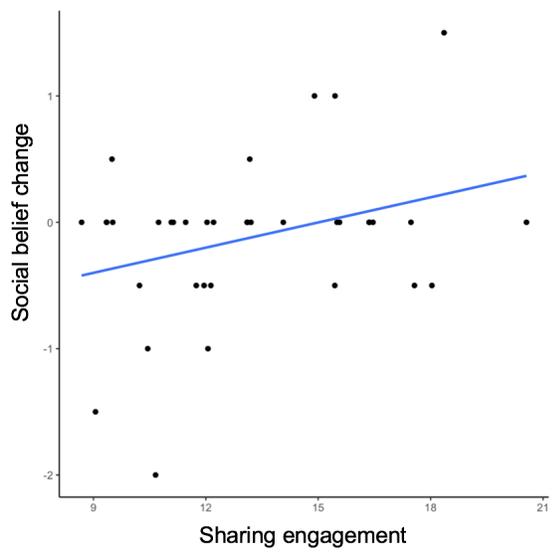
## MPFC neural activity and sharing engagement

Figure 2



MPFC neural activity and sharing engagement

Figure 3.



## MPFC neural activity and sharing engagement

Table 1. Results from ordinary least square regressions linking sharing engagement and belief change, controlling for age, sex, and baseline belief ratings.

	$\beta$ [95% CI]	t (df)	p
Health risks	0.0029 [-0.032, 0.037]	0.17 (32)	0.87
Harmful chemicals	0.0018 [-0.051, 0.054]	0.07 (32)	0.94
Loss of control	-0.0045 [-0.072, 0.063]	-0.14 (32)	0.89
Social concerns	0.065 [0.0038, 0.13]	2.16 (32)	0.038

## Supplementary materials

Adolescents' neural response to  
tobacco prevention messages and sharing engagement

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**FMRI acquisition and analyses**

Neuroimaging data were acquired using a 3 Tesla Siemens MRI scanner with a 64-channel head/neck array. Functional images were recorded using a multiband sequence (TR = 1000 ms, TE = 32 ms, flip angle = 60, 56 axial slices, FOV = 208 mm, slice thickness = 2.50mm; voxel size = 2.5 x 2.5 x 2.5 mm). We also acquired in-plane T1-weighted images (160 slices; slice thickness = 1.00 mm; voxel size = .9 x .9 x 1.0 mm) and high-resolution T1-weighted images for use in coregistration and normalization.

Functional data were pre-processed and analyzed using FSL and Statistical Parametric Mapping.<sup>1</sup> To allow for the stabilization of the BOLD signal, the first 3 volumes (3 seconds) of each run were discarded prior to analysis. Data were corrected for differences in the time of slice acquisition using sinc interpolation, spatially realigned, and co-registered to the structural image. Data were then normalized to MNI space and functional images were smoothed using a Gaussian kernel (8 mm FWHM).

*Regions of interest.* We included two regions of interest (ROIs) based on their theoretical relevance to persuasion processes. The ROI corresponding to self-relevance was taken from a meta-

## MPFC neural activity and sharing engagement

analysis of 25 studies on self-related processing.<sup>2</sup> The self ROI was taken from the MPFC subregion of Figure 1(A). The ROI corresponding to subjective valuation was taken from a quantitative meta-analysis of 206 studies that reported subjective value-related neural signals during decision-making.<sup>3</sup> The value ROI was taken from the MPFC subregion of Figure 9, which is the conjunction of several valuation-relevant contrasts.

*Voxelwise whole brain searches.* To complement the ROI analyses described above, we subsequently ran whole brain searches to identify activations outside of our primary hypothesized ROIs. The fMRI data were modeled for each participant using the sharing engagement score for each PSA as a parametric modulator of the neural response during the 30-second period during which they were exposed to each video. The six rigid-body translation and rotation parameters derived from spatial realignment were also included as nuisance regressors in all first level models. Data were high-pass filtered with a cutoff of 128s. Data were modeled at the first level using the general linear model as implemented in SPM8.<sup>4</sup> To correct for multiple comparison, we used 3DClustSim<sup>5</sup> from AFNI package to calculate the cluster size for whole-brain corrected significance. 3DClustSim makes estimate the cluster size needed to provide corrected p-values at an uncorrected p-value based on the observed smoothness of the data. We calculated the whole-brain corrected thresholds at  $p < 0.05$  (cluster size  $> 464$ ,  $p$  uncorrected  $< 0.005$ ).

## Whole brain analysis results

## MPFC neural activity and sharing engagement

To examine whether neural activity in regions outside our a priori hypothesized ROIs during message exposure predicts subsequent sharing engagement, we ran a whole-brain search using participants' sharing engagement scores as a parametric modulator on neural activity during viewing. In this analysis, regions significantly associated with subsequent sharing engagement include the MPFC, ventral striatum, parahippocampus, and the posterior cingulate cortex (see supplementary Table 1 and supplementary Figure 1). These results reinforce the results of our ROI analyses, and additionally suggest that activity in additional brain regions, such as the striatum and the medial temporal lobe, predicts subsequent message sharing engagement.

### **Results linking MPFC activity and individual sharing engagement category**

In this study, sharing engagement was defined as “the extent to which participants elaborated on the message themes” and contained two components: theme-relevance and specificity (the level of details). Additional multi-level and individual level analyses were conducted to examine if MPFC activity in the self and value ROI is associated with each subcategory of sharing engagement separately.

First, four multilevel mixed-effects regression models were constructed to examine the association between MPFC neural activity and the *theme-relevance / specificity* scores.

Participants' theme-relevance scores were significantly associated with their neural activity in the self ROI ( $\beta = 0.63$ , 95% CI: (0.13, 1.13),  $p = .014$ ), but were not significantly associated with their neural activity in the value ROI ( $\beta = 0.37$ , 95% CI: (-0.076, 0.81),  $p = .11$ ). In comparison, participants' specificity scores were marginally associated with their neural activity in the self

## MPFC neural activity and sharing engagement

ROI ( $\beta = 0.98$ , 95% CI: (-0.004, 1.96),  $p = .062$ ), and were significantly associated with their neural activity in the value ROI ( $\beta = 0.958$ , 95% CI: (0.068, 1.85),  $p = .047$ ). The results were also reported in Supplementary Table 2.

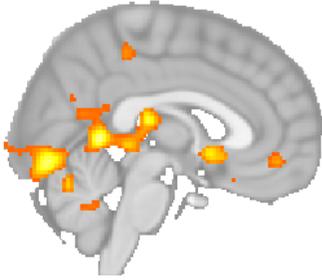
In addition to the multilevel mixed-effects regression models, linear regression models were also constructed at individual level to investigate if participants with higher average MPFC activity across 12 ads are also likely to have higher theme-relevance and specificity scores in the message sharing task. The results suggest that participants' mean theme-relevance scores across all 12 ads were significantly associated with their mean neural activation in the self ROI ( $\beta = 0.96$ ,  $t(33) = 2.09$ ,  $p = 0.045$ ), but were not significantly associated with their neural activity in the value ROI ( $\beta = 0.23$ ,  $t(33) = 0.53$ ,  $p = 0.60$ ); In comparison, participants' mean specificity scores across 12 ads were marginally associated with their self ROI neural activity ( $\beta = 1.65$ ,  $t(33) = 1.94$ ,  $p = 0.06$ ), and were significantly associated with their value ROI neural activity ( $\beta = 1.65$ ,  $t(33) = 2.23$ ,  $p = 0.03$ ). The results were also reported in Supplementary Table 2.

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Supplementary Figure 1. Brain regions in which neural activation during message exposure is correlated with sharing engagement. MNI  $x = 2$ .



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Supplementary Table 1. Whole brain table exploratory analysis showing brain regions in which neural activation during message exposure is correlated with sharing engagement. Whole-brain corrected significance at  $p < 0.05$  (determined by 3DClustSim).

Brain Region	Volume (voxels)	Peak intensity	MNI coordinates		
			x	y	z
L superior temporal gyrus	2625	5.38	-30	-54	2
R cerebellum Posterior Lobe	1216	4.87	18	-38	-48
L ventral striatum	625	4.83	-8	22	-8
L/R posterior cingulate cortex	1635	4.79	2	-52	2
R medial prefrontal cortex	498	4.24	6	48	-26
L cingulate gyrus	625	3.83	-12	-34	28

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Supplementary Table 2. Multilevel and individual level regression results of linking neural activity in the hypothesized ROIs (IV) and the linguistic measures in the message sharing task (DV).

	DV IV	Theme-relevance score (LIWC score in the “biological processes” category)	Specificity score (LIWC score in the “relativity” category)	Sharing engagement score (LIWC “biological processes” score + “relativity” score)
Multilevel regressions	Self MPFC	0.63*	0.98†	1.63**
	Value MPFC	0.37	0.96*	1.36**
Individual level regressions	Self MPFC	0.96*	1.65†	2.62*
	Value MPFC	0.23	1.65*	1.87*

*Note.* Each individual cell in the table represents a separate regression, as specified in Methods under Analyses. Unstandardized regression coefficients are reported. †  $p < .1$ , \*  $p < .05$ , \*\*  $p < .01$ .

Supplementary Table 3. Short descriptions and public links (if available) of all ad stimuli.

<b>Ad name</b>	<b>Ad description</b>	<b>Public link</b>
Alison	A girl in a cafeteria complains about a controlling presence in her life, which turned out to be cigarettes.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/726581264041096/">https://www.facebook.com/KNOWTheRealCost/videos/726581264041096/</a>
Fingers	A girl on the bleachers refuses to smoke because she doesn't want to break up her finger puppets on both her hands.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/978701128829107/">https://www.facebook.com/KNOWTheRealCost/videos/978701128829107/</a>
Band	A tiny bully drags a drummer away from band practice in a garage to smoke cigarettes.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/1018756794823540/">https://www.facebook.com/KNOWTheRealCost/videos/1018756794823540/</a>
Bully	A tiny man drags a teenage boy outside, takes money from a teenage girl, and forces a youth to smoke.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/721541524545070/">https://www.facebook.com/KNOWTheRealCost/videos/721541524545070/</a>
Dance	A tiny bully forces a teenage boy to leave his prom date to smoke cigarettes.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/1144576132241605/">https://www.facebook.com/KNOWTheRealCost/videos/1144576132241605/</a>
Found it	A scary creature crawls into a teenage boy's mouth before running into a cigarette pack.	No public link available.
Skinny Jeans	A teenage boy explains that he does not smoke because he cannot fit a pack of cigarettes in his skinny jeans.	<a href="https://www.facebook.com/KNOWTheRealCost/videos/987540941278459/">https://www.facebook.com/KNOWTheRealCost/videos/987540941278459/</a>
Science Class	A scary creature escapes when it was being dissected in a science class and crawls into a cigarette pack.	No public link available.

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Contract	A teenage girl talks about giving up her freedom by signing a contract that rolls into a cigarette.	<a href="https://www.youtube.com/watch?v=WnqZoKZuHCg">https://www.youtube.com/watch?v=WnqZoKZuHCg</a>
7,000	Thousands of creatures turn into 7,000 toxic chemicals as a guy inhales cigarette smoke.	No public link available.
Skin	A teenage girl tears off a piece of her skin in a convenience store to pay for a pack of cigarettes.	<a href="https://www.youtube.com/watch?v=asarKLMCvdo">https://www.youtube.com/watch?v=asarKLMCvdo</a>
Teeth	A young man uses pliers to pull out a tooth to pay for a pack of cigarettes.	No public link available.

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Supplementary Table 4. Example transcripts from message sharing task with high and low sharing engagement scores (Bold words are from the Biological process LIWC category, and underlined words are from the relativity LIWC category).

PSA Name	High sharing engagement	Low sharing engagement
#7000 chemicals	Uh this one was that one <u>where</u> it looks like this kids trying his <u>first time</u> <b>smoking</b> . So he sits <u>out</u> behind the house, and a bunch of these crazy alien-looking things <u>run out</u> of the woods, and <u>when</u> they are right about to hit them they all funnel themselves <u>into</u> a <b>breath</b> and <u>enter</u> the guy's <b>mouth</b> . And <u>then</u> he <b>coughs</b> it <u>back up</u> as it was the <b>cigarette smoke</b> . Uh sort of showing all the <b>toxic</b> and dangerous things that are <u>going in</u> every <u>time</u> you take a <b>breath</b> of the <b>cigarette</b> , and it was pretty creepy as well (Sharing engagement score = 27.03).	This one I thought was cool, because, like it was like a war type thing and it was really interesting. And like I would probably share it with my friends because they think it's cool too. And-and it would probably <u>stop</u> them from <b>smoking</b> if they did and uh, yeah (Sharing engagement score = 3.78).
Dance	Shows how you miss <u>out on</u> a lot of good opportunities because you're <b>addicted</b> to <b>smoking</b> . You know he's <u>at</u> a <u>dance</u> , probably a prom, and leaving his <u>date</u> all because he wants to <u>go</u> <b>smoke</b> a <b>cigarette</b> and is <b>addicted</b> to <b>cigarettes</b> and the <u>little</u> man got him <b>smoking</b> a <b>cigarette</b> . What is wrong with you, <u>stop</u> <b>smoking</b> the <b>cigarettes</b> , you need to be able to <u>go</u> to prom you know. <b>cigarettes</b> are bad, you get <b>addicted</b> and it ruins your <b>life</b> (Sharing engagement score = 25.59).	um, this is another one of those ones with the little guys who are really possessive and annoying, and basically he was ruining this guy's prom, um, by just sort of taking <u>over</u> and being like no we got to <u>go</u> we got to <u>go</u> . Oh you can't do this- and it was the same sort of idea with that other drummer boy, um, these were really cool and I kind of like these commercials (Sharing engagement score = 5.33).

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Supplementary Table 5. Items in the belief questionnaire and the belief category each item belongs to.

	Belief question	Theme
1	If I smoke every day, I will develop headaches.	Health risks
2	If I smoke every day, I will develop sexual and/or fertility problems	Health risks
3	If I smoke every day, I will develop cancer.	Health risks
4	If I smoke every day, I will get wrinkles.	Health risks
5	If I smoke every day, I will lose my teeth.	Health risks
6	If I smoke every day, I will get yellow fingers.	Health risks
7	If I smoke every day, I will become addicted to nicotine.	Loss of control
8	If I smoke every day, I will be controlled by smoking.	Loss of control
9	If I smoke every day, I will breathe in thousands of chemicals.	Dangerous chemicals
10	If I smoke every day, I will look uncool.	Social concern
11	If I smoke every day, it will be a turnoff to other people.	Social concern