



Neural activity in self-related brain regions in response to tailored nutritional messages predicts dietary change

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ABSTRACT

Overweight and obesity have become international public health problems, so there is an urgent need to implement effective interventions that prevent these concerning 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. To the best of our knowledge, our study may be the first to use neuroimaging, namely functional magnetic resonance imaging (fMRI), aiming to evaluate the neural basis of tailored and untailored nutritional messages and assess how these neural responses predict unhealthy food intake reduction after a month receiving tailored nutritional messages. To that goal, 30 participants were scanned while reading tailored and untailored nutritional messages. Subsequently, for a month, they received tailored interventions encouraging healthy food intake. The neural findings reveal that when compared to untailored communications, tailored messages elicit brain networks associated with self-relevance, such as the precuneus, the middle temporal gyrus, the hippocampus, the inferior orbitofrontal cortex (OFC), the dorsomedial prefrontal cortex (dMPFC), and the angular gyrus. Interestingly, among these self-related brain areas, the dMPFC, OFC, angular gyrus, and hippocampus forecast reductions in unhealthy food intake after a one-month tailored intervention for the cessation of unhealthy eating. These results may offer implications for clinicians, practitioners, and/or policymakers who should implement substantial efforts in creating individualized campaigns focused on their target's perceived needs, goals, and drivers in relation to eating healthy to reduce overweight issues. This research therefore constitutes a step forward in showing a direct association between the neural responses to tailored nutritional messages and changes in real-life healthy eating behavior.

1. Introduction

According to the World Health Organization (World Health Organization, 2021), 39% of adults over 18 years were overweight in 2020 and 13% were obese (World Health Organization, 2021). The prevalence of obesity and overweight constitute, furthermore, major risk factors for noncommunicable diseases such as diabetes, cardiovascular issues, musculoskeletal disorders, and some cancers (including endometrial, breast, ovarian, and prostate). These growing health-related problems 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” (World Health Organization,

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

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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).

Health communication literature has evaluated the effectiveness of tailored vs. untailored interventions and unanimously concluded that tailored messages elicit greater perceived relevance and salience, which are crucial to increase motivation to process health-related information and enhance message receptivity, information processing, and behavior change more broadly (Noar, Grant Harrington, Van Stee, & Shemanski Aldrich, 2011). The increased effectiveness of tailored messages to help individuals change health-related behaviors has been traditionally proven in quitting smoking (Chua, Liberzon, Welsh, & Strecher, 2009), increasing physical activity (Cobiac, Vos, & Barendregt, 2009), and, of interest for the current study, reducing fat and sugar intake (Kaptein, De Ruyter, Markopoulos, & Aarts, 2012).

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, such as the message delivery channel, sociodemographic features, or the type of participant population (e.g., Updegraff, Sherman, Luyster, & Mann, 2007), 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. For example, while some studies point to attention and emotional arousal as the psychological mechanisms leading behavior change (Kessels, Ruiter, Brug, & Jansma, 2011; Lang et al., 2002), others emphasize the perceived relevance and salience, cognitive resource allocation (i.e., message processing), or deliberative processes as drivers of changes in healthy behavior (Rimer & Kreuter, 2006). 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 neural processes triggered by tailored messages that may be associated with dietary changes.

Aiming to fulfill this research gap, to the best of our knowledge our study may be the first to use fMRI to (i) explore the underlying neural underpinnings of tailored vs. untailored nutritional messages and (ii) evaluate how these neural activations predict changes in unhealthy food intake after a one-month tailored dietary intervention. The results will not only facilitate an understanding of the origin of the greater effectiveness of using tailored messages in eating behavior change, but can also help in the design of more effective tailored health intervention programs.

2. Background

2.1. 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, Delucchi, & Hall, 2004; Rimer et al., 1994). It wasn't until the early 2000s that the rise of tailored health communication took place. The growth of this strategy of individualized public health interventions was encouraged, first, because of the substantial interest of marketing departments to customize information and services (Rogers, 2003). Furthermore, they

were strengthened by the growing use of theoretical models that considered the characteristics of each person as crucial to design efficient individual healthy communication interventions (Rimer & Kreuter, 2006).

Particularly, two of the most widely spread models to explain message tailoring in public health are the Transtheoretical Model of Change (Prochaska et al., 2004) and the Precaution Adoption Process Model (Weinstein, Sandman, & Blalock, 2008). Both schemes presume that message contents should match the behavioral readiness state of each person, that is, the degree to which an individual is ready to change his or her behavior. 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 (such as unhealthy food intake reduction), namely, perceived obstacles and drivers or personal goals (Walthouwer, Oenema, Soetens, Lechner, & De Vries, 2013) or sources of support or motivations (e.g., social influence) (Latimer, Brawley, & Bassett, 2010), and then design messages that include references to that individual's beliefs, needs, and interests. Other models of tailored health communication propose that the channel and style of the message could also be tailored based on individuals' access to health care, learning style, personality characteristics, individual social environment, age, race, or gender (Smit, Linn, & van Weert, 2015). For example, Kreuter, Caburnay, Chen, and Donlin (2004) tested the effectiveness of tailoring in the context of childhood vaccination: in this study parents were exposed to calendars with tailored information about home safety, injury prevention, clinical preventive services, parenting skills, and child development. All information matched to their child's current age in months, height and weight, and ethnic, name or a digital picture of the baby. More recently, advances in computing, digitalization, and big data have facilitated the development of population-wide customization of health information and web-based computer-tailored interventions for modifying dietary behavior (Ryan, Dockray, & Linehan, 2019).

Health communication literature has particularly specified several methods for tailoring messages. According to Woolford, Clark, Strecher, and Resnicow (2010), if we attempt to develop tailored nutritional messages, it is crucial to assess individual baseline healthy behaviors (such as breakfast, fruit and vegetables, sweetened beverages, and fast food) as well as other features of the participants, such as their values, motivations, or sources of support. Walthouwer et al. (2013) concluded that tailored dietary messages should be based on the following: information about the participant's kcal consumption; body weight and general dietary intake and physical activity patterns; attitudinal, self-efficacy, and social influence beliefs regarding dietary intake; and goals for (not) changing their nutritional behavior. Latimer, Katulak, Mowad, and Salovey (2005), in turn, state that tailored messages should highlight the perceived barriers (such as lack of time, unachievable guidelines, the high cost and limited availability of fresh fruit) and benefits (such as good source of vitamins and minerals, excellent source of dietary fibre or feeling good about oneself) associated with (un) healthy eating behavior. Strecher et al. (2008) used three main categories of questions that should be asked to participants in order to develop tailored nutritional programs: outcome expectations (personal and family history, perceived health status, monetary savings, and goals), efficacy expectations (barriers and benefits related to reduce unhealthy eating), and personalization (the use of "you" or participants' names in the messages).

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. For example, several meta-analyses on the effectiveness of tailored smoking cessation programs (Hartmann-Boyce et al., 2014; Noar, Chabot, & Zimmerman, 2008) showed evidence that, after four-month intensive tailored campaigns, participants' learning and memory toward the messages increased, and this critically enhanced quitting efforts. Along the same line, print and online tailored physical activity programs have been

shown to increase walking and physical activity after three months (Dunton & Robertson, 2008; Marcus et al., 2007; Pyky et al., 2017). Of interest for the current study, health communication literature has corroborated that diet-focused tailored interventions are useful in changing dietary behaviors and, more specifically, in decreasing fat and sugar consumption (Burke et al., 2020; Kaptein et al., 2012).

The 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, & Goldman, 1981). As explained above, tailoring simply means including recognizable features of the receiver in the message and providing feedback about the individual considering their personal needs, goals, and interests. Therefore, this customized information may be viewed as more personally relevant and engage self-referential processing, which will increase the likelihood that message contents will be read and cognitively processed. The increased self-relevance could, in turn, improve learning and memory and ultimately easily stimulate individual behavioral change (Chua et al., 2011).

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. Following recent research lines in the field of health communication (Chua et al., 2011; Cooper et al., 2018), we contend that neuroimaging could help in identifying the neural mechanisms to tailored messages associated with changes in dietary behavior. In the next section, we explain the role of neuroscience in identifying the underlying mechanisms explaining the association between brain responses to tailored messages and changes in dietary behavior.

2.2. Brain responses to tailored messages: predicting health behavior change

The brain is the place where message reception, motivation, and relevance take place (Kranzler et al., 2018). Neuroimaging tools, such as functional magnetic Resonance Imaging (fMRI) or Electroencephalography (EEG), allow for monitoring of the neuropsychological processes engaged by different message contents occurring in the brain regions. Unlike prior subjective and relatively biased self-reporting techniques (e.g., questionnaires, focus groups, or surveys), which are poor predictors of future healthy behaviors (Casado-Aranda et al., 2018, 2019), the application of neuroimaging to communication research enables an objective, unobtrusive, and simultaneous measurement of the introspective brain activity during (and not after) message exposure.

Recent neuroimaging studies are making 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; Sánchez-Fernández, Casado-Aranda, & Bastidas-Manzano, 2021). Particularly, research concludes that brain networks involved with reward, self-relevance, value, and mentalizing are powerful predictors of purchase attitudes (He, Pelowski, Yu, & Liu, 2021) and intentions towards the advertised products (Casado-Aranda, Martínez-Fiestas, & Sánchez-Fernández, 2018), online consumer behavior (Couwenberg et al., 2017; Dimoka, 2010), and even viral marketing success on social media (Motoki, Suzuki, Kawashima, & Sugiura, 2020).

The field of health communication is no stranger to this neuroimaging stream. Prior studies at this regard have identified which brain mechanisms in response to health communications predict behavioral changes in unhealthy individuals. Particularly, several health psychology scholars (Cooper, Tompson, Brook O'Donnell, & Emily, 2015; Cooper et al., 2018; Doré, Cooper, Scholz, O'Donnell, & Falk, 2019; Falk, Berkman, Whalen, & Lieberman, 2011; Kaye, White, & Lewis, 2017)

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. Along the same line, Vezich, Katzman, Ames, Falk, and Lieberman (2016) found that messages integrated with one's current beliefs and self-concept elicits the self-related brain network (including the MPFC), which ultimately was associated with increases in the use of sunscreen.

Closer to our study's aim, two neuroimaging studies (Chua et al., 2009, 2011) have identified the neural mechanisms underlying the processing of tailored antismoking messages and their ability to predict quitting after a four-month tailored intervention. These authors particularly tailored messages based on participants' motives for quitting, self-efficacy enhancement, stress and coping, and social support. They report that activation in self-related processing brain regions (namely, the dorsomedial prefrontal cortex, angular gyrus, and precuneus) during exposure to antismoking tailored messages forecasted quitting in active smokers. Nevertheless, to the best of our knowledge, no earlier study assessed the link between the neural response to tailored health messages and different real-life health behavior changes, such as dietary modifications. Although the study by Falk et al. (2015) on neural predictors of physical activity constituted a first attempt, prior research has shown that physical activity and food intake are behaviors of a different nature (e.g., food intake is a more primary and impulse-driven behavior, Beckford, 2018), and sometimes they are not even related (Field, Wolf, Herzog, Cheung, & Colditz, 1993). It is scientifically and societally relevant, therefore, to expand this research line and corroborate whether these self-related brain areas, which are activated during tailored antismoking interventions, are also activated during the evaluation of tailored nutritional messages and are associated with a real-life dietary behavior change.

2.3. The current research

The current research builds on the extensive literature on the neural predictors of persuasive communication campaigns by using fMRI (i) to better understand the neural basis of evaluating tailored and untailored nutritional messages and (ii) to assess how these neural responses predict unhealthy food intake reduction after a month receiving tailored nutritional messages.

Specifically, the greater relevance and salience provoked by the recognition of personal information included in tailored nutritional messages may engage in self-related processing and then activate brain regions within the self-related network. Neuroimaging meta-analyses have consistently confirmed that the dorsomedial prefrontal cortex (dMPFC), precuneus/posterior cingulate cortex (PC/PCC), and orbitofrontal cortex (OFC) constitute brain areas particularly engaged with the processing of self-relevant and self-related stimuli (Murray, Schaer, & Debbané, 2012). In their studies on the processing of tailored antismoking messages, Chua et al. (2009, 2011) found, first, that the dMPFC, angular gyrus, inferior frontal gyrus, precuneus, and cerebellum were greatly activated in tailored vs. untailored antismoking messages; secondly, the authors reported that, among the above-mentioned brain regions, the dMPFC, precuneus, and angular gyrus predicted smoking-cessation outcome at the four-month follow-up.

Accordingly, we propose that, when compared with untailored messages, tailored nutrition interventions elicit stronger activation in the self-related neural substrates (such as the dMPFC, precuneus, angular gyrus, OFC, or inferior frontal gyrus) among participants with moderate to high unhealthy food habits (namely ≥ 3.5 points on the 7-point Likert scale of Unhealthy Eating Behavior Scale—HUEBS—). Furthermore, we expect that these self-related processing brain areas involved with the exposure to tailored messages forecast changes in

dietary behavior (indexed by unhealthy food intake reduction) after a one-month tailored intervention. To the best of our knowledge, our findings may constitute a first in identifying the underlying neural mechanisms by which tailored nutritional messages elicit positive dietary behavior change.

3. Method

3.1. Participants

By means of an online questionnaire distributed through the University of Granada website, a sample of 30 Spanish-speaking, right-handed, adult participants were selected to undergo the fMRI and tailored intervention tasks. Data from one participant was not included in the analysis because of excessive movement during the fMRI task. Table 1 includes the descriptive statistics of the final sample ($n = 29$). In line with prior research on health communication, only participants who exhibited moderate to marked unhealthy behaviors were selected in order to identify how tailoring improves their baseline situation (Chua et al., 2011; Rimal, 2000). Particularly, we used the Unhealthy Eating Behavior Scale recently developed by Guertin, Pelletier, and Pope (2020) to assess the unhealthy eating behavior of our potential sample. This scale comprises a 7-point Likert scale (1 = never and 7 = always) with which participants report to what extent they consumed 11 specific categories of unhealthy food within the last month, such as “I eat refined grains”, “I use white sugar or artificial sweeteners”, or “I drink sugar-sweetened beverages”. As this scale is relatively new, we included some psychometrics developed on purpose in Appendix A. The assessment of these statistics show that: (i) all the items are highly correlated and then are measuring the same construct (namely, Cronbach Alpha); (ii) that there is a high consistency of the HUEBS results as they stay constant in the sample at different points of tailoring (namely, test-retest reliability), (iii) and that there is a high degree of confidence that the unhealthy eating behavior is well measured by the indicators proposed by Guertin et al. (2020) (namely, convergent validity). Due to the satisfactory performance of these psychometric measures and because our experimental objective is associating a single measure summarizing participant’s unhealthy behavior with neural activation, we calculated an average composite score of these unhealthy eating behavior-related items.

Our eligibility criteria included having reported, on average, more than 3.5 points (on a scale 1–7), indicating moderate to high unhealthy eating (following similar approaches for other behaviors than eating, as developed by Katagiri, Asakura, Kobayashi, Suga, & Sasaki, 2014 and Casado-Aranda, Martínez-Fiestas, & Sánchez-Fernández, 2018). Subjects were not enrolled in other dietary routines or pharmacological nutritional treatments. Further exclusion criteria were having neurological diseases, claustrophobia, or other MRI-related issues, such as body metals, pregnancy, or vision problems. 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 (No. 1824) and followed the principles of the Declaration of Helsinki.

3.2. Procedure

The main objective of the experimental design was to expose selected participants to two types of messages that encourage healthy consumption behavior, namely tailored and untailored, and a neutral topology serving as a comparison baseline. Particularly, the timeline is distributed as follows: (i) a **baseline session** for evaluating, in the previously selected sample, individual unhealthy eating behavior as well as psychosocial, health, and demographic features relevant to unhealthy eating cessation, which are crucial for the development of tailored messages; (ii) the **fMRI session**, in which participants are exposed to two types of nutritional messages and a control condition; (iii) the **tailored intervention**, in which participants received tailored dietary-related messages during one month; and (iv) a **follow-up appointment**, to assess changes in unhealthy eating behavior after the intervention treatment. We now detail the structure of each of these four sessions.

3.2.1. Session 1: baseline session

This first session aimed to assess participants’ habits, goals, characteristics, behaviors, and barriers/constraints relevant for the reduction of their unhealthy eating behavior. These responses were used to create the tailored messages. Participants were contacted to complete a questionnaire and a video call interview for the purpose of assessing individual characteristics relevant to unhealthy eating cessation based on the protocol used by previous tailored unhealthy-food-cessation programs (Latimer et al., 2005, 2010; Walthouwer et al., 2013; Woolford et al., 2010).

More specifically, following these prior recommendations for developing tailored nutritional messages (Walthouwer et al., 2013 or; Woolford et al., 2010), we used baseline questionnaires to quantitatively ask about participants’ (un)healthy habits and efficacy expectations, while interviews were useful to gain knowledge about open subjective and personal beliefs and opinions about outcomes and efficacy expectations. We particularly were interested in the following: (a) **unhealthy eating habits**, including health-related baseline questions, such as their weekly expenditure on healthy food (“How much money do you spend weekly on healthy food?” and “What percentage of food in your shopping basket is healthy?”), their intention to reduce their unhealthy eating behavior within the next 30 days (on a scale 1–7), and the extent to which they thought that “Healthy eating is already a part of my lifestyle” (1 = Nothing; 7 = Absolutely); (b) **outcome expectations**, including open questions about individual sources of support (eating behavior associated with family, friends, and their general environment), goals, and monetary savings; and (c) **efficacy expectations**, such as attitudinal, self-efficacy beliefs regarding dietary intake (Rimal, 2000) (i.e., we asked participants questions on how confident they were that they would be able to stop eating unhealthy food in the next month on a 7-point scale —anchors: 1 = not at all confident/easy, 4 = confident/easy, and 7 = extremely confident/easy), perceived risk (“how much participants thought that eating unhealthy can harm or had already harmed their health”, Cooper, Tompson, O’Donnell, & Falk, 2015), as well as barriers/failures (stress, level of work, etc.) and benefits related to healthy dietary behavior. Appendix B incorporates the specific questions included in the questionnaire and interview following these three tailoring approaches. We subsequently used the responses to these questions to design the tailored messages.

3.2.2. Session 2: fMRI experiment

3.2.2.1. *Messages.* We designed statements for each of the following three message categories: tailored, untailored, and neutral messages.

Table 1
Descriptive characteristics of the sample size.

Characteristics	Sample
N	29
Gender (M/F)	17/12
Age (years)	21.5 ± 2.1
Education (years)	19.0 ± 2.1
Annual income (frequencies)	
< €12.000	44.82%
€12.001-€15.000	55.18%
Weight (kg)	69.9 ± 14.2
Height (meter)	1.7 ± 0.1
BMI ^a	23.3 ± 3.6

^a Body Mass Index: Weight/(Height)².

Both the structure and overall content of these three message types were similar and shared approximately the same number of words. Tailored messages included a self-relevant customization about the person and matched with the individual responses derived from the questionnaire and video call interview that took place in the baseline session (see Appendix B). More particularly, the messages contained information based on participants' responses accompanied by the positive (or negative) consequences of improving (or continuing with) his/her (un) healthy eating behavior. Untailored messages were based on the Guide to Reducing Unhealthy Behavior of the Spanish Society of Community Nutrition (2020). Following prior research (e.g., Chua et al., 2019), we minutely ensured that both tailored and untailored messages included comparable topics as well as an equal number of loss- and gain-framed messages. Neutral messages, in turn, worked as a control condition and added information unrelated to healthy habits. Table 2 includes examples of statements of each message typology.

3.2.2.2. fMRI task. A week after Session 1, participants participated in the fMRI session. During the fMRI scan they were exposed to 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' Session 1 responses. Each series of presented messages (8 s) was preceded by a fixation period (1–3 s). Messages were displayed in random order. After each message, the participant was presented with an unhealthy eating behavior cessation intention rating screen with the statement "This message makes me want to reduce my unhealthy intake" and a four-point rating scale (from 1, "definitely does not", to 4, "definitely does"). The total scan duration was approximately 24 min, including the anatomical imaging acquisition (5 min). We used the E-Prime Professional 2.0 software to present the fMRI task.

3.2.3. One-month intervention

During the month after the scan session, each participant received the intervention, which consisted of receiving tailored messages based on their responses to the questions in Session 1 regarding unhealthy eating habits, outcome expectations, and efficacy expectations. More

Table 2
Examples of tailored, untailored, and neutral messages.

Tailored messages
John, the Pepsi you drink at noon has high levels of fructose, which is bad for your circulation.
Your friend Ana could help you improve your diet and do more physical activity per week, John.
John, if you ate fewer Nestlé chocolate bars you could increase your life expectancy by 5%.
Joan, a proper time planning would help you to cook better and healthier
You are too addicted to eating Italian pizzas, even though they increase the risk of heart failure by 5%.
Untailored messages
Drinking too many sugary beverages or beer may increase the risk of developing type 2 diabetes.
Someone we trust can provide support once we get started with eating healthy habits.
Avoiding chocolates could reduce the probability of becoming overweight in the future by 55%
A healthy diet prevents fatigue and slows down the aging process in the general population.
For every 10% of preprocessed food ingested, the risk of mortality increases by 14%.
Neutral messages
We can measure the age of a fish by using a magnifying glass to count the scale rings.
The African elephant has larger ears, eyes, and trunk than the Indian and Asian elephants.
The equinoxes are the times when the Sun is located in the plane of the celestial equator.
Wind is a large-scale flow of air, pressure, and intensity that occurs in the earth's atmosphere.
Petroleum was formed from the remains of animals and plants that lived millions of years ago.

specifically, participants received 60 tailored messages (two messages each day of the month after the scan session) that were very similar to those they watched during the fMRI based on their responses during the baseline session. Particularly, each participant received via WhatsApp in the mornings and in the afternoons each of the 60 messages encouraging the reduction or elimination of their unhealthy food intake. Together with each message, participants were asked to report feedback (e.g., what they think about the instructions, contents, or need to change the behavior described in the message) to ensure they had read and understood it.

3.2.4. Session 3: follow-up appointment

Immediately after the one-month intervention, participants were contacted via e-mail to report on their dietary status and reduction of unhealthy eating. Participants answered similar behavioral and intentional questions as reported in Session 1. Particularly, our primary outcome measure was the standard 30-day unhealthy eating behavior based on the HUEBS scale provided by Guertin et al. (2020). A negative difference between the average composite of the unhealthy eating behavior-related items before and after the one-month tailored intervention corresponded to a reduction in unhealthy eating at the follow-up appointment relative to the baseline session. Furthermore, questions related to dietary status (money spent on healthy food or the percentage of healthy food consumed) as well as outcome and efficacy expectations (perceived health lifestyle, risk, and self-efficacy) were included. Finally, subjects were compensated for their participation after the follow-up questionnaire.

3.3. MRI image acquisition and fMRI analyses

Scanning was implemented by means of a 3T Trio Siemens Scanner equipped with a 64-channel head coil. We obtained anatomical images by using a sagittal orientation with a 1 mm³ voxel size. Functional scans were acquired by a T2*-weighted echoplanar imaging (EPI) sequence (TR = 2000 ms, TE = 25 ms, FA = 90°, thickness = 3.5 mm; slices = 35, slice order = descending). A distance factor of 20% resulted in a total of 790 slices with a FoV of 238 mm.

We analyzed the neuroimaging data using standard software (SPM12, Wellcome Department of Cognitive Neurology, London, UK, <https://www.fil.ion.ucl.ac.uk/spm/software/spm12/>) run on MATLAB R2012a. We applied default settings in SPM where appropriate. After visually inspecting the mean functional images for artefacts, they were realigned to correct for motion, coregistered, segmented, normalized into standard stereotactic space, and smoothed (7 × 7 × 7 mm Gaussian kernel FWHM). Afterwards, we generated statistical maps for each participant by fitting a boxcar function to the time-series convolved with a canonical hemodynamic response function. 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. Additionally, six covariates associated with movement-related noise, and fixation crosses were included as regressors of no interest.

To explore which brain regions showed significant activations during exposure to tailored, untailored, and neutral messages, four contrasts were calculated on the first level: tailored vs. untailored, untailored vs. tailored, tailored vs. neutral, and untailored vs. neutral, applying a T-contrast to the first, second, and third regressors of the model, respectively. On the second level, the above-mentioned resulting contrasts were subjected to one-sample *t*-test analysis, in order to identify brain activation networks common to all participants.

3.4. ROI and whole-brain analyses

For the Region of Interest (ROI) analysis, we used a recent approach implemented by neuroimaging researchers in the field of health

communication (Guerrero Medina, Martínez-Fiestas, Casado Aranda, & Sánchez-Fernández, 2021; Scholz, Baek, O'Donnell, & Falk, 2019). Particularly, we first selected the main construct of interest (i.e., self-referential) that is theoretically expected to be involved with the processing of tailored nutritional messages, namely, self-related/self-referential processing (see Sections 2.2. and 2.3 above). We then extracted a ROI mask by implementing a search referring to that construct conducted in the Neurosynth reverse inference meta-analysis database (Yarkoni, Poldrack, Nichols, Van Essen, & Wager, 2011). Neurosynth contains fMRI datasets from 14,371 published peer-reviewed articles and instantly generates meta-analytic FDR-corrected maps for neuroimaging keywords. These Neurosynth maps are appropriate candidates for unbiased ROI analyses, as we can use the maps as ROI masks and evaluate the peak voxel coordinates that survive the contrasts of interest within such masks. We particularly downloaded the map of the “self referential” term (for self-related processing during tailored message exposure, 5073 studies). Then we used such map as an inclusive mask in SPM in each of the main contrasts of interest (i.e., tailored vs. untailored and tailored vs. neutral), aiming to confirm the peaks coordinates that are significant within the self-related ROI mask. We specifically used a strict Family-wise Error Rate (FWE) in approach at $p = .05$ with an extent threshold of 10 ($k = 10$). Fig. 1 includes the ROI mask for the self-related extracted map. As expected, it incorporates brain areas such as the dMPFC, precuneus, angular gyrus, OFC, or inferior frontal gyrus.

To explore brain areas responding to tailored interventions outside of our hypothesized ROI mask, we also implemented a whole-brain exploration in the main contrasts of interest by using a threshold of 10 contiguous voxels at an uncorrected p value of .001, which equals to a FWE correction of $p = .05$ (following previous studies such as Casado-Aranda, Martínez-Fiestas, & Sánchez-Fernández, 2018, 2019).

3.5. Using self-related brain activity to predict dietary change

To assess the extent to which neural responses to tailored nutritional messages forecast dietary change (indexed by the unhealthy eating behavior reduction) after the one-month intervention, we ran separate multiple regression analyses, i.e., one for each of the peaks coordinates that are significant in our contrasts of interest within the self-related ROI mask. First, to create the independent variables, we used Marsbar to extract parameter beta estimates (10 mm radius spheres) from each of the significant peak voxel coordinates derived from the tailored vs. untailored contrast within the self-related ROI mask. The dependent variable was the result of a subtraction of the average scores of unhealthy eating behavior of participants at the baseline session vs. after the tailored intervention. Therefore, we ran several multiple linear regression models with the parameter estimates of the significant tailored-related (i.e., self-referential) peak coordinates of the ROI mask as predictors in the models and changes in dietary behavior as a dependent variable.

3.6. Summary of statistics

First, we used Mann-Whitney-Wilcoxon Signed Rank tests to evaluate the difference between before and after the tailored intervention in reported unhealthy eating behaviors, money spent on healthy food, perceived health lifestyles, intentions to reduce their unhealthy behavior, perceived risk of such unhealthy dietary habits and self-efficacy.

As regards the neural analyses, we primarily used a ROI approach based on the Neurosynth reverse inference meta-analysis database. Once we extracted the maps, we applied them to the contrasts of interest as masks within SPM and used the Family-wise error rate (FWE) at $p = .05$, and $k = 10$ to control multiplicity. We also applied the same threshold in the whole-brain analysis. Finally, to evaluate the extent to which neural responses to tailored nutritional messages forecast dietary change we

ran separate multiple linear regression models with the parameter estimates of the peak coordinates that were significant within the self-related ROI mask as predictors in the models and changes in dietary behavior as a dependent variable.² As it can be seen in Table 4, we finally implemented 10 multiple regression analyses, one for each of the resulting significant peak coordinates located within the self-related ROI mask.

4. Results

4.1. Dietary behavior change

Firstly, we ran a Mann-Whitney-Wilcoxon Signed Rank test in IBM SPSS Version 20 to evaluate differences in terms of which tailored vs. untailored nutritional messages during the fMRI task made participants want to reduce their unhealthy food intake. Results indicate that tailored messages ($M = 2.6$, $SD = 0.4$) did not yield a significant greater willingness to reduce unhealthy eating than untailored messages ($M = 2.2$, $SD = 0.3$) across the subjects ($t(28) = -2.01$, $p = .063$).

Then, we assessed the pre-post intervention effects. Particularly, Mann-Whitney-Wilcoxon Signed Rank tests were ran in IBM SPSS Version 20 revealed that, after the one-month tailoring nutritional intervention, participants reported significantly lower average unhealthy eating behavior ($M_{\text{unhealthy eating after intervention}} = 3.7$, $SD = 0.2$) when compared with their baseline levels ($M_{\text{unhealthy eating before intervention}} = 4.7$, $SD = 0.2$), $t(28) = 6.16$, $p < .001$). Participants also expressed significantly having spend more money on healthy food in the last week ($t(28) = 5.14$, $p < .001$): while before the intervention, participants spent weekly on average 11.55€ ($SD = 1.51$), after the intervention they spent 18.79€ ($SD = 2.13$) on healthy food (see Table 3). It is worth noting that while no participant spent between €31 and €40 per week on healthy food before the intervention, 20.7% of them spent that amount after the tailored treatment (Appendix C). They also significantly increased the percentage of healthy foods in their weekly shopping basket ($M_{\text{healthy food before intervention}} = 33.97\%$, $SD = 2.88$; $M_{\text{healthy food after intervention}} = 47.93\%$, $SD = 3.75$), $t(28) = 5.94$, $p < .001$ (Table 3). Particularly, before the intervention, any participant incorporated more than 40% of healthy food in their diets; however, after the tailored intervention, 34.50% of participants incorporated between 41% and 50% of healthy foods in their diet (Appendix C). Furthermore, whereas their perceived health lifestyle improved significantly ($M_{\text{perceived lifestyle after intervention}} = 3.6$; $SD = 0.26$; $M_{\text{perceived lifestyle baseline}} = 2.9$, $SD = 0.3$; $p < .001$), their intention to reduce their unhealthy behavior within the next month ($p = .21$) and the extent to which they thought that eating unhealthy food can harm or has already harmed their health (namely their perceived risk) ($p = .81$) did not (see Table 3). We also compared the self-efficacy of participants after the tailoring intervention. Even though they were more confident in reducing their unhealthy eating behavior after the one-month treatment, it was not significant ($p = .16$).

4.2. Functional image results

4.2.1. Neural responses to tailored and untailored messages

First, we identified the neural activation patterns related to tailored vs. untailored unhealthy food intake reduction messages in the whole sample. 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 exploratory whole-brain analysis revealed, apart from the prior self-related brain regions, the activation of the cerebellum,

² Brain data, behavioral change self-reports, subjects' characteristics and other replication files are available at <https://hdl.handle.net/10481/63114>.

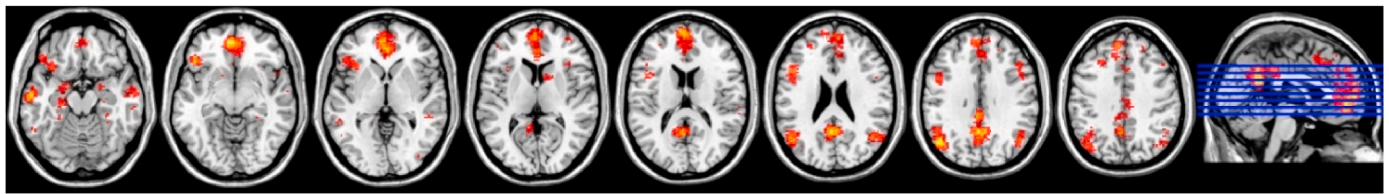


Fig. 1. Multi-slice brain images based on the meta-analysis reverse inference maps extracted from www.neurosynth.org related to the self-referential brain areas during the exposure to tailored messages (FDR <0.01).

Table 3
Main statistical results derived from comparisons of the measures included in the questionnaire before and after the tailored intervention.

Questions included in the survey	Tailoring period				p Value
	Before tailoring		After tailoring		
	Mean	SD	Mean	SD	
Unhealthy Eating Behavior (1–7 scale)	4.7	.2	3.7	0.2	<.001
Money spent a week in healthy food (€)	11.55	1.51	18.79	2.13	<.001
% Healthy food in the shopping cart	33.97	2.88	47.93	3.75	.001
Perceived healthy lifestyle (1–7 scale)	2.9	0.3	3.6	0.26	<.001
Intention to reduce unhealthy behavior within the next month (1–7 scale)	4.76	1.84	5.28	1.57	.21
Perceived risk of unhealthy dietary habits (1–7 scale)	6.29	1.12	6.36	1.15	.81
Self-efficacy (level of self-confidence) of stopping healthy dietary habits (1–7 scale)	4.01	1.05	4.38	1.27	.16

Table 4
Peak activations to tailored relative to untailored messages during the fMRI task.

Brain regions	Peak of coordinates MNI (mm) x y z			T	Z	Effect size	k ^a
Tailored vs Untailored messages							
Peaks coordinates that are located within the self-related ROI mask							
Precuneus	-5	-56	23	9.06	6.19	1.15	166
Middle temporal gyrus	-61	-14	-13	8.72	6.06	1.13	20
Middle occipital gyrus	-36	-77	40	8.41	5.94	1.10	106
Angular gyrus	-50	-63	33	8.33	5.94	1.10	48
Inferior orbitofrontal gyrus	-43	28	-6	8.08	5.80	1.08	74
Superior temporal gyrus	-43	11	-34	7.36	5.48	1.02	11
Hippocampus	-22	-11	-16	7.11	5.37	0.99	32
Inferior frontal gyrus	-43	14	30	7.10	5.48	1.02	41
dMPFC	-12	60	26	7.02	5.85	1.09	263
Superior temporal gyrus	55	-7	-13	6.02	5.32	0.99	22
Whole-brain							
Precuneus	-5	-56	23	9.06	6.19	1.15	441
Posterior cingulate	-5	-49	33				
Middle occipital gyrus	-33	-77	40	8.73	5.94	1.10	338
Angular gyrus	-47	-70	30				
Middle temporal gyrus	-61	-14	-13	8.72	6.06	1.13	1887
Superior temporal	-57	-21	9				
Middle temporal pole	48	7	-30	8.55	6.00	1.11	579
Inferior orbitofrontal gyrus	27	21	-20				
Superior frontal gyrus	-12	60	26	7.02	5.32	0.98	570
dMPFC	-8	56	37				
Cerebellum	24	-77	-44	5.57	4.64	0.86	78

^a Spatial extent of the cluster in voxels (10 voxel minimum).

hippocampus, medial temporal lobe, and occipital gyrus. Table 4 shows a table of results for this analysis. The opposite contrast (i.e., untailored vs. tailored messages) did not reveal supra-threshold activations within the self-related ROI mask (see Appendices D, E and F).

For completeness, we also explored the neural activation patterns associated with the tailored or untailored unhealthy dietary cessation messages in relation to the neutral ones. Along the same line of prior studies (Chua et al., 2009, 2011), both the tailored and untailored messages elicited a robust pattern of activation in the precuneus and angular gyri. Nevertheless, only tailored messages provoked stronger activations in peak coordinates within the hypothesized self-related ROI mask, such as the dMPFC. Appendices 2 and 3 provide deeper details on the specific coordinates and activations.

4.2.2. Neural activity during tailored messages predicts dietary behavior change

We then assessed the extent to which the previous 10 significant peak coordinates that are located within the self-related ROI mask in response to the tailored messages were able to predict changes in dietary behavior (indexed by the unhealthy eating behavior cessation) after the one-month tailored intervention. Particularly, we ran 10 multiple regression tests, that is, the beta parameter estimate for each of the 10 significant peak coordinates resulting from the tailored vs. untailored contrast was used as a predictor in separate multiple regression models. Four regions, i.e., the dMPFC, OFC, angular gyrus, and hippocampus, predicted individually unhealthy eating behavior reduction. We specifically found that those who showed greater activation in the dMPFC during tailored vs. untailored nutritional messages reduced their unhealthy eating behavior after the intervention (peak x,y,z coordinates = -12, 60, 26, $\beta = -0.37$, R square = 0.143, $t(29) = -2.13$, $p = .04$). The activation in the OFC during tailored messages significantly predicted reductions in unhealthy dietary habits (peak x,y,z coordinates = -43, 28, -6, $\beta = -0.46$, R square = 0.214, $t(29) = -2.71$, $p = .012$). Similarly, those who showed greater activity in the hippocampus during tailored nutritional message exposure also expressed greater declines in unhealthy eating behavior after the follow-up (peak x,y,z coordinates = -22, -11, -16; $\beta = -0.39$; R square = 0.150, $t(29) = -2.71$, $p = .038$). Furthermore, the activation of the angular gyrus during tailored messages marginally predicted reductions in unhealthy dietary practices (peak x,y,z coordinates = -50, -63, 33, $\beta = -0.367$, R square = 0.134, $t(29) = -2.04$, $p = .05$). Fig. 2 includes the localizations of brain regions forecasting unhealthy eating behavior while Fig. 3 incorporates scatter plots of those relationships.

We further applied the Bonferroni correction for multiple testing (as we ran 10 separate regression models) but any α level of the 10 prior peak coordinates (i.e., Table 4) survived to the multiple testing adjustment. Nevertheless, the Bonferroni correction could be considered too conservative (Armstrong, 2014) and may not be appropriate to use in our models since, by design, the 10 significant peak coordinates within the self-related ROI are not completely independent, but are all associated with the self-related mental process.

5. Discussion

Obesity and overweight are the second leading cause of preventable

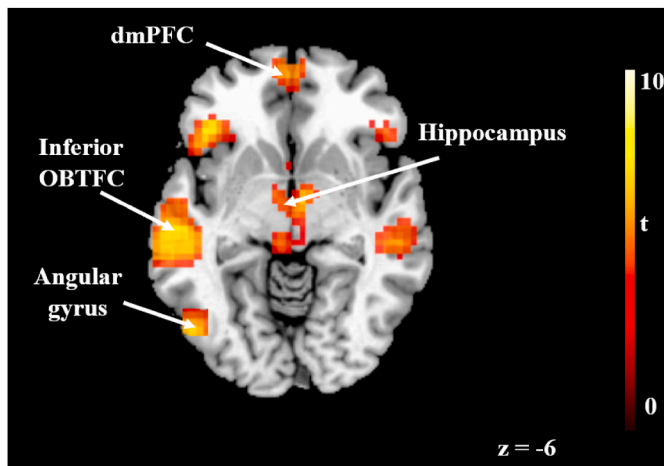


Fig. 2. Neural activity in the dorsomedial prefrontal cortex (dmPFC), hippocampus, inferior orbitofrontal gyrus (OFC), and angular gyrus during tailored nutritional messages predicts reductions of unhealthy eating behavior. The color map depicts the t score, and image coordinates are in the Montreal Neurological Institute (MNI) brain atlas space. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

mortality after tobacco use (World Health Organization, 2021). Designing tailored, personalized dietary communication has become one of the most effective tools in unhealthy eating behavior cessation (Sempionatto, Montiel, Vargas, Teymourian, & Wang, 2021). 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 may constitute a first attempt to use neuroimaging to address this research gap and reveals that brain areas mainly involved with self-relevance during the processing of tailored messages may be involved in the reduction of unhealthy food intake after a one-month tailored intervention. Consequently, this study demonstrates a direct association between the neural responses to tailored nutritional messages and real-life unhealthy eating cessation.

First, we proposed that the greater perceived self-relevance of customized information included in tailored nutritional messages may make them more effective than untailored communications and thus

activate strongly brain areas within the self-related network. Our self-reported findings did not fully support this reasoning: tailored resulted only in a marginally (not statistically significant) higher willingness to reduce unhealthy eating. The neural data suggest that such perceived greater effectiveness of tailored messages may have 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 (Ebner et al., 2013; Potvin, Gamache, & Lungu, 2019). It is worth mentioning that the coordinates shown in Table 4 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, Lang, 2006) and imagining the future (Schacter et al., 2012). The medial temporal role has also been associated with persuasive health messages and thinking about intentions (Langleben et al., 2009; Ramsay, Yzer, Luciana, Vohs, & MacDonald, 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 Rimal, 2000, and 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. Furthermore, the involvement of self-related brain areas during tailored messages may result from the explicit reference to the participant's name (e.g., "John, the Pepsi you drink...") as compared to untailored messages, more related to societal habits (e.g., "the others" vs. self). Prior literature indeed corroborated that the dmPFC constitutes a brain area typically involved with thinking about the self-vs. others (Ebner et al., 2012).

Our second main goal was to elucidate whether these neural mechanisms derived from the exposure to tailored nutritional messages correlate with dietary behavior change after a one-month tailored intervention. Our findings highlight that the daily tailored messages sent

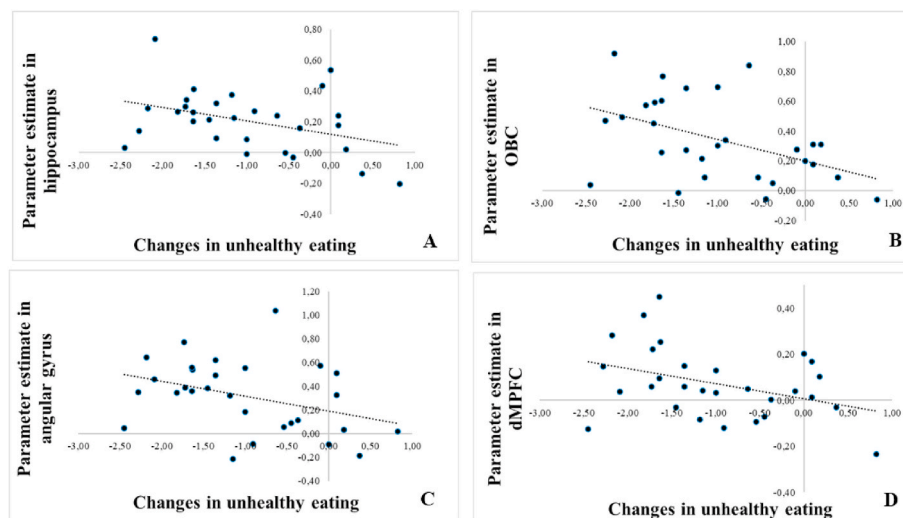


Fig. 3. Scatter plots of the relationship between changes in unhealthy eating (namely, subtraction of the composite index of unhealthy eating after and before the one-month tailored intervention) and (A) parameter estimate of hippocampus, (B) parameter estimate of orbitofrontal cortex (OBC), (C) parameter estimate of angular gyrus, and (D) parameter estimate of dorsomedial prefrontal cortex (dmPFC).

during the month after the fMRI scanner may have been useful in significantly reducing the eating behavior reported by the participants and increasing their proportion of purchase and the amount of money spent on healthy food. Interestingly, we corroborated that the superiority of tailored nutritional messages in promoting such a desirable dietary behavior change may stem from an enhanced engagement of self-related and memory encoding processes. Particularly, activity of the dmPFC, hippocampus, OFC, and angular gyri, all brain networks largely associated with self-relevance, predicted prospective reductions in unhealthy eating behaviors. Thus, it is possible that the enhanced cognitive processing and self-relevance triggered by tailored messages may integrate more effectively with the individual's learning system and future plans, which in turn may lead to greater dietary change aligned with the message. These neural findings extend the results of prior neuroimaging work in the field of health communication (Cooper, Tompson, O'Donnell, & Falk, 2015; Darmawan, Xu, & Huh, 2021; Doré, Tompson, et al., 2019; Vezych et al., 2016) and corroborate that the engagement of self-related processing derived from tailored messages is crucial not only for changes in smoking cessation, physical activity, or sunscreen use but also for modifications in dietary intake.

Theoretically, our results represent a two-fold contribution. **First**, prior research has evaluated the effectiveness of tailored vs. untailored nutritional messages (Dunton & Robertson, 2008; Ryan et al., 2019), or even assessed potential moderators or mediators of changes in unhealthy eating behavior (Noar et al., 2008), but to the best of our knowledge, no previous studies have focused on the neural mechanisms underlying the processing of customized nutritional information. Recent neuroimaging studies centered their attention on evaluating the neural processing of messages in the areas of smoking, physical activity, or sunscreen use. The current paper provides a first attempt at increasing our understanding on the cognitive and psychological processes underlying tailored nutritional messaging. **Second**, our research constitutes an advance in incorporating a neuroimaging approach in the field of healthy behavior that enables to establish a link between intervention induced brain responses and actual nutritional behavior. Prior studies have evaluated the neural predictors of anti-drug and anti-alcohol message effectiveness (Imhof, 2010; Weber, Huskey, Mangus, Westcott-Baker, & Turner, 2015), the brain responses moderating the relationship between opportunities for exposure to anti-smoking campaigns and message recall (Kranzler et al., 2018), the neural processes involved in the understanding of consumer aversion to new food and agricultural technologies (Lusk et al., 2015; Manippa, Padulo, van der Laan, & Brancucci, 2017) or the brain activation and affective judgments in response to personal dietary images (Dodd, Long, Hou, Kahathuduwa, & O'Boyle, 2020). Our results may, in turn, represent an advance in the understanding of the psychophysiological origin of consumer decision making in nutrition communication campaigns.

Empirically, our findings provide key implications for policymakers who wish to reduce overweight issues by means of effective communication campaigns. Our behavioral findings suggests that nutritional messages tailored to the characteristics of the audience may be effective and their effect may derive from the greater self-relevance and deeper processing triggered by these messages in the individuals. Our results, combined with the findings of previous behavioral studies showing similar effects, suggest that clinicians, practitioners, and/or policymakers should implement individualized campaigns focused on their citizen's perceived needs, goals, barriers, and drivers in relation to eating healthy. Customized messages engage self-related processes which in turn may translate into greater nutritional behavior change. 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 (Sempionatto et al., 2021).

The current manuscript has several drawbacks that should be considered in future research. Though we have used a sample of participants with 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. In our research, we have designed tailored messages based on established protocols used by previous tailored unhealthy food-cessation programs, and we included tailoring strategies related to participants' (i) unhealthy eating habits, (ii) outcome expectations, and (iii) efficacy expectations (Guertin et al., 2020; Rimal, 2000). Future studies could further explore the extent to which each of these three types of tailoring differently affects the (neural) persuasion of tailored nutritional messages. Despite we designed the tailored and untailored messages in a simple, easy to understand way and following previous research (e.g., Chua et al., 2009) with the aim of avoiding the effect of confounding variables on the underlying brain processes, future research should test the effect of more complex messages and those of real communication campaigns. Though our findings claim that self-processing during messaging is a pillar predictor of dietary behavior modification, we must be cautious with the reverse inference interpretation, which consists of using the location of brain activations to infer the underlying mental processes (e.g., self-related processing) (Poldrack, 2006). To avoid this problem, however, we have minutely used theory-driven coordinates and ROIs of hundreds of neuroimaging studies focused on self-related processing. Furthermore, the assessment of participants' diet was limited to a self-report "recall" of past unhealthy food intake without considering real future eating behavior change. These findings lay the groundwork for subsequent studies that utilize a dietary recall measure that has solid validity/reliability for an accurate assessment of food intake. Despite 29 participants could constitute a reasonable sample size because of the ROI approach we followed, the considerable large or very large effect and the use of multiple trials, further studies should corroborate these findings by using larger sample sizes, especially for the brain-behavior correlations. Furthermore, 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. Finally, the main effects resulting from the current study might have been partially driven by the motivation or interest of the participant with the study or the message itself. The current study employed a pre-post design which limits the conclusions we can draw from the tailoring intervention effects. Future research should employ a randomized trial with a control condition in which untailored messages are provided in the follow up session.

To conclude, with our findings, we demonstrate the neural underpinnings of processing tailored nutritional messages. Interestingly, we have shown that self-related brain areas elicited by tailored dietary messages may be useful for forecasting changes in dietary behavior after a month of intensive nutritional communications.

Author's contribution

Author1: conceptualization, formal analysis, methodology, resources, writing – original draft, software.

Author2: data curation, project administration and supervision, writing – review & editing.

Author3: software, writing – review & editing, validation.

Ethical statement

All experimental sessions were conducted in a lab located in the campus of the University of Granada, and we received approval from the university's ethics committee (No. 1824) and followed the principles of the Declaration of Helsinki.

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Appendix A

Internal consistency reliability. The results of the internal consistency analysis (Cronbach’s alpha) of the 11 items related to the Unhealthy Eating Behavior were acceptable before ($\alpha = 0.85$) and after ($\alpha = 0.78$) the tailored intervention. The Average Inter-item Correlation also measures if individual questions on a test give consistent results which could mean that they are measuring the same construct, namely unhealthy eating behavior. This average inter-item correlation falls within acceptable limits in the items asked before (M before intervention = 0.36, $SD = 0.002$) and after the intervention (M after intervention = 0.24, $SD = 0.002$).

Test-Retest reliability. As we conducted the same test on our sample at two different points in time (namely before and after the tailoring treatment), we were able to calculate the Pearson’s r , which constitutes the test-retest reliability coefficient. Particularly, we designed a column including the sum of the scores given by each participant to each of the 11 items of the scale before treatment and after treatment. Subsequently, we calculated the correlation between both columns, and obtained a $r = 0.621$ ($p < .001$), which informs about a high consistency of our results and reveals that the Unhealthy Eating Behavior scale stays constant in the sample at different timeframes.

Convergent validity refers to the degree of confidence we have that the unhealthy eating behavior is well measured by the indicators proposed by Guertin et al. (2020). We evaluated this convergent validity through the Average Variance Extracted (AVE) and Composite Reliability (CR) as implemented in AMOS. The results show that the standardized coefficients of the 11 items are high (above 0.7), implying minimum individual reliabilities of 0.5. The final composite reliability is 0.72 and the variance extracted is 0.51. Consequently, it can be concluded that there is a high degree of confidence that the unhealthy eating behavior is well measured by the indicators proposed by Guertin et al. (2020).

Further studies have evaluated the convergent validity through the pattern of correlations between the construct of interest and self-concept related measures. Particularly, the unhealthy eating behavior has been traditionally associated with perceived habits of healthy eating (Pope, Pelletier, & Guertin, 2018 or Guertin et al., 2020). We particularly run in SPSS 20 a correlation between an average composite of the unhealthy eating behavior-related items and the self-reported lifestyles. The results showed that these two measures were negatively and directionally associated ($r = -.345$; $p = .067$).

Appendix B

Questionnaire

Question	Tailoring approach
Healthy and unhealthy dietary behavior scale (HUEBS) based on Guertin et al. (2020)	Unhealthy eating habits
Intention to reduce the unhealthy eating behavior within the next 30 days (on a scale 1–7)	Unhealthy eating habits
The extent to which participants thought that “Healthy eating is already a part of my lifestyle” (1 = Nothing; 7 = Absolutely)	Unhealthy eating habits
Self-efficacy beliefs regarding dietary behavior: “How confident are you that you would be able to stop eating unhealthy food in the next month?” on a 7-point scale (1 = not at all confident/easy, 4 = confident/easy, and 7 = extremely confident/easy)	Efficacy expectations
Perceived risk: “How much do you think that eating unhealthy food can harm or had already harmed your health?”, Cooper, Tompson, O’Donnell, & Falk, 2015)	Efficacy expectations

Video call interview

Question	Tailoring approach
Personal questions: - Age - Name (nickname) - Number of brothers/sisters - Live alone or in company - What do you study/what is your job? - What do you usually do in your free time?	Introductory
How would you define your lifestyle in terms of food eating?	Unhealthy eating habits
Do you practice physical activity? How often?	Unhealthy eating habits
Has the COVID-19 affected your daily eating habits? To what extent?	Unhealthy eating habits
How much money do you spend weekly on healthy food (food like vegetables, fruits, quinoa or boiled food)?	Unhealthy eating habits
What percentage of food in your shopping basket is healthy (food like vegetables, fruits, quinoa or boiled food)?	Unhealthy eating habits
Do you usually snack between meals? What is your favorite food to snack? Preferred brand?	Unhealthy eating habits
Do you drink sugary drinks or orange juice? What is your favorite brand?	Unhealthy eating habits
Goals: Would you like to start a healthier diet? Why?	Outcome expectations
What are your main goals by which you would change towards a healthier lifestyle?	Outcome expectations
Let’s talk about your family/friends: Do they have healthy eating habits?	Outcome expectations
Tell me the name of a person in your family/friend who does and does not develop a healthy lifestyle	Outcome expectations
Is someone in your environment in the process of changing eating habits towards healthier ones? Explain	Outcome expectations
Do you think that healthy food is more expensive than unhealthy food? Does it discourage you?	Outcome expectations
Do you think your family or friends can help you improve your eating habits? Why?	Outcome expectations
Perceived risk: How do you feel when you eat snacks, fried chicken, sausage or fast food? Do you think they damage your health? Do you feel satisfied?	Efficacy expectations

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(continued)

Question	Tailoring approach
Have you tried to change your diet towards a healthier one?	Efficacy expectations
What are the main barriers you have faced when trying to eat healthy food?	Efficacy expectations
What are the main benefits derived from eating healthy food, such as vegetables, fruits, quinoa or boiled foods?	Efficacy expectations

Appendix C. Table of proportions of money and percentage of the shopping basket spent on healthy food

		Before intervention		After intervention	
		Percentage	Cumulative percentage	Percentage	Cumulative percentage
Distribution of frequencies of money spent weekly on healthy food	0€	3.4%	3.4%	6.9%	6.9%
	1€-10€	51.7%	55.1%	24.1%	31%
	11€-20€	24.1%	79.3%	20.7%	51.7%
	21€-30€	20.7%	100%	27.6%	79.3%
	31€-40€	0%	–	20.7%	100%
	>41€	0%	–	0%	–
Distribution of frequencies of percentage of shopping basket spent weekly on healthy food	0%	3.4%	3.4%	3.4%	3.4%
	1%-10%	27.6%	31%	10.3%	13.7%
	11%-20%	24.1%	55.2%	3.4%	17.2%
	21%-30%	34.5%	89.7%	21.4%	41.4%
	31%-40%	10.3%	100%	20.7%	62.1%
	41%-50%	0%	–	34.5%	96.6%
	51%-60%	0%	–	3.4%	100%

Appendix D. Peak activations to untailored vs. tailored messages in the fMRI task

Brain regions	Peak of coordinates MNI (mm) x y z			T	k ^a
Untailored vs. Tailored					
Whole-brain					
Rolandic operculum	–43	–21	19	7.33	1586
Precuneus	–15	–42	51		
Calcarine	31	–56	9	6.17	470
Rolandic operculum	41	–32	23		

^a Spatial extent of the cluster in voxels (10 voxel minimum).

Appendix E. Peak activations to tailored vs. neutral messages in the fMRI task

Brain regions	Peak of coordinates MNI (mm) x y z			T	k ^a
Tai vs Neutral					
Peak coordinates that survived to the self-related ROI mask					
Precuneus	–8	–56	23	11.45	182
Angular	–50	–63	26	8.41	110
dMPFC	–5	60	2	8.25	263
Inferior temporal gyrus	–47	11	–37	7.67	11
Insula	–33	18	16	6.14	54
Middle temporal gyrus	59	–7	–20	5.88	26
Caudate	13	11	5	4.86	10
Whole-brain					
Precuneus	–8	–56	23	11.45	535
Medial orbitofrontal gyrus	6	63	–6	8.51	596
dMPFC	–5	53	40		
Angular gyrus	–50	–63	26	8.41	298
Inferior temporal gyrus	–47	7	–37	8.00	1418
Middle temporal gyrus	–61	–11	–16		
Middle frontal gyrus	–33	11	51	7.21	97
Cerebellum	10	–53	–48	7.02	88
Inferior temporal	52	11	–37	6.92	207
Superior temporal gyrus	48	–8	–9		

^a Spatial extent of the cluster in voxels (10 voxel minimum).

Appendix F. Peak activations to untailored vs. neutral messages in the fMRI task

Brain regions	Peak of coordinates MNI (mm) x y z			T	k ^a
Untailored vs. Neutral					
Whole-brain					
Middle frontal gyrus	-33	11	47	7.56	340
Postcentral	-43	-25	51		
Precentral	-29	-11	58		
Precuneus	-5	-70	33	6.52	288
Posterior cingulate	-12	-49	30		
Angular	-43	-60	33	5.46	99

^a Spatial extent of the cluster in voxels (10 voxel minimum).

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