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Adolescent neural responses to antismoking messages, perceived effectiveness, and sharing intention

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ABSTRACT

Health communication delivered via media channels can substantially influence adolescents' choices, and the effects of messages are amplified through interpersonal sharing. However, the underlying psychological and neurocognitive mechanisms that influence message effectiveness and likelihood of sharing are not well understood, especially among adolescents. Based on research in adults, we hypothesized and preregistered that message-induced neural activation in regions associated with self-reflection, social processing, and positive valuation would be related to greater perceived ad effectiveness and intentions to share messages. We focused on brain activity in meta-analytically defined regions associated with these three processes as 40 adolescent nonsmokers viewed advertisements from "The Real Cost" antismoking campaign. Perceived message effectiveness was positively associated with brain activity in the hypothesized social processing regions and marginally associated with brain activity in self-relevance regions, but not associated with brain activity in valuation regions. By contrast, intentions to share the messages were not associated with neural response in these 3 systems. In contrast to previous neuroimaging studies with adult subjects, our findings highlight the role of social cognition in adolescent processing of persuasive messages. We discuss the possibility that the mental processes responsive to effective and shareworthy messages may reflect developmental processes pertinent to media effects.

Introduction

Tobacco use is a major public health threat throughout the world and the leading cause of preventable death and disease in the United States. Initiation of smoking typically begins during adolescence, with 88% of smokers having initiated tobacco use before age 18 (US Department of Health and Human Services, 2014). Antismoking campaigns can influence young people's anti-smoking cognitions, which in turn predict campaign effects, including reduced intention to smoke and decreased smoking behavior (Allen et al., 2015;

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/hmep.
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US Department of Health and Human Services, 2014). Interpersonal communication about media content provides an important link between mass media messages and message effects (Jeong & Bae, 2017; Katz & Lazarsfeld, 1955; Southwell & Yzer, 2007, 2009). Antismoking campaigns can prompt conversations about campaign messages, which can influence targeted campaign outcomes for antismoking campaigns targeting adults and adolescents (Hafstad & Aaro, 1997; Hwang, 2012). Less is known about the message-induced psychological and neural processes that make messages effective and shareworthy among adolescents, a key target audience for anti-smoking campaigns.

One promising approach to improve our understanding of these mechanisms is to examine how antismoking messages are received and processed by the adolescent brain, and to link neural responses during message receipt to subsequent message effects. Neuroimaging, and functional magnetic resonance imaging (fMRI) in particular, offers a means for probing implicit cognitive processes in real time, and has been used to study the neural mechanisms associated with effective health messages, including messages from antismoking campaigns (for a review, see Whelan, Morgan, Sherar, Orme, & Esliger, 2017). However, little research has examined adolescent neural response to antismoking messages. In our study, we measured neural response in a sample of adolescents, and investigated the relationship between message-induced brain response and two outcomes of interest: perceived message effectiveness and sharing intention. *Perceived message effectiveness* can be defined as judgments of the effectiveness of a particular message (i.e., the extent to which the message is deemed convincing, informative, attention-grabbing, and/or memorable). *Sharing intention* is defined as an individual's intention to retransmit information through interpersonal communication channels.

Current theoretical accounts of the mechanisms underlying effective and shareworthy messages are based primarily on empirical evidence from adult studies. However, theoretical and empirical research on adolescents suggest that the cognitions that drive message effects in adolescents may differ from those in adults. The period of adolescence, which coincides with pubertal onset, represents a period of remarkable development in the adolescent brain (Crone & Dahl, 2012). Neural development is accompanied by sociocultural changes, as an increased awareness of and receptivity to social signals exert substantial influence on individuals' thoughts and actions (Blakemore & Mills, 2014; Crone & Dahl, 2012). Adolescents demonstrate both a shift from self-oriented to social-oriented behavior (Eisenberg & Fabes, 2006) and an enhanced desire for autonomy as they become increasingly independent (Steinberg & Silverberg, 1986). In light of these developmental changes, it is unclear what neurocognitive processes drive message effects in adolescents. Here, we review literature about the neural correlates of effective and shareworthy messages in adults and neurodevelopmental considerations in adolescents to highlight what is already known about these processes and how they may present during adolescence.

Self-relevance and message effectiveness

A great deal of communication research has identified characteristics of effective health messages. One strategy for maximizing message effects involves increasing the personal relevance of messages (e.g., through message tailoring), which in turn enhances motivation to process health information (Rimer & Kreuter, 2006). This increased motivation, generated by personal relevance, can lead to greater message elaboration and persuasive effects (Petty & Cacioppo, 1986). More broadly, messages that are rated as self-relevant (they contain content that is deemed personally relevant; Strecher, Shiffman, & West, 2006) or prompt enhanced activation in brain regions implicated in self-related processing (Chua et al., 2011; Cooper, Tompson, O'Donnell, & Falk, 2015; Falk et al., 2016) are more effective in changing health behaviors. In particular, judgments about self-relevance have been shown to engage specific regions of the brain, namely the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC; Murray, Schaer, & Debbané, 2012). Several studies have identified links between neural activity in the MPFC during message exposure and targeted outcomes, including calls to a smoking quitline (Falk, Berkman, & Lieberman, 2012), clicks in an antismoking email campaign (Falk et al., 2016), smoking reduction (Falk, Berkman, Whalen, & Lieberman, 2011), and smoking cessation (Chua et al., 2011). This link is thought to stem from MPFC's role in integrating multiple cognitive and affective inputs to arrive at a summary judgment of how valuable and self-relevant a piece of information might be to a given individual (Falk & Scholz, 2018).

In one such study, adult smokers viewed antismoking advertisements during an fMRI scan (Falk et al., 2011) and completed self-report ratings of the ads. Expired carbon monoxide (CO), a biological measure of recent smoking, was measured at baseline and one month post-scan. Results demonstrated that neural activity in MPFC and ad-specific self-report ratings (intention to quit, self-efficacy to quit, and self-relevance of ads) predicted independent variance in changes in CO, suggesting that MPFC may capture an implicit form of self-relevance not indexed by these self-reports. In another study (Chua et al., 2011), smokers interested in quitting completed an fMRI scan during which they viewed tailored, untailored, and neutral smoking cessation messages. Participants then completed a web-based tailored smoking cessation program and a follow-up interview 4 months later to assess smoking status. Analyses indicated that brain regions including the dorsomedial prefrontal cortex (DMPFC; a subregion of the MPFC), precuneus, and angular gyrus were preferentially engaged by both tailored messages and self-related processing. Relative to a neutral condition, mean neural response in the DMPFC during exposure to tailored smoking cessation messages significantly predicted the odds of quitting smoking. These findings complement other communication research demonstrating that messages

with higher personal relevance have a greater influence on health behavior than comparison or control conditions (Noar, Benac, & Harris, 2007).

Together, these findings suggest that self-related considerations during message exposure, as indexed by response in specific regions of the brain, may partially influence health behavior change. Furthermore, neural response to messages can complement self-report measures of campaign efficacy by explaining additional variance in campaign effects. However, as detailed in the following section, these findings were all obtained in adult samples, and scant research has tested the link between neural response to campaign messages and messages effects among adolescents. Despite evidence that self-relevant processing in adolescents is also indexed in the MPFC (Pfeifer et al., 2009), it is unclear whether the same form of self-related processes are as central to messages that are influential for adolescents. In light of the developmental changes characteristic of adolescence that may influence self-related considerations (Crone & Dahl, 2012; Eisenberg & Fabes, 2006; Steinberg & Silverberg, 1986), a lack of research in this domain warrants an examination of whether adolescent neural response in regions involved in self-relevant processing associate with message effectiveness.

Social processing and message effectiveness

Theories of behavior change highlight the role of normative beliefs—perceptions about peer engagement in a particular behavior—in predicting behavioral outcomes across populations (Fishbein & Ajzen, 2011). Among adolescents in particular, there is empirical support for this theorized relationship in the domain of tobacco use research (Liu, Zhao, Chen, Falk & Albarracín, 2017) and particularly in studies of message effects (Ho, Poorisat, Neo, & Detenber, 2014; Moran & Sussman, 2014; Paek, 2008). Taken together, findings suggest that people take the perspectives, beliefs, and behaviors of their peers into account when forming their own intentions to engage in a particular behavior, and that this normative information can be obtained through exposure to health messages. The influence of normative beliefs and behaviors are especially heightened among adolescents (Brown, Clasen, & Eicher, 1986), suggesting that adolescents' consideration of normative information, as relayed through health messages, may exert substantial influence on subsequent message effects.

Neuroimaging research has identified a group of brain regions implicated in mentalizing, or the ability to understand the mental states of others (Frith & Frith, 2006), and social processing more broadly, which includes interpreting social feedback, considering the repercussions of others' actions, and anticipating the social consequences of one's own actions (Blakemore, 2008). This social processing system, comprised of regions within the dorsal, middle, and ventral components of the medial prefrontal cortex (DMPFC, MMPFC, and VMPFC), precuneus (PC), bilateral temporal parietal junction (TPJ), and right superior temporal sulcus (rTPS), was activated in a large sample of participants while

they considered others' beliefs (Dufour et al., 2013). In adolescents, activation of regions within this system scales with receiving social feedback (Welborn et al., 2015), incorporation of peer feedback into product recommendations (Cascio, O'Donnell, Bayer, Tinney, & Falk, 2015), and viewing photos that are liked by peers (Sherman, Payton, Hernandez, Greenfield, & Dapretto, 2016). Neural response in these brain regions may also index self-relevant processing in adolescents; previous research that has shown greater activity in brain regions relevant to social processing in adolescents, relative to adults, when prompted to self-reflect (Pfeifer et al., 2009), suggesting that adolescents incorporate others' perspectives into their own self-concept. Given theories and research that link social norms with message effects (Cialdini et al., 2006; Goldstein, Cialdini, & Griskevicius, 2008), and the prospect that adolescents use social information in determining self-relevance (Pfeifer et al., 2009), neural response in the social processing system may be important in determining perceived message effectiveness in adolescents.

In the few studies that have examined the neural processes underlying perceived message effectiveness, findings offer evidence consistent with the notion that effective ads inspire social thought. In one recent study, young adults viewed anti-drug public service announcements (PSAs) during an fMRI scan, then rated their perceived message effectiveness of each ad (Donohew et al., 2017). Results demonstrated that greater neural activation in the left temporal pole and dorsomedial prefrontal cortex, regions previously linked to social processing and mentalizing (Dufour et al., 2013; Olson, Plotzker, & Ezzyat, 2007), while viewing antidrug messages was associated with higher ratings of perceived message effectiveness. Findings suggest that ads that elicit socio-cognitive processing may be perceived as more effective; however, the results were specific to young adults and may or may not translate to adolescent samples. In another study, adolescents viewed anti-drug PSAs and nondrug ads during an fMRI scan and rated the perceived convincingness of these ads (Ramsay, Yzer, Luciana, Vohs, & MacDonald, 2013). Participants demonstrated increased activity in brain regions involved in self-related, social, and emotional processing, including the amygdala and a region of the MPFC, while viewing PSAs relative to nondrug ads. Furthermore, individual differences in neural response to messages in the lateral prefrontal cortex, a brain region implicated in executive control functions, was correlated with aggregates of participants' self-reported perceived convincingness of these PSAs. Findings demonstrate that among adolescents, messages that are rated as persuasive engage activation in brain regions involved in self-related, social, and emotional processing and executive control.

Though results offer evidence somewhat consistent with prior theoretical and empirical research regarding the role of normative information on health behavior, they provide insufficient evidence with which to make claims about the neural correlates of persuasive messages in adolescents. Considering the

central role of normative information as a determinant of adolescent behavior (Liu et al., 2017) and the extent to which adolescence is marked by social and neural development (Blakemore, 2008; Crone & Dahl, 2012), a lack of conclusive evidence regarding the link between social processing and perceived message effectiveness warrants additional adolescent research.

Positive value and message effectiveness

More broadly, messages that are more effective might also prompt positive valuation, or consideration of the worth of the information contained in the messages, thus engaging the value system in their receivers, including the ventromedial prefrontal cortex (VMPFC) and ventral striatum (VS; Bartra, McGuire, & Kable, 2013). Indeed, several major theories have argued that helping a message recipient find personal value in messages is key to behavior change (Darke & Chaiken, 2005; Fishbein & Ajzen, 2011; Glanz, Rimer, & Viswanath, 2008). Theories of behavior change, such as the Theory of Reasoned Action and Health Belief Model, operate on the premise that beliefs about the benefits of engaging in (or abstaining from) a behavior are key predictors of behavioral outcomes (Fishbein & Ajzen, 2011; Rosenstock, 1974). According to these theories, we would expect messages that prompt individuals to consider the value of engaging in a behavior to influence their behavioral performance.

Likewise, activity in brain regions that compute the expected value of outcomes, including the VMPFC and VS, have been associated with positive message effects (Cooper et al., 2015; Falk et al., 2015; Vezich, Katzman, Ames, Falk, & Lieberman, 2017). In adolescents, this value system is particularly sensitive to social inputs (for a review see Telzer, 2016) and may aid in determining the extent to which adolescents perceive messages to be valuable.

The role of self-relevance, social processing, and valuation in sharing

The sharing of campaign content may increase the effectiveness of an antismoking campaign (Hafstad & Aaro, 1997; Hwang, 2012) through the diffusion of messages to individuals who would otherwise be unexposed to the campaign or by reinforcing the social norms pertinent to a campaign message (Jeong, Tan, Brennan, Gibson, & Hornik, 2015). Consequently, we are also interested in neurocognitive processes associated with adolescents' desires to share about the campaign. Preliminary neuroimaging studies have linked activation in regions within the social processing system to the successful transmission of ideas and recommendations, and emphasize the role of activity in the communicator's DMPFC (Falk, Morelli, Welborn, Dambacher, & Lieberman, 2013; Falk, O'Donnell, & Lieberman, 2012) and TPJ (Cascio et al., 2015; Falk et al., 2013; Falk, O'Donnell, et al., 2012) in this process. These findings are

complemented by evidence that neural activity in regions implicated in self-related processing during message exposure, including MPFC and PCC, as well as positive valuation, including VMPFC and VS, are associated with greater enthusiasm for sharing ideas (Falk, O'Donnell, 2012) and greater intention and success in propagating messages (Falk et al., 2013) in adults. Neural activity in self-relevance, social processing, and value systems during exposure to health news headlines was positively related to self-reported intention to share (Baek, Scholz, O'Donnell, & Falk, 2017) and population-level measures of actual sharing behavior (Scholz et al., 2017). Together, these findings suggest that activity in these brain regions may index an intention to share and successful transmission of content.

Perceived message effectiveness and sharing in adolescents

Are the psychological processes evident in adults key to perceived message effectiveness and sharing intent in adolescents? As touched on previously, despite initial findings in adults, no prior fMRI study has examined perceived message effectiveness and sharing intention in the same cohort, nor explored these processes in a sample of adolescents. Observed differences between adolescent and adult neural response in brain regions within these systems (Barkley-Levenson & Galván, 2014; Pfeifer & Blakemore, 2012; Pfeifer, Lieberman, & Dapretto, 2007; Pfeifer et al., 2009; Richards, Plate, & Ernst, 2013) raise questions about the nature of neural activity in adolescents' self-relevance, social processing, and value systems and how it relates to their intention to share content on social media. More broadly, adolescence is a key period in which sensitivity to social cues is heightened and rapid changes occur in social and brain development. The increased influence of peers leads adolescents to alter their behavior as a means to gain social acceptance (Steinberg & Monahan, 2007), as the rewards and threats that are most salient to adolescents are typically social in nature (Crone & Dahl, 2012). The hormonal changes that stimulate adolescent pubertal maturation are accompanied by complex social-cognitive changes (for a review, see Crone & Dahl, 2012). One relevant social-cognitive process is the ability to mentalize, or make inferences about the mental states of others (Frith & Frith, 2006). The ability to mentalize develops during childhood, but during adolescence individuals exhibit a more marked shift from self-oriented to social-oriented behavior (Eisenberg & Fabes, 2006). As such, self and social cognitions may contribute differently to perceptions of campaign effectiveness, and ultimate valuation of ideas, in adolescents relative to other groups that have been studied.

This study

The goal of this study was to understand the neural processes underlying the perceived effectiveness of ads and how these processes may relate to adolescents' sharing of ads on social media. Neuroimaging methods afford the measurement of multiple processes, simultaneously, during exposure to messages in real time, thus providing information about the cognitive mechanisms associated with message effects that take hold in real time as participants are exposed to messaging. By contrast, self-report measures must either actively interrupt the process of natural exposure, or can offer retrospective, summary reports of individuals' thoughts and feelings about a message during the exposure period (as we use as the outcomes in this study). Here, we were particularly interested in understanding the message-induced cognitive processes during exposure that are associated with later perceiving a message to be effective and shareworthy, thus combining the strengths of different tools (neuroimaging and self-reports of subjective experience). We focused our study on adolescents for two central reasons. Most of the research that has examined the neural correlates of effective and shareworthy messages has been conducted in adults, and thus there is a lack of adolescent research in this domain. Furthermore, adolescents are an important target population for health campaigns; though adolescence is associated with increased health risks given the tendency to engage in risky behaviors (Albert, Chein, & Steinberg, 2013), it also presents opportunities to enhance long-term health outcomes through educational and preventive efforts (Kleinert, 2007).

To examine the aforementioned relationships, we combined measures of adolescent neural response to advertisements from "The Real Cost" national antismoking campaign with subsequent ratings of perceived ad effectiveness and intention to share these ads on social media. "The Real Cost" campaign, launched in February 2014, is an ongoing, national campaign funded by the US Food and Drug Administration (FDA) that aims to prevent adolescent nonsmokers from initiating smoking by educating youth about the "real costs" of smoking (Duke et al., 2015). The campaign targets antitobacco beliefs that are expected to influence behavior, including the loss of control due to smoking addiction, the dangerous chemicals found in cigarettes, and the negative health and cosmetic effects associated with smoking.

Considering theories and empirical research relevant to the neural correlates of effective and shareworthy messages in adults, and developmental considerations in adolescents, we preregistered hypotheses that neural activity in these self-relevant, social, and value systems during ad exposure would be positively associated with participants' evaluations of the efficacy of the messages. Specifically, we hypothesized that in a sample of adolescents, a composite measure of perceived ad effectiveness would scale with neural activity in all three systems during exposure to the ads. Further, we hypothesized that neural activity in these systems during message exposure would be positively related to participants' intention to share

ads, and preregistered this hypothesis.¹ Specifically, we anticipated that the more likely an individual was to share a message on social media, the stronger the neural response to the message would be in these sets of brain regions.

Methods

Participants

Forty-four adolescent nonsmokers between the ages of 14 and 17, from the greater Philadelphia area, were recruited to participate in this fMRI study. All participants provided informed assent and parental consent was obtained in accordance with the procedures of the Institutional Review Board at the University of Pennsylvania. One participant was excluded from the study due to scheduling issues and three participants were excluded from data analyses due to excessive head motion ($n = 1$), discomfort in the scanner ($n = 1$), and lack of variance in sharing ratings ($n = 1$).

Eligibility screening

To be included in the study, participants had to report that they were nonsmokers, defined as not having smoked in the previous 30 days and a lifetime history of having smoked fewer than 100 cigarettes, and were required to meet standard fMRI eligibility criteria, including having no metal in their bodies and no history of psychiatric or neurological disorders. We oversampled high sensation seekers (a combined score of at least 12 out of 16 on the Brief Sensation Seeking Scale [BSSS-4]) as they are at greater risk of smoking initiation (Sargent, Tanski, Stoolmiller, & Hanewinkel, 2010); thus, eligibility was contingent upon sensation seeking as assessed during the eligibility screen. Potential participants of all sensation-seeking levels were eligible to participate. Participants were recruited until a cap was met for each subgroup (low-moderate- and high-sensation seekers). This resulted in a study sample with 21 high-sensation seekers and 19 low-moderate-sensation seekers.

Demographic distributions

The study sample was comprised of 40 adolescents aged 14–17, with a mean age of 16.1 years ($SD = 0.94$). The sample was approximately evenly distributed by sex, with 21 girls (52.5%). There was variation in participants' race, with 13 White (23.5%), 13 Black/African American (23.5%), and 8 Asian participants (20%), and 6 participants of Other or multiple races (15%). Sensation-seeking scores ranged from 7 to 16, with a mean of 11.7 ($SD = 1.88$). Among low-moderate sensation seekers, the mean score was 10.05 ($SD = 1.03$), and among high sensation seekers, the mean score was

13.19 ($SD = 1.03$). High-sensation seekers scored significantly higher on the Brief Sensation Seeking Scale (BSSS-4) than low-moderate-sensation seekers ($t = 9.64, p < .001$).

Prescan tasks

During the week prior to the fMRI scan session, participants completed a web-based baseline questionnaire to assess prior exposure to “The Real Cost” ads, demographic information (e.g., age, sex, race), as well as smoking-relevant cognitions and behaviors and individual difference measures not addressed here. At the in-person scanning session, prior to the fMRI scan, participants completed a practice run of the fMRI task in which they viewed a preparation countdown and an ad from “The Real Cost” campaign, rated their intention to share the ad, then closed their eyes and reimagined the ad. The practice run was conducted with a “Real Cost” ad not included in study stimuli.

Stimuli

The stimuli for this study consisted of 12 antismoking public service announcements (PSAs) from the FDA’s “The Real Cost” smoking prevention campaign. Each 30-sec, high-quality audiovisual advertisement was professionally produced. Examples of the content of these ads include a teenage girl who tears off a piece of her skin in exchange for cigarettes, a teenage boy who yanks out one of his teeth in exchange for cigarettes, and a teenage girl who complains about cigarettes being “bossy,” as if describing a boyfriend. See [Table 1](#) for descriptions of each ad used in this study and links to the campaign page and sample videos.

fMRI PSA task

During the PSA viewing task ([Figure 1](#)), participants viewed, rated their intention to share, and reimagined each of 12 PSAs from “The Real Cost” campaign. For each ad, participants first viewed a 4-sec preparation countdown and were then instructed to view one of the 30-sec “Real Cost” ads, presented in random order. Subsequently, participants were instructed to rate their intention to share the ad using an MRI-compatible button box. Last, participants were asked to close their eyes and instructed to reimagine the ad over a 10-sec period.² Each participant completed the preparation countdown, view, sharing rating, and reimagine tasks in the same order for all 12 ads, however the order in which ads were presented was randomized.

Table 1. Names and descriptions of 12 advertisements from The Real Cost campaign.

Ad name	Ad description
Alison	A girl in a cafeteria complains about cigarettes being so bossy.
Any Reason	A girl won't smoke because she doesn't want to break up her finger puppets.
Band	A tiny bully drags a drummer away from band practice to smoke.
Bully	A tiny man bullies young people into smoking cigarettes.
Dance	A tiny bully makes a teen leave his prom date for a smoke.
Found it	A disgusting creature crawls into a teen's mouth before hiding in a cigarette pack.
#ReasonsNotToSmoke	A skater doesn't smoke because he can't fit a pack of cigarettes in his skinny jeans.
Science Class	A disgusting creature escapes while being dissected in a science class and crawls into a cigarette pack.
Stay in Control	A girl gives up her freedom by signing a contract that turns into a cigarette.
The 7,000	Swamp creatures turn into 7,000 toxic chemicals as a guy inhales cigarette smoke.
Your Skin	A girl tears off a piece of her skin to pay for a pack of cigarettes.
Your Teeth	A guy yanks out a tooth to pay for a pack of cigarettes.

Note. Links to the campaign page and sample videos are listed below:

<https://www.fda.gov/TobaccoProducts/PublicHealthEducation/PublicEducationCampaigns/TheRealCostCampaign/default.htm>

<https://www.youtube.com/user/KnowTheRealCost/videos>

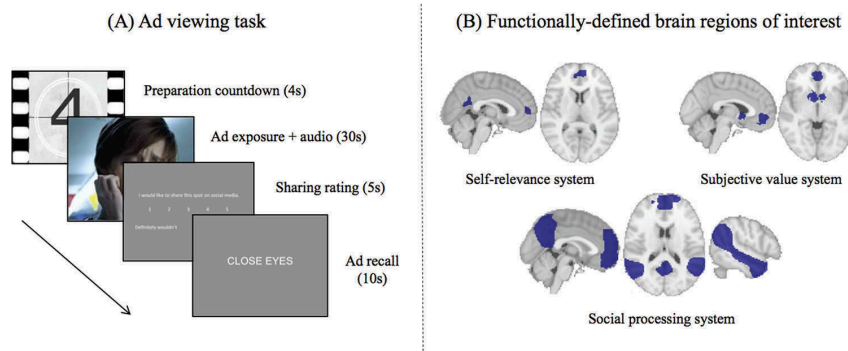


Figure 1. (A) The ad viewing task was completed as part of the fMRI scan. For each of 12 ads, participants first viewed a 4-sec preparation countdown and were then instructed to view one of the 30-sec “Real Cost” ads, presented in random order. Subsequently, participants were instructed to rate their intention to share the ad using an MRI-compatible button box. Lastly, participants were asked to close their eyes and instructed to reimagine the ad over a 10-sec period. Each participant completed the preparation countdown, view, sharing rating, and reimagine tasks in the same order for all 12 ads, however the order in which ads were presented was randomized. (B) The self-relevance system is comprised of the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC), the subjective value system is comprised of the ventromedial prefrontal cortex (VMPFC) and ventral striatum (VS), and the social processing system is comprised of the right temporal parietal junction (rTPJ), left temporal parietal junction (lTPJ), dorsal, middle, and ventral components of the medial prefrontal cortex (DMPFC, MMPFC, and VMPFC), precuneus (PC), and right superior temporal sulcus (rSTS). Each set of regions was treated as a system (self-relevance, social processing, and subjective value) in all analyses.

Postscan tasks

After the scanning session, participants completed a web-based questionnaire that included perceived effectiveness items for the ads shown in the scanner. For

each ad, participants were shown three screenshots of the ad and asked to indicate their level of agreement with six statements pertinent to ad effectiveness. Participants completed this task in random order for all 12 “Real Cost” ads.

In previous research examining the neural underpinnings of effective health messages, the outcomes of interest have most commonly been operationalized as behavioral intentions or actual behavior (Baek et al., 2017; Cooper et al., 2015; Falk et al., 2011). In this study, however, we opted to use perceived ad effectiveness in lieu of intentions to smoke or smoking behavior for several reasons. We recruited adolescent nonsmokers for this study, so as to align our study sample with the target population of “The Real Cost” campaign (12- to 17-year-old nonsmokers and smoking experimenters); as such, they reported no smoking behavior and very low intention to smoke. With virtually no variation in these variables, we would have been unable to detect any differences in these outcomes as a function of neural activity with the sample size available for a neuroimaging experiment. Given findings from studies indicating that perceived effectiveness is substantially associated with actual effectiveness (Dillard, Weber, & Vail, 2007) and a causal antecedent to it (Dillard, Shen, & Vail, 2007), we focused on participants’ perceived ad effectiveness ratings as a primary outcome of interest.

Measures

Perceived ad effectiveness

The first dependent variable was participants’ perceived effectiveness of ads from “The Real Cost” campaign. Participants were shown each of the following statements and asked to indicate their agreement on a 5-point scale (1 = *strongly disagree*, 5 = *strongly agree*): “This ad is worth remembering,” “This ad grabbed my attention,” “This ad is powerful,” “This ad is informative,” “This ad is meaningful,” and “This ad is convincing.” Responses to one additional statement, “This ad is terrible,” were excluded from analyses to align the perceived effectiveness scale with that used in the FDA-funded campaign evaluation. Results from analyses based on the 6- and 7-item perceived effectiveness scales were not substantively different.

We assessed participants’ ratings of perceived ad effectiveness by averaging their responses to six perceived effectiveness items for each ad (Cronbach’s $\alpha = 0.92$). Across all 12 “Real Cost” ads, participants rated them as moderately effective ($M = 3.55$, $SD = 1.00$). Mean perceived effectiveness varied both within and between ads. Within ads, mean perceived effectiveness across participants ranged from 2.83 ($SD = 1.06$) to 4.12 ($SD = 0.82$). In other words, some ads were generally perceived to be more effective than other ads. Within participants, mean perceived effectiveness across ads ranged from 2.06 ($SD = 1.42$) to 4.67 ($SD = 0.48$). That is, some participants generally rated ads as more effective than other participants. We calculated

intraclass correlation coefficients (ICC) to determine the proportion of individual variance in perceived effectiveness ratings accounted for by between-subject and between-ad differences (Bliese, 2016). Results indicated that 20% of the variance in perceived effectiveness ratings was explained by between-subject differences, indicating that perceived effectiveness varied more within subjects than between subjects ($ICC1 = 0.20$). Similarly, 17% of the variance in perceived effectiveness ratings was explained by between-ad differences, indicating that perceived effectiveness varied more within ads than between ads ($ICC1 = 0.17$). In other words, there was variation in which ads different people preferred, and participants provided a range of ratings across ads.

Intention to share

The second dependent variable was participants' intention to share ads from "The Real Cost" campaign on social media. After viewing each ad, participants were shown the statement "I would like to share this spot on social media" and asked to indicate their agreement on a 5-point scale (1 = *definitely wouldn't*, 5 = *definitely would*). Participants reported moderate intention to share ads on social media across all 12 "Real Cost" ads ($M = 3.07$, $SD = 1.28$). Intention to share varied both within and between ads. Within ads, mean intention-to-share ratings ranged from 2.70 ($SD = 1.20$) to 3.62 ($SD = 1.14$). That is, some ads were rated as more shareworthy than others. Within participants, mean intention-to-share ratings ranged from 1.25 ($SD = 0.45$) to 4.75 ($SD = 0.45$). In other words, across all ads, some participants had greater intention to share ads relative to their peers. ICC coefficients indicated that 37% of the variance in intention-to-share ratings was attributed to between-subject differences, indicating that intention to share varied more within than between subjects ($ICC1 = 0.37$). Conversely, only 2% of the variance in intention-to-share ratings was explained by between-ad differences, indicating that intention to share varied almost entirely within ads, rather than between ads ($ICC1 = 0.02$). In other words, although some individuals were mildly biased to share more or less across ads, participants generally varied in which ads they preferred.

fMRI data acquisition

All neuroimaging data were acquired using a 3 Tesla Siemens Magnetom MRI scanner equipped with a 32-channel head coil at the Center for Functional Neuroimaging at the University of Pennsylvania. The primary task of interest included one functional run for each participant (735 volumes), presented among other tasks that are not the focus of the current investigation. Functional images were recorded using a multiband sequence ($TR = 1000$ ms, $TE = 32$ ms, flip angle = 60 deg, 56 axial slices, $FOV = 208$ mm, slice thickness = 2.5 mm; voxel size = $2.5 \times 2.5 \times 2.5$ mm). We also acquired a high-resolution T1-weighted image using

an MP-RAGE sequence (TR = 1850.0 ms, 160 slices, voxel size = $0.9 \times 0.9 \times 1.0$ mm) for use in coregistration and normalization. To allow for the stabilization of the BOLD signal, the first six volumes of each run were immediately discarded during the scan.

Preregistered region of interest selection

In line with a set of pre-registered hypotheses, we selected a series of a priori theory-driven regions of interest (ROIs) that belong to three systems. Specifically, our analyses focused on activity in the MPFC and PCC (see [Figure 1](#)), as defined by a meta-analysis of self-relevant processing (Murray et al., 2012); the right TPJ (rTPJ); left TPJ (lTPJ); DMPFC, MMPFC, and VMPFC; PC, and right superior temporal sulcus (rSTS; see [Figure 1](#)), as defined by a large-scale study of mentalizing (Dufour et al., 2013); and the VMPFC and VS (see [Figure 1](#)), as defined by a meta-analysis of the neural correlates of subjective value (Bartra et al., 2013). We treated each set of regions as a system (self-relevance, social processing, and subjective value) in all analyses.

Analyses

fMRI data preprocessing

Functional data were preprocessed and analyzed using FSL and Statistical Parametric Mapping (SPM12, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). Data were corrected for differences in the time of slice acquisition using sinc interpolation, spatially realigned to correct for head motion, and coregistered to the structural image. Data were then normalized to the skull-stripped Montreal Neurological Institute (MNI) template provided by FSL (FMRIB Software Library; MNI152_T1_1 mm_brain.nii). Functional images were smoothed using a Gaussian kernel (8 mm full width at half maximum).

fMRI data extraction and analyses

We first adopted an ROI approach to investigate the relationship between parameter estimates of neural activity during ad exposure and, separately, self-reports of perceived ad effectiveness and sharing intention. Analyses were conducted using sets of a priori theory-driven regions of interest implicated in self-relevant processing, social processing, and subjective valuation (as defined in Methods; see [Figure 1](#)).

The fMRI data were modeled using the general linear model (GLM) as implemented in SPM8 (SPM8, Wellcome Department of Cognitive Neurology, Institute of Neurology, London, UK). At the first level, a separate

regressor was defined during the viewing period (30 sec) for each of the 12 ads, resulting in 12 ad-specific regressors for each participant. The same procedure was employed during the reimagine period (10 sec), resulting in an additional 12 ad-specific regressors for each participant. The preparation countdown task period was captured in a single regressor. The six rigid-body translation and rotation parameters derived from spatial realignment were also included as nuisance regressors in all first-level models.

We extracted parameter estimates from these sets of regions during the viewing period using the MarsBar toolkit from SPM (Brett, Anton, Valabregue, & Poline, 2002) and converted them to percent signal change, resulting in 12 values for each brain system for each participant. These values were combined with perceived effectiveness and sharing ratings by participant and ad in R (R Core Team, 2015). Prior to analyses, we standardized (z-scored) mean neural activity and self-report data across subjects and used standardized variables in all regression models. We used the *lmerTest* package (Kuznetsova, Brockhoff, & Christensen, 2016) in R to create mixed-effect multilevel models in which neural response in each system (self-relevance, social processing, and subjective value) was used to separately predict each outcome of interest (perceived effectiveness and intention-to-share ratings). In all models, participants and ads were treated as random effects, with random intercepts to account for nonindependence of repeated measures within subjects,³ and analyses controlled for age, sex, race, and prior recall of each “The Real Cost” ad as assessed during the baseline questionnaire.

Subsequently, we conducted exploratory whole-brain analyses to determine brain regions outside of hypothesized regions of interest in which neural activity during ad exposure scaled with subsequent ratings of perceived ad effectiveness and sharing intention (i.e., whole brain models in which participant ratings are treated as predictor variables and the brain is treated as the outcome variable). Two additional models were built for each subject with a single regressor for the viewing period for all ads with participants’ standardized (a) perceived effectiveness and (b) sharing ratings used as a parametric modulator of brain activity. An additional regressor was used to capture the reimagine period and six movement nuisance regressors were used. Data were high-pass filtered with a cutoff of 128 sec in all models.

Parametric modulation analyses of the effects of variation in perceived effectiveness ratings on neural response during each ad exposure, described previously, were combined using a random effects model in SPM. As described earlier, we built individual models for each participant, modeling the period of exposure to each ad in one regressor, a parametric modulator of perceived effectiveness, and a final regressor modeling other periods of no interest to this analysis (preparation countdown, sharing rating, and reimagining). These individual maps were combined in a random effects analysis at the group

level. The resulting image maps were cluster corrected using 3dClustSim (version AFNI_16.2.02) at $p = .005$, $k > 504$, corresponding to $p = .05$, corrected. Likewise, parallel models were built using a parametric modulator of standardized sharing rating.

Results

Neural activity during ad exposure and perceived ad effectiveness

We first examined perceived ad effectiveness as a function of neural activity within self-relevance, social processing, and value regions of interest during ad exposure (Table 2). Within the social processing system during ad exposure, neural activity was significantly associated with mean perceived effectiveness

Table 2. Results from separate multilevel regression models assessing the relationship between neural activity in self-relevance, social processing, and subjective value systems during ad exposure, mean perceived effectiveness, and intention to share ads.

	Perceived Effectiveness					Intention to Share				
	<i>B</i>	<i>SE</i>	β	<i>t</i>	<i>df</i>	<i>B</i>	<i>SE</i>	β	<i>t</i>	<i>df</i>
Self-relevance ^a	0.19	0.10	0.10	1.89	348	-0.16	0.14	-0.06	-1.16	408
Age	0.03	0.09	0.03	0.36	34	0.02	0.14	0.01	0.14	34
Sex	-0.32†	0.16	-0.16	-1.98	34	-0.37	0.25	-0.14	-1.49	34
Black	0.28	0.20	0.13	1.42	35	0.67*	0.30	0.24*	2.20	35
Asian	-0.19	0.22	-0.08	-0.85	35	-0.13	0.34	-0.04	-0.39	35
Other/multiple	0.32	0.26	0.11	1.24	34	0.79*	0.39	0.22*	2.03	34
Ad recall	0.18*	0.09	0.09	2.02	470	0.11	0.11	0.04	0.94	430
Social processing ^b	0.32*	0.13	0.12	2.37	390	0.05	0.17	0.01	0.26	421
Age	0.02	0.09	0.02	0.22	34	0.01	0.14	0.01	0.10	34
Sex	-0.29†	0.16	-0.15	-1.78	34	-0.39	0.24	-0.15	-1.57	34
Black	0.28	0.20	0.13	1.39	34	0.71*	0.30	0.26	2.36	35
Asian	-0.17	0.23	-0.07	-0.73	35	-0.13	0.34	-0.04	-0.38	35
Other/multiple	0.31	0.26	0.11	1.18	34	0.77†	0.39	0.21	1.97	34
Ad recall	0.19*	0.09	0.09	2.09	470	0.10	0.11	0.04	0.90	432
Subjective value ^c	0.12	0.12	0.05	1.02	400	-0.21	0.16	-0.07	-1.35	435
Age	0.03	0.09	0.03	0.37	34	0.02	0.14	0.02	0.15	34
Sex	-0.29†	0.16	-0.15	-1.79	34	-0.39	0.24	-0.15	-1.61	34
Black	0.27	0.20	0.13	1.35	35	0.64*	0.30	0.23	2.11	36
Asian	-0.19	0.23	-0.07	-0.82	34	-0.13	0.34	-0.04	-0.40	35
Other/multiple	0.33	0.26	0.12	1.28	34	0.80*	0.39	0.22*	2.07	34
Ad recall	0.19*	0.09	0.10*	2.10	471	0.11	0.11	0.04	0.92	433

Note. Separate regression models were estimated for each system (3) and each outcome of interest (2), controlling for age, sex, race (reference category = White), and prior recall of each The Real Cost ad. Parallel analyses excluding control variables (not shown) produced similar results.

SE = standard error. † $p < .10$, * $p < .05$

^a The self-relevance system is comprised of the medial prefrontal cortex (MPFC) and posterior cingulate cortex (PCC).

^b The social processing system is comprised of the bilateral temporal parietal junction (TPJ), dorsal, middle, and ventral components of the medial prefrontal cortex (DMPFC, MMPFC, and VMPFC), precuneus (PC), and right superior temporal sulcus (rSTS).

^c The subjective value system is comprised of the ventromedial prefrontal cortex (VMPFC) and ventral striatum (VS).

($\beta = .12, t(390) = 2.37, p < .05, 95\% \text{ CI } [0.02, 0.21]$). By contrast, neural activity in the self-relevance system was marginally associated with mean perceived effectiveness ($\beta = .10, t(348) = 1.89, p < .10, 95\% \text{ CI } [-0.00, 0.20]$), and neural activity in the value system did not predict mean perceived effectiveness ($\beta = .05, t(400) = 1.02, p > .10, 95\% \text{ CI } [-0.05, 0.15]$). We conducted a parallel set of analyses in which we controlled for age, sex, race, prior ad recall, and sensation seeking (high vs. low or moderate). Results indicated that, in all models, the coefficient for sensation seeking was nonsignificant and the coefficients for all other variables did not differ substantively from the original models. Exploratory whole brain analyses, cluster corrected using 3dClustSim at $p < .005, k > 504$, corresponding to $p < .05$ corrected, did not produce any other activations that survived whole brain correction.

Neural activity during ad exposure and intention to share

We next examined intention-to-share ratings as a function of neural activity in the self-relevance, social processing, and subjective value regions of interest during ad exposure (Table 2). Neural activity during ad exposure in the hypothesized regions of interest within the self-relevance ($\beta = -.06, t(408) = -1.16, p > .10, 95\% \text{ CI } [-0.16, 0.04]$), social processing ($\beta = .01, t(421) = 0.26, p > .10, 95\% \text{ CI } [-0.09, 0.11]$), and subjective value ($\beta = -.07, t(435) = -1.35, p > .10, 95\% \text{ CI } [-0.17, 0.03]$) systems was not significantly associated with intention to share ads. We conducted a parallel set of analyses in which we controlled for age, sex, race, prior ad recall, and sensation seeking (high vs. low or moderate). Results indicated that, in all models, the coefficient for sensation seeking was nonsignificant and the coefficients for all other variables did not differ substantively from the original models. Additionally, no regions of interest within these systems survived more stringent correction ($p < .005, k > 504$, corresponding to $p < .05$ corrected) within a whole brain analysis.

Discussion

This study assessed the relationships between adolescents' neural activity during exposure to ads from "The Real Cost" antismoking campaign and two outcomes relevant to campaign ads: perceived ad effectiveness and the intention to share ads on social media. Mean perceived ad effectiveness was positively associated with neural activity in the social processing system and marginally associated with neural response in the self-relevance system. However, perceived effectiveness was not associated with neural activity in the subjective value system. Conversely, intention to share ads on social media was not associated with neural activity in the social processing, self-relevance, or subjective value systems.

Our findings are consistent with the idea that the mental processes responsive to effective messages in adolescents are more focused on social processing than self-related cognitions. Substantial research with adult samples has demonstrated that effective messages elicit activity in brain regions implicated in self-relevance and value, and that messages that are likely to be shared elicit value, self-relevant, and social processing. Results suggest a more central role for socio-cognitive effects than has previously been emphasized, which may reflect adolescents' heightened sensitivity to social cues in both decision-making and judgments of self-relevance.

Perceived effectiveness

Our data suggest that adolescents' ratings of message efficacy may be attributable, in part, to their consideration of social factors when they are initially exposed to messages, rather than more self-focused considerations observed in adults. Whereas effective health messages evoke a neural response in the MPFC (implicated in self-relevance and value) in adult samples (Cooper et al., 2015; Chua et al., 2011; Falk, Berkman, et al., 2012, Falk et al., 2011), our findings indicate a marginal, positive relationship between perceived message effectiveness and brain response in the self-relevance system, and no relationship with activity in the value system. Thus, message efficacy may be driven by different processes in adolescents than in adults. Indeed, studies of message effects suggest that greater weight is placed on social factors in adolescents. In particular, studies of the effects of antismoking messages on adolescents have shown that a range of social factors influence the relationship between message exposure and message-relevant outcomes. These social factors include peer group identification (Moran & Sussman, 2014), social norms about substance use (Ho et al., 2014), and actual substance use by peers (Paek, 2008). These findings also echo social components from prominent theories of behavior change, which posit that behavioral outcomes are influenced by normative beliefs about a behavior—both perceptions of who is or is not engaging in the behavior—and perceptions of others' approval or disapproval of the behavior (Fishbein & Ajzen, 2011). Thus, our data highlight the idea that social factors and information about peers' preferences may be especially important to the perceived effectiveness of campaign materials in adolescents.

Another possibility is that self-reported perceived effectiveness may rely more heavily on social considerations than objectively-measured behavior change. Despite the aforementioned link between the neural response in MPFC and targeted health outcomes (Chua et al., 2011; Falk et al., 2016; 2011; Falk, Berkman, et al., 2012), one previous study of the neural correlates of self-reported perceived message effectiveness in youth and young adults did not show a link between MPFC or any other regions implicated in social

processing in adults and self-reported perceived effectiveness in adolescents (Weber, Huskey, Mangus, Westcott-Baker, & Turner, 2015). However, with only limited studies of the neural correlates of perceived effectiveness, our data provide a reference point to which future research can be compared.

There are several implications of these findings for the development of influential media campaigns and more broadly in relation to how adolescents respond to social and self-relevant cues. The first implication pertains to the design of effective messages. One popular approach to message design is tailoring, or the customization of messages to match individual characteristics in a population (Kreuter & Skinner, 2000). Evidence points to the efficacy of tailoring: a meta-analysis of 57 tailored health behavior change interventions conducted largely in adult samples (mean age of 45) indicated that tailored messages had a greater influence on health behavior than comparison or control conditions (Noar et al., 2007). These past findings suggest that messages are more effective when they incorporate self-relevant content. Given evidence that messages rated as more self-relevant (Chua et al., 2011; Strecher et al., 2006) and those that elicit greater neural activity in brain regions implicated in self-relevance (Cooper et al., 2015; Falk et al., 2016) are more apt to influence behavioral outcomes, we can infer that self-relevant content may drive self-relevant cognitions, which in turn contribute to the efficacy of the messages in adults.

In this study, messages that were perceived to be more effective were associated with brain activity in the social processing system, rather than brain regions implicated in self-relevant thought. One possibility is that a form of social tailoring that focuses on peer norms or takes them into account may be especially impactful in adolescents. Future research should examine whether messages that elicit specific socially-focused and self-relevant thoughts in adolescents are perceived as effective when the intended audience is adolescents. Alternatively, self-relevant messages may prompt socio-cognitive processing in the form of reflected appraisals (i.e., what others will think of me if I like this). Though the ability to mentalize develops during childhood, during adolescence individuals exhibit a marked shift from self-oriented to social-oriented behavior (Eisenberg & Fabes, 2006). During this process, the tendency for self-relevant messages to elicit social cognitive processing may reflect adolescents' struggles to disentangle the *self* from the *social*, given their reduced tendency to differentiate between their perception of what others think about them and what others actually think about them (Elkind, 1967). Our findings warrant additional research to elucidate the mechanisms that account for self-relevant and social thoughts as they relate to effective messages.

Intention to share

Contrary to our hypotheses, we find that brain activity in hypothesized regions of interest within the self-relevance, social processing, and

subjective value systems is not associated with sharing intentions. Our findings diverge from previous research by Scholz et al. (2017) and Baek et al. (2017), which showed a positive relationship between neural activity in the self-relevance, social processing, and subjective value systems used here, in response to health articles and adults' self-reported intention to share health news articles with others.

There are several potential explanations for our null findings. One possibility is that for adolescents, self-relevant, social, and subjective value processing during message exposure is not predictive of intention to share messages on social media. That is, the extent to which ads inspire adolescents to think more about themselves, others, and their subjective value may have no bearing on message retransmission. Our hypothesis that ad-induced neural processing in these brain regions drives adolescent sharing was based, in part, on parallel findings from adult studies (Baek et al., 2017; Scholz et al., 2017). However, our results may signal that adolescents hold different motivations for sharing than adults.

Another possible explanation for these findings is specific to the outcome in question—self-reported intention to share ads on social media. Recent neuroimaging research examining the psychological processes underlying information sharing has shown that self-disclosure (Tamir & Mitchell, 2012), and information sharing more broadly (Tamir, Zaki, & Mitchell, 2015), are intrinsically rewarding. Findings from the latter of these studies, conducted with young adults (aged 18–28), highlight the role of the VS and VMPFC in these processes. Though the VS is implicated in reward processing in both adolescents and adults, neural response in this region differs by age group according to the specific type of processing involved. When receiving rewards, adolescents consistently demonstrate increased response in the VS. However, in anticipation or expectation of rewards, adolescents tend to show less activation in the VS relative to adults (Richards et al., 2013). Thus, even if the act of sharing is deemed rewarding, considering one's intention to share information may constitute the anticipation of a reward (as compared with engaging in the act of sharing), and this could explain the lack of association between adolescents' sharing intention ratings and brain response in the reward system.

An alternative explanation for these findings is that the relationship between adolescent brain response to ads and sharing intention is contingent on developmental or motivational differences. Adolescence is characterized by changes in social development (Crone & Dahl, 2012), and the increasing influence of peers may prompt adolescents to change their behavior in an effort to gain social acceptance (Steinberg & Monahan, 2007). Concurrently, adolescence is characterized by a desire for autonomy, as children become increasingly independent (Steinberg & Silverberg, 1986). The act of sharing information with others involves considering how it will reflect upon oneself and influence others (Berger, 2014). Thus, differences in the relative influence of these developmental phenomena could alter the relationship between neural response to ads and their

intention to share them with others on social media. Additionally, it is unclear what specific motivations prompt adolescents in our sample to share antismoking messages. It is feasible that adolescents are more inclined to share messages that contain particular content, such as information that would reflect positively upon the sharer or be particularly relevant for the receiver. These considerations warrant additional research to examine the role of adolescent sharing motivation on the link between brain response and sharing intention.

Furthermore, our null findings may stem from greater variability in adolescents, relative to adults, in the brain systems examined in this study. Adolescence is characterized by developmental changes that affect brain structure and function (Crone & Dahl, 2012). According to one account of adolescent development, brain regions implicated in social and emotional processing mature more quickly than those involved in cognitive control (Steinberg, 2010). It is possible that different rates of maturation across study participants led to greater variation in neural activation in corresponding regions of the brain. Indeed, in a recent study that examined the moderating effect of development on the neural correlates of social influence processing and conformity, adolescents demonstrated significantly more variability in neural response in regions involved in social influence relative to adults (Casio, 2017). Variability in brain activation within our study sample could make it more difficult to detect the expected relationships between brain response in self-relevance, social, and value processing systems and sharing intention. Last, the small number of ads in our stimuli (12) and variability across ads may have limited our power to detect true effects. Our measure of sharing intention was based on a single item that lacked specificity about intention to share on a specific social media platform; these factors may have added noise to our findings, potentially impeding our ability to detect true effects.

Conclusion

Projections based on current smoking rates estimate that 5.6 million of today's American youth will die prematurely due to a smoking-related illness (US Department of Health and Human Services, 2014), underscoring the vital importance of adolescent smoking prevention. Over the past 15 years, a number of mass media smoking-prevention campaigns have been broadcast via mass media channels to target this demographic, and evaluations of this work have largely pointed to their success in influencing smoking-relevant beliefs and behaviors (Allen et al., 2015). Despite progress in this domain, questions remain about the neural mechanisms that account for a link between campaign exposure and targeted outcomes in adolescents, which may influence message design and dissemination. Our findings shed light on the neural underpinnings of adolescents' perceptions of ad effectiveness,

potentially highlighting a stronger role for social processes than self-focused processes and subjective valuation, while raising questions about what might account for sharing among adolescents. Future research should examine whether individual differences can better explain the relationship between ad-induced brain response and sharing intention, and whether engagement of these three systems during message exposure predicts actual sharing behavior in adolescence. Furthermore, future research should examine whether neural activity in self-relevance, social processing, and subjective value systems in this group predicts population-level measures of ad effectiveness.

Notes

1. Hypothesis preregistration document can be accessed via <https://osf.io/gz5uv/>.
2. The reimagine task was administered during the fMRI scan for purposes orthogonal to this study (to understand the neural mechanisms underlying how people reimagine messages). As this task was beyond the scope of this investigation, we did not examine brain response during the reimagine task in the study.
3. We tested whether allowing both slopes and intercepts to vary at the participant and ad levels improved model fit. Original models specified random intercepts at both participant and ad levels. We created models that also included (a) random slopes for participants, (b) random slopes for ads, and (c) random slopes for both participants and ads. We then conducted analysis of variance (ANOVA) to compare each of these models with the original reduced model, for each ROI and outcome of interest. Using Bayesian information criteria as our criterion for model selection, we determined that these models were not a better fit to the data as compared with the original models, and hence opted for the more parsimonious models.

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