

Neural Bases of Psychological Reactance:

An fMRI Study on Dogmatic and Suggestive Health Communications

Abstract

This study aims to elucidate the neurobiological mechanisms of psychological reactance—a motivational state aroused when an individual perceives their freedom of choice is threatened—when unhealthy food eaters are exposed to two types of health-related message frames that differentially threaten individual autonomy: dogmatic (“You must...”) versus suggestive ones (“It would be a good idea to...”). By using both functional Magnetic Resonance Imaging (fMRI) and self-reported measures, our study gives strong support to the Psychological Reactance Theory, such that dogmatic messages provoked stronger self-reported levels of anger and counterarguments (i.e., psychological reactance) which led increased activation in brain areas associated with such psychological mechanisms, namely the inferior frontal lobe, fusiform gyrus, anterior insula and dorsomedial prefrontal cortex. In contrast, suggestive messages engage brain areas linked to reward and self-reference (ventromedial prefrontal cortex), suggesting greater persuasion. These results could suggest policymakers should incorporate self-relevant features in dogmatic messages to reduce persuasion resistance.

Keywords:

Health communication; Psychological Reactance Theory; neuroimage; dogmatic messages; suggestive messages.

According to World Health Organization (WHO), 43% of adults were overweight in 2022, and one in eight people lived with obesity worldwide (WHO, 2024). The World Obesity Atlas 2024 highlights the United States, Greece, United Kingdom, and Spain are among the 20 countries with higher Body Mass Index (BMI) (World Obesity Federation, 2024). One of the tools that has recently become more relevant to inform, educate and persuade individuals to develop healthier behaviors is the design of health communication campaigns, that is, the use of communication evidence, strategy, theory, and creativity to advance the health and well-being of people and populations (European Centre for Disease Prevention and Control et al., 2014). Persuasive health messages aim to encourage positive behavioral changes, such as adopting healthier diets. Scholars in the field of health communication have evaluated how several message features impact desired attitudes, intentions, and behaviors differently. For example, studies have documented that using tailored (over untailored) messages, emphasizing gains (over losses) of developing such behavior, highlighting the how (over the why) to develop the healthy behavior, or focusing on the future (over the past) increase message persuasion and promote most greatly healthy habits (Author et al., 2022; Lutrell & Trentadue, 2024; Vezich et al., 2016).

Communication literature has vastly documented that the persuasion of health communication campaigns, nevertheless, can be significantly undermined by the psychological reactance, a concept introduced by Brehm (1966) in his Psychological Reactance Theory (PRT hereafter), which refers to the negative emotional and cognitive response that occurs when an individual perceives that his or her freedom of choice is threatened because of an external stimulus, such as the contents of a persuasive message. Reactance can lead, therefore, to resistance against the recommended behavior and, in some cases, result in a boomerang effect where individuals adopt the opposite behavior (Byrne and Hart, 2009). Extant research in health communication has shown that certain features in persuasive health messages can create a sense of freedom threat, leading to psychological reactance. For instance, message elements such as warning labels (LaVoie et al., 2017), vivid imagery (Quick & Stephenson, 2008) or red public service announcements (Armstrong et al., 2021) are all associated with triggering this response.

One of the most testable propositions from PRT is that persuasive messages using language explicitly aimed at limiting autonomy are likely to strongly evoke a sense of freedom threat and consequent reactance (Brehm and Brehm, 1981). Several labels have been used to describe this type of language, including “controlling language” (Miller et al., 2007, p. 222), “dogmatic language” (Quick and Stephenson, 2008, p. 450), “freedom-threatening language” (Clayton et al., 2024, p. 2), and “forceful language” (Quick and Considine, 2008, p. 483). Dogmatic language is directive, highly explicit, and contains commands (e.g., “you must”), as opposed to “suggestive” or “freedom-enhancing” language, which uses indirect propositions to promote the desired behavior (e.g., “it might be a good idea to...” or “it is impossible to deny...”) (Reynolds-Tylus, 2019). Here, we characterize dogmatic language similarly to Quick and Stephenson (2007) and Clayton et al. (2020), as forceful language that explicitly pressures audiences to engage in a specific behavior. Over the past 20 years, communication studies have reached a broad consensus, based on self-reported measures, that a combination of negative affect (i.e., anger) and negative cognitions (i.e., counterarguments) best defines the psychological reactance triggered by such dogmatic language—known as the intertwined model (Dillard & Shen, 2005). This model contrasts with other reactance paradigms, including the single cognitive model (only negative cognitions), the single affective model (only anger), and the dual-process model (where reactance is treated as separate components of anger and negative cognitions rather than as a combined latent variable) (Dillard & Shen, 2005; Rains & Turner, 2007). Such heightened psychological reactance (i.e., anger and negative cognitions) and consequent boomerang effects via behavioral intentions have been consistently demonstrated across a wide range of health domains—such as alcohol and drug use, COVID-19 compliance, and tobacco use (Miller et al., 2007; McGuire & Ball, 2022; Quick & Stephenson, 2008)—as well as among diverse consumer groups, including adolescents, college students, and adults (Quick & Kim, 2009; Clayton, 2022; Quick & Considine, 2008).

Despite the well-established interplay of negative cognitive and affective responses (i.e., the intertwined model of psychological reactance) triggered by health-related dogmatic messages, a new generation of PRT studies is emerging to capture the nature of reactance more

objectively. Particularly, there is a call for the use of neural and physiological tools that enable moment-by-moment, implicit measurement of responses during message exposure, facilitating the examination of defensive reactions to dogmatic messages that arise at an unconscious level (Rains & Turner, 2007). This new approach holds significant potential because, unlike self-reported measures, neurophysiological tools can help investigate the temporal dynamics of reactance, capture its cognitive and/or affective underlying mechanisms in real time, and reduce individual biases, such as social desirability and subjective perspective. Some scholars have already contributed to this line of research. Notably, Sittenthaler et al. (2015) used heart rate to measure physiological arousal associated with perceived threats to freedom, while Clayton (2019) employed heart rate (as a proxy for defensive responses), self-report, and memory measures to capture reactance. More recently, Clayton et al. (2023, 2024) utilized heart rate, skin conductance, facial EMG (to measure unpleasantness via the corrugator muscle), along with self-report and memory measures to operationalize reactance.

While such studies advance our understanding of the physiological mechanisms underlying reactance, they are limited in capturing the deeper neural, cognitive and affective processes that drive defensive reactions, such as anger and counterarguing. Neuroimaging techniques like functional Magnetic Resonance Imaging (fMRI) can address this limitation by identifying activations in deep brain structures associated with high- and low-order mental processes in response to persuasive messages, a field known as persuasion neuroscience (Weber et al., 2015; Bakalash et al., 2021). Despite there are studies exploring the neural correlates of message features (such as tailored messages, how vs. why messages or normative messages, e.g., Author et al., 2022; Vezich et al., 2016), to the best of our knowledge, only the study by Mühlberger et al. (2024) has used fMRI to explore the neural mechanisms associated with freedom-threatening, anger-inducing, and neutral statements. The authors found that in freedom-threatening scenarios, brain areas involved in perspective-taking and mentalizing—inferring others' thoughts—were more strongly activated than in anger-inducing conditions. This suggests that high-order mental states, rather than anger, may underlie experienced reactance. While this study represents an important advance, certain limitations may have influenced the results. First,

although the authors pretested three scenarios (freedom-threatening, anger-inducing, and neutral), which covered a wide range of topics (e.g., exams, loans, parties, seminars) on an independent sample aged 24 to 71, only participants aged 20 to 35 took part in the fMRI session. We argue that some pretested scenarios (e.g., a rescheduled exam in the reactance-eliciting condition) might not have been equally acted as freedom-threatening, involving, or anger-inducing for a 20-year-old college student versus a 35-year-old participant (who may no longer take exams and thus may not experience the same level of anger). This disparity in topic relevance, along with the lack of pretesting of the language used, could have confounded the neural processing of anger and freedom threat. Second, the sample size of 18 participants is extremely small for an exploratory fMRI study, which could impact the robustness of the findings (Author et al., 2023). Moreover, the study by Mühlberger et al. (2024) was not conducted within the field of persuasive communication but instead in a more general social behavior domain.

Aiming to overcome these drawbacks, the current research aims to explore the neural bases of psychological reactance when unhealthy food eaters are exposed to persuasive dogmatic vs. suggestive health communications. Unlike Mühlberger et al. (2024)'s research, all participants in our study had a similar level of topic involvement (i.e., health), the only element differing in the freedom threatening scenarios was the language, which was pretested (dogmatic vs. suggestive messages), and the sample size was 37, a more acceptable sample size for fMRI studies in persuasion neuroscience. By integrating findings from health communication research, psychological theories and persuasion neuroscience, we seek to provide a comprehensive framework able to illuminate the neural nature of reactance and the operation in the persuasion process of health nutritional messages. The following sections will review the theoretical underpinnings of reactance theory, its application to the use of dogmatic vs. suggestive language in health communication and the potential neural mechanisms involved in reactance.

Theoretical Background

Psychological Reactance Theory (PRT)

Originating in the field of social psychology, PRT is based on the foundational principle that individuals value their freedom, choice, and autonomy (Brehm, 1966; Brehm and Brehm, 1981). Accordingly, when an external stimulus is perceived to threaten, restrict, or eliminate an individual's freedom to choose, an aversive motivational state known as psychological reactance occurs. This state of reactance motivates the individual to restore their threatened freedom or perceived autonomy. For example, when confronted with a persuasive message that imposes a desired behavior in an authoritarian or dogmatic manner, the recipient may perceive it as a threat to their freedom of choice, resulting in resistance, rejection of the message, and potentially even adopting the opposite behavior (Reynolds-Tylus, 2019).

Traditional psychology studies have devoted considerable efforts to clarify the nature of reactance and identify their underlying mechanisms. Initially it was thought reactance could not be measured (Brehm, 1966) but the pioneering works by Dillard and Shen (2005), as well as Rains & Turner (2007), have shown it to be best captured following the intertwined model (i.e., emotional anger and cognitive counterarguments combined) relative to only anger (i.e., single affective), only negative cognitions (i.e., single cognitive), or anger and negative cognitions separately (i.e., dual model). Most PRT literature has conceptualized reactance as a two-step process involving the perception of a threat to freedom followed by a reactive response characterized by negative cognitions and emotions (namely, the intertwined model). This approach was largely confirmed by Quick and Considine (2008), Clayton et al. (2020, 2023, 2024), Miller et al. (2024) or Sittenthaler et al. (2015). However, the studies by Erceg-Hurn & Steed (2016) and Rains & Turner (2007) operationalized reactance just as a purely emotional response (i.e., single affective) while Tukachinsky & Sangalang (2016) gave empirical support to the primarily negative cognitions (i.e., single cognitive).

Despite the advance in the operationalization of reactance implied by such self-reporting studies, most recent scholars question whether this is the unique or most objective way to measure reactance (Clayton, 2022). The lack of unanimity on the cognitive, affective or mixed nature of reactance (Ratcliff, 2021), together with the low-order, implicit origin of the motivational arousal experienced by the person whose behavioral freedom has been threatened (Bolls et al., 2019), opens the way to the use of additional tools that favor the creation of a more objective, direct index of reactance. Lining up with this rationale, social psychologists are lately making use of biometrics and psychophysiology theories and methods to evaluate the psychophysiological mechanisms underlying the processing of threatening contexts (see reviews by Reynolds-Tylus, 2019, and Ratcliff, 2021). In that sense, tools such as eye-tracking (that monitors the movement of a person's eyes to determine visual attention), skin conductance (that measures the activity of eccrine sweat glands, which are indicative of the emotional arousal of the sympathetic autonomic nervous system), electrocardiogram (a measurement of the number of heart contractions, which have been associated with motivational and attentional states) or facial electromyography (which records the electrical signals associated with movements of facial muscles which have been associated with positive and negative emotions) are gaining relevance in the communication field with the aim to capture the cognitive and/or affective underlying mechanisms of PRT in real time and thus reduce individual biases (Clayton, 2019, 2022; Clayton et al., 2024; Sittenthaler et al., 2015). In the following section, we discuss how persuasive health communication has largely assessed (both with traditional and psychophysiology-related tools) the underlying processes of reactance and their effects on individual's attitude, intentions and behavior.

PRT in Communication Research: Dogmatic vs. Suggestive Messages

In communication research, reactance has primarily been explored in the area of persuasion, especially persuasive health communication. Consumers regularly face official guides to balanced nutrition, such as that of the Spanish Society of Community Nutrition (2021), which include dogmatic messages like “At dinner, you must eat foods that are easy to digest, such as cooked vegetables, fish or dairy products”. To what extent do these types of messages

encourage adherence to healthy behaviors, as opposed to indirect messages (suggestive messages), such as “Making a list of foods to buy weekly might be a good way to buy healthy products”? The primary difference between these messages is the degree to which they limit freedom or autonomy—that is, the extent to which the message implies that the recipient is obligated or pressured to comply rather than given the option to refuse (Kim et al., 2017; Kronrod et al., 2012). Depending on the greater or lesser degree of autonomy limit, we can differentiate between dogmatic messages, which are directive and forceful and contain commands, orders, and rules, such as “You are doing a lot for your health, but you must do more! Consume sugar-free products”; and suggestive messages, that include indirect propositions or suggestions to promote the desired behavior, such as “You are doing a lot for your health, maybe you could also eat sugar-free products!”.

Building upon the PRT, precedent research has evaluated the persuasion of using dogmatic and suggestive messages to promote healthy habits. A primary and extensive line of research supports the view that dogmatic messages—due to their more forceful and threatening tone—elicit higher levels of anger and prompt individuals to counterargue the content (i.e., psychological reactance), leading to a reduced intention to follow the recommended behavior (Fitzsimons & Lehmann, 2004) or even adopt the opposite behavior (Byrne and Hart, 2009). The study by Quick and Stephenson (2007), for example, confirmed that condom ads that elicited threat-to-choice perceptions increased reactance, which negatively associated with ad persuasion. Lining up with such findings, the recent study by McGuire and Ball (2022) found that a heightened perception of freedom threat from dogmatic videos promoting COVID-19 guidelines was associated with increased psychological reactance, which in turn was linked to lower intentions to follow COVID-19 guidelines, reduced willingness to share the video within one’s online social network, and a stronger tendency to deny COVID-19 as a public health risk. Similar findings were reported with dogmatic messages promoting exercise (Quick & Considine, 2008) and reducing drug use (Miller et al., 2007). Another research line, however, qualifies these results and concludes that the persuasion of dogmatic messages depends on the individual’s degree of involvement with the issue in question: in high-involvement settings,

dogmatic messages elicit greater intention to develop the desired behavior (because of greater alignment with prior beliefs) in the audience, while they may require more suggestive appeals when lacking initial conviction (Dahl & Gordon-Wilson, 2013). Although dogmatic messages can be effective in certain high-stakes scenarios, they often risk eliciting reactance, particularly among audiences that value autonomy and self-determination (Dillard & Shen, 2005). However, other studies on suggestive messages concluded that they may reduce the likelihood of reactance but require careful consideration of the audience's perceived importance of the behavior and level of involvement (Kronrod et al., 2012). Additional research postulates that dogmatic messages are more persuasive in hedonic (vs. utilitarian) purchase environments due to the positive context in which persuasion occurs (Kronrod et al., 2012). Similarly, Dillard and Chen (2005) found that when individuals perceive the outcome of the behavioral outcome to be hedonic, they are more likely to be persuaded by dogmatic language.

To further clarify the nature of reactance caused by dogmatic messages and its effects on persuasion, communication scholars are adopting tools and theories from psychophysiology. These methods are less prone to issues like inaccurate recall and social desirability biases, which can sometimes affect self-report measures, allowing for a more objective identification of the biological mechanisms underlying reactance elicited by persuasive dogmatic and suggestive messages. Sittenthaler et al. (2015), for example, used heart rate to measure physiological arousal associated with perceived threats to freedom and found that illegitimate restrictions (i.e., unexpected and inappropriate) led to an immediate physiological arousal, whereas legitimate restrictions (i.e., unexpected but appropriate) led to a time delayed physiological arousal. Along the same line, Sittenthaler et al. (2016) turned to heart rate and skin conductance in order to evaluate motivational arousal and found increases in heart beat and level of skin sweating quickly after participants imagined their own freedom being restricted. Lining up with such rationale, Clayton et al. (2018) found accelerated heart rate in response to freedom threatening antitobacco messages that are highly arousing and unpleasant, indicative of less attention and higher defensive message processing. Further, Clayton (2022) found dogmatic anti-vaping messages to have greater corrugator muscle activation (indicative of unpleasantness), high

levels of arousal via skin conductivity, and faster heart rate reflective of less attention (or cognitive resource allocation). Together, these measures reflect defensive message processing via the defensive cascade model, which was further supported via participants' self-report. More recently, Clayton et al. (2023, 2024) used heart rate and facial electromyography to measure reactance. They found that when participants were not inoculated prior to receiving a freedom-threatening health message, they reported higher psychological reactance, showed less heart rate deceleration (indicating fewer cognitive resources allocated to the messages), and exhibited greater corrugator muscle activation, reflecting a more negative emotional response.

Persuasion Neuroscience: Neural Bases of PRT

Despite the advances in the operationalization of reactance by physiological studies, however, no study so far has cleared up the neural underpinnings of reactance in health communication contexts. That could constitute a step forward as neuroimaging in general, and fMRI in particular could enable a moment-by-moment measurement of neurophysiological processes; localize activation to deep brain structures indicative of mental processes that cannot be accessed with other physiological techniques (such as anger, effortful processing, mentalizing, self-relevance, moral cognition, credibility or reward); spatially distinguish the neural bases of constructs that, although subjectively perceived as a part of a single continuum, are in fact processed differently, such as trust and distrust; and tackle unanswered questions in persuasion research without requiring participants to engage in conscious introspection (Cacciopo et al., 2018; Weber et al., 2015). The study of neural mechanisms underlying how persuasive messages influence attitudes, beliefs, and behaviors is known as persuasion neuroscience. Today, it stands as one of the most promising research areas in communication, with significant potential to reveal the neural foundations of persuasion and persuasion resistance (Falk and Scholz, 2018). Accordingly, the fMRI is uniquely positioned as a tool to inform about the neuroanatomical framework underlying reactance.

Research in social cognitive and affective neuroscience is plenty of neuroimaging studies that have already cleared up the neural mechanisms involved with mental events of

interest for reactance, such as anger or counterarguing, and thus may shed light on its neural nature. On the one hand, and following traditional studies on the PRT (Erceg-Hurn & Steed, 2016; Fitzsimons & Lehmann, 2004), the threat to freedom elicited by reactance may cause **anger** in the audience, an “emotion characterized by tension and hostility arising from frustration, real or imagined injury by another, or perceived injustice” (American Psychological Association, 2024). In their voxel-based meta-analysis of basic emotions, Vytal & Hamann (2010) found out that clusters located primarily in the inferior frontal gyrus (IFG hereafter) and fusiform were associated with angering stimuli. The study even corroborated an overlap between these clusters and those associated with the emotional state of disgust, which activated, apart from the IFG, the anterior insula. The review of neuroscience of anger implemented by Alia-Klein and colleagues (2020) further confirmed that anger induction activate salience, affective and regulation networks, including the IFG, prefrontal cortices and the dorsal anterior cingulate cortex (ACC). Furthermore, the coordinate-based meta-analysis by Sorella et al. (2021) confirmed that the perception and the experience of anger share common neural mechanisms, such as the IFG. Similarly, angry faces processing involved affective regions, such as insula, amygdala, anterior cingulate cortex (ACC) and prefrontal cortices (Golliet-Briant et al., 2016). Along the same line, Denson et al. (2009) provided evidence that the ACC is linked to the subjective experience of anger.

The resistance against the recommended behavior in directive communication contexts may provoke, furthermore, message rejection and negative thoughts which could lead to the involvement of brain regions associated with **counterarguing**, a cognitive mental state in which a person reasons arguments against an advocated position (Ratcliff, 2021). Counterarguing requires a relatively high level of cognitive effort and self-awareness, which tend to be higher when individuals show a strong confidence in their initial attitude and involvement with the topic. The studies by Clayton et al. (2019) and Clayton (2022) demonstrated that as counterarguing increases individuals allocate less attention to message processing. That is, counterarguing requires cognitive resources which depletes available cognitive resources for message processing. Weber et al. (2015) carried out a neuroimaging study evaluating the neural

basis of counterarguing when high and low-drug-risk individuals were exposed to messages differing in strength and sensation value. Their findings revealed greater involvement of brain networks associated with effortful processing (i.e., inferior frontal lobe) and semantic language (i.e., dorsomedial prefrontal cortex, dMPFC, or superior temporal gyrus) in high-risk individuals while weighting the antidrug message against existing conflicting beliefs. More recently, Liu et al. (2021) attempted to unpack neurocognitive mechanisms associated with counterarguing among a sample of established smokers in response to anti-smoking messaging and found increased activity in the dorsal lateral prefrontal cortex (DLPFC) to be associated with cognitive deliberation and negative argumentation. Similar brain regions were found in prior studies evaluating executive processing and cognitive effort (Radua et al., 2014).

Neural Bases of Persuasion

If anger and counterarguing are more likely to be elicited by forceful communication contexts during persuasion resistance, neural mechanisms associated with persuasion might come into play during the exposure to more indirect propositions to change behavior. Traditional media persuasion theories, such as the elaboration likelihood model (ELM; Petty & Cacioppo, 1986), or the limited capacity model of motivated mediated message processing (LCM4P; Lang, 2009) show consistent results regarding the affective, cognitive and behavioral mechanisms underlying (health) persuasive messages: behavior change is more likely when individuals are exposed to personally relevant and motivational information, which can lead to a central processing route, meaning that it maybe considered more thoroughly by the person, integrated it into their learning process and compared it with prior individual experiences. Thus, to make a message more persuasive it should involve mental states associated with self-relevance and personal value (Cacioppo, Cacioppo, & Petty, 2018). Social learning theories add, furthermore, that mentalizing (i.e., the ability to understand one's own and others' mental states, thereby comprehending one's own and others' intentions and affects) could also play a crucial role as they conceive that "behavior change can result from encoding information about social norms, incorporating those norms into one's own self-concept, and planning to execute the

relevant behaviors” (Falk, Berkman et al., 2010, p. 8423). Theories of social influence emphasize the power of social norms in persuasion processes (Rimal & Lapinski, 2015) and suggest that norms are influenced by both external social pressures and individuals’ internal perceptions of value. Therefore, mentalizing (i.e., the cognitive process of considering the mental states of others) may assist in understanding others’ perspectives and potentially suppressing one’s own views in favor of aligning with social norms.

Persuasion neuroscience studies have corroborated these expectations and revealed that brain regions linked to **self-referential processing and reward** (ventromedial prefrontal cortex, VMPFC hereafter, and ventral striatum) as well as **mentalizing** (temporo-parietal junction) were highly present during exposure to persuasive communication campaigns (Falk and Scholz, 2018; Weber et al., 2015). These findings have been supported during the processing of health persuasive tailored nutritional messages (Author et al., 2022), antismoking messages which led smoking reduction (Cooper et al., 2018) and messages promoting improvements in mental and physical health outcomes (Falk et al., 2015). Neural evidence highlights the importance of social relevance in conformity. For example, when adolescents received feedback indicating that others’ ratings of mobile game apps differed from their own, increased activity in the mentalizing system was linked to a higher likelihood of adjusting their recommendations to align with group feedback (Cascio et al., 2015). Additional studies have even confirmed that brain networks associated with self, reward and mentalizing predict message propagation and viral marketing (Scholz et al., 2023).

The Current Research

Building on the literature on health communication research, PRT and persuasion neuroscience, we intend to explore the neural mechanisms underlying reactance in the persuasion process of dogmatic vs. suggestive nutritional messages. Particularly, the more direct and forceful nature of dogmatic (vs. suggestive) messages may elicit higher reactance and provoke persuasion resistance and hence activate to a greater extent brain regions linked to anger and counterarguing. Therefore, we formally propose the following:

H1: Dogmatic (vs. suggestive) messages elicit brain responses associated with anger (IFL, fusiform, anterior insula, amygdala and ACC) and counterarguing (IFL and dMPFC).

In contrast, suggestive messages, which are more autonomy-supportive, may reduce reactance and increase persuasion when compared to dogmatic commands, which could lead to the involvement of brain regions associated with self-referential processing, positive valuation and mentalizing. Consequently:

H2: Suggestive (vs. dogmatic) messages elicit brain responses associated with self-relevance and positive value (VMPFC and ventral striatum) as well as mentalizing (temporo-parietal junction).

Accordingly, we expect that dogmatic (vs. suggestive) show lower self-reported levels of persuasion and higher reactance in healthy consumption promotion.

Method

Participants

We recruited 39 right-handed participants between 18 and 35 years to undergo the fMRI task. Data from two participants were discarded because of incomplete scanning procedure. In order to determine if our sample size is sufficient to detect a required effect, we implemented a power analysis using G*Power. Considering that the literature is lacking an fMRI study design investigating memory processes of tailored ad messages, we used a more general approach and took Cohen's original high effect classification ($d = 0,5$; 1988, 1992). Thus, in order to detect a statistical effect size of $d = 0,5$ with a one-sample t-test at the power level of 0,80 and $\alpha = 0.05$, we found the recommended total sample size to be 27. Therefore, our sample size of 37 is confirmed to be sufficient in order to detect such an effect. Our sample, indeed, aligns with the sample size of prior fMRI studies in persuasion neuroscience (Falk et al., 2015). Because the baseline nutritional behavior could affect the processing of persuasive messages, we followed prior health communication studies and only participants who showed moderate to marked unhealthy nutritional behaviors were chosen (Author et al., 2022; Chua et al., 2011). Specifically, we employed the Unhealthy Eating Behavior Scale recently created by Guertin,

Pelletier, and Pope (2020) to evaluate the unhealthy eating habits of our potential sample. This scale includes a 7-point Likert scale (1 = never to 7 = always) where participants indicate how often they consumed 11 specific types of unhealthy food in the past month, such as “I eat refined grains,” “I use white sugar or artificial sweeteners,” or “I drink sugar-sweetened beverages.” Our eligibility criteria required participants to have an average score of more than 3.5 points (on a scale of 1–7), indicating moderate to high levels of unhealthy eating, as suggested by Katagiri et al. (2014). Participants also had to meet common MRI criteria (e.g. no implants, no pregnancy, no claustrophobia). All participants provided informed consent before the fMRI sessions in accordance with the Ethics Committee of a large University and the Declaration of Helsinki (World Medical Association, 2017).

Message Design

The primary goal of the experimental design was to expose participants to two types of messages promoting healthy consumption behavior—dogmatic and suggestive—as well as a neutral message type serving as a comparison baseline. We first developed an initial set of 30 dogmatic and 30 suggestive messages promoting healthy nutritional habits. For the design of these messages, we strictly followed the procedure by Minich et al. (2023), that is, each used the outcomes of adopting or failing to adopt the desired behavior and added an action or recommendation component by using either a dogmatic or suggestive tone. For example, in the message *The World Health Organization is clear: if you eat healthy, you will be less tired and perform better at work. You have no choice. Do it*, the first part (*The World Health Organization is clear: if you eat healthy, you will be less tired and perform better at work*) informs about the positive outcomes from eating healthy, while the second part (*You have no choice. Do it*) refers to the action or recommendation component using dogmatic language. We also controlled the word count (from 10 to 30 words).

An independent sample (n = 51) in a preliminary test allowed us to corroborate the manipulation of the level of freedom threat and select those that were more typically perceived as dogmatic (i.e., freedom-threatening) and suggestive (i.e., freedom-enhancing). Specifically, and

after the definition of “dogmatic” and “suggestive”, participants in the pretest were asked to rate the freedom-threat level of each message on a Likert-type scale from 1 (low) to 7 (high). Only the messages that obtained less than 3.5 points were selected and classified as suggestive messages (e.g. “Did you know that eating fruit and plain yogurt could be a good combination for mid-morning? Perhaps you could incorporate them into your diet more regularly.”), while those higher than 5 points were categorized as dogmatic messages (e.g. “The World Health Organization is clear: if you eat healthy, you will be less tired and perform better at work. You have no choice. Do it now.”). A paired-samples t-test revealed significant differences ($p < .001$) between the 15 messages finally selected and qualified as dogmatic messages ($M = 5.54$; $SD = .853$) and the 15 selected as suggestive messages ($M = 3.39$; $SD = 1.149$). Neutral messages added information unrelated to healthy habits (“Petroleum was formed from the remains of animals and plants that lived millions of years ago”). The completed list of messages shown during the fMRI task can be found in Appendix 1.

Procedure

After recruitment of the 37 participants, the fMRI task was scheduled to be performed following a within-subject experimental design. The subjects arrived at the fMRI lab one hour prior to the task to verify their informed consent data and to recheck for common fMRI exclusion criteria (e.g. pregnancy, metal implants, claustrophobia). Then, participants were instructed to watch 15 dogmatic messages, 15 suggestive messages about health consumption, and 15 neutral messages. Each series of messages started with a display of a short period of fixation (3 seconds) followed by an 6-second display of an dogmatic or suggestive messages. The order of presentation of each of the 45 messages was random. Immediately after each message, participants had 4 seconds to indicate, using a 4-button box, the extent to which each message encouraged them to eat healthily (a proxy of persuasion, Author et al., 2022) (1 = “No, strongly disagree”, 4 = “Yes, strongly agree”). Then, a distracting task was displayed for 6 seconds. Particularly, mathematical calculations were used prior to the memory-related task to serve as a cognitive load or baseline activity, ensuring participants were not actively engaging in memory

processes immediately before the task. This helps isolate memory performance by minimizing potential influences from previous cognitive states and primes participants for a clear transition into the memory-focused activity. Finally, participants were instructed to close their eyes to reimagine the message (i.e., to test memory formation) they had just previously viewed for 8 seconds (see Figure 1). The total duration of the task was around 20 minutes, including the anatomical image acquisition. E-Prime Professional 2.0 software was used to present the fMRI stimuli.

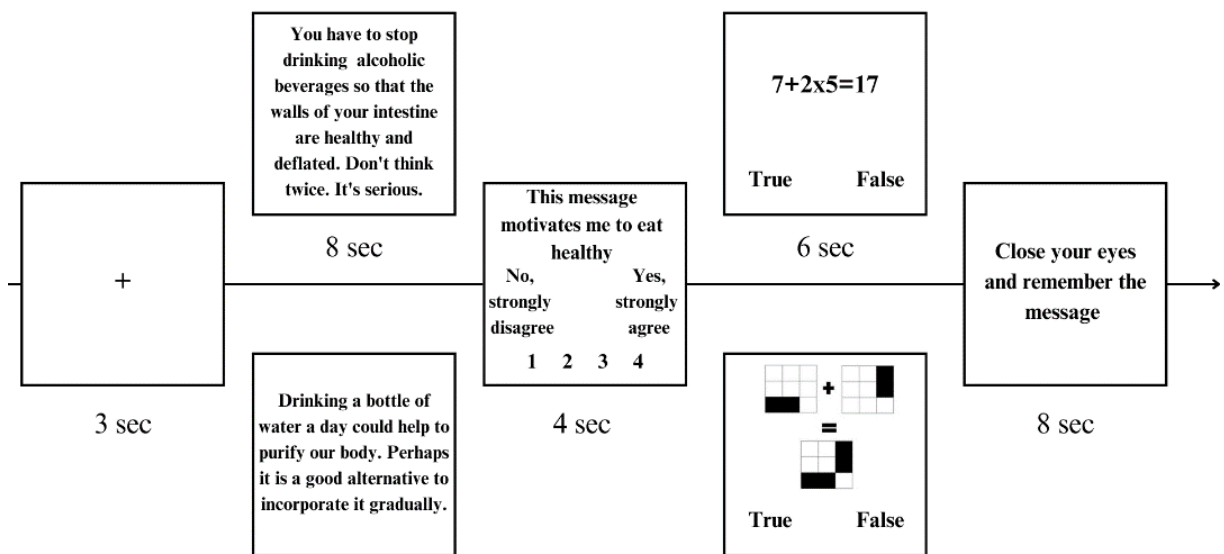


Figure 1. Visual diagram of the experimental fMRI task

After the fMRI task, each participant completed a questionnaire aimed at capturing self-reported persuasion and reactance toward each type health message. Particularly, participants were exposed to messages viewed during the fMRI task and were required to answer some computerized questions as proxies of perceived persuasion as proposed by Venkatraman et al. (2015) or Scholz et al. (2020): “On a scale of 1 to 7 (1 = minimum level, and 7 = maximum level), answer honestly about the following messages aimed at improving your diet: (i) Shocking to improve your diet; (ii) Convincing to improve your diet; (iii) Makes you think about your diet; (iv) Useful to improve your diet”. The reliability test showed that these four items (i.e., shocking, convincing, makes someone think, and useful) could be used as a single measure of self-reported persuasion ($\alpha=.78$). Self-reported cognitive reactance was measured

following a thought-listing task by Dillard & Shen (2005): (i) “What thoughts/feelings do you have as you read the message?”. Every thought was coded for “valence”, which measures how positively the thought regarded either message (Rains & Turner, 2007). To that end, each thought/feeling could be coded as positive (+1), negative (-1) or neutral (0). Thus, by balancing between positive, neutral or negative thoughts/feelings, we encode each message as such for each participant (reliability tests were assessed for each code). For the anger assessment, we followed the standard 4-item index (Likert scale from 1 to 7) used via Dillard and Shen (2005). Considering the relatively small sample size of our study ($n = 37$) and the shortcomings of standard methods in detecting problems with parametric assumptions (Wilco, 1988), we considered robust bootstrapped ($n = 2000$) trimmed mean (%10) paired samples t-tests using the *ybdt* function in the R package *WRS* (Wilcox and Schönborcht, 2015) which utilizes Yuen’s test (1974).

fMRI Analyses

Image acquisition, preprocessing, and statistical analysis

Scanning was conducted using a 3T Trio Siemens Scanner with a 64-channel head coil. Anatomical images were obtained in sagittal orientation with a voxel size of 1 mm^3 . Functional scans were acquired using a T2*-weighted echoplanar imaging (EPI) sequence (TR = 2000 ms, TE = 25 ms, FA = 90° , thickness = 3.5 mm; 35 slices, descending order), yielding a total of 790 slices with a FoV of 238 mm.

We analyzed the neuroimaging data with standard software (SPM12, Wellcome Department of Cognitive Neurology, London, UK, <https://www.fil.ion.ucl.ac.uk/spm/software/spm12/>) on MATLAB R2012a, using default settings where appropriate. After visually inspecting the mean functional images for artifacts, they were realigned to correct for motion, coregistered, segmented, normalized into standard stereotactic space, and smoothed with a $7 \times 7 \times 7 \text{ mm}$ Gaussian kernel (FWHM). Statistical maps were generated for each participant by fitting a boxcar function to the time-series convolved with a canonical hemodynamic response function. We constructed a general linear model (GLM) for

each subject, considering the following regressors of interest: (i) exposure to dogmatic nutritional messages (ASS), (ii) exposure to suggestive nutritional messages (NONASS), and (iii) exposure to neutral messages. Additionally, motion related artifacts were scrubbed from outlier slices using the Artifact Detection Toolbox (ART). ART flagged slices as outliers based on global BOLD signal changes, in this case, above 5 standard deviations as well as above 1mm frame-wise displacement (3 translational and 3 rotational). These flagged slices and the six covariates related to movement noise and fixation crosses were included as regressors of no interest in the subject level analysis. Lastly, a high-pass filter was applied to functional time series data with a cutoff of 128s and an autoregressive model corrected for autocorrelation.

To identify brain regions with significant activations during exposure to dogmatic, suggestive, and neutral messages, four contrasts were calculated at the first level: dogmatic vs. suggestive, suggestive vs. dogmatic, dogmatic vs. neutral, and suggestive vs. neutral, applying a T-contrast to the first, second, third, and fourth regression models, respectively. At the group level, the resulting contrasts were subjected to one-sample t-test analyses to identify brain activation clusters common to all participants. A family-wise error rate of $p < 0.05$ at the cluster level (FWE_c) was applied to all resulting statistical parametric maps of the whole-brain analysis and clusters above the number stated in the SPM results panel as such are considered as significant.

Results

Self-reported Findings

Particularly, for the differences in perceived anger levels, the results of the robust t-test suggest that the self-reported reactance to dogmatic messages ($M=2.5$) was significantly higher than that provoked by the suggestive messages ($M=1.4$; difference = 1.2, 95% CI [0.47, 1.8], $p < .006$) (see Figure 2). The self-reported reactance results at the cognitive level indicate that there are also significant differences in the number of negative thoughts generated by the dogmatic versus suggestive messages. More specifically, the results of the robust t-test show suggest that negative thoughts regarding the dogmatic messages ($M=3$) were significantly

higher than those elicited by the suggestive messages ($M=0.8$; difference =2.2, 95% CI [1.724, 2.676], $p < .000$). A Pearson correlation analysis revealed a significant positive correlation between anger and negative cognitions ($r = 0.6$, $p < 0.001$).

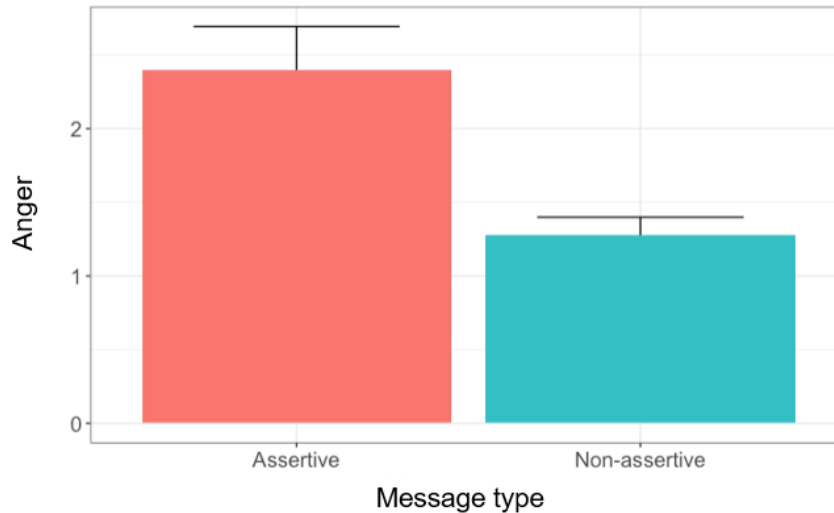


Figure 2. Bar chart of the perceived affective reactance (i.e., anger) between dogmatic and suggestive messages. Bars represent %10 trimmed means and error bars represent their standard errors.

As to the differences in self-reported persuasion inside the scanner, the results of the robust t-test suggest that the encouragement to act healthier (a proxy of inside perceived persuasion) elicited by dogmatic messages ($M=2.6$) was significantly lower than that caused by the suggestive messages ($M=3.3$; difference = -0.71, 95% CI [-1, -0.39], $p < .001$). Along the same line, the results of the robust t-test show that the outscanner self-reported persuasion of dogmatic messages ($M = 4.4$) was significantly lower than the persuasion of the suggestive messages ($M = 5.1$; difference = -0.73, 95% CI [-1.3, -0.12], $p < 0.025$) (Figure 3).

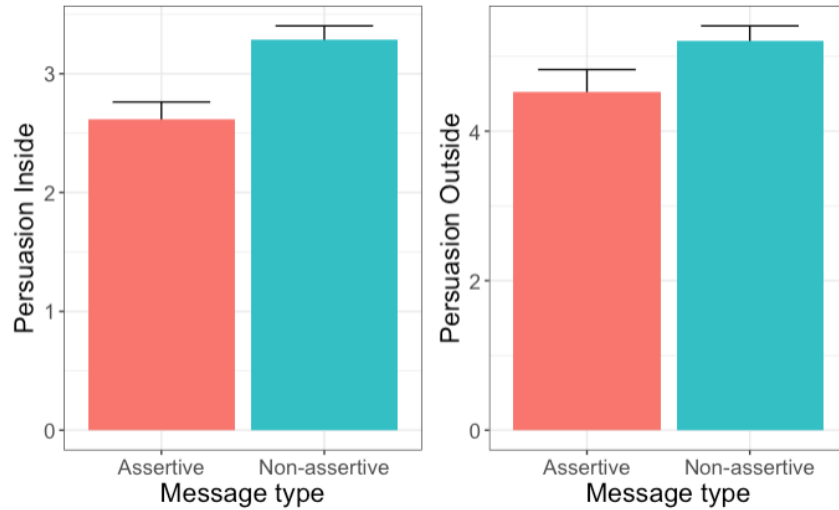


Figure 3. Comparative bar chart of the perceived persuasion between dogmatic and suggestive messages inside and outside of the MRI scanner. Bars represent %10 trimmed means and error bars represent their standard errors.

Functional Image Findings

First, we identified the neural activation patterns associated with dogmatic vs. suggestive messages. Particularly, the dogmatic > suggestive contrast showed a spread out activation, among other regions, within the left fusiform gyrus, inferior frontal gyrus/anterior insula, middle frontal gyrus, dMPFC, right angular gyrus and the left superior parietal lobule (Table 1, Figure 4).

Table 1. Significant clusters in which activity was stronger during the encoding of dogmatic messages than suggestive messages (FWE_c $p < 0.05$; coordinates are given in MNI space).

Region	Hemi	n voxels	T	x	y	z
Fusiform Gyrus	L	120	6.05	-41	-66	-21
	L		5.13	-44	-66	-10
	L		4.5	-27	-74	-14
Inferior Frontal Gyrus/Anterior insula	R	53	5.56	40	28	-7
	R		5.19	54	28	-7
	R		4.49	36	24	-14
Superior Parietal Lobule	L	278	5.21	-27	-66	49
	L		4.94	-24	-63	35
	L		4.36	-34	-91	7
Angular Gyrus	R	134	5.14	32	-66	46
	R		4.22	50	-35	49
	R		3.77	29	-74	32
Inferior Frontal/ lateral prefrontal Gyrus	R	60	4.64	46	14	28

Region	Hemi	n voxels	T	x	y	z
	R		4.38	46	28	24
	R		3.69	36	10	24
Middle Frontal Gyrus	L	34	4.46	-34	0	60
dMPFC	L	66	4.45	-2	28	52
	L		4.08	8	32	42
	L		3.9	4	21	56
Middle/Inferior Frontal Gyrus	L	38	4.24	-44	14	32
	L		4.18	-52	10	35
	L		4.16	-41	18	21

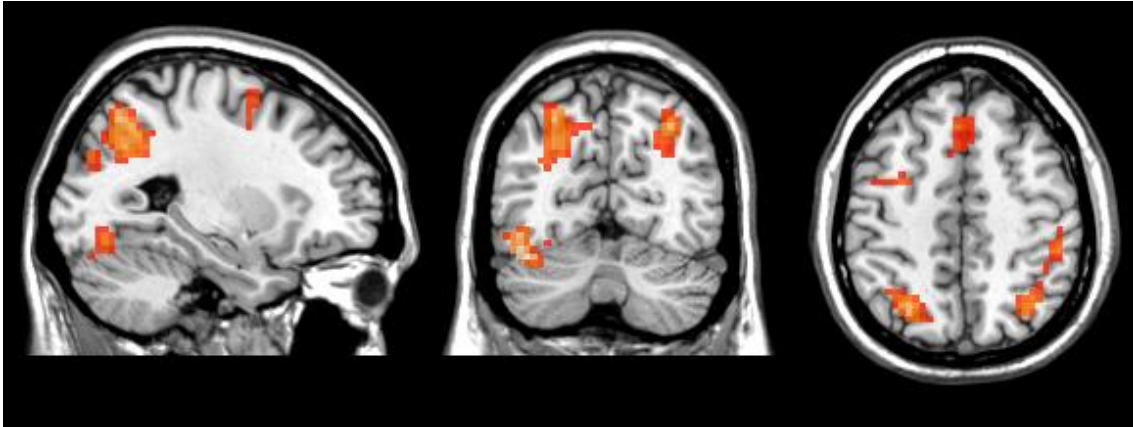


Figure 4. Brain activation for the dogmatic > suggestive condition (x = -27, y = -66, z = 49)

The comparison of the suggestive > dogmatic contrast, in turn, showed a fewer number of clusters around the brain, which included the right orbitofrontal cortex, left parietal operculum, and left cuneus (Table 2, Figure 5). The statistical maps of the contrast images resulting from the main comparisons of interest, namely dogmatic vs. suggestive and vice versa, are openly available at NeuroVault (<https://identifiers.org/neurovault.collection:17520>), where they can be viewed, downloaded, and fed into the integrated Neurosynth decoder. The T1 and T2* weighted brain scans are available at <https://openneuro.org/datasets/ds005304/>. The findings of the group-level whole brain analysis referred to the dogmatic and suggestive comparisons against the neutral messages can be consulted in Appendices 2A and 2B, respectively.

Table 2. Significant clusters in which activity was stronger during the encoding of suggestive messages than dogmatic messages (FWE_c $p < 0.05$; coordinates are given in MNI space).

Region	Hemi	n voxels	T	x	y	z
Orbitofrontal Cortex (VMPFC)	R	126	5.31	15	49	-7
	R		5.28	-16	46	-4
	R		4.8	1	49	-4
Parietal Operculum	L	67	4.8	-52	-28	14
	L		4.61	-44	-32	7
	L		3.78	-38	-24	14
Cuneus	L	139	4.56	-2	-80	14
	L		4.29	8	-88	18
	L		4.12	-10	-66	7

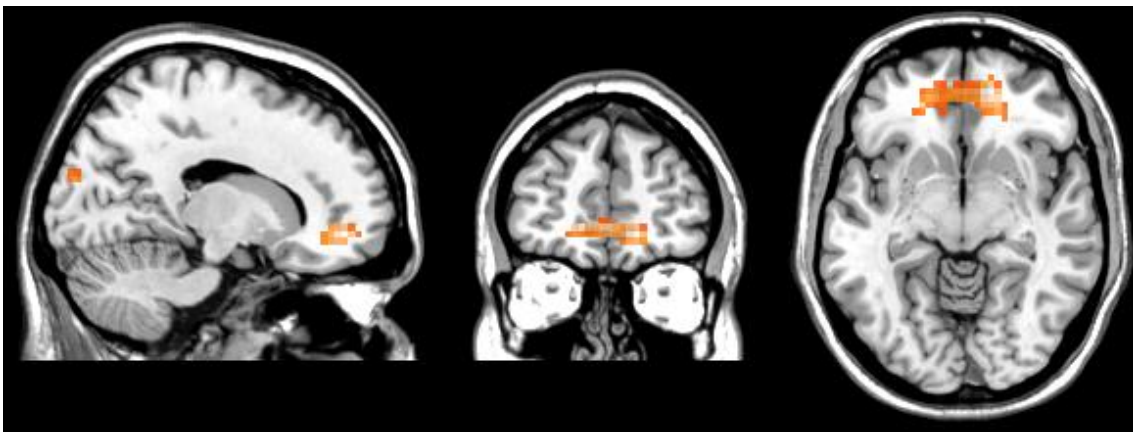


Figure 5. Brain activation for the suggestive > dogmatic condition ($x = 15, y = 49, z = -7$)

Discussion

Main Contributions

Our results offer a three-fold contribution. **Firstly**, we reveal the neurobiological processes underlying reactance. Specifically, we found that neural systems associated with anger and aversion (affective) and those related to cognitive effort and self-awareness (cognitive) are engaged in processing the reactance experienced when exposed to dogmatic messages. These findings provide insights into the ongoing debate in PRT regarding the cognitive, affective, or mixed origin of reactance. Consistent with most studies that identify the nature of PRT (e.g., Dillard and Shen, 2005; Rains and Turner, 2007; Clayton et al., 2020, 2023, 2024; Miller et al.,

2024; or Sittenthaler et al., 2015), our neuroimaging data gives strong support to the intertwined model of psychological reactance and demonstrate that cognitive and affective neural processes are closely intertwined and challenging to separate when participants encounter forceful and freedom-threatening nutritional messages. Giving strong support to such dual-process model, recent studies in the field of communication are employing techniques from psychophysiology to advance the understanding of reactance nature and reveal that accelerated heart rate, high levels of arousal and activation in the corrugator face muscle correspond to experienced psychological reactance (Clayton and Russel, 2022; Clayton et al., 2019). Our research aligns with these studies, highlighting that reactance is operationalized in the activation of brain areas associated with anger (IFL, fusiform, anterior insula) and counterarguing (IFL and dMPFC), thereby contributing to a deeper understanding of the cognitive and affective dimensions of resistance to persuasion.

Secondly, our study provides novel insights into the mechanisms of persuasive health communication, specifically regarding the use of suggestive versus dogmatic language to encourage healthy behaviors. We emphasize that the higher self-reported persuasiveness of indirect recommendations for promoting healthy habits originates from mental processes associated with value and reward. These findings align with previous health communication studies (Quick and Considine, 2008; Zemack-Rugar et al., 2017; Author et al., 2022) and underscore the critical role of using message frames that resonate with the target's personal goals and rewards to enhance persuasion, thus corroborating the foundations of traditional theories of persuasion, such as the Elaboration Likelihood Model (ELM). The involvement of self- and reward-related brain areas during the processing of dogmatic language could advance the current research line in PRT that examine the ways in which dogmatic language can be used without generating reactance/resistance (Richards et al., 2021). It may be reasonable to suggest that incorporating elements into dogmatic messages that engage self- and reward-related mental processes could help reduce the resistance to persuasion that these messages often provoke. This aligns with prior studies highlighting the importance of self-transcendent media experiences to reduce psychological reactance (Clayton et al., 2024).

Thirdly, this research represents a significant advancement in the burgeoning field of persuasion neuroscience in social contexts (Pozharliev et al., 2017), uncovering the neural mechanisms underlying persuasion/persuasion resistance and their potential to enhance our understanding of the fundamental processes driving attitude and behavior change. In alignment with prior research in the field of health communication (for a review, see Cacioppo, Cacioppo & Petty, 2018), our study corroborates the role of the VMPFC as a neural basis for message-induced persuasion. The role of such value- and reward-related brain area in persuasion contexts has been corroborated during persuasive tailored vs. untailored nutritional messages (Author et al., 2022), messages targeting sedentary behavior (Falk et al., 2015), others reaching smoking cessation in cigarette (Falk et al., 2011) or antidrug public service announcements (Donohew et al., 2018). No study, however, had evaluated neural differences in the presence of persuasive messages that, using various levels of freedom threat, encouraged healthy behaviors. To our knowledge, only the Mühlberger et al. (2024) used fMRI to study brain responses to freedom-threatening, anger-inducing, and neutral statements (and not persuasive messages). Their results reveal that freedom-threatening scenarios activated brain regions linked to perspective-taking more than anger-inducing ones, suggesting that complex thought processes, not just anger, drive reactance. However, the study has some limitations: only participants aged 20 to 35 were scanned, which may have affected the perceived relevance of scenarios like rescheduled exams, potentially influencing reactions; the small sample size (18 participants) could limit the reliability of the findings; and the study was conducted in a general social behavior context rather than focusing specifically on persuasive communication. The present study aimed to address these limitations.

Neural Bases of Psychological Reactance to Dogmatic Messages: Validation of the Intertwined Model

Particularly, our H1 proposed that the greater freedom restriction caused by dogmatic (vs. suggestive) messages would increase psychological reactance in participants and thus activate strongly brain areas associated with both the affective component of reactance (namely, anger)

and its cognitive one (namely, counterarguing). The neural data confirm our expectations and showed that dogmatic messages engaged the IFL, anterior insula, fusiform, as well as the dMPFC.

On the one hand, social affective neuroscience studies have largely evidenced the role of the (right) IFL in both perception and experience of anger (Sorella et al., 2021). Activity in the IFL has been traditionally associated with the saliency of an emotional stimulus (Lieberman, 2011) and reappraisal (i.e., changing thoughts about a situation in order to modify emotions elicited by that situation; Grecucci et al., 2013). Beer et al. (2006) found specifically that activation in the IFL was linked to the subjective experience of anger and the subsequent evaluation of the emotional information in decision making. Following the rationale by Sorella et al. (2021), we believe that the IFL might play here a crucial role in the affective labeling or evaluation (and reevaluation) necessary to comprehend and experience the anger-related sensory information derived from the exposure to dogmatic messages. Our significant cluster $x=40$, $y=28$, $z=-7$ also incorporates substrates of the anterior insula, one of the brain regions linked to core affect, which includes motivational states related to personal feelings and objectives (Gu et al., 2013). The voxel-based meta-analysis of basic emotions by Vytal and Hamann (2010) validated that the anterior insula not only characterizes anger (similarly to the IFL) but also disgust. Additional studies also found evidence for increased activation in the anterior insula during the observation of disgusting images about pollution and mutilation (Wright et al., 2004) and experiencing disgust (Wicker et al., 2003). Accordingly, the presence of the anterior insula during the processing of dogmatic messages might be indicative of its crucial role in characterizing the aversive mental state experienced by individuals during emotional resistance to persuasion. The activation of the fusiform gyrus during the exposure to dogmatic messages also aligns with prior neuroimaging studies, which related fusiform activity to face and emotional stimuli processing, as well as to the arousal and valence of emotional significance of a stimulus (Pizzagalli et al., 2002), these latter being defining characteristics of reactance.

Unexpectedly, dogmatic messages did not significantly engage the amygdala nor the ACC, which have been traditionally associated with negative emotions and feelings in reaction

to threatening stimuli (Gilam and Hendler, 2017). Most previous social neuroscience research that found activation in the amygdala and ACC in anger contexts concluded that these areas are responsible for the perception (but not experience) of the threatening mood resulting in anger (Sorella et al., 2021). Indeed, a significant amount of such studies made use of interpersonal provocative paradigms (such as actual interpersonal induction of anger through an insult by a rude experimenter; Denson et al., 2009) and stated that the presence of the amygdala and ACC may be derived not from the experienced disgust or frustration, but from the perceived fear and/or pain caused by the threatening stimuli. The voxel-based meta-analysis of basic emotions by Vytal and Hamann (2010) gives support to such rationale as it indicated that fear (and not anger or disgust) is spatially sensitive to amygdala and ACC. We contend that the nonexistence of amygdala and ACC activation during dogmatic messages in our study might be due to the less aggressive style used in dogmatic messages (vs. insults) and the absence of a provocative social person-to-person frame (namely, experimenter to participant) during the anger induction. Subsequent research is in a good position to clear up this elaboration. All in all, these findings may suggest that reactance (in our study elicited by dogmatic messages) is characterised by unique affective neural mechanisms based not on the perceived fear during exposure to messages boosting healthier behaviors (as evidenced by the absence of amygdala and ACC activation), but on the affective tension and exasperation arising from the frustration and real imagined injury (i.e., anger: IFL and fusiform gyrus) as well as the experienced aversion (i.e., disgust: anterior insula) by individuals when confronted to a forceful message promoting healthy nutritional habits.

On the other hand, our findings showed additional activation in the IFL and dMPFC during the processing of dogmatic messages. Apart from the above-mentioned role of the IFL in emotional anger, social cognitive neuroscience literature has substantially corroborated that the IFL is also involved in a range of tasks that demand cognitive and inhibitory effort, such as reasoning against an advocated position, executive control, reappraisal and emotion regulation (Tabibnia et al., 2011). Of great interest for the current study, the work by Weber et al. (2015) revealed higher IFL activation while participants weighted antidrug messages against their

existing conflicting beliefs, thus disclosing the involvement of the IFL during the demanding task of counterarguing message contents. Lining up with that reasoning, Fabiansson et al. (2012) found activation in the IFL during cognitive reappraisal, which entails rethinking an emotional event (e.g., the anger experienced during the processing of dogmatic messages) to lessen its negative emotional effect and potentially enlarge its resistance (against that message contents). The MPFC has been largely linked to self-awareness of emotions and self-relevant cognition (Eisenberger, Lieberman, & Satpute, 2005). Particularly, the dorsal zone of the MPFC appears to be closely related to self-referential thinking and self-reflection (Ochsner and Gross, 2008). Accordingly, it would be reasonable to argue that when encountered with dogmatic messages, individuals think and focus on themselves including their own values, interests, prior beliefs and experiences, and cognitively regulate their own affective state through the involvement of the dMPFC. Taken together, these findings validate the additional cognitive nature of the psychological reactance, and confirm the involvement of brain regions associated with cognitive effort and reappraisal (e.g., IFL) as well as self-awareness (e.g., dMPFC) during persuasion resistance and counterarguing to messages that use forceful language to encourage healthier nutritional habits in unhealthy individuals. These findings, consequently, give strong support to the intertwined model of psychological reactance (Dillard & Shen, 2005).

Suggestive Messages Engage Brain Mechanisms Linked to Persuasion

In our H2 we postulated that suggestive (vs. dogmatic) messages, because of the more indirect language used to promote the desired behavior, would increase persuasion and then activate brain regions linked to reward, self-relevance and social/mentalizing, as those are processes traditionally present in persuasive contexts (Petty and Cacioppo, 1986). The neural findings greatly support our expectations and revealed enlarged activation in the orbitofrontal cortex (OFC) while suggestive messages were presented to individuals. De la Vega and colleagues (2016) recently utilized a meta-analytic, data-driven method on nearly 10,000 fMRI studies to differentiate between various regions of the medial frontal cortex and identify which psychological processes are more likely to activate these areas. One of the most prominent

subregions was a ventral cluster (VMPFC), which encompassed both the pregenual parts of the ACC and the medial orbitofrontal cortex (OFC). Their meta-analysis showed that the VMPFC was mainly linked to affective processes like reward and valuation. In the field of persuasion, this would imply that heightened VMPFC activation is responsible for how individuals perceive the value of messages in relation to their personal goals and motivations. In their review on the neuroscience of persuasion, Cacioppo, Cacioppo & Petty (2017) highlighted that most investigations that evaluated the neural correlates of persuasion commonly found activations in the VMPFC during exposure to successful communication. For example, Falk et al. (2015) identified that activity in the VMPFC during exposure to messages targeting sedentary, even after controlling for baseline sedentary behavior and demographics, predicted declines in sedentary behavior. Similarly, Falk et al.'s (2011) investigation reported that activity in the MPFC predicted smoking cessation in cigarette users even after accounting for self-reported intentions, self-efficacy, and the ability of smokers to relate to the messages. The study by Nook and Zaki (2015) showed that agreement with peer opinions about food correlated with heightened activity in the brain's value system located in the VMPFC. Analogous findings were disclosed during exposure to messages encouraging healthier nutritional habits (Author et al., 2022) or pro-environmental behaviors (Minich et al., 2023). Hence, the elevated activation of the VMPFC when exposed to suggestive (vs. dogmatic) messages may indicate that indirect appeals promoting healthier habits enhance personal relevance, value, and reward among individuals with unhealthy eating habits, which could potentially facilitate a shift towards the desired nutritional lifestyles.

Contrary to expectations, our results did not show increased activation in brain areas associated with mentalizing during suggestive compared to dogmatic messages. Previous studies have observed greater activity in mentalizing-related regions, such as the temporoparietal junction (TPJ) and temporal lobes, in communications that were shared more widely (Imhof et al., 2017), or facilitated social interaction (Scholz et al., 2023). Recently, in a context similar to our study, we propose that the lack of activation in social cognition areas in our study might be due to the anonymous source of the health recommendations, which

precludes social interaction. Indeed, previous research supports the absence of mentalizing-related brain activations in persuasive messages under similar conditions (Chua et al., 2009). The unexpected activity in the parietal operculum and cuneus, regions typically involved in primary sensory and visual processing, may result from the easier visual integration and comprehension of suggestive messages compared to dogmatic ones.

Our self-reported findings fully corroborate the neural data, indicating that suggestive messages were perceived as more persuasive and motivating for developing better eating habits. Additionally, these messages elicited significantly less reactance, both cognitive and affective, compared to dogmatic messages, lining up with prior studies (Fitzsimons & Lehmann, 2004; Clayton et al., 2019).

Key Recommendations for Policymakers

Our research provides important insights for policymakers seeking to address overweight issues through effective communication campaigns. They could specifically advance current PRT research by exploring how to use dogmatic language without triggering reactance or resistance (Richards et al., 2021). We argue that identifying the neural patterns associated with the processing of suggestive messages (namely, value, self-relevance and reward) can help pinpoint message features that trigger similar neural responses. These features can then be incorporated into dogmatic messages to reduce the persuasion resistance and reactance they typically provoke. Thus, framing dogmatic content to align with the audience's core values, personality traits, or characteristics in a way that is relevant and rewarding to the individual may help reduce the resistance these messages often encounter. For example, incorporating personalized information, such as the individual's name, has been shown to engage the self-referential neural system (Author et al., 2022), so that adding such element to dogmatic messages could help reduce reactance: ***Paul**, The World Health Organization is clear: if you eat healthy, you will be less tired and perform better at work. You have no choice. Do it now*). Similarly, incorporating information specifically related to the individual, such as age, nationality, or personal habits, may help reduce reactance., e.g., *According to the Spanish Association Against Cancer, **25-years-old students like you** should consume 4 to 6 servings a day of whole grain rice and pasta.*

You have no choice but to follow this guide. Now. These practices, indeed, would line up with recent studies highlighting the importance of audience's values to reduce psychological reactance in self-transcendent media experiences (Clayton et al., 2024) or preemptive script strategies (Richard et al., 2022) to reduce psychological reactance.

Limitations and Future Research Lines

Our manuscript has several limitations that should be taken into account in prospective studies in the field of health communication. While our study utilized a sample of participants with unhealthy eating behaviors, future research should examine neural differences in response to dogmatic vs. suggestive nutritional messages between individuals with high versus low levels of unhealthy eating behavior, or even test dogmatic persuasion in different consumption contexts, namely hedonic versus utilitarian. This approach would enable the creation of tailored communication campaigns that align with the dietary lifestyles or purchase contexts of the audience. Further, as certain individual personality traits (such as trait sensation-seeking or trait universality) are known to influence reactance outcomes in research on the PRT (Clayton et al., 2019, 2023), future research should evaluate how such individual differences may affect the neural processing of dogmatic and suggestive health communications. Despite we designed both dogmatic and suggestive messages to be simple and easy to understand, following previous research (e.g., Chua et al., 2009) to minimize confounding variables in the brain processes, future studies should examine the effects of more complex messages and real communication campaigns. Furthermore, although participants in the pretest reported the extent to which they perceived the messages as dogmatic or suggestive (based on the definition we provided), we did not explicitly measure perceptions of freedom threat as a manipulation check. Our findings indicate that value- and reward-related mental processes during messaging are key for increasing persuasion; however: (i) we must be cautious about reverse inference, which involves using brain activation locations to infer underlying mental processes (e.g., self-related processing) (Poldrack, 2006), and (ii) our assessment of participants' persuasion and reactance was limited to a self-reported test within the sample. Future research is in a good position to use

brain data associated with persuasion and persuasion resistance to predict aggregate market behavior (i.e., neuroforecasting).

The researchers conducted whole-brain analyses to identify brain regions involved in psychological reactance and resistance to persuasion in an unbiased way, given the exploratory nature of the field. This approach allows for discovering unexpected patterns, which might be missed with region-of-interest (ROI) methods that require pre-existing theoretical justification. While specific ROI tests could deepen understanding of how certain regions relate to persuasion outcomes, the lack of established theoretical frameworks limits the ability to choose ROIs confidently. The whole-brain analysis thus provides a broad foundation, which future, more targeted studies can build upon as the field matures and theories develop. To conclude, our findings demonstrate for the first time the neural underpinnings of reactance and the mechanisms at play in the persuasion process of dogmatic and suggestive messages promoting healthy habits. Notably, we have given support to the mixed nature of reactance, which involves brain regions associated with anger and disgust (affective) as well as brain systems linked to cognitive processing and self-reflection (cognitive).

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