Brain responses to Tailored Nutritional Messages: A Neuroimaging Study

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1. Abstract

Overweight and obesity have become international public health problems, so there is an urgent need to implement efficient interventions that prevent these worrying health issues. Designing personalized (tailored) dietary communications has become one of the most effective tools in reducing unhealthy eating behavior, when compared with one-size-fits-all messages (untailored). However, more research is required to gain a complete understanding of the underlying mechanisms by which tailored nutritional messages elicit reductions in unhealthy dietary behavior. Our study is the first to use neuroimaging (namely, functional magnetic resonance imaging (fMRI)) to address this research gap and reveals that increases in brain areas involved with self-related processing are present during the exposure to tailored nutritional messages. To our knowledge, this is the first research that evaluates the neural mechanisms of nutritional healthy messages.

2. Key Words

neuroimaging; fMRI; behavior change; unhealthy eating behavior; tailored messages

3. Introduction, Objectives and Research Question

According to the World Health Organization (WHO, 2021), 39% of adults over 18 years were overweight in 2020 and 13% were obese (WHO, 2021). The prevalence of obesity and overweight constitute, furthermore, major risk factors for noncommunicable diseases such as diabetes, cardiovascular issues and musculoskeletal disorders. These growing health-related problematics not only raise public health care costs but also make obesity a world public health concern. There is a thread of hope, though: "obesity and overweight are preventable" (WHO, 2021), and public nutrition interventions to discourage dietary fat and sugar intake are therefore greatly needed.

One of the most promising and widely accepted strategies to reduce undesirable habits in general, and the consumption of unhealthy food in particular, is the development of tailored health communication programs, which consist in the design of personalized message interventions based on the individual's current beliefs, knowledge structure, attitudes, affect, and behavior related to a given health outcome (Rimer & Kreuter, 2006). These **tailored messages** use information that is customized to an individual (rather than a group) based on characteristics that are unique to that person, related to the outcome of interest (e.g., dietary behavior), and derived from an individual assessment. In turn, one-size-fits-all messages (also called **untailored messages**) are designed to reach a broad audience and communicate information useful to a general public (e.g., the food pyramid, which communicates what specific foods to eat to meet dietary guidelines).

Emerging research calls for a next generation of tailoring studies that explore why and under what conditions tailoring is more persuasive and modifies behavior. Understanding the underlying mechanisms may constitute an important next step in this regard. Though some efforts have been recently made to evaluate the moderator and mediator roles of variables, there is an urgent need to more objectively understand the psychological mechanisms involved with eliciting a real-life health-behavior change by means of tailored nutritional communications. Because of the inability of traditional techniques (such as surveys and questionnaires) to objectively assess these more implicit and introspective mechanisms present during (and not after) message exposure, we contend that neuroimaging methods (such as functional magnetic resonance imaging (fMRI)) could constitute a step forward in

determining the inner, neural processes triggered by tailored messages that may be associated with dietary changes.

Aiming to fulfill this research gap, our study is the first to use fMRI to explore the underlying neural underpinnings of tailored vs. untailored nutritional messages. The results will not only facilitate an understanding of the origin of the greater effectiveness of using tailored messages in the prevention of obesity, but can also help in the design of more effective tailored health intervention programs.

4. Literature Review

4.1. Effectiveness of tailored health messaging

Nutritional pyramid brochures and pamphlets, starting in the mid-1980s, recommended to undifferentiated audiences foods to consume in order to meet standardized nutritional needs (Rimer & Glassman, 1998). Later on, in the late 1990s, public health institutions took the first steps in designing self-help guides for unhealthy behavior cessation (e.g., smoking) that were modified according to demographic or behavioral variables of the target group (i.e., different versions for pregnant women, elderly smokers, or adolescents) (Prochaska, 2004). It wasn't until the early 2000s that the rise of tailored health communication took place due to the growing use of theoretical models that considered the characteristics of each person as crucial to design communication strategies that efficiently modify their individual unhealthy behaviors (Rimer & Kreuter, 2006).

Precisely in order to understand the stage each individual is at, scholars contend that it is key to assess individual characteristics relevant to the behavior of interest namely, perceived obstacles and drivers or personal goals (Walthouwer et al., 2013) or sources of support or motivations (e.g., social influence), and then design messages that include references to that individual's beliefs, needs, and interests. The greater effectiveness of these tailored over untailored interventions has been proven in a multitude of health domains, including physical activity, smoking cessation, and dietary behavior (Noar et al., 2007). The traditional communication Elaboration Likelihood Model (ELM) has often been used to explain the mechanism behind tailoring. ELM suggests that personally relevant and motivational information can lead to a central processing route, meaning that it may be considered more thoroughly by the person and compared it with past individual experiences, hence making behavior change more likely (Petty & Cacioppo, 1981).

Although the effectiveness of tailored nutritional campaigns has been extensively demonstrated, little is known about the neural processes through which tailored messages provoke behavioral decreases as to the consumption of unhealthy food.

4.2. Brain responses to tailored messages

Recent neuroimaging studies are making great strides in explaining the extent to which brain areas elicited by communication campaigns can even predict message-related intentions or behaviors of high interest for the advertiser (Couwenberg et al., 2017). Particularly, research concludes that brain networks involved with reward, self-relevance, value, and mentalizing are powerful predictors of purchase attitudes and intentions towards the advertised products, online consumer behavior (Couwenberg et al., 2017), and even viral marketing success on social media (Motoki et al., 2020).

The field of health communication is no stranger to this neuroimaging stream. Prior studies focused its efforts in recent years on identifying which brain mechanisms in response to health communications predict behavioral changes in unhealthy individuals. Particularly, several health psychology scholars (Doré, Cooper, et al., 2019) have shown that greater neural activation in the brain's valuation and self-related network during antismoking messages (namely, the medial prefrontal cortex (MPFC), precuneus, cingulate cortex, and insula) forecasts later smoking reduction. Similarly, Falk et al. (2015) found that messages promoting an active lifestyle elicited the self-related and positive valuation neural systems that in turn predicted increases in physical activity among sedentary participants.

5. Method

5.1. Participants

A sample of 30 Spanish-speaking, right-handed, adult participants (M = 27.25 years, SD = 4.23; 12 women) were selected to undergo the fMRI task. In line with prior research on healthy communication, only participants who exhibited marked unhealthy behaviors were selected in order to identify how tailoring improves their baseline situation (Chua et al., 2011). Particularly, we used the Unhealthy Eating Scale recently developed by Guertin et al. (2020) to assess the unhealthy eating behavior of our potential sample. Our eligibility criteria included having reported, on average, more than 3.5 points (on a scale 1–7), indicating moderate to high unhealthy eating. Within our final recruited sample, 82.8% of participants reported more than 4 points (out of 7) in having eating unhealthy food, and 48% expressed more than 5 points. All experimental sessions were conducted in a lab located in the campus of a large Spanish university, and we received approval from the university's ethics committee.

5.2. fMRI task

We designed statements for each of the following three message categories: tailored, untailored, and neutral messages. Both the structure and overall content of these three message types were similar and shared approximately the same number of words. An example of tailored message is: "John, the Pepsi you drink at noon has high levels of fructose, which is bad for your circulation"; untailored message: "Drinking too many sugary beverages or beer may increase the risk of developing type 2 diabetes", and neutral message "We can measure the age of a fish by using a magnifying glass to count the scale rings". Participants were introduced into an fMRI scanner and instructed to read 20 tailored, 20 untailored, and 20 neutral messages. All participants received the same untailored and neutral statements, but tailored messages varied according to the participants' prior needs, attitudes and perceived barriers. Each series of messages began with a fixation period (1–3 s), followed by a randomly exposed tailored/untailored/neutral message (8 s).

5.3. fMRI analysis

We analyzed the neuroimaging data using standard software (SPM12, Wellcome Department of Cognitive Neurology, London, UK, https://www.fl.ion.ucl.ac.uk/spm/software/spm12/) run on MATLAB R2012a. We applied default settings in SPM where appropriate

We then built a general linear model (GLM) for each subject, considering the following regressors of interest: (i) exposure to tailored nutritional messages (TAI), (ii) exposure to untailored nutritional messages (UNTAI), (iii) exposure to neutral messages.

6. Findings

As expected, the theoretically driven coordinates associated with self-related processing, namely, the precuneus, angular gyrus, inferior OFC, dMPFC, inferior frontal gyrus, and hippocampus, were more strongly activated during tailored vs. untailored nutritional messages. The opposite contrast (i.e., untailored vs. tailored messages) did not reveal supra-threshold activations within the self-related Region of Interest (ROI) mask.

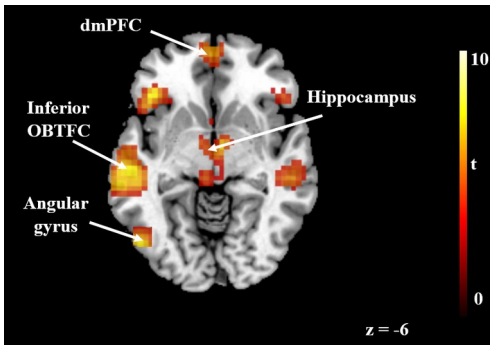

Figure 1. Self-related ROI mask

7. Discussion

Obesity and overweight are the second leading cause of preventable mortality after tobacco use (WHO, 2021). Designing tailored, personalized dietary communications has become one of the most effective tools in unhealthy eating behavior cessation. More research is required, however, to gain a complete understanding of the underlying mechanisms by which tailored nutritional messages predict reductions in unhealthy dietary behavior. Our study is the first to use neuroimaging to address this research gap and reveals that brain areas mainly involved with self-relevance are present during the processing of tailored messages. To our knowledge, this is the first study that demonstrates a direct association between the neural responses to tailored nutritional messages and real-life unhealthy eating cessation.

The neural data reveal for the first time that such perceived greater effectiveness of tailored messages has its origin in self-related processes evoked by the personalized information that they include. Particularly, tailored messages engaged the precuneus, angular gyrus, and OFC, brain areas largely associated with the processing of self-related stimuli (Potvin et al., 2019) . It is worth mentioning that the coordinates of the angular gyrus and dMPFC ROIs that survived the self-related mask coincide with the coordinates reported by Chua et al. (2009), which were associated with the processing of tailored smoking-cessation messages. Tailored nutritional messages also elicited the hippocampus and the medial temporal lobe. Apart from its role in self-relevance, the hippocampus plays a key role in memory encoding (the process of selecting relevant information and bringing it to our memory system), and imagining the future (Schacter et al., 2012). The medial temporal role has also been associated with persuasive health messages and thinking about intentions (Ramsay et al., 2013). Taken together, these results may suggest that the greater effectiveness of tailored messages derives from their greater psychological self-importance and deeper processing engaged in the audience (which aligns with prior studies by (Smit et al., 2015), while making them reflect and question their future behavior aligned with the objective of the

nutritional message. A potential alternative explanation for the recruitment of memory-related brain areas during tailored messages is that participants were simply remembering during the fMRI task what they responded in the inventory on their habits and needs (i.e., Session 1 for creating tailoring messages), a situation which is not the case during the evaluation of untailored messages.

8. Conclusion

To conclude, with our findings, we are the first to demonstrate the neural underpinnings of processing tailored nutritional messages. Interestingly, we have shown that self-related brain areas elicited by tailored dietary messages have the ability to forecast changes in dietary behavior after a month of intensive nutritional communications.

9. Limitations and future research

The current manuscript has several drawbacks that should be considered in further research. Though we have used a sample of participants with marked unhealthy eating behaviors, future research should evaluate neural differences in the exposure to tailored nutritional messages between users with high vs. low unhealthy eating behavior. This would allow tailored communication campaigns to be designed according to the dietary lifestyle of the audience. Prospective studies can consider other psychophysiology techniques (such as skin conductance, eye-tracking, heart rate, or electromyography) to offer new psychological insights and corroborate the results of the present investigation.

10. Managerial Implications

Public health and governmental institutions should implement substantial efforts in creating individualized campaigns focused on their target's (e.g., obese or overweight people) perceived needs, goals, barriers, and drivers in relation to eating healthy. For example, the use of wearable and mobile sensors for personalized nutrition recommendations based on personal information entered by the target individual should be emphasized

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