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Dynamic Motivational Processing of Antimarijuana Messages: Coactivation Begets Attention

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In the theoretical framework of dynamic motivational activation, this study reveals the dynamics of antimarijuana public service announcement (PSA) processing, especially the processing of co-occurring positive and negative content. It specifies the important role of endogenous feedback dynamics of the information processing system and teases them apart from exogenous message effects. As suggested by real-time psychophysiological responses (heart rate, skin conductance level, and facial electromyography), the copresence of positive and negative content is most attention eliciting and is not moderated by individuals' marijuana experience. Marijuana experience, however, increases attention to arousing content in the PSAs, increases smiling responses to positive content, and escalates arousal to the PSAs in general. Implications for designing and evaluating PSAs and health campaigns are discussed.

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Marijuana is the most frequently used illicit drug in the United States, with 6.6% of the population as current users in 2009. Those aged 18–25 have higher prevalence: Current marijuana users reached 18.1% in 2009, an increase by 10% from 2008 (Substance Abuse and Mental Health Services Administration, 2010). To reverse this worrisome trend, a better understanding of young adults' real-time, dynamic processing of antimarijuana public service announcements (PSAs) is useful.

PSAs are a key component of public health campaigns. They vary a great deal in both content and presentation. Even for a given PSA, audience reactions are often diverse and sometimes deviate from the expected (Keller, Wilkinson, & Otjen, 2010). Therefore, a systematic examination of the effects of message design elements of PSAs has been a focus of health campaign research (e.g., Lang, 2006; Morgan, Palmgreen, Stephenson, Hoyle, & Lorch, 2003; Noar, Palmgreen, Chabot, Dobransky, & Zimmerman, 2009; Sanders-Jackson et al., 2011; Stephenson, 2003). Among various design elements, a well-studied feature is emotional content (e.g., Dillard & Peck, 2000; Lang, 2006). This research focus is warranted because health campaigns often

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Corresponding author: Zheng Wang; e-mail: wang.1243@osu.edu target emotionally charged topics such as drug abuse and sexually transmitted diseases. Furthermore, PSAs are often created with appeals to emotions, such as fear and humor, to increase attention and persuasion (e.g., Leshner, Bolls, & Thomas, 2009; Witte & Allen, 2000). This study aims to systematically examine the dynamic interplay between three basic emotional content features (positivity, negativity, and arousing content) and individuals' substance use during the processing of PSAs. This multilevel approach of simultaneously examining media content variables and media user variables has been shown fruitful for our understanding of the interactive nature of media and audience members (e.g., Southwell, 2005). Extending previous work, the current study emphasizes the causal dynamics in the message–individual interaction. Specifically, it examines the influences of "mixed feelings" in antimarijuana PSAs on real-time attentional and emotional responses among college students.

The time course of emotion variations in PSAs

While PSAs are typically brief (15 or 30 seconds), they are rich in information complexity, conveying dozens of concepts through video and audio channels (e.g., Lee, Roskos-Ewoldsen, & Roskos-Ewoldsen, 2008). Different concepts are activated in a viewer's mind within a single PSA through a sequence of combinations of images, objects, situations, phrases, music elements, and production effects. These concepts induce various emotional responses that surge and subside at different speeds. At one time, more than one response can be induced, and across time, each response waxes and wanes, blending into or giving way to others (Wang & Lang, 2012; Wang, Morey, & Srivastava, 2010, 2012).

In previous work, however, PSAs are generally categorized by a single distinct emotion, such as negative PSAs, positive PSAs, and fear appeal PSAs. This typical categorization enjoys the advantage of parsimony but disregards the rich information hidden in the time course of the emotional variations within a message. The intricate relationship between different emotional content elements, such as the sequence and copresence of positive and negative content in a single PSA, is often overlooked. For instance, different message structures could fit into the category of "fear appeals." One type might be a continuous stream of fear-inducing content, such as showing a series of quick scenes demonstrating devastating effects of drug abuse on a young man and his family. Some other types, however, might actually include positive content. They might begin on a happy note and then end with a twist that induces fear. For example, a PSA could start with a happy party scene, which then turns into chaos because of a friend's drug overdose. Alternately, a PSA might begin with fear-inducing content but end on a positive twist. For example, a PSA could show that a young man's friend offers him drugs, and then we see the man in an ambulance racing to the hospital. However, it turns out that the ambulance was in this young man's imagination—he actually turns down the offer and walks away contentedly. It stands to reason that these different PSAs, although contained in the same fear appeal category, could elicit quite divergent attentional and emotional responses during message processing. Those responses, in turn, may influence their effectiveness (Witte & Allen, 2000; Wang, Morey, et al., 2010, 2012).

Furthermore, emotional content varies not only in its valence (positive or negative) but also in its level of arousing content or emotional intensity (Lang, 2006). More importantly, even if the message content is kept exactly the same, changing the sequence or duration of the content can lead to large differences in responses (Wang, Lang, & Busemeyer, 2011). For example, a succession of negative images in a PSA might have a reinforcement effect or could conversely lead to habituation, depending on the duration of each image. As evidenced by formal dynamic modeling, these variations occur because the effects on audiences are determined not only by the current message content but also by responses elicited earlier in the message (Wang et al., 2011). Therefore, our understanding of the processing of PSAs may benefit from conceptualizing them as continuously changing stimuli. As reviewed in the following sections, because appetitive and aversive motivations are the fundamental organization of various emotional responses, and because they drive cognition, the emotion-inducing content of PSAs is called motivational content in this study. The motivational theories reviewed provide a parsimonious yet flexible way to conceptualize the intricate, continuously changing content features of PSAs.

Dynamic motivational activation

Attentional and emotional responses are dynamic processes (Kelso, 1995; Ward, 2002). The dynamic complex system approach to cognition identifies self-causation as a fundamental operation of the brain and cognition (Buzsàki, 2006; Gros, 2008). More specifically, the human brain and cognitive system self-generates and sustains itself, and external stimuli can cause effects that vary in size (or there may be no effect at all) depending on the internal system (Buzsàki, 2006, pp. 10–11). This self-causing feature of the brain and cognition is identified as one of the novel and most important ideas of the dynamic system approach (Buzsàki, 2006; Luenberger, 1979). This feature is also referred to as "self-organizing," "self-generating," "endogenous," and "emergent" (Buzsàki, 2006; Kampis, 1991; Gros, 2008).

This perspective differs from the traditional stimulus–response view of causality, which was favored by behaviorism and dominated psychology in the first half of the 20th century. This stimulus–response paradigm is illustrated in Figure 1a. The cognitive revolution during the 1950s and 1960s challenged behaviorism and shifted the focus of research to understand the mental processes (i.e., the "black box" of human cognition) between the stimulus and the response, as illustrated in Figure 1b. In particular, from the dynamic complex system approach, a system's response to an exogenous stimulus (such as media and substance use) cannot be understood by looking at the exogenous stimulus alone. Instead, the self-causing nature of cognitive systems must be accounted for if we wish to understand the system's behavior. This theoretical emphasis is illustrated in Figure 1c: a system that is regarded as a dynamic complex system in that it is history- or time-dependent through its feedback loops (Buzsàki, 2006, p. 11). The feedback process accumulates the output of a system,

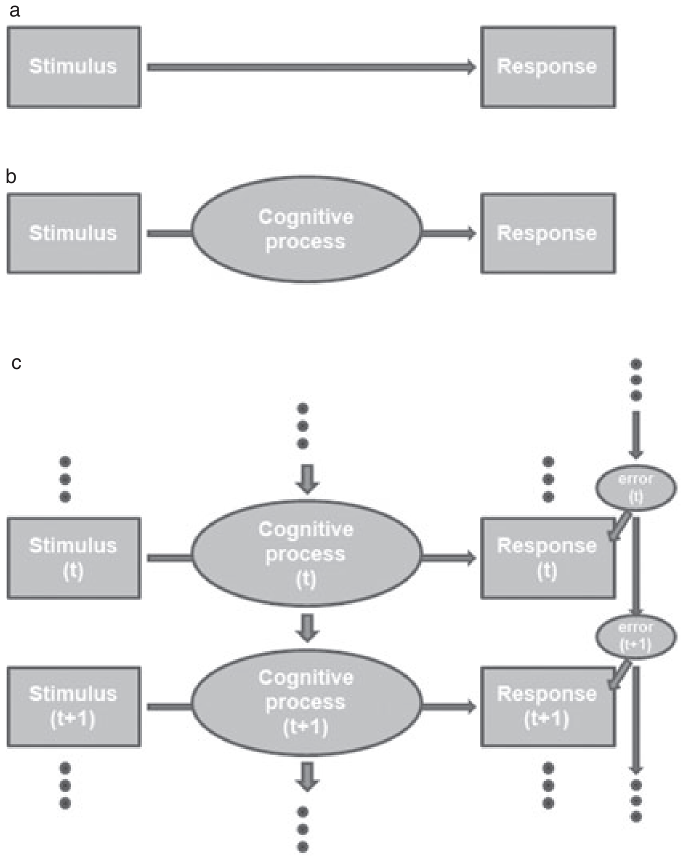

Figure 1 Conceptual schematic diagrams of three causal models: focus on exogenous stimulus' causal effects (a), focus on cognitive process between stimulus and response (b), and focus on time-dependent self-causing dynamics of cognitive system that integrates exogenous effects (c).

feeds it back into the system, and integrates it with the current system input. That is, the system contains a loop of its outputs and inputs and becomes self-causing. This process moderates exogenous influences in that it changes the direction or magnitude of exogenous effects by integrating previous responses of the system into the current response (Buzsàki, 2006; Gros, 2008; Kampis, 1991; Wang et al., 2011).

Within the dynamic complex system framework, the dynamic motivational activation (DMA) model (Wang et al., 2011; Wang, Morey, et al., 2010, 2012; Wang & Tchernev, 2012) was developed to formalize the dynamic causation of exogenous message variables (particularly motivational features) and the self-causation of cognitive processing systems on cognition, emotion, and behavior. Drawing upon convergent evidence from basic motivational processing research (e.g., Bradley, 2009; Cacioppo & Berntson, 1994; Williams, 2006) and motivated media processing research (Lang, 2006), the DMA takes the following theoretical stance: (a) Emotions are fundamentally organized by two motivational systems—appetitive and aversive, which guide organisms to react appropriately toward their environments. This is a critical difference from the discrete emotions approach (e.g., Izard, 1972), which proposes that emotions are hierarchically organized by basic emotions and their combinations. The two theoretical approaches to emotion complement each other, but they differ on the question of the fundamental organization of emotions. Following the dual motivational approach, the DMA proposes that the appetitive system is activated by positive stimuli and elicits positive emotions, while the aversive system is activated by negative stimuli and elicits negative emotions. How arousing or intense the stimuli are determines the activation strength of motivational systems. The motivational and dimensional approach to emotion parsimoniously describes emotional media stimuli and experience (Lang, 2006; Ravaja, 2004). (b) The two motivational systems possess distinct adaptive functions and activation characteristics. The appetitive system is characterized by *positivity offset*—that is, neutral or calm environments tend to activate the appetitive more than the aversive system. This encourages the organism to forage in a neutral (i.e., relatively peaceful and safe) environment. The aversive system is characterized by *negativity bias*—that is, the aversive system is more sensitive to (i.e., responds more strongly to) increases in negative stimuli than the appetitive system is to comparable increases in positive stimuli. This feature enables the organism to respond intensely to threats. (c) The two motivational systems are functionally independent, although they may be correlated, and can be coactivated. (d) Our motivational processes operate in mediated experience as they do in real, nonmediated life. (e) Because of the dynamic nature of information processing, the feedback (or self-causing) effects of the cognitive system are critical to an understanding of the dynamics of motivational processing. The estimation of the effects of exogenous stimuli is not accurate without considering the endogenous influences of the cognitive system.

Using entertainment movies (2011) and political ads (2010, 2012), Wang and colleagues examined the dynamic effects of three basic message motivational variables (arousing content, positivity, and negativity) on four psychophysiological measures that indicate real-time attentional and emotional responses during media information processing, along with a behavioral measure of media channel choice. Their findings support the DMA in general. First, the temporal variance in psychophysiological responses and channel choices can be explained by the dynamic interplay between continuously changing message motivational inputs and the processing system. Specifically, both studies found evidence that physiological systems examined in the studies indeed can be formalized as dynamic systems with significant first- and second-order feedback effects. The first- and second-order feedback effects are the lag 1 and 2 autoregressive effects of the physiological variables. Referring to Figure 1c, this means that the physiological system at time point $t + 1$ can be modeled as a function of the system itself at time point t and time point $t - 1$. However, it is worthwhile to point out: This does not mean that only the previous two time points have influence on the current state of the system. Because the system at those previous time points had already integrated earlier responses, the system's self-causing influence can be remarkably enduring. Exogenous stimulus inputs to the system are moderated and accumulated by this endogenous influence of the system over time, which can generate quite complicated system behavior. For example, previous DMA studies have shown that the psychophysiological or cognitive processing feedback effects can change the magnitude of exogenous media effects (e.g., Wang et al., 2011) or even change the direction of exogenous media effects (e.g., Wang, Morey, et al., 2010, 2012). Additionally, in DMA models, to accurately estimate the theoretically interesting feedback effects, autoregressive error in the data (i.e., unexplained variance in the physiological responses) is modeled simultaneously. In other words, we model both (a) systematic autoregressive responses, which are the cognitive processing feedback effects—indicated by the arrow connecting cognitive processes from time t to time $t+1$ in Figure 1c, and (b) the autoregressive errors, which are indicated by the arrow connecting errors from time t to time $t+1$ in the same diagram. The complicated relationships between exogenous feedback, endogenous variables, and autoregressive errors are among the reasons why formal mathematical dynamic models are necessary to help tease them apart across time to understand them accurately.

The first-order feedback produces an inertia behavior pattern to keep the system in the same state over time, which is consistent with the homeostatic view of our physiological systems (Stern, Ray, & Quigley, 2001). The second-order feedback produces an oscillation in behavior patterns, which is consistent with the fundamental role of neural oscillations (i.e., rhythmic and repetitive neural activity) in cognitive processes (Buzsàki, 2006; Ward, 2002). Together, the first- and second-order feedback effects can produce various complicated nonlinear dynamic response patterns, and computer simulations are often employed to illustrate their effects based on estimated parameters (e.g., Ward, 2002; Wang et al., 2011). In summary, empirical work within the DMA framework supports the idea that the feedback effects of dynamic information processing systems integrate responses to prior information inputs into the current response, which in turn affects subsequent responses to ongoing real-time motivational information inputs.

Using the DMA approach, this study tests the DMA mechanism in explaining variance in attentional and emotional physiological reactions during the processing of antimarijuana PSAs (Hypothesis 1). Similar to the two previous empirical tests of the DMA, the physiological systems are proposed to have first- and second-order feedback effects (Hypothesis 2). In addition, the dynamic motivational effects are expected to be moderated by individuals' substance use, especially marijuana experience, because the messages are marijuana relevant and might have greater motivational significance to those who have more experience with marijuana or other substances than those who do not (Lang, 2006). The question of which specific motivational inputs are moderated by substance use will be explored (Research Question).

Coactivation of dual motivational systems during PSA processing

As reviewed earlier, generally positive content activates the appetitive system and negative content activates the aversive system. Then, what if both positive and negative content are presented simultaneously in a message? This question is of particular interest for research on antidrug PSAs because “mixed feelings” are often presented in these PSAs. For example, some PSAs warn audiences of the serious harms of drugs, while, simultaneously, drug-related cues appear appetitive to drug users (Sanders-Jackson et al., 2011). Other PSAs may present negative images of drug abuse consequences, while promoting self-efficacy through positively framed audio arguments (Leshner et al., 2009). In addition, PSAs with “a surprise twist” (Morgan et al., 2003, p. 516) often produce the twist by juxtaposing positive and negative content.

Although these types of “mixed feelings” messages have rarely been systematically investigated thus far, they are predicted to activate both the aversive and appetitive motivational systems (Wang et al., 2011). Hence, they are called “coactive” messages in this study. As introduced earlier, following the dual motivational system theories, the DMA postulates that the appetitive and aversive motivational systems are independent. Different neural substrates and response patterns have been identified for evaluating negative and positive stimuli (Berntson & Cacioppo, 2008). Also, because the two motivational systems have different functions for survival, the separability of the two systems may have provided an evolutionary advantage by allowing relatively independent adaptations of each system (Berntson & Cacioppo, 2008). This dual motivational systems conceptualization allows for singular, dual, and reciprocal activation of the appetitive and aversive systems.

Activation of motivational systems helps the organism mobilize metabolic and cognitive resources, enhance perceptual processing, and prepare for action (Bradley, 2009). The appetitive system facilitates approach tendencies and behaviors, which are characterized by the mobilization of attentional resources for sensory information intake. The aversive system may also help mobilize attentional resources to external stimuli, but only at low to moderate levels of activation—that is, when the stimulus is not highly arousing. With greater aversive activation, the attentional mode changes from information intake (e.g., threat identification) to information rejection to facilitate appropriate actions (e.g., decision making and fight or flight; Lang, 2006). Therefore, when the emotional intensity of a message is low or moderate, it is likely that coactivation of both motivational systems elicits greater attentional resources to the message compared with when only a single motivational system is activated. However, when the message intensity increases and leads to greater motivational activation (especially greater aversive activation than appetitive activation on account of the negativity bias), attentional resources allocated to encode the message will decrease and will be shifted to behavior preparation. In other words, the attention eliciting effect of the copresence of negative and positive motivational content is predicted to be moderated by the arousing level of the content (Hypothesis 3).

Methods

The pretest and the stimuli

Twenty-four televised antimarijuana PSAs were selected for the pretest, including eight PSAs in each of three overall valence categories (positive, negative, and coactive) as judged by two coders. All PSAs were 30 seconds long and had been released in recent years by the Office of National Drug Control Policy (2010). Seventy-nine undergraduate students from a large university in the Midwestern United States participated in the pretest for course credit. Participants completed the experiment in groups of 2–6 on individual desktop computers. All participants viewed all PSAs once in a randomized order and answered the same postexposure questions after each PSA. As they watched, the participants rated each PSA using continuous response measures (CRMs; Biocca, Prabu, & West, 1994). Three CRM scales were used, anchored by values 1 and 100: *arousing content* (not at all arousing—extremely arousing), *positivity* (not at all positive—extremely positive), and *negativity (*not at all negative—extremely negative). When the PSA was displayed on screen, one of the CRM scales was randomly selected and presented at the bottom of the screen. The participant used right and left arrow keys to move a slider on the CRM scale to indicate her or his evaluation of the motivational content of the PSA in real time. The data were transformed by MediaLab software (Jarvis, 2008) into values between 0 and 2, rounded to the hundredth decimal place, and were recorded at 20 Hz. All PSAs were rated on the three CRM scales by roughly the same number of participants. After each PSA, the participants made postexposure judgments on the overall levels of arousing content, positivity, and negativity using 9-point Likert response scales. On the basis of these postexposure evaluations, 12 PSAs were selected for the psychophysiological experiment: four PSAs in each valence category, with two arousing and two calm PSAs.

The selection of PSAs across overall valence and arousing content levels was to ensure the inclusion of a wide range of emotional content, especially PSAs that activated both motivational systems. Repeated analysis of variance showed successful factorial manipulation of the overall valence and arousing content (*p*s $< .05$). (Detailed information is available upon request.) In addition, the Cronbach's α tests indicated that the CRM ratings were reliable ($M\alpha = 0.90$, $SD\alpha = 0.06$) as assessed by a random sample of the CRM data points (one random data point per 10 seconds). On the basis of the CRM data, typical positive content included parties, playing, and sports scenarios; happy, confident, hopeful, trustful, or funny facial and verbal expressions; humorous narratives or actions; beautiful landscapes; and sunny weather. Typical negative content included death, illness, safety threats, and social isolation; verbal and facial expressions showing disappointment, desperation, fear, regret, guilt, or indifference; boredom; and gloomy weather. These are consistent with the general understanding of motivational content in media (Lang, 2006; Wang et al., 2011). Coactive content is typically constructed by juxtaposing or closely sequencing positive and negative content.

It is necessary to point out that for the subsequent psychophysiological experiment and modeling, three time series were computed of the medians of the three CRM ratings across viewers at each second of each PSA. In other words, each second of each PSA was assigned three values: the median scores for how positive, how negative, and how arousing viewers had rated the content to be at that moment. These time series data, in 1-second increments, served as real-time inputs to predict physiological responses to the PSA (Wang et al., 2011).

The psychophysiological experiment

In total, 59 undergraduate students from the same university participated in the experiment in exchange for cash compensation and course credit. None of them had participated in the pretest. The experiment was conducted individually. After obtaining informed consent, the experimenters prepared the participant for physiological measures and then left the room to provide privacy. Participants watched 14 PSAs. Preceding the 12 stimulus PSAs, two relatively calm PSAs, which were selected based on the pretest rating, served as practice. The presentation order of the two practice PSAs was randomized and so was the order of the 12 stimuli. Four physiological measures were recorded during the viewing of the PSAs using Coulbourn instruments, controlled by the data acquisition software VPM (Cook, 2000). The measures are described in the following paragraphs.

Heart rate (*HR*) is affected by both branches of the autonomic nervous system (ANS): the parasympathetic nervous system (PNS) and the sympathetic nervous system (SNS). The relative excitation of the two ANS branches determines HR. SNS dominance results in HR acceleration, which indicates external sensory information rejection, internal mental activities, and preparation for action. On the other hand, PNS dominance tends to be exhibited through HR deceleration, which has been used to indicate attention to external sensory information (Lang, 1994; Obrist, Webb, Sutterer, & Howard, 1970). HR data were collected through two 7-mm Ag/AgCl electrodes on the right and left forearms (i.e., Lead I placement). Beats per minute were derived from the intervals between R peaks.

Zygomatic electromyography (*EMG*) measures the zygomaticus major muscle group located between the cheekbone and the corner of the mouth on each side of the face. The muscle group raises the corner of the mouth in a smile and often indicates a positive emotional response. *Corrugator EMG* measures the corrugator supercilii muscle group located at the medial end of the eyebrow, which contracts during frowning. It often indicates a negative emotional response. However, increased corrugator EMG also has been used as an indicator of increased attention to sensory information (i.e., "frowning in concentration"). When HR deceleration occurs simultaneously with increased corrugator activity, the coupling pattern of the two measures provides particularly strong, convergent evidence of a participant's attention to external stimuli (Cohen, Davidson, Senulis, Saron, & Weisman, 1992).

The two facial EMG measurements were taken using a pair of 4-mm Ag/AgCl electrodes on the muscle group sites on the left side of the face and were sampled at 20 Hz.

Skin conductance level (*SCL*) is a tonic measure of electrodermal activity. It is often measured in the palms of the hand and soles of the feet, where eccrine sweat glands are concentrated and respond primarily to psychological and sensory stimuli instead of temperature. The eccrine sweat glands are innervated by the SNS. Higher SCL indicates greater sympathetic arousal, regardless of emotional valence (Bradley, 2009). Measurement was collected using the exosomatic method (Stern et al., 2001) from two 7-mm Ag/AgCl electrodes on the palm of the nondominant hand and sampled at 20 Hz.

After viewing the PSAs, participants completed measures of demographic information and substance use, which previously have been used in a similar line of research (Lang, Chung, Lee, Schwartz, & Shin, 2005; Lang, Shin, & Lee, 2005). The participants were 18–33 years old ($M = 21.03$, $SD = 2.50$), and 59% were female. More than half (57.6%) self-identified as Caucasian, and the rest as Asian (23.7%), Black (11.9%), Hispanic (1.7%), or "Other" (5.1%). Participant *marijuana experience* was computed as the sum of three items asking about the past 30 days (Cronbach's $\alpha = .77$): "How many times have you smoked marijuana?" (1 = *never* to 4 = *five times or more*), "How many times have you been with people who were smoking marijuana?" (1 = *never* to 4 = *five times or more*), and "How many of your friends do you think smoked marijuana even once or twice?" (1 = *no one* to 5 = *all*). The index of marijuana exposure ranged from 3 to 13 ($M = 5.93$, $SD = 2.38$), with 3 indicating no experience and 13 maximum experience. Following previous research (Lang, Chung, et al., 2005; Lang, Shin, et al., 2005), we created a single index of marijuana experience because high levels of marijuana experience (whether directly from personal use or indirectly from people and friends around them) should affect the motivational relevance of the PSA content. In addition, other substance use could possibly affect responses to antimarijuana PSAs (Lang, Shin, et al., 2005; S. Lee, Cappella, Lernman, & Strasser, 2011), and thus alcohol and cigarette use were also measured to serve as statistical controls in the analysis. *Alcohol use* was measured by a six-item scale, which asked participants about three separate types of alcoholic beverages (how many beers, glasses of wine, and hard liquor drinks they consumed) for two time frames (on a typical weekday and on a typical weekend day). The six measures, each ranging from 0 (no drinks) to 7 (six drinks or more), were summed to create an index of the number of alcoholic drinks consumed in a typical week (Cronbach's $\alpha = .79$). This aggregated alcohol use score had a possible range of 0 to 42 ($M = 7.61$, $SD = 8.05$). *Cigarette use* was calculated as the product of the frequency of smoking occasions (from 0 = *never* to 7 = *daily*) and the number of cigarettes smoked per occasion (from 0 = *none* to 12 = *more than 20*) in the past 30 days. The resulting cigarette use index ranged from 0 to 36 ($M = 4.05$, $SD = 7.74$).

Analysis

Time series data of the model inputs and outputs

The three time series created from the CRM ratings of positivity, negativity, and arousing content (as described earlier) were used as our indicators of message motivational content inputs, at the rate of one data point per second. For each of the four physiological outputs of each individual, raw data were averaged for each second, producing a 360-observation time series over the time spent viewing the 12 stimulus PSAs. A detrending procedure was implemented using PROC GLM in SAS software to remove the linear influence of time because of potential habituation or fatigue effects, which were not stimulus specific and were not the focus of the study. There were not significant higher order polynomial trend functions of time found in this detrending procedure. The detrended data were standardized for each physiological variable across all participants to facilitate easier interpretation and comparison of coefficients between physiological models.

Time series cross-sectional analysis and model fitting

Time series cross-sectional (TSCS) analysis was conducted on the time series data of all participants using PROC TSCSREG in SAS software. In our analysis, individuals were considered as sections ($n = 59$) and second-by-second physiological measures of each individual were the time series per section ($n = 360$), creating $360 \times 59 = 21,240$ data points in total. TSCS analysis simultaneously estimates the cross-time and cross-individual variations of responses to the second-by-second message stimulus inputs. A two-way random-effects error model structure was specified, which included both the individual- and time-related random effects in the error disturbances. The error model also assumes a first-order autoregressive effect of the error. The estimated generalized least squares method was used to estimate the coefficients.

Each of the four physiological responses was separately tested for the full model. The hypothesized full model includes (1) the first- and second-order physiological system feedback terms; (2) linear and quadratic main effects of message motivational inputs (A, P, N, A^2, P^2, and N^2), and their two- and three-way interactions (A × P, A × N, P × N, and P × N × A); (3) main effects of individuals' substance use (marijuana experience, alcohol use, and cigarette use); and finally, (4) interaction effects between message motivational variables and substance use. For each physiological variable, to identify the best delay lags for message motivational inputs to reach and activate the physiological system, six models were compared, with lags varying from 0 to 5 (indicating no delay to a 5-second delay). Of the six models, the one with the largest regression R^2 was selected as the preferred full model: The input lag was 2 for the SCL model and 1 for the other three psychophysiological models. This procedure of estimating the best input lag for each physiological response is not the focus of the study but is needed to help more accurately estimate coefficients of the key variables of interest in the models. Then, to test the proposed hypotheses, three models were compared for each physiological response: (a) the full model with the estimated input lag coefficients as described above; (b) a reduced version of the full model, which excluded insignificant interactions terms between message motivational variables and individual substance use variables; and (c) a reduced model, which excluded the "dynamic" part [i.e., terms listed in (1) above] and the "motivational" part [i.e., terms listed in (2) and (4) above] of the full model. The three models are nested. Model comparisons were conducted by testing R^2 changes and Bayesian information criterion (BIC). The two criteria rendered convergent results.

Results

Across all four physiological responses, the simpler dynamic motivational model (Model b) was preferred over the full model (Model a). The R^2 decrease was not significant and BIC was smaller for the simpler model, indicating a better balance between goodness of fit and model parsimony (Busemeyer & Deiderich, 2010). Hence, consequent hypothesis tests are based on this preferred model.

Model selection and the effects of message motivational inputs and individuals' substance use

Hypothesis 1 predicted that the proposed DMA mechanism explains significant amounts of variance in cognitive and affective physiological responses during antimarijuana message processing. This was tested by comparing the dynamic motivational model (Model b) to the model without dynamic motivational terms (Model c). On the basis of the R^2 changes and BICs, the dynamic motivational model is preferred for all physiological responses. Thus, Hypothesis 1 is supported.

Estimated coefficients of the final selected models are summarized in Table 1. As indicated by R^2 statistics in Table 1, the final selected dynamic motivational model accounts for 47–69% of the variance in each of the four physiological responses, across time and across all participants. Table 1 summarizes message motivational input effects and their interactions with individual differences in substance use on psychophysiological responses. All these exogenous effects are moderated and integrated by the significant physiological feedback effects, which are reported in the following sections.

Physiological system feedback effects

Supporting Hypothesis 2, all four physiological responses showed significant order one and order two feedback effects. This is a critical direct test of the dynamic, time-dependent, and self-generating nature of physiological systems. Each system's feedback effects integrate and accumulate the exogenous influences from the PSA motivational inputs to influence physiological outputs that indicate real-time affective and cognitive responses to the PSA. In other words, the physiological system feedback effects determine how quickly the PSA motivational inputs can elicit a physiological response, what the response trajectory looks like across time, and how lasting the response is. This moderating and accumulating effect of system feedback on the influence of message motivational content is illustrated in detail later.

Table 1 Model Fit and Estimated Coefficients of Selected Models

	HR *M* (*SE*)	SCL *M* (*SE*)	Corrugator EMG *M* (*SE*)	Zygomatic EMG *M* (*SE*)
Intercept	0.10 (0.14)	−0.25 (0.10)*	0.02 (0.13)	−0.07 (0.13)
Feedback (lag 1)	0.74 (0.01)***	0.46 (0.01)***	0.51 (0.01)***	0.76 (0.01)***
Feedback (lag 2)	−0.11 (0.01)***	0.29 (0.01)***	0.18 (0.01)***	−0.02 (0.007)***
A	0.16 (0.07)*	0.13 (0.04)**	0.005 (0.02)	0.01 (0.01)
P	0.13 (0.03)***	−0.04 (0.02)*	−0.002 (0.02)	−0.04 (0.01)**
N	−0.06 (0.03)	−0.10 (0.03)***	−0.01 (0.02)	−0.004 (0.007)
A^2	−0.27 (0.07)***	−0.13 (0.05)**	0.02 (0.03)	0.006 (0.01)
P^2	−0.13 (0.03)***	0.01 (0.02)	−0.001 (0.01)	0.04 (0.01)***
N^2	−0.07 (0.03)*	0.04 (0.03)	0.009 (0.02)	0.002 (0.008)
A × P	0.16 (0.05)***	0.03 (0.03)	−0.01 (0.03)	−0.01 (0.01)
A × N	0.27 (0.08)***	0.03 (0.05)	−0.02 (0.04)	−0.01 (0.02)
P × N	−0.53 (0.14)***	0.09 (0.09)	0.14 (0.07)*	−0.01 (0.03)
P × N × A	0.43 (0.13)***	0.10 (0.08)	−0.12 (0.07)	−0.01 (0.03)
Marijuana	−0.02 (0.03)	0.05 (0.02)*	0.01 (0.03)	0.02 (0.03)
Alcohol	−0.004 (0.008)	−0.004 (0.006)	−0.01 (0.01)	−0.001 (0.007)
Cigarettes	0.01 (0.006)	−0.003 (0.006)	−0.003 (0.006)	−0.006 (0.006)
Marijuana × A	−0.04 (0.01)***	−0.02 (0.006)***		
Marijuana × P				0.007 (0.002)***
Marijuana × N		0.01 (0.003)***		
Alcohol × A	0.01 (0.003)**			
Alcohol × P				
Alcohol × N				
Cigarettes × A		0.006 (0.002)**	0.004 (0.001)**	
Cigarettes × P				−0.002 (0.001)*
Cigarettes × N				
Marijuana × A^2	0.03 (0.01)**	0.02 (0.006)**		
Marijuana × P^2				−0.006 (0.002)***
Marijuana × N^2		−0.007 (0.002)**		
Alcohol × A^2	−0.01 (0.003)**			
Alcohol × P^2				
Alcohol × N^2				
Cigarettes × A^2		−0.005 (0.002)**	−0.003 (0.001)**	
Cigarettes × P^2				0.001 (0.0005)*
Cigarettes × N^2				
Model R^2	0.4700	0.5456	0.4694	0.6861

$^{***}p < .001$. $^{**}p < .01$. $^{*}p < .05$.

The interaction of positivity, negativity, and arousing content

Among the various motivational inputs' effects as summarized in Table 1, of the most interest for the current study is the evidence supporting Hypothesis 3, which predicted

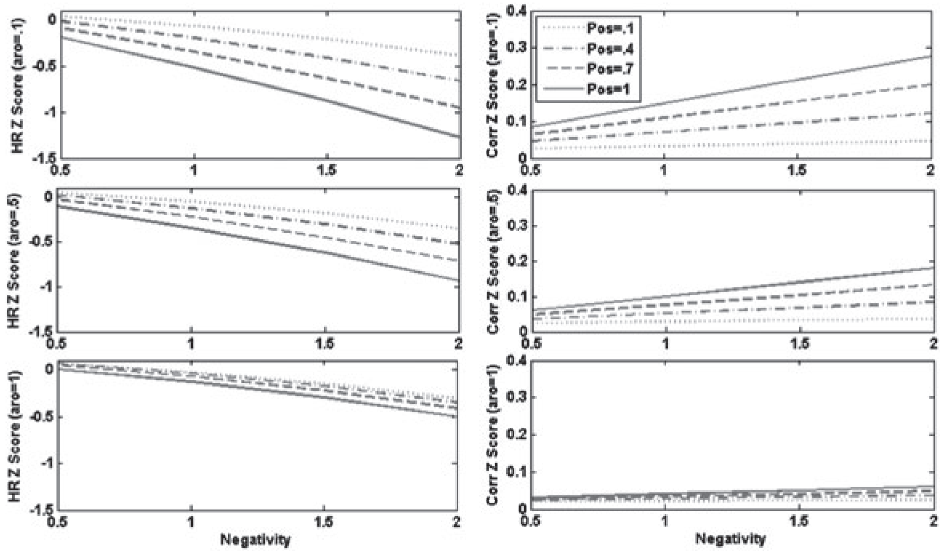

Figure 2 Message Positivity × Negativity interaction on HR (left panels) and corrugator EMG (right panels) is further moderated by arousing content (arousing content $= 0.1, 0.5$, and 1 for the first, second, and third rows of panels).

that the attention-eliciting effects of coactive content should be moderated by the arousing level of the content. The hypothesis is tested by the two-way interaction term Positivity × Negativity, and its further interaction with arousing content, for physiological responses indicating attention (HR and facial EMG). Significant Positivity × Negativity interaction effects were found on HR and corrugator EMG. For both, the significant two-way interactions are further moderated by arousing content (i.e., P × N × A in Table 1). Figure 2 illustrates the effects based on the range of the actual motivational input values in our experiment: the positivity, negativity, and arousing content inputs ranged from 0–1, 0–2, and 0–1, respectively, on the 0–2 scale. The three panels on the left show HR and the three on the right show corrugator EMG. The scale of the plotted physiological changes is presented in terms of their standard deviations.

Across the three HR panels on the left, we can see that, in general, an increase in negativity decreases HR, but this decreasing effect is steeper for more positive inputs. For example, when arousing content is kept at 0.1 (the top left panel), with an increase in negativity from 0.5 to 2, HR decreases by about half of a standard deviation if positivity is 0.1 (the dotted line) but decreases by more than one standard deviation if positivity is 1 (the solid line).

When arousing content increases to 0.5 (the middle left panel), this Positivity × Negativity interaction effect becomes smaller. When arousing content increases to 1 (the bottom left panel), which is moderately arousing on the measuring scale but is the highest arousing content value in our actual data, the HR deceleration effect of positivity and negativity reduces to less than half of one HR standard deviation, and their interaction is hardly observed.

The three panels on the right show a similar moderation pattern of arousing content on the Positivity × Negativity interaction effect on corrugator EMG, but the Positivity × Negativity effect increases, instead of decreases, corrugator EMG. An increase in negativity increases corrugator response, and this increasing effect is greater for more positive content. For example, when arousing content is 0.1 (the top right panel), with an increase in negativity from 0.5 to 2, corrugator EMG increases by about 0.2 standard deviation if positivity is 1 (the solid line) but shows only a tiny increase if positivity is 0.1 (the dotted line).

The combination of HR deceleration and increased corrugator EMG activity is a strong indicator of attention, providing support for Hypothesis 3. Copresence of negative and positive motivational content (i.e., coactive content) indeed leads to increased attention, which is moderated by the arousing level of the content.

Dynamics of motivational effects across time as moderated by marijuana experience

In the preceding sections, we have disentangled and examined the influences of motivational inputs and substance use, and the impact of the psychophysiological system's feedback effects on information processing, which are estimated *per second* (Table 1). The numerical values of the feedback terms are difficult to directly interpret at face value. Instead, we will put it all together to examine how the system feedback effects integrate, accumulate, and moderate the influences of message motivational inputs and viewers' marijuana experience to generate reactions that dynamically evolve *across time*.

Significant coefficients estimated for each physiological system are entered into the final selected models (Table 1) to simulate the integrated effects across time (Figure 3). Following the common analytic strategy in dynamic analysis (e.g., Luenberger, 1979; Wang et al., 2011), eight combinations of the three motivational inputs (A, P, and N) are selected to systematically demonstrate their effects on the physiological systems. They are (a) all three inputs are off (baseline); (b) only A is on; (c) only P is on; (d) only N is on; (e) A and P are on, but N is off; (f) A and N are on, but P is off; (g) P and N are on, but A is off; and (h) all three inputs are on. To facilitate interpretation, the magnitudes of all three motivational inputs are kept at 0.8, which is within the actual range of the PSA stimuli and is at a moderate level on the scales. The motivational inputs are controlled as a step input (i.e., being turned on from zero to a fixed magnitude for a certain duration), which helps examine the accumulation and evolution of dynamic effects. The step input duration is set to be 45 seconds each, a little longer than the actual PSAs in our experiment but within the range of most PSAs (15–60 seconds). Thus, we can gain a clear observation of the effect trajectories while remaining realistic. After each step input, a 15-second zero setting (i.e., no input) is used to allow the system to return to its baseline, which enables us to observe the decay of the previous input's effect and also avoids

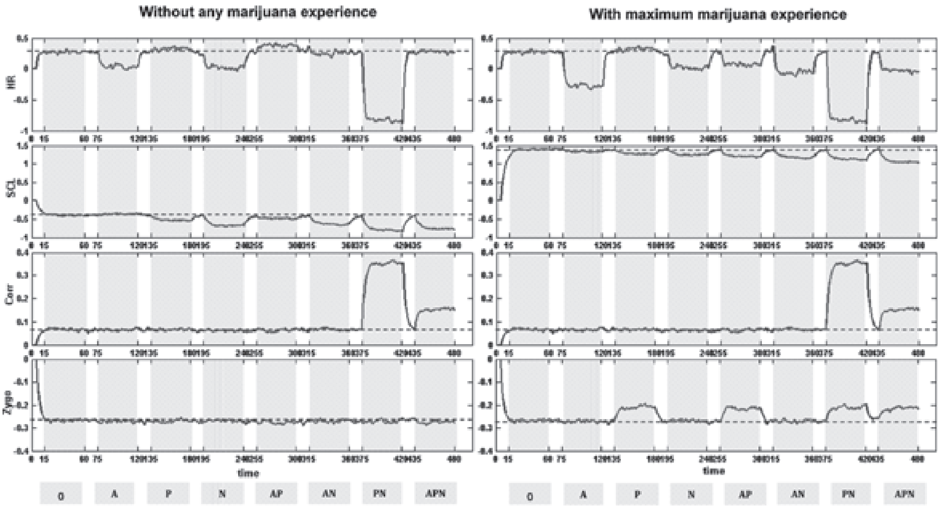

Figure 3 Dynamic HR, SCL, corrugator EMG, and zygomatic EMG responses to message motivational inputs (magnitude = 0.8) among individuals without any direct marijuana experience (left panels) and with maximum marijuana experience (right panels).

confounding the next input's effect. The eight input conditions are labeled as (a) 0, (b) A, (c) P, (d) N, (e) AP, (f) AN, (g) PN, and (h) APN at the bottom of Figure 3. The left panels illustrate dynamic physiological responses of individuals without any direct marijuana experience (score = 3), and the right panels show responses of those with maximum marijuana experience (score = 12). From the top to the bottom, HR, SCL, corrugators, and zygomatic EMG dynamics are presented, respectively.

Across the panels, three general patterns are evident. First, the figures illustrate the dynamic nature of the physiological systems. The onset and offset of a motivational input does not instantaneously bring the system to its equilibrium state. Instead, it takes time for the physiological system to grow to its equilibrium state in response to an input onset, and it takes time for the system to decay to its baseline after the offset of the input. During this dynamic growth and decay, a primary role is played by the system feedback effects, which integrate the motivational input effect to generate the dynamic trajectories depicted in Figure 3. Second, motivational inputs affect the various physiological systems in different ways, and the coactivation of positivity and negativity show opposite patterns for HR and corrugator EMG (Condition "PN"). Third, corrugator EMG is the only response that is not moderated by marijuana experience. The following section reviews each physiological response in detail.

As shown in the top panels, the HR dynamic response model is in line with previous research measuring HR in response to emotional media messages. That is, arousing content (Condition "A") elicits large HR deceleration, nonarousing (or calm) positive messages (Condition "P") elicit slight HR acceleration, and negativity elicits slower HR (e.g., Bradley, 2009; Lang, 1994). However, arousing content has a greater effect on those with maximum marijuana experience and decreases their

HR by 0.3 to 0.4 standard deviations more compared with its effect on those without marijuana experience (Conditions "A," "AP," "AN," and "APN"). Previous static analyses seldom closely examined coactive messages (Conditions "PN" and "APN"). Our estimated dynamic model clearly shows HR deceleration, as dramatic as more than one standard deviation, when the copresence is calm (Condition "PN"), whereas adding arousing content (Condition "APN") makes this HR deceleration smaller.

The dynamics of SCL, shown in the second row of panels, illustrate two patterns. First, the main effect of marijuana experience is apparent. For individuals with maximum marijuana experience, SCL is around 1.8 standard deviations higher than for those without any experience. Recall that the estimated main effect of marijuana experience is only 0.05 per unit time in the model (Table 1). This is an interesting example showing how the physiological system feedback effects can accumulate the seemingly small effects from message and individual audience variables across time to reach a large magnitude. Another clear pattern is shared by both panels: positivity, negativity, and arousing content all decrease SCL, and the largest decrease is when all three inputs are presented (Condition "APN"), which is a decrease of about half a standard deviation. This is contrary to the general findings of static methods; however, this is in line with the findings by Wang, Morey, et al. (2010), where the presence of arousing content (Conditions "A," "AP," "AN," and "APN") caused a decrease of SCL during the processing of political ads. The authors proposed that because of the media bombardment of a political campaign, viewers might have habituated to the arousing content of campaign ads and perhaps even showed emotional responses indicating annoyance (Hastings, Stead, & Webb, 2004). This remains one of the plausible explanations for our current findings as well.

The dynamic patterns of corrugator EMG appear to be the simplest among the four physiological systems. Interestingly, only corrugator EMG is not found to be moderated by marijuana experience in our data. It is highly responsive to coactive content (Conditions "PN" and "APN") and displays the same pattern as HR, only in the opposite direction.

Finally, the dynamic responses of zygomatic EMG are shown in the bottom panels. For people without any direct marijuana experience, zygomatic EMG appears nonresponsive to the motivational inputs except for tiny fluctuations in the presence of positivity (Condition "P," "AP," "PN," and "APN"). However, for those with a lot of marijuana experience, the increase in zygomatic response is nearly 0.1 standard deviation.

Taken together, the results indicate that the copresence of positivity and negativity is most attention eliciting, as suggested by the coupling patterns of decreased HR and increased corrugator EMG. This further supports our Hypothesis 3. In addition, this attentional reaction is not moderated by individuals' marijuana experience. However, marijuana experience moderates the effect of arousing content on HR and the effect of positivity on zygomatic EMG. Also, it moderates the effects of arousing content and negativity on SCL, but the large main effect of marijuana experience on SCL dominates SCL response patterns in that those with heavy marijuana experience show significantly escalated SCL compared with those without experience. Although not the focus of this study, it is interesting to note that alcohol use and cigarette use also moderate the processing of motivational content in antimarijuana PSAs (Table 1).

Discussion

This study reveals attentional and emotional processing of PSAs as driven by DMA. The dynamic motivational activation model provides a strong analytical framework to reveal message effects per time unit and across time. It helps specify the important role of endogenous feedback dynamics of the processing system during media processing and teases them apart from exogenous media message effects. In addition, media processing, which has been theorized as media–individual interaction (e.g., Lang, 2000, 2006), and has been formalized using multilevel models to simultaneously examine media-level and individual-level variables (e.g., Southwell, 2005), is further tested using a formal dynamic model. The formal dynamic model enables us to estimate the effects of media and individual variables per time point, which avoids cofounding effects of time (e.g., different stimulus durations) and also affords the examination of the integrated, aggregated effects of media and individual variables across time.

If we were to only look at a summary of the aggregated effects, without considering the influence of time and of cognitive system feedback, we would have less understanding of the processing system or the process. We would not be able to generalize the findings of one set of stimuli to other sets of stimuli because changes in stimuli duration or motivational inputs can alter the integrated effects significantly. However, with the estimation of the "pure" message effects (as summarized in Table 1), which are not confounded by processing system feedback or time duration, we have the ability to simulate various combinations of the stimulus inputs (in our case, A, P, and N) with various combinations of stimulus durations. For example, Figure 3 provides just one of many possible illustrations.

Coactivation begets attention

A prominent finding is that the copresence of positivity and negativity in a PSA, which is theorized to activate both the appetitive and aversive motivational systems, is the most attention eliciting type of content. This is indicated by the coupling patterns of decreased HR and increased corrugator EMG during the coactive conditions (conditions PN and PNA) in our integrative dynamic models (Figure 3).

On the basis of the sensory information intake–rejection interpretation (e.g., Lacey, 1967) and the cardiac–somatic coupling theory of attention (e.g., Cohen et al., 1992; Obrist et al., 1970; Van Boxtel, Damen, & Brunia, 1996; Wang, Morey, et al., 2010, 2012), an increase in sensory intake is associated with an increase in PNS excitation, and when the PNS becomes dominant over the SNS, HR decelerates. Additionally, EMG activity in the corrugator muscle group, which are task-relevant muscles in our sensory information intake task, is expected to increase to facilitate the task, whereas the zygomatic muscle group, which is irrelevant to the sensory intake task, is expected to be inhibited. Different from this sensory-intake mode, in the sensory-rejection mode, the SNS becomes dominant, which leads to HR acceleration. Sensory rejection facilitates internal mental activities (e.g., decision making) as well as action or action preparation (e.g., fight or flight) by blocking out external disruptions and allocating metabolic resources to the action-relevant muscles.

Comparing the dynamic effects figures of HR and corrugator EMG, our results are consistent with these physiological theories of attention. The pattern of sensory information intake is clearly shown in the coactive conditions. At first glance, it seems that none of the conditions elicits a clear information-rejection mode. However, compared with nonarousing coactive condition (the PN condition), the arousing coactive condition (the APN condition) elicits much smaller HR deceleration and corrugator activity. This may indicate the start of a shift in attention and resource allocation from external sensory information to internal mental activity or preparatory actions, although the mode is still primarily sensory-intake compared with the baseline. A similar sensory-rejection response to highly arousing content in antisubstance PSAs has been recently observed by Leshner, Bolls, and Wise (2011).

We should further test this interaction of arousing content with coactive content using more arousing PSAs that may elicit the completion of the shift from sensory intake to sensory rejection. According to the physiological theories of attention, when the shift completes, HR acceleration is expected. Indeed, this is exactly what was observed by Leshner et al. (2011). Also, they found that recognition of PSA information decreased in this condition, which provides further support to the sensory-rejection interpretation of this physiological response pattern. In addition to recognition tests, thought-listing is another postexposure measure that can be useful in future studies. It may help identify what are the mental activities and/or behavioral tendencies brought out by arousing coactive content in the sensory-rejection mode. These might be counterarguing tendencies, self-referencing, or perhaps avoidance tendencies. Or, is the viewer simply overloaded by the arousing and coactivating information? If the sensory-rejection mode is characterized by active self-referencing or by avoidance tendencies triggered by risky products or behaviors presented in the PSAs, then the PSAs are likely achieving their intended effects. If the sensory-rejection mode, however, is characterized by counterarguing or information overload, unintended effects are likely being elicited (e.g., Keller et al., 2010).

It is interesting to note that zygomatic EMG is primarily responsive to positivity among those with a lot of marijuana experience. This is consistent with the more common interpretation of zygomatic EMG as an emotional response (smiling). It is plausible that corrugator and zygomatic EMG do not always work in sync to only indicate attentional or emotional responses. Depending on the context and stimuli, it is possible that one response is more closely affected by cognitive processes, while the other is more tied to emotion. These types of variations in facial EMG have been documented (e.g., Van Boxtel et al., 1996).

Moderating effects of marijuana experience on the processing of antimarijuana PSAs

Dynamic motivational processing of antimarijuana PSAs results from the interplay between the message motivational content and an individual feature that alters the relevance and significance of the motivational content—viewers' marijuana experience (Lang, 2006; Wang, Morey, et al., 2010). The moderating effects of marijuana experience provide some interesting suggestions for designing antimarijuana messages.

First, marijuana experience moderates the effect of arousing content on HR. Arousing content causes a larger decrease in HR among those with more marijuana experience, suggesting greater attention to arousing content. This finding is consistent with the generally accepted notion that drug users are more likely to attend to stimuli associated with their drug use which are also more arousing to them (e.g., Geier, Mucha, & Pauli, 2000; Sanders-Jackson et al., 2011). Overall, when arousing content is presented (Conditions A, AP, AN, and APN), people with heavy marijuana experience show a HR deceleration that is 0.3 to 0.4 standard deviation larger than those without marijuana experience. This HR drop is striking considering the significantly heightened SCL, which indicates large SNS excitation among people with heavy marijuana experience during the processing of the PSAs. As introduced earlier, HR is dually influenced by both the PNS and SNS. Hence, the HR deceleration highlights the PNS's dominance over the SNS, which itself, as indicated by SCL, is excited and can increase HR. Taken together, the HR and SCL patterns show that antimarijuana PSAs are more likely to catch the attention of those with marijuana experience—who are often the targeted audiences of the PSAs—particularly through arousing content features. Nevertheless, we need to bear in mind a caveat: Increased attention does not necessarily translate into persuasion. Smoking cues in PSAs, for example, may actually undermine the effects of arguments against smoking (S. Lee et al., 2011).

Second, marijuana experience moderates the effects of arousing content and negativity on SCL, but the large main effect of marijuana experience on SCL dominates the SCL patterns. That is, heavy marijuana experience greatly increases the baseline SCL, indicating greater sympathetic arousal, during the viewing of antimarijuana PSAs. This may result from the nervousness or anxiety associated with watching messages directly targeting one's behaviors; it may also be caused by the higher motivational relevance and significance of the message, in general, due to marijuana cues (Geier et al., 2000). This finding implies that when researchers assess the persuasion tactics to use in PSAs, it is probably safe to assume that the target audiences of antidrug PSAs are highly aroused. Arousal levels have been shown to affect evaluation of advertising content. For example, arousal increases people's selectivity and reliance on diagnostic cues in ads, resulting in more polarized evaluations of what was advertised (Pham, 1996). An interesting direction for future studies would be to investigate the relationship between experience with drugs, arousal elicited by antidrug messages, and message evaluation.

Third, marijuana experience moderates the effect of positivity on zygomatic EMG. For positive content (Conditions P, AP, PN, and APN), individuals with heavy marijuana experience show increased zygomatic activity, suggesting smiling or smiling tendencies, while those without marijuana experience do not. One possible explanation is that those with marijuana experience (through personal use or by being around its use frequently) were smiling nervously, given the experimental setting. If that were the case, however, the zygomatic EMG for those people would be heightened in all conditions. Thus, it is more plausible that their smiling when viewing positive content—even when negative content is also present—may be due to a sense of relief or encouragement when the positive content is about self-efficacy or due to happy feelings elicited by drug-related cues (Geier et al., 2000). In motivational processing theories, zygomatic activity is often used to indicate appetitive activation and an approach tendency (Bradley, 2009; Lang, 2006). Our finding here suggests that positive content may make the antidrug PSAs more acceptable and elicit less counterargument among people with heavy drug experience.

Feedback effects of the psychophysiological systems

Consistent with a dynamic complex systems view of cognition (Buzsàki, 2006; Ward, 2002) and the DMA framework of message processing (Wang et al., 2011), the current study provides evidence of self-organizing, self-causing cognition in media processing. The DMA specification illustrates how the endogenous feedback effects of physiological responses determine the dynamic evolution of exogenous message influences and the final aggregated effects. As illustrated by a simulated example in the study by Wang et al., while holding exogenous message input effects constant, a tiny change in the processing system feedback effects can lead to dramatic differences in the integrated outputs, which are normally what researchers can observe in their studies. The processing system feedback effects integrate the exogenous message effects across time and determine the growth rate, the equilibrium, and the decay rate of the integrated effects.

The findings of the first and second feedback effects of physiological systems in this study and other DMA studies (Wang et al., 2011; Wang, Morey, et al., 2010, 2012) have some important implications for designing and evaluating messages. First, not only the message design elements, but their sequence matters. Because the dynamic feedback effects integrate previous responses into the current state, which in turn is integrated into future states, prior design elements can have enduring influences on emotion and cognition. Therefore, the same PSA content or production elements, such as the same images and arguments, if presented in different sequences, may produce divergent effects (Wang et al., 2011). Second, message durations matter. This has been recognized in previous research (e.g., Southwell, Barmada, Hornik, & Maklan, 2002). The dynamic system feedback effects tested in this study provide critical theory-driven evidence. Because the dynamic system feedback effects integrate and accumulate exogenous message effects across time, the magnitude and sometimes the direction of the message effects observed depend on where the observation occurs in the evolving trajectory of the effects. In addition, the observed effects are contingent on whether the processing system has reached its equilibrium and how long the system has been activated (Wang et al., 2011). Hence, media studies with the same design but different stimulus durations and/or measurement timing may produce different or even contradictory results based on static analyses. This problem arises from the fact that time acts as a confounding variable in static analysis. Dynamic analysis, in contrast, places time at center stage. It disentangles exogenous message effects from the cumulating effects of endogenous feedback and estimates them per time unit. For example, two PSAs with the same design—one 15 seconds in length and the other 30 seconds—may differ in effectiveness because in the latter case, the exogenous message effects are accumulated by the feedback effects across a longer time period. Moreover, research on aggregate long-term media effects, such as multiple exposures to campaign messages, and exposure to both anti- and prodrug information, would benefit from this dynamic systems approach. Finally, message contexts matter. The results support the longstanding view of contextual effects in communication research: Preceding stimuli or other contextual factors can affect the processing of subsequent media stimuli (e.g., Zillmann, 1971). This can help guide our selection of media campaign message placement within an appropriate media context.

Implications for future research

The DMA approach formally specifies and tests the hypothesized order dependence of information processing through system feedback terms. Media producers can take advantage of the dynamic modeling approach in this study to formally evaluate their message designs and placement before the campaign starts. However, much work that continues to test and develop the model in media contexts is still needed. In addition to the aforementioned potential follow-up studies, four general lines of work will be especially useful. First, the current study focuses on the real-time dynamic processing of coactive PSAs. This is necessary for our understanding of PSA effects because exposure to the PSAs does not necessarily mean they are being attended to and processed, which are prerequisites for any effects (Lang, 2006). However, formal dynamic research is needed to connect and extend real-time information processing to postexposure memory, attitude, and behavioral measures, which are more typical indices of message effectiveness in campaign research. Second, this study used self-report CRM ratings from a pretest as motivational inputs for the physiological responses. A better approach is to develop a CRM model first to model the rating responses to the message content (Wang et al., 2011). Third, although the DMA is rooted in dimensional and motivational theories of emotion, it can also be used to study the use of discrete emotions in PSAs. As discussed, the dimensional and discrete emotions theories are complementary to each other. Especially some oft-used discrete emotional appeals, such as fear and guilt, are likely to be coactive when used together with self-efficacy (Dillard & Nabi, 2006; Witte & Allen, 2000). Finally, cues of various substances or risk products can affect the motivational states of substance users (e.g., Lang, Shin, et al., 2005; S. Lee et al., 2011). This study indeed found that not only individuals' marijuana experience but also their cigarette use and alcohol use moderate their attentional and emotional responses to antimarijuana PSAs. Further exploration is warranted to specify how experiences with different types of substances or risky activities can influence the effects of PSAs targeting a specific type of substance. This understanding may help maximize the influence of antisubstance PSAs—not only directly on the users of the targeted substance but also for audiences at higher risk in general.

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